ANNUAL ENVIRONMENT REPORT 2016

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

August 2017

POR ENV 1/17

Cover Photo: Lake Murray Sunset 2016

Acknowledgements: ALS Laboratories, CSIRO, National Measurement Institute, Hydrobiology and Wetlands Research & Management.

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CSIRO

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

25 August 2017

Dear Charlie,

Re: Porgera Joint Venture 2016 Annual Environmental Report

Dr Graeme Batley and Dr Simon Apte have reviewed a draft of the 2016 Porgera Joint Venture Annual Environmental Report (AER) and provided detailed comments for consideration. Overall, the draft report was found to be technically sound and of extremely high quality. However, as might be expected with a report of this size, a small number of recommendations were made for improvement. Porgera Joint Venture responded positively to the review team's recommendations and the report was revised in the light of the comments made.

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

Sincerely

Dr Simon Apte
Senior Principal Research Scientist

Dr Graeme Batley
Chief Research Scientist

EXECUTIVE SUMMARY

Porgera Gold Mine is located in the Porgera Valley of Enga Province in the Papua New Guinea highlands, approximately 130 km WNW of Mt Hagen. The mine is owned jointly by Barrick Gold (47.5%), Zijin Mining (47.5%) and Mineral Resources Enga (5%). The mine is known as the Porgera Joint Venture (PJV) and is managed by Barrick (Niugini) Limited. 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 500 koz of gold. The site employs approximately 2,960 local, national and expatriate staff and contractors.

The operation 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 ensure compliance with legal and other requirements, mitigation of potential environmental risks and continual improvement of environmental performance. The EMS was first certified to the ISO14001:2004 standard in December 2012 and was re-certified in December 2015.

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 purposes 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 performance throughout the previous ten calendar years. The objectives of this report are thereby 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; waste rock generation; water extraction and discharge; transport, storage and use of hazardous substances and waste management.

There was no change to the area of land held by the PJV and the quantity of ore and gold production were comparable with the previous five years.

Tailings production also was consistent with previous years, and a significant proportion (12.4% by volume) was diverted from riverine disposal and used for cemented backfill in the underground mine. The volume of tailings diverted to paste in 2016 was the highest in the mine's history and is attributed to the high rate of availability of the paste plant and increased underground mining.

Tailings quality achieved 100% compliance with the internal site-developed end-of-pipe criterion for cyanide. Variation from the pH target occurred as a result of a high pH event in November due to an operational requirement to divert flotation tailings directly into the final neutralization tank during a major shut-down of the autoclaves and the leach circuit.

Total suspended sediment (TSS) concentrations were comparable to previous years. Concentrations of TSS, dissolved cadmium, copper, nickel and zinc, were elevated compared to upper river reference conditions. Concentrations of weak-acid-extractable arsenic, cadmium, copper, mercury, lead and zinc in tailings solids were elevated relative to the upper river reference conditions. Concentrations of dissolved and total cadmium, total chromium, total copper, dissolved and total nickel and dissolved zinc exhibited an increasing trend over the past ten (10) years, while all other metals were either stable or decreasing.

Contact rainfall runoff from the site was typical of neutral mine drainage and exhibited elevated sulfate, TSS and concentrations of dissolved cadmium, chromium and zinc. The volumes of runoff generated in 2016 were historically high, driven by historically high rainfall at the site.

Background Environmental Conditions

Background environmental conditions in 2016 were influenced by high annual rainfall within the Porgera Valley and throughout the downstream catchments, which consequently resulted in high river flows throughout the upper rivers in the highlands, the lower river along the Strickland floodplain and at Lake Murray and off-river water bodies (ORWBs). High flows resulted in high rates of dilution of mine-related inputs within the receiving aquatic ecosystem.

Background conditions for environmental indicators of water quality, sediment quality, metals within the tissue of fish and prawns (tissue metals) and ecosystem health (fish and prawn abundance), 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 potentially influenced by the operation (i.e. reference sites).

Although concentrations of physical and chemical parameters were generally lower at the upper river reference sites than the baseline data from the upper river test sites, the reference sites did exhibit moderate TSS concentrations and detectable concentrations of total arsenic, chromium, nickel and zinc. This indicates that tributaries to the Lagaip-Strickland system have the potential to contribute non-mine derived TSS and some metals to the system. Trends for pH, TSS and dissolved metals at the upper and lower river and at the Lake Murray and ORWB reference sites displayed no statistically significant changes over time.

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 2016, with non-compliance related to short-duration events of elevated TSS in discharge from four (4) of the five (5) sewage treatment plants on at least one occasion during the year.

Environmental Risk, Impact and Performance

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" trigger values, 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 triggers further investigation to determine whether impact is actually occurring.

Impact assessment was based on the comparison of biological environmental indicators at test sites against biological indicators at reference sites 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.

The risk assessment determined that the consistent nature of inputs from the mine, coupled with high river flows, increased the dilution of mine inputs by natural runoff and sediments within the receiving environment during 2016, resulting in overall low risk to the receiving environment. It should be noted that the 2016 assessment applies to sites downstream of SG1 on the Porgera River. Monitoring was not conducted at SG1 during 2016 due to security concerns, therefore the assessment could not be performed at this location.

Total suspended solids inputs from the tailings, Anjolek and Anawe erodible dumps, and discharges from 28 Level and from Yarik Portal were elevated relative to the upper river reference sites and posed potential risk to the receiving environment. Inputs from the mine and high river flow rates resulted in a decrease of the proportion of mine derived TSS within the rivers downstream of the mine compared to 2015 and the long term average. The proportion of mine derived sediment at SG3, 164 km downstream of the mine, was 13% in 2016 compared with 49% in 2015 and a long-term median of 23%. This did not result in increased sediment aggradation within the rivers or increases to median concentration of TSS within the rivers, and therefore there was a low risk of impact to the receiving environment associated with the physical effects of sediment inputs from the mine during 2016.

Metals dissolved in water and weak-acid-extractable (WAE) metals bound to particulates are considered bioavailable and are therefore used to assess the risk of toxicity to aquatic organisms within the receiving environment.

Concentrations of dissolved cadmium, copper, nickel and zinc in tailings were elevated compared with upper river reference conditions and posed a potential risk, as did dissolved cadmium and zinc in drainage discharged from the Kogai and the Anawe North competent waste rock dumps.

WAE arsenic, cadmium, copper, mercury, lead and zinc concentrations in tailings solids posed potential risk, as did WAE silver, arsenic, cadmium, lead and zinc in sediment discharged from 28 Level, WAE cadmium, lead and zinc concentrations in sediment discharged from Kogai and Anawe North competent waste rock dumps, and WAE lead in sediment discharged from Yarik Portal.

Environmental Risk

pH

Water discharged from the lime plant exhibited elevated pH, however, the volume of water discharged from this location was relatively small and the influence of elevated pH was limited to the immediate downstream environment. The pH values of all other discharges from the operation were consistent with upper river water quality TVs and posed low risk of impact to the receiving environment. This was confirmed by the risk assessment results for pH in the upper and lower rivers, Lake Murray and ORWBs where all sites were within the respective upper and lower TVs.

TSS

The tailings discharge and drainage from the open pit, underground mine and the erodible dumps contributed elevated concentrations of TSS to the receiving environment. The risk assessment results indicated that TSS concentrations at all receiving environment sites downstream of the Porgera River during 2016 were below the respective TVs and therefore posed a low risk.

Silver

Concentrations of dissolved silver in water discharged from the mine were less than the respective upper river TV, indicating low risk to the receiving environment. This was confirmed by low dissolved silver concentrations throughout the receiving environment in 2016.

WAE silver concentrations in sediment discharged from 28 level exceeded the upper river TV, which indicated potential risk. However, WAE silver concentrations in benthic sediment at all test sites were below their respective TVs in 2016 indicating low risk within the receiving environment.

Arsenic

Dissolved arsenic concentrations in all discharge sources were below the upper river TV. WAE arsenic concentrations in sediment discharged in tailings and from 28 Level exceeded the upper river TV, indicating potential risk.

In the receiving environment, sampling was not able to be carried out at SG1 on the Porgera River, where previous monitoring had shown potential risk to aquatic ecosystems. Concentrations of dissolved arsenic in water and WAE arsenic in benthic sediment were below the respective TVs in all receiving environment test sites, indicating low risk to aquatic ecosystems downstream of the Porgera River.

Arsenic in prawn abdomen at Bebelubi and SG4 exceed the TV, and in the absence of potential risk through water and benthic sediment indicates the potential for an alternative exposure pathway of arsenic to prawns in the lower river. It should be noted that the concentrations of all metals within prawn and fish tissue at all sites within the upper and lower rivers were below applicable food standards and therefore do not pose a risk to human health if consumed. A comparison against food standards is provided in Section 7.7.

Overall, given the low concentrations of arsenic observed in water, sediment and fish tissue throughout the receiving environment, the system-wide risk posed by arsenic to aquatic ecosystems is considered low.

Cadmium

Dissolved cadmium concentrations in tailings and mine contact runoff from Kogai dump toe, Wendoko Creek D/S Anawe North dump, and 28 Level exceeded the upper river TV, indicating potential risk. WAE cadmium in sediment discharged in tailings and from 28 Level, Kogai dump toe and Wendoko Creek D/S Anawe North dump also exceeded the upper river TV, indicating potential risk.

Within the receiving environment downstream of the Porgera River, concentrations of dissolved cadmium in water and WAE cadmium in benthic sediment were below the respective TVs at all sites, indicating low risk.

Cadmium in prawn abdomen at Wasiba, Wankipe and SG4 exceeded the respective TV indicating potential risk. This observation was similar to arsenic, whereby the exceedance of the TV for cadmium in prawn abdomen at Wasiba, Wankipe and SG4 in the absence of potential risk through water and benthic sediment indicated the potential for an alternative exposure pathway of cadmium to prawns in the lower river.

Overall, the system-wide risk posed by cadmium to aquatic ecosystems is considered low.

Chromium

The lime plant was the only discharge point which exhibited elevated dissolved chromium concentrations. Throughout the receiving environment, dissolved chromium in water, benthic sediments and in tissue metals of fish and prawns indicated low potential risk.

Copper

Elevated dissolved copper and WAE copper in tailings solids posed potential risk to the aquatic environment. Throughout the receiving environment, dissolved copper in water, benthic sediments and in tissue metals of fish and prawns indicated low potential risk.

Mercury

WAE mercury concentrations in tailings sediment posed a potential risk to the receiving environment, but all other discharges from the mine did not. Dissolved mercury concentrations in water and WAE mercury concentrations in benthic sediment were below their respective TVs throughout the receiving environment, indicating low risk.

Mercury concentrations in the tissue of fish flesh at SG4 in the lower river indicated potential risk. However, due to low concentrations of mercury in water and sediment, fish and prawn tissue at all other sites throughout the upper and lower rivers, elevated mercury in fish tissue at SG4 indicates that an alternate exposure pathway may be present that is not directly related to mine inputs.

Nickel

Dissolved nickel in water was elevated in tailings but was low at test sites throughout the river system. WAE nickel in tailings and in all other discharges from the mine was less than the upper river TV indicating low risk. WAE nickel in benthic sediment at Wasiba in the upper river exceeded the TV, indicating potential risk. Dissolved nickel, WAE nickel in benthic sediment and nickel in fish and prawn tissue were low throughout all other upper and lower river sites, indicating that overall, nickel posed a low risk to the receiving environment.

Lead

Concentrations of dissolved lead in waters discharged from the mine site posed low risk, and were reflected by low concentrations of dissolved lead in water throughout the receiving environment.

With the exception of the Lime Plant, WAE lead concentrations in sediment in all discharges from the mine exceeded the upper river TV, indicating potential risk.

In the receiving environment, the concentration of WAE lead in benthic sediment exceeded the respective TVs at SG2, Wasiba, Wankipe, Southern Lake Murray and the off-river water body Kukufionga, indicating the presence of mine-derived sediment.

Lead concentration in prawn abdomen at Wasiba was not significantly different from the TV, indicating potential risk. Lead in fish flesh and prawn abdomen at all other sites fell below the respective TVs, indicating low risk. Again, it should be noted that the concentrations of all metals within prawn and fish tissue at all sites within the upper and lower rivers were below applicable food standards and therefore do not pose a risk to human health if consumed. A comparison against food standards is provided in Section 7.7.

The results of the risk assessment indicated that WAE lead in discharges from the mine led to elevated concentrations in benthic sediment extending downstream to Wasiba in the upper river, and that this in turn was contributing to elevated concentrations of lead in prawn abdomen at Wasiba.

Given the elevated concentrations of WAE lead in sediments discharged from the mine, the potential risk indicated by elevated WAE lead in benthic sediment at SG2 and Wasiba, and lead in prawn abdomen at Wasiba, lead is considered to have posed a potential risk to aquatic ecosystems in the upper river between the mine and Wasiba. Downstream from Wasiba, lead posed a low risk to aquatic ecosystems.

Selenium

Dissolved selenium concentrations in water and WAE selenium concentrations in sediment discharged from the mine site were below the respective upper river TVs and therefore posed low risk to aquatic ecosystems. This was reflected in the receiving environment by low concentrations of dissolved selenium in water and WAE selenium in benthic sediment at all sites, indicating low risk.

Selenium concentrations in prawn abdomen at Wasiba, Wankipe, Bebelubi and SG4, indicated potential risk to aquatic ecosystems at these locations. Again, it should be noted that the concentrations of all metals within prawn and fish tissue at all sites within the upper and lower rivers were below applicable food standards and therefore do not pose a risk to human health if consumed. A comparison against food standards is provided in Section 7.7.

Similar to arsenic and cadmium however, the exceedance of the TV for selenium in prawn abdomen at Wasiba, Wankipe, Bebelubi and SG4 in the absence of potential risk through water and benthic sediment indicates the potential for an alternative exposure pathway of arsenic to prawns in the lower river.

Overall, given the low concentrations of dissolved selenium in water and WAE selenium in mine-derived sediments and throughout the receiving environment, the system-wide risk of selenium is considered low.

Zinc

The concentrations of dissolved zinc were elevated in tailings and in the water discharged from Starter Dump A (SDA) toe, Kogai dump toe and Wendoko Creek D/S Anawe North dump. WAE zinc in tailings and in suspended sediment in contact runoff discharges from the mine site, exceeded the upper river TV indicating potential risk.

Dissolved zinc in water at SG2 was not significantly different from the TV, indicating potential risk, and was attributable to the discharges from the mine. Zinc in prawn abdomen at Wasiba was not significantly different from the TV which indicated potential risk.

In the lower river at Bebelubi and SG4, concentrations of dissolved zinc in water exceeded the TV, which was postulated as due to remobilization of zinc from mine-derived and from natural particulates, and also that the risk assessment methodology contributed to the use of a conservatively low TV, which in turn resulted in the exceedance. These factors in addition to the absence of risk indicated in benthic sediment and in prawn abdomen, indicated that the overall system-wide risk posed by zinc discharged from the mine in 2016 downstream of SG2 was low.

It should be noted however, that increasing trends of dissolved and particulate zinc in discharges from the mine, particularly in tailings, and increasing trends of zinc concentrations in water and sediment within the receiving environment were observed. These results serve as a cautionary indication that if current trends continue, zinc has the potential to pose a risk to the receiving environment in future years, a scenario that would be exacerbated during lower rainfall years when dilution is reduced.

Human Health Risk

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

Risk assessment showed that discharges from the mine did not pose a risk to drinking water sources for villages within the SML and LMPs. Risk was posed to people who trespass on the mine lease and are exposed to low pH and elevated concentrations of dissolved nickel and zinc through dermal contact with undiluted tailings when panning for gold at the tailings discharge. However, within the rivers downstream of the mine, low risk was posed through water-based activities. All tissue metals in fish and prawns at Wasiba and Wankipe in the upper river, and Bebelubi and SG4 in the lower river were less than the relevant food standard, confirming that they were fit for human consumption.

The concentrations of all metals measured in point source emissions at the mine site were less than the relevant Australian National Environment Protection Measure, indicating low risk. However, localised risks to air quality were posed by elevated concentrations of oxides of nitrogen from the stand-by Anawe Generator, and elevated particulate matter in discharge from the lime kilns.

Environmental Impact Assessment

Impact assessment was performed based on biological indicators of aquatic ecosystem health to determine whether potential environmental risks were resulting in actual environmental impact to aquatic ecosystems.

The results showed that the mean abundance of indicator fish and prawn species in 2016 was not significantly different than the respective TVs at all test sites within the upper and lower rivers. The results therefore indicated no detectable impact to fish or prawn abundance at test sites within the receiving environment downstream of the mine. It is acknowledged that the use of abundance as the sole indicator of impact on fish and prawn populations limits the assessment to this aspect of the respective populations. PJV is continuing to investigate options for improving the assessment methodology.

Macroinvertebrate monitoring is conducted on an annual campaign basis by an expert consultant over a two-week period. The 2016 campaign was conducted in July 2016. Indicators selected to describe the condition of macroinvertebrate populations were total species richness (*S*); EPT species richness; SIGNAL 2 score, and multivariate Bray-Curtis similarity. The results of the 2016 campaign showed moderate impact between the mine site and SG3, except at SG2 where the impact rating was low. The results also showed that the level of impact at SG2 increased from a rating of no impact in 2015 to low impact in 2016, and impact at Wasiba increased from no impact to medium impact. The impact rating at Kogai, within the SML boundary, and at Wankipe and SG3 in the upper rivers remained unchanged from 2015 to 2016.

The environmental performance of the operation in 2016 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. A reduction in risk to the receiving environment was noted in 2016, driven by uniform inputs from the mine coupled with high natural river flows and sediment loads throughout the upper and lower rivers system, resulting from the historically high annual rainfall within the Porgera Valley and throughout the receiving environment. The results of the macroinvertebrate sampling indicated impact to macroinvertebrate populations between the mine and SG3 in the upper river. Overall, the condition of the receiving aquatic ecosystem remains consistent with predictions made prior to operations commencing in 1990.

Recommendations for Improvement

Recommendations are proposed to improve the certainty of the findings of future reports; the assessment methodology; environmental performance; communication of the findings to the many stakeholders, and to reduce environmental risk and impact.

Note that a number of the recommendations from the 2015 AER are still in progress and appear in the list below in addition to new recommendations raised from this year's AER.

Findings and Assessment Methodology

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. Include EC as indicator parameter, develop an EC TV and include EC in the risk assessment for subsequent Annual Environment Reports.
3. Investigate suitable methods for statistical analysis of fish and prawn population data to improve confidence in the impact assessment results.
4. Reduce the frequency of macroinvertebrate monitoring to every 2 years.
5. Investigate suitable test and reference sites downstream of SG3 for performing macroinvertebrate monitoring.
6. Conduct a study to examine the speciation of dissolved copper, zinc and cadmium in the river system.

Reduce Environmental Risk and Impact and Improve Performance

7. Continue to investigate options for reducing the concentrations of bioavailable metals and mass loads of metals in mine discharges;
8. Continue to implement the Waste Rock Management Plan to minimise the release of metalliferous drainage from the competent waste rock dumps.

Communication and Engagement

9. Continue to develop and apply a communication plan to the AER each year, including a presentation to the PNG Conservation and Environmental Protection Authority (CEPA) and a Report Card on the river system.

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LIST OF ABBREVIATIONS & DEFINITIONS

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 Nino 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.

ISQG: Interim Sediment Quality Guidelines.

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.

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 outside of the zone of potential influence of the operations environmental aspects.

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.

TARP: Trigger Action Response Plan.

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.

WAD-CN: Weak Acid Dissociable Cyanide.

WAE: Weak Acid Extractable.

WWCB: West Wall Cut-back.

1 INTRODUCTION

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

The operation consists of an open cut and underground mine, processing facility, gas fired power station, competent and erodible waste rock dumps, a water supply dam, limestone quarry, lime plant, waste management infrastructure and buildings. Production commenced in 1990 and is expected to continue until 2028 at an annual rate of approximately 500 koz of gold per annum. The site employs approximately 2,960 local, national and expatriate staff and contractors.

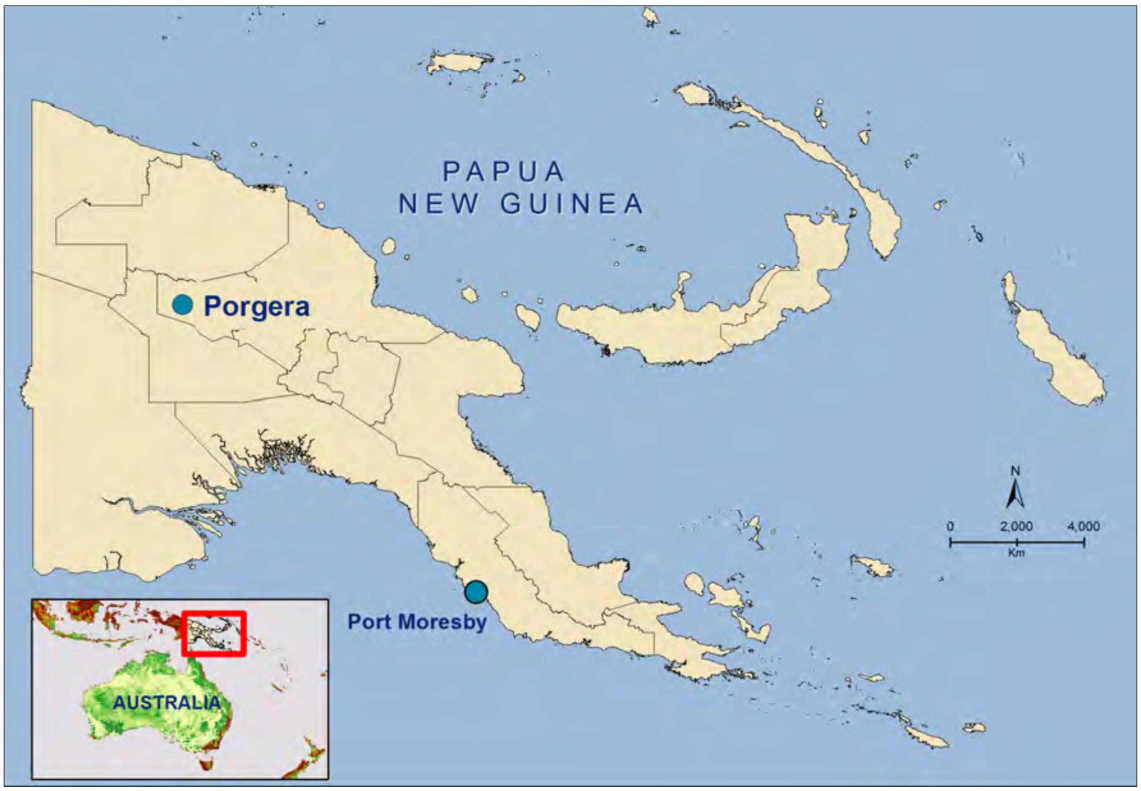

Figure 1-1 Location of Porgera operation

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.

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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 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 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 environmental indicators at test sites against biological indicators at reference sites. When the performance of biological indicator values at the test site is below that of the reference site, it indicates that environmental impact is occurring (i.e. species abundance at a test site lower than at the reference site). If the same performance of biological indicators is observed at both the test site and the reference site, then it indicates no potential impact is detected or there is a system-wide change that is not related to the mine.

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 tonne per day to 17,500 tonne per day. The four stages of project development are described below and summarised in Table 1-1.

Stage 1 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 tailing containing the remaining 40% of the gold was stored in a lined pond for later reclaim and processing through the pressure oxidation circuit. The barren flotation tailing was 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 tailing 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 tailing) to detoxify and neutralise the tailing 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 tailing 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 <0.2ppm 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 and managed accordingly.

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 and mines 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 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 floatation tailings are sent to the tailings treatment circuit.

Prior to being fed into the autoclaves for oxidation, flotation concentrate is pumped to the carbonate destruction circuit, consisting of a series of three carbonate reaction tanks. Here the concentrate slurry is mixed with an acidic stream of recycled oxidized concentrate from the autoclaves for reaction with the carbonates in the flotation concentrate. This pre-heats the concentrate and reduces the production of carbon dioxide in the autoclaves which otherwise would strip oxygen from the slurry and adversely affect the oxidation rate within the autoclaves.

After carbonate destruction, the concentrate is sent to the four autoclaves. The autoclaves are 4 m diameter, 27 m long, steel pressure vessels that are lined with lead and acid-proof brick and operated at a pressure of 1,750 kPa and a temperature of 198ºC. Approximately 98% of the sulfides are oxidised in the autoclave process. Oxidation liberates gold bound to sulfides within the concentrate by oxidising sulfide to form sulfuric acid and subsequently makes any associated gold amenable to recovery by cyanide leaching.

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 500 oz bars of doré bullion that average about 80% gold. The mercury is condensed and disposed to a licensed facility. 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. Additional water is delivered to the Tawisakale grinding circuit from the nearby Kogai Creek.

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 13 MW diesel power station at the mine site.

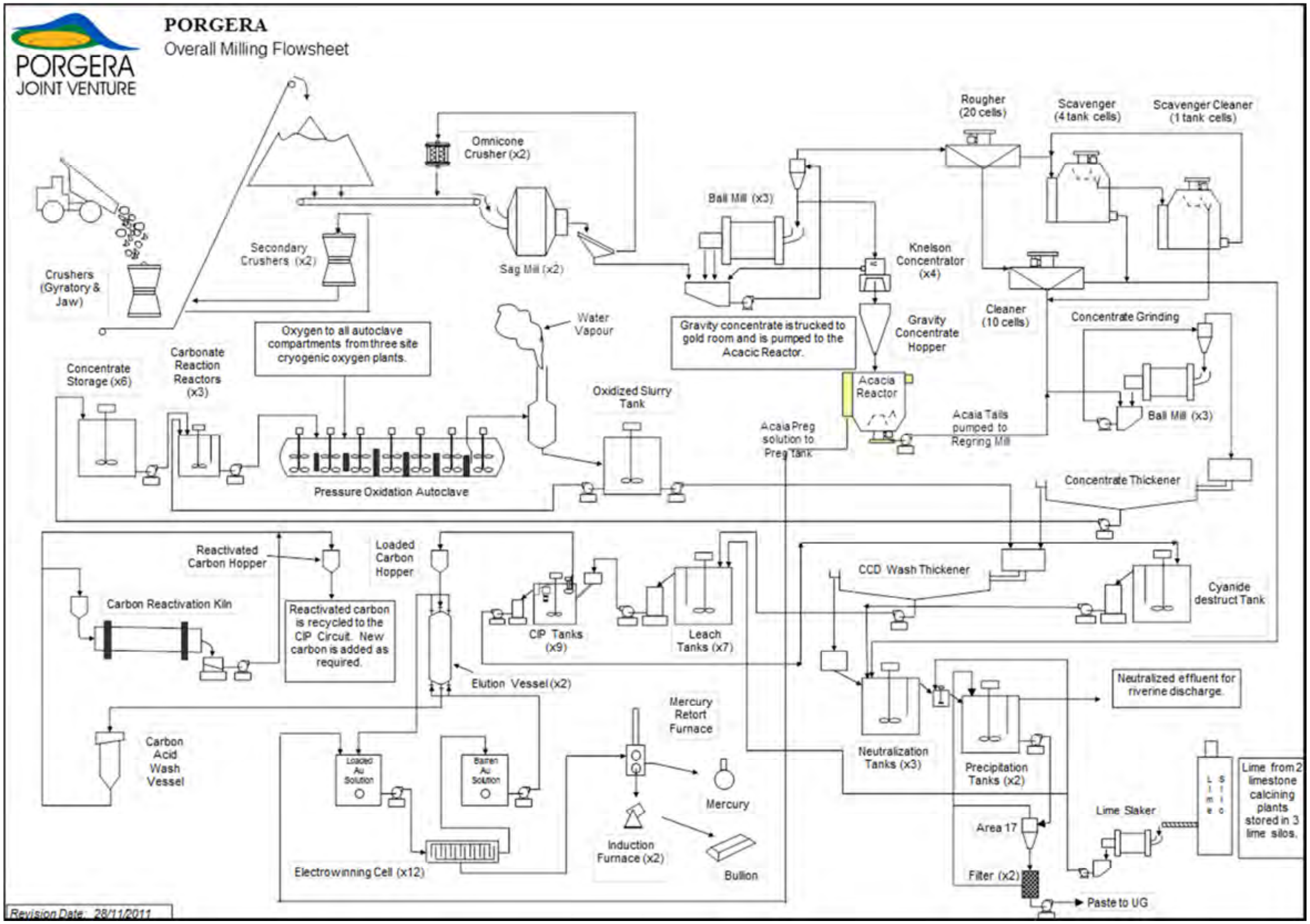


Figure 1-2 Process flow chart

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 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 Environment 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 in Figure 2-1.

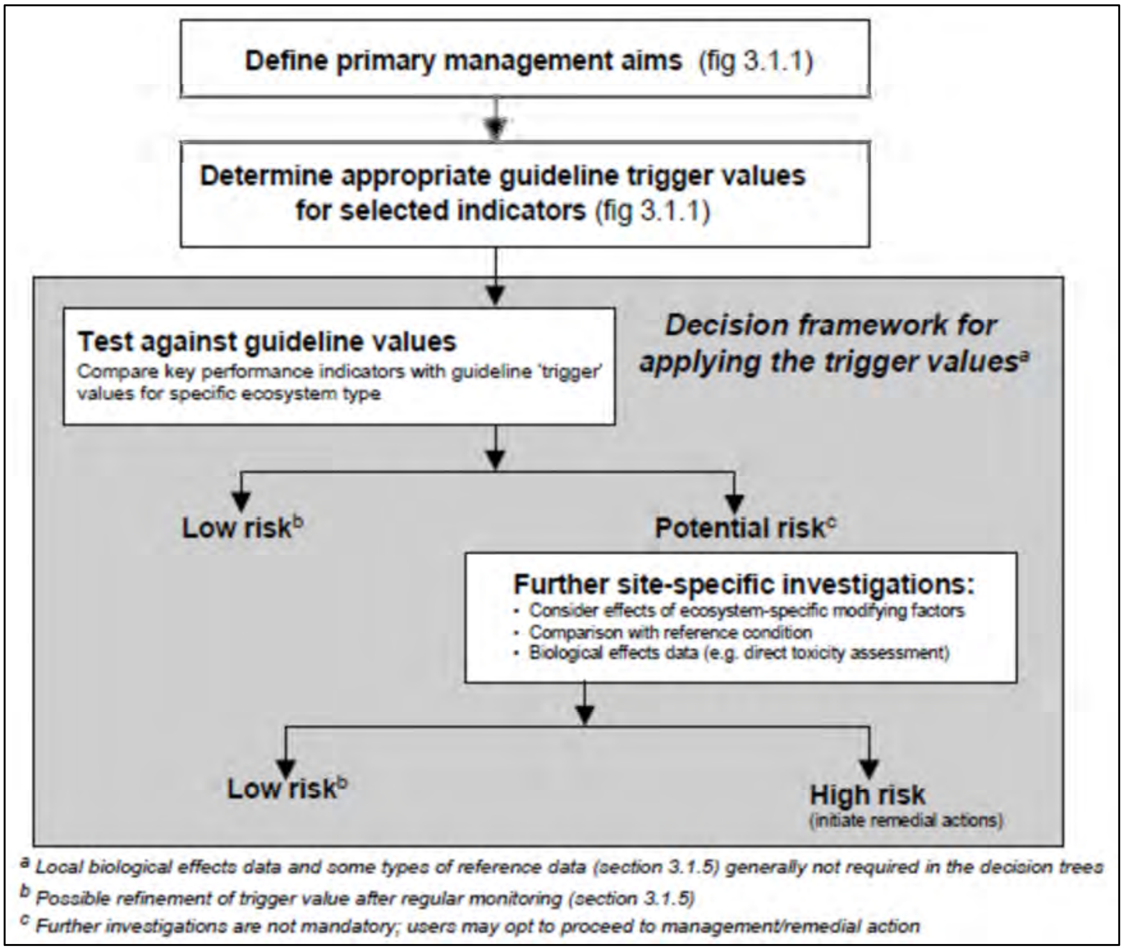


Figure 2-1 ANZECC/ARMCANZ Risk assessment framework (ANZECC/ARMCANZ, 2000: Fig 3.3.1)

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 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 PJV project.

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.

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%ile or 20%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%ile and 20%ile are deemed to be approximately equivalent to ± 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%ile or 20%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 artifact 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

In cases where ecological effects data, baseline data and reference site data are unavailable or unsuitable, default TVs provided by guidelines and standards can be adopted to support the risk assessment. Guidelines and standards are typically developed by governments, industry or subject matter experts based on available evidence and a precautionary risk-based approach. They provide guidance on levels of physical and chemical indicators at discharge points or within the receiving environment, below which there is a low risk of environmental impact. In some cases guidelines and standards form part of legislation to protect human health, the economy or the environment.

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	ANZECC/ARMCANZ (2000)
	Tissue metal	USEPA (2016) – Selenium only
Drinking water	Water quality	*PNG Public Health (Drinking Water) Regulation 1984* – Schedule 1 Standards for Raw Water (PNG 1984)
Aquatic recreation	Water quality	ANZECC/ARMCANZ (2000) Guidelines for recreational water quality and aesthetics (Chapter 5) *PNG Public Health (Drinking Water) Regulation 1984* – Schedule 1 Standards for Raw Water (PNG 1984)
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 90%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 are unsuitable or consistently exceed the guideline TV.

The locally-derived TV is established by firstly comparing the TVs derived from baseline data, reference site data and the guideline or standard TV, and then adopting whichever is highest.

Where the baseline or reference site TV is higher than the 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 guideline level is higher than the baseline or reference TV, it indicates that pre-disturbance levels of those indicators are naturally lower than the dataset upon which the guideline TVs are derived. 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 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 levels 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 through 2.7. The comparison between baseline, reference and guideline data for water quality, sediment quality and tissue metal is 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%ile value from baseline data, the 80%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 pollution 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. (AZECC/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 have 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%ile hardness value from all test sites within each of the respective groups. Adoption of the 20%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%ile (full data set) - Regional reference site 80%ile (most recent 24-month data set), or - ANZECC/ARMCANZ default guideline for 95% species protection (hardness modified where appropriate)

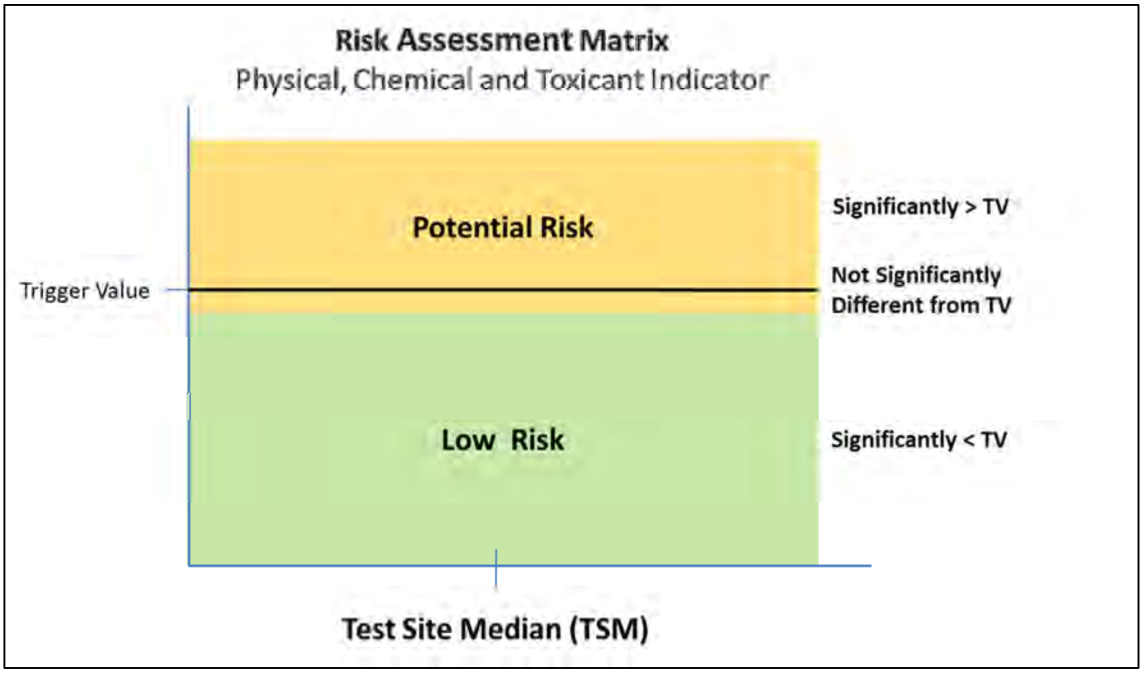


Figure 2-2 Risk assessment matrix – physical, chemical and toxicant indicators in water

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

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

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

2.3.2 pH

Upper and lower TVs for pH in the upper river were established by comparing the 80%ile and 20%ile 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 80%ile and 20%ile 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 80%ile (full data set) - Regional reference 80%ile (most recent 24 months data set), or - ANZECC/ARMCANZ upper limit for upland rivers in tropical Australia
Water: pH – lower	Adopt whichever is lower: - Baseline 20%ile (full data set) - Regional reference 20%ile (most recent 24 months data set), or - ANZECC/ARMCANZ lower limit for upland rivers in tropical Australia

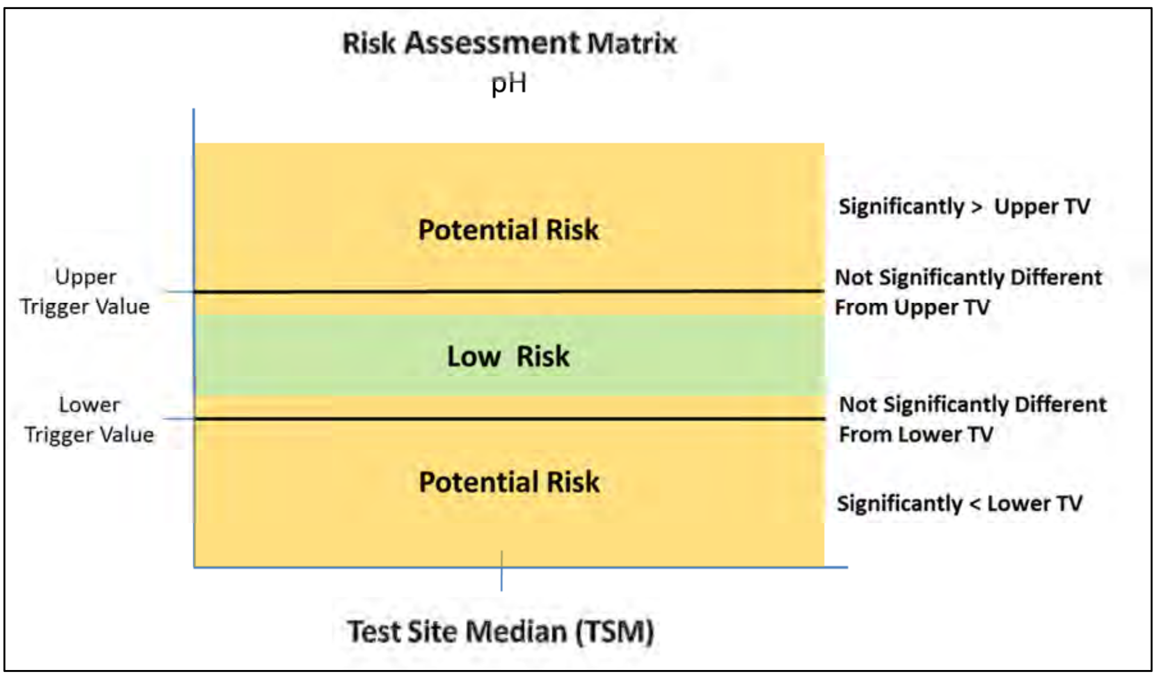


Figure 2-3 Risk assessment matrix – pH in water

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) interim sediment quality guidelines (ISQGs). These guidelines were developed from United States effects databases (Long et al. 1995) and are termed 'interim' because an understanding of the biological impacts from sediment contamination is still being developed (Batley and Simpson 2013). The guidelines include ISQG-Low and ISQG-High values, which represent the 10th percentile (10%ile) and 50th percentile (50%ile) values for chemical concentrations associated with acute toxicity effects respectively.

The ISQG-Low value 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 ISQG-High value corresponds to the median effect concentration as detailed in 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) ISQG.

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) ISQG.

TVs for sediment quality for all parameters except selenium (Se) have been established by comparing the WAE whole sediment 80%ile value from the most recent 24-month reference site data against the ANZECC/ARMCANZ (2000) interim sediment quality low guideline value (ISQG-low), 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%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) ISQG-low 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 80%ile WAE in whole sediment (most recent 24months data set), or - ANZECC/ARMCANZ (2000) ISQG-low

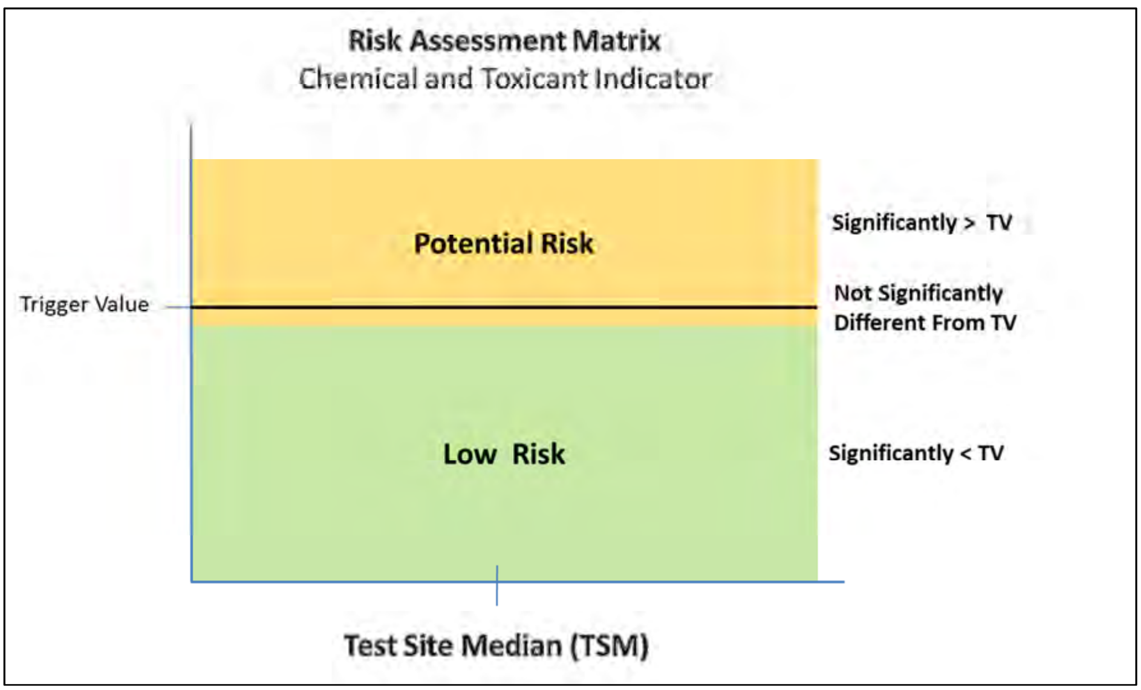


Figure 2-4 Risk assessment matrix – Chemical and toxicant indicators in benthic sediment

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 source by 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 parameters, except selenium in fish flesh, have been established by comparing the reference site 80%ile value from the most recent 24-month data against the 80%ile of the test site baseline data and adopting the higher value. 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%ile value from the most recent 24-month data, the 80%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 80%ile (full data set) - Reference site 80%ile (most recent 24 months), or - USEPA criterion (available for selenium (Se) only)

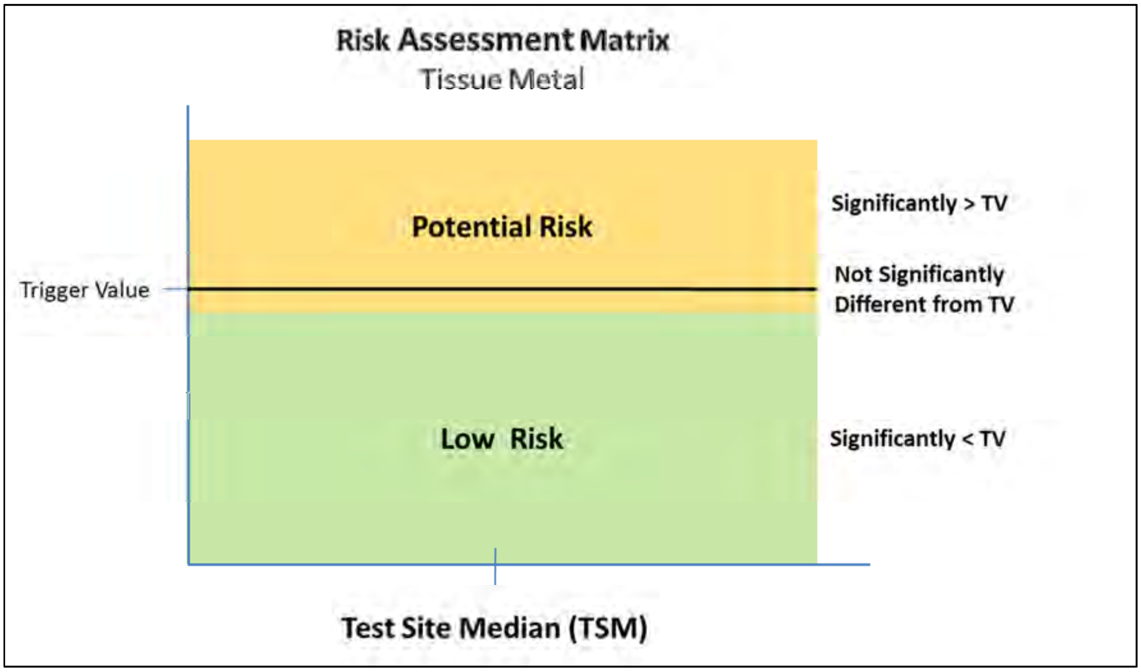


Figure 2-5 Risk assessment matrix – tissue metal concentrations

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 PNG Public Health (Drinking Water) Regulation 1984 – Schedule 1 Standards for Raw Water 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: dermal contact with the water body and 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. 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.

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	*PNG Public Health (Drinking Water) Regulation 1984* – Schedule 1 Standards for Raw Water (PNG 1984)
Water-based activities: Water quality – receiving environment 2016 TSM	ANZECC/ARMCANZ (2000) Guidelines for recreational water quality and aesthetics (Chapter 5) *PNG Public Health (Drinking Water) Regulation 1984* – Schedule 1 Standards for Raw Water (PNG 1984)
Fish and prawn consumption: Tissue metals – fish and prawns 2016 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 90%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 > PNG Drinking Water Guidelines	Potential risk	Conduct health risk assessment
	TSM ≤ PNG 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 actual impact has occurred within the receiving environment, and if so to determine the level or significance 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 an assessment of impact to aquatic ecosystems within the receiving environment, regardless of the risk assessment result. This is done to provide confirmation of the risk assessment conclusions and 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 direct assessment of the health of the aquatic ecosystem through the use of biological indicators such as abundance, richness, biomass and condition of aquatic fauna, specifically fish, prawns and macroinvertebrates. The impact assessment is conducted by comparing biological indicators from the test sites against impact assessment criteria.

2.6.1 Fish and Prawns

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 univariate non-parametric tests, used to assess the difference in mean values of a single indicator between two locations, to multi-variate parametric tests, used to assess the interrelationship between population and physical and/or chemical indicators between multiple locations. Typical population indicators are total number of species (species richness); total number of organisms (abundance); biomass; presence of disease; and population composition (age, sex, length).

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.

The impact assessment method applied in this AER is based on a comparison of mean abundance of selected indicator fish and prawn species during 2016, between paired test and reference sites within the upper and lower rivers using a non-parametric statistical method, the two-sample t-test. It is acknowledged that the use of abundance as the sole indicator of population limits the ability of the assessment to describe the potential breadth of changes between the populations. PJV continues to apply the standard methods for fish and prawn population monitoring within the upper and lower rivers, and will commence a study to determine whether the methods can be further improved and to establish the most appropriate impact assessment methodology for the data being generated.

A summary of the TV development method is provided in Table 2-12 and the decision matrix is shown in Figure 2-6 and Table 2-13. Indicator species are shown in Table 2-14.

Abundance is measured as the total number of individuals of all species of fish and/or prawn from five (5) replicates performed on each sampling day, for the particular catch method being used for the region. Changes in abundance of key species of fish and prawns (indicator species) were also assess against respective TVs.

Table 2-12 Fish and Prawn Impact Assessment

Indicator Parameter	Trigger Value (TV) Derivation
Abundance of indicator fish and prawn species.	Reference site mean from the most recent 12 months data set.

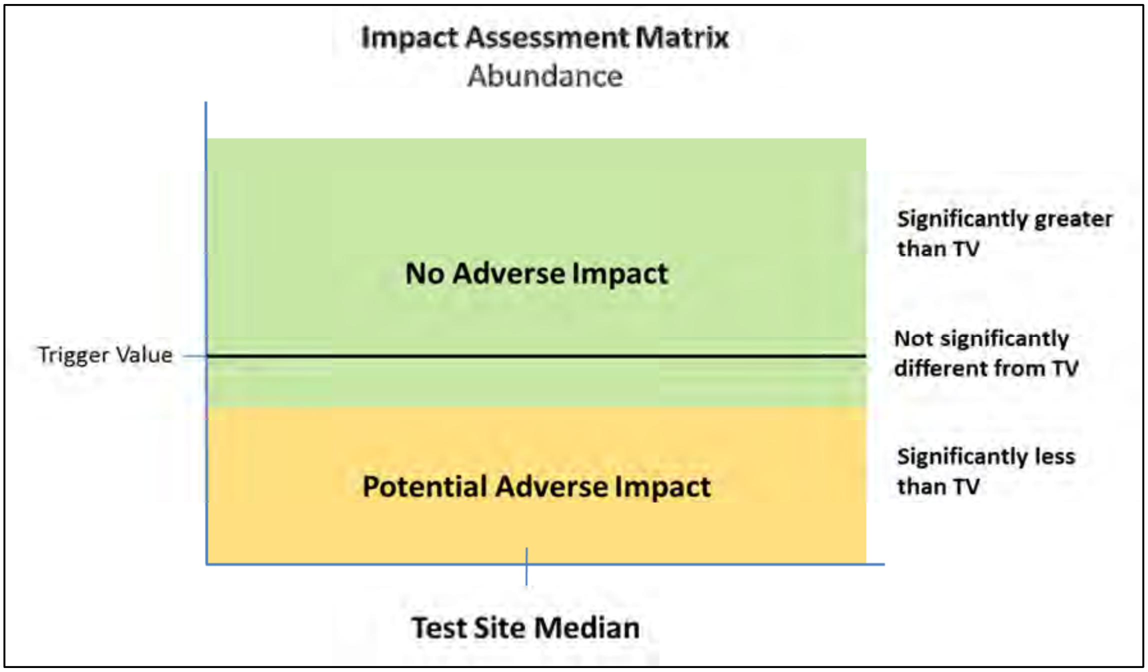


Figure 2-6 Impact assessment matrix – Fish and prawn abundance

Table 2-13 Impact assessment matrix – Fish and prawn abundance

Assessment Result	Impact Rating
Test Site Mean significantly > Trigger Value	No Adverse Impact
Test Site Mean not significantly different from TV	
Test Site Mean significantly < TV	Potential Adverse Impact

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

Table 2-14 Fish and Prawn Indicator Species

Region	Species Type	Scientific Name	Common Name
Upper River	Fish	*Neosilurus equinus*	Mountain tandan
	Prawn	*Macrobrachium handschini*	Mountain prawn
		Macrobrachium lorentzi	River prawn
Lower River	Fish	*Potamosilurus latirostris*	Broad-snouted catfish
		Potamosilurus macrorhynchus	Sharp-snouted catfish
	Prawn	*Macrobrachium rosenbergii*	Giant river prawn

2.6.2 Macroinvertebrate Populations

In addition to the use of fish and prawn abundance to assess impact on aquatic ecosystems, PJV has investigated the use of additional biological indicators to support the impact assessment stage.

In 2014, a scoping study (WRM 2015) was performed to investigate the suitability of benthic macroinvertebrate populations as indicators of mine-related impact upstream of SG3. The 2014 study supported the use of benthic macroinvertebrates, and monitoring was subsequently repeated in August 2015 and again in July 2016 to provide 3 years of data in order to characterise temporal variability in the macroinvertebrate fauna of reference sites and thereby allow development of more robust trigger values. Macroinvertebrates are used as a key indicator group for bioassessment of the health of Australia's streams and rivers under the National River Health Program (NRHP) (Schofield and Davies 1996), and have inherent value for biological monitoring of water quality (ANZECC/ARMCANZ 2000; WRM 2016).

Benthic macroinvertebrates are more easily sampled, function at a lower spatial scale than prawns and fish, are less mobile, are likely more sensitive to changes in water quality, and would not be so susceptible to the challenges that are faced by fish and prawn sampling (WRM 2016). There is also limited likelihood of fauna moving from test sites to reference sites and transferring a mine impact signature (i.e. elevated tissue metal levels) to reference sites as occurs with fish and prawns. The data therefore benefit from higher sample replication and tend to provide higher catch rates and higher data range and variability than the fish and prawn sampling. This supports the application of more complex statistical analysis which ultimately increases confidence in the impact assessment results.

The monitoring program was designed around sampling of water and benthic sediment quality, physical habitat descriptors and benthic macroinvertebrate assemblages from test and reference sites between the Porgera Mine and SG3 (Ambi) on the Strickland River. The sites were chosen to allow direct, pairwise comparison of data between the test and the reference sites. Macroinvertebrates (i.e. fauna visible to the eye and retained by a 250 µm aperture mesh) typically constitute the largest and most conspicuous component of aquatic invertebrate fauna in both lentic (still) and lotic (flowing) waters.

Selected indices that show sensitivity to mine impacts include univariate measures of total species richness (*S*), EPT species richness, and SIGNAL 2 score, and multivariate Bray-Curtis similarity that measures change in whole assemblage composition. This provides four (4) separate indicators of the condition of macroinvertebrate populations at each site (WRM, 2016).

An overall impact rating is then determined for each site by applying a weight of evidence approach using the results of the four (4) selected indicators. Firstly, the result of each indicator at the test site is compared against the respective TV and assigned an impact score depending on the degree of change observed between the test site and the TV, this shown in Figure 2-7 and Table 2-15.

The impact scores for each index are then added together for each site, and an overall impact score is assigned based on the criteria shown in Table 2-16.

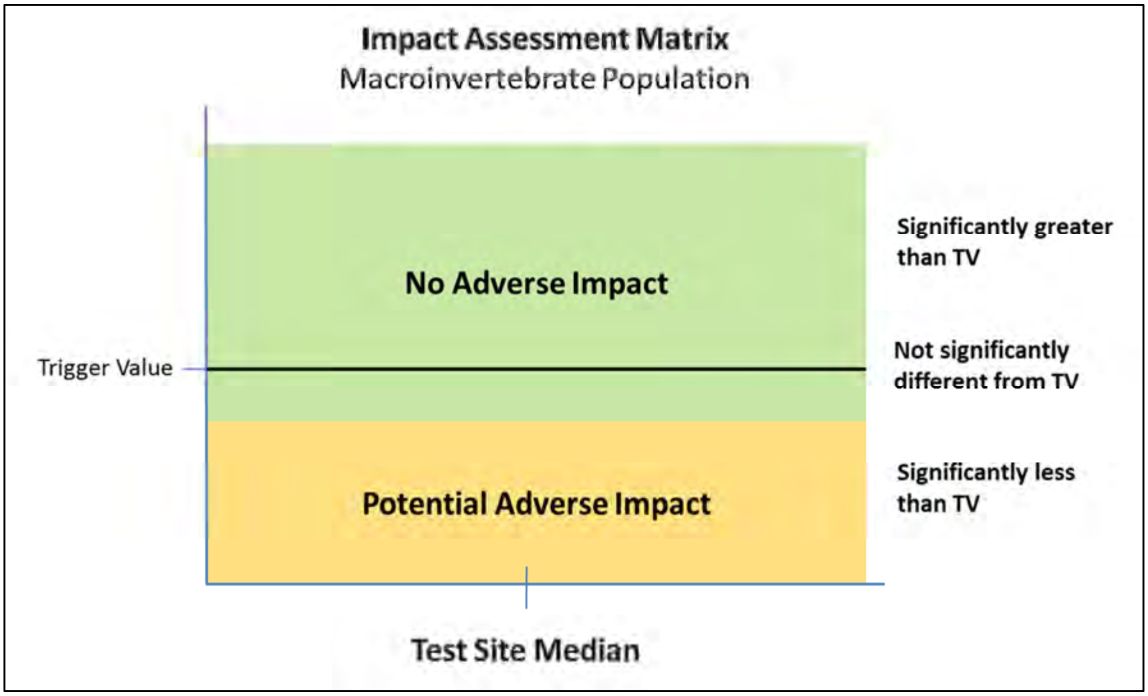


Figure 2-7 Impact assessment matrix – macroinvertebrate populations

Table 2-15 Weight of evidence scoring system for macroinvertebrate impact grades – Score applied to each of the four (4) indices used to show sensitivity to mine inputs

Assessment Result	Impact Category	Degree of Change	Impact Score
TSM significantly > or not significantly different from trigger value	No Adverse Impact	NA	0
TSM significantly < TV	Potential Adverse Impact	TSM <10% different from TV	1
		TSM >10% different from TV	3

Table 2-16 Macroinvertebrate overall site impact grade criteria

Total of weight of evidence score for the four (4) macroinvertebrate indices	Overall Impact Grade
0	No Impact
1 - 4	Low Impact
5 - 9	Medium Impact
>9	High 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 Wilcoxon Signed-rank Test with a probability threshold of $p = 0.05$. The Wilcoxon test is a non-parametric statistical hypothesis test used when comparing two related samples, which uses the rankings of the data and is independent of the absolute values.

The Spearman Rank Test is used to assess trends over time, with a probability threshold of $p = 0.05$. This test also 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).

The impact assessment based on fish and prawn populations is based on a comparison of mean abundance of selected indicator fish and prawn species during 2016, between paired test and reference sites within the upper and lower rivers using a non-parametric statistical method, the two-sample t-test.

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 D, E, F and G respectively.

For macroinvertebrates, a range of univariate and multivariate statistical tests was performed to support the impact assessment using a weight of evidence approach across multiple indices derived from the benthic macroinvertebrate data. The indices include those related to direct taxa richness, as well as indices dependent on number of taxa known to be sensitive to a range of contaminants, and also similarity in overall assemblage composition between reference and test sites.

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 km 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 (2004) 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 operations 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.	Abundance of fish and prawns. Macroinvertebrate assemblages.
Waste rock disposal to water	River profiling: cross-sections. Water quality: TSS concentration, pH, conductivity.	Water quality: pH, conductivity, metal concentration. Benthic sediment quality: Metal concentration. Fish and prawn tissue: metal concentration.	Abundance of fish and prawns. Macroinvertebrate assemblages.
Waste rock disposal to land	Area of disturbance. Volume 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.

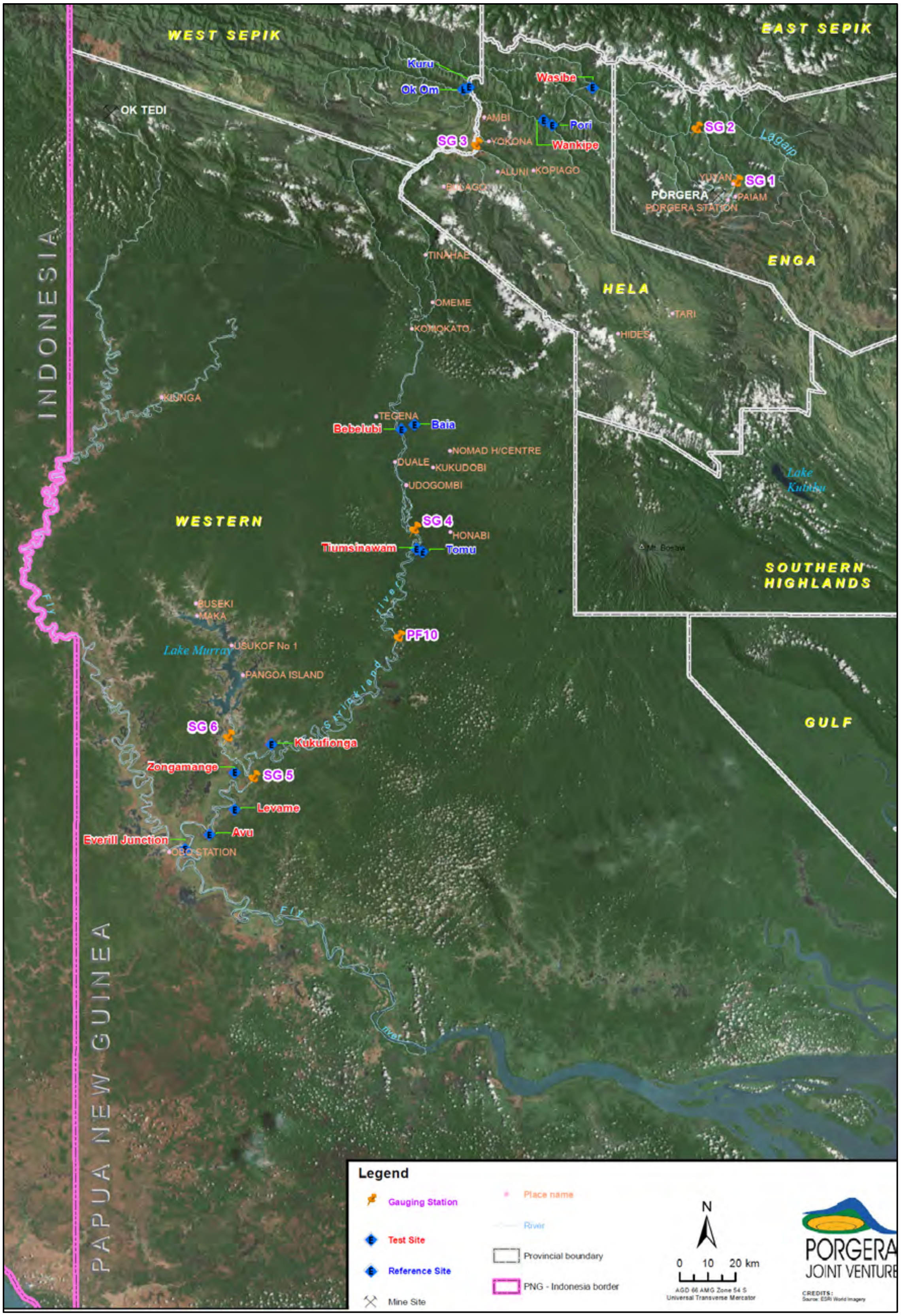


Figure 3-1 Receiving environment monitoring sites

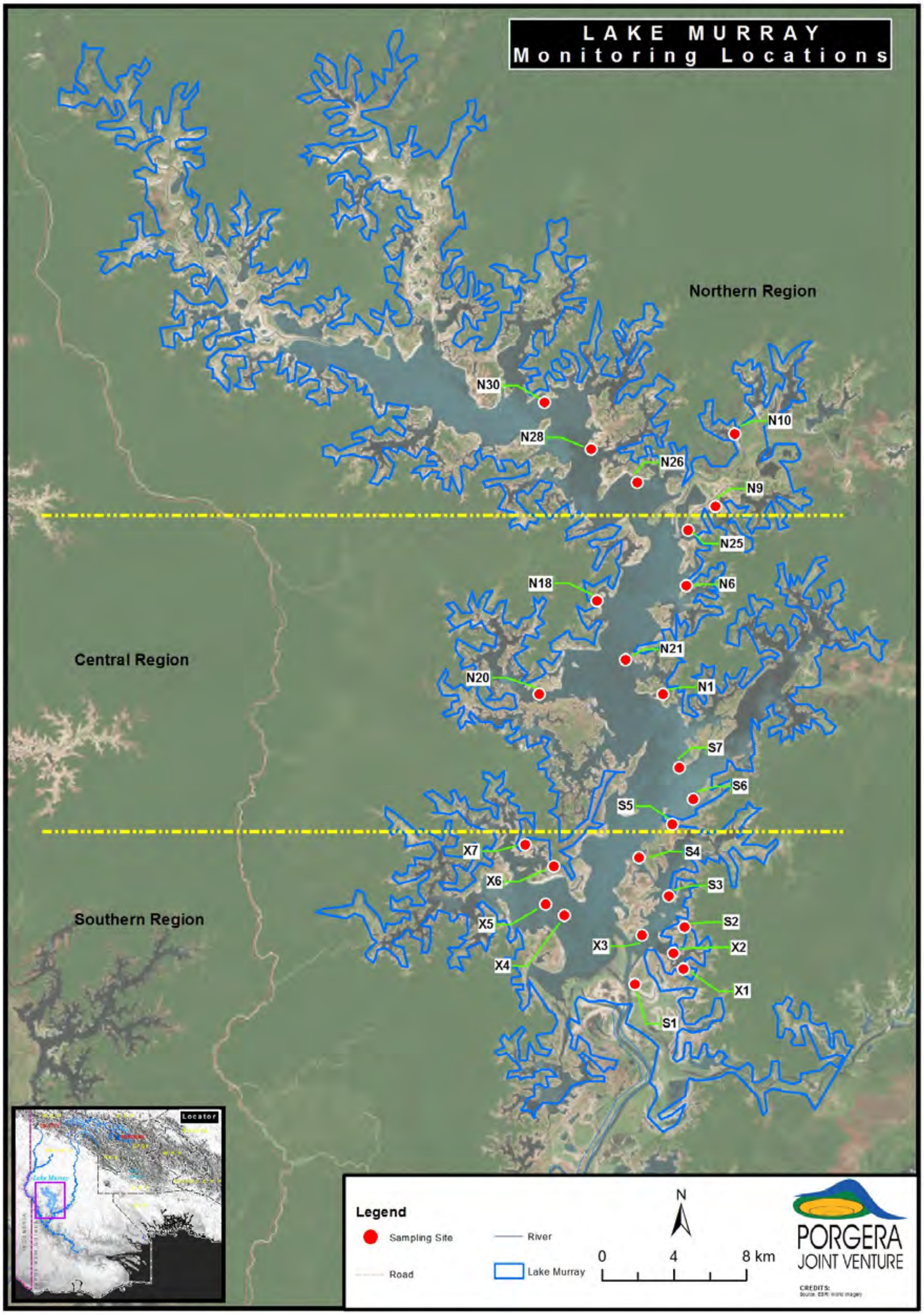


Figure 3-2 Lake Murray monitoring locations

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

<table>
<tr><th colspan="2" rowspan="2">Receiving Environment Test Site</th><th colspan="5">Reference Sites and Parameters</th></tr>
<tr><th>Profile</th><th>Water and/or Sediment</th><th>Tissue Metal</th><th>Fish & Prawn Ab.</th><th>Macro-invertebrate</th></tr>
<tr><td rowspan="5">Upper River</td><td>SG1</td><td>NAR</td><td>Upper Lagaip
Pori
Kuru
Ok Om</td><td>NA[1]</td><td>NA[1]</td><td>NA[1]</td></tr>
<tr><td>SG2</td><td>NAR</td><td>Upper Lagaip
Pori
Kuru
Ok Om</td><td>NA[1]</td><td>NA[1]</td><td>Upper Lagaip</td></tr>
<tr><td>Wasiba</td><td>NA[1]</td><td>Upper Lagaip
Pori
Kuru
Ok Om</td><td>Pori
Kuru
Ok Om</td><td>Ok Om</td><td>Upper Lagaip</td></tr>
<tr><td>Wankipe</td><td>NA[1]</td><td>Upper Lagaip
Pori
Kuru
Ok Om</td><td>Pori
Kuru
Ok Om</td><td>Ok Om</td><td>Upper Lagaip</td></tr>
<tr><td>SG3</td><td>NA[1]</td><td>Upper Lagaip
Pori
Kuru
Ok Om</td><td>NA[1]</td><td>NA[1]</td><td>Ok Om</td></tr>
<tr><td rowspan="4">Lower Strickland River</td><td>Bebelubi</td><td>NA[1]</td><td>Baia</td><td>Baia</td><td>Baia</td><td>NA[1]</td></tr>
<tr><td>SG4</td><td>NA[1]</td><td>Tomu</td><td>Tomu</td><td>Tomu</td><td>NA[1]</td></tr>
<tr><td>PF10</td><td>NAR</td><td>NA[1]</td><td>NA[1]</td><td>NA[1]</td><td>NA[1]</td></tr>
<tr><td>SG5
Upstream of Everil Junction</td><td>NA[1]</td><td>Baia
Tomu</td><td>Baia
Tomu</td><td>Baia
Tomu</td><td>NA[1]</td></tr>
<tr><td>Lake Murray</td><td>South Lake Murray
Central Lake Murray
SG6</td><td>NA[1]</td><td>North Lake Murray</td><td>North Lake Murray</td><td>North Lake Murray</td><td>NA[1]</td></tr>
<tr><td>Off-River Water Bodies</td><td>Kukufionga
Zongamange
Avu
Levame</td><td>NA[1]</td><td>Baia
Tomu</td><td>NA[1]</td><td>NA[1]</td><td>NA[1]</td></tr>
<tr><td>Drinking Water</td><td>Villages surrounding Porgera Mine</td><td>NA[1]</td><td>NA[2]</td><td>NA[1]</td><td>NA[1]</td><td>NA[1]</td></tr>
<tr><td>Air Quality</td><td>Hides Power Station boundary
Villages surrounding Porgera Mine</td><td>NA[1]</td><td>NA[2]</td><td>NA[1]</td><td>NA[1]</td><td>NA[1]</td></tr>
</table>

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 Ab.	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 elevated metals 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 elevated metals 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 elevated metals 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 metals 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 Ab.	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 elevated metals if migrating between test and ref sites.
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 elevated metals if migrating between test and ref sites.
North Lake Murray	Good	Good	Good	NA	North Lake Murray is physically connected to the central and southern lake and can be theoretically potentially impacted by mine aspects.

1 – For water

2 – For water, benthic sediment and tissue metals

3.2.3 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.

Table 3-5 Monitoring compliance to plan in 2016

Discipline	Compliance to Plan (%)
Biology	95
Hydrology	95
Chemistry	95

3.2.4 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 and benthic sediment was performed by the NATA-certified Australian Laboratory Services (ALS) laboratory in Brisbane, and in prawn and fish tissue by the 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. Some contamination of blanks and deviation from the required levels of recovery for duplicates was observed on occasion during the year. However, for the monitoring of contaminants, this is considered acceptable as it leads to an overestimation of risk. Based on positive field blank and field duplicate results, 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:

- Completion of training and competency system development and implementation.
- Inclusion of field duplicates and field blanks with each tissue metal batch.
- More timely investigation of poor QA&QC results to allow for corrective action to be taken.

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 2016 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 2016

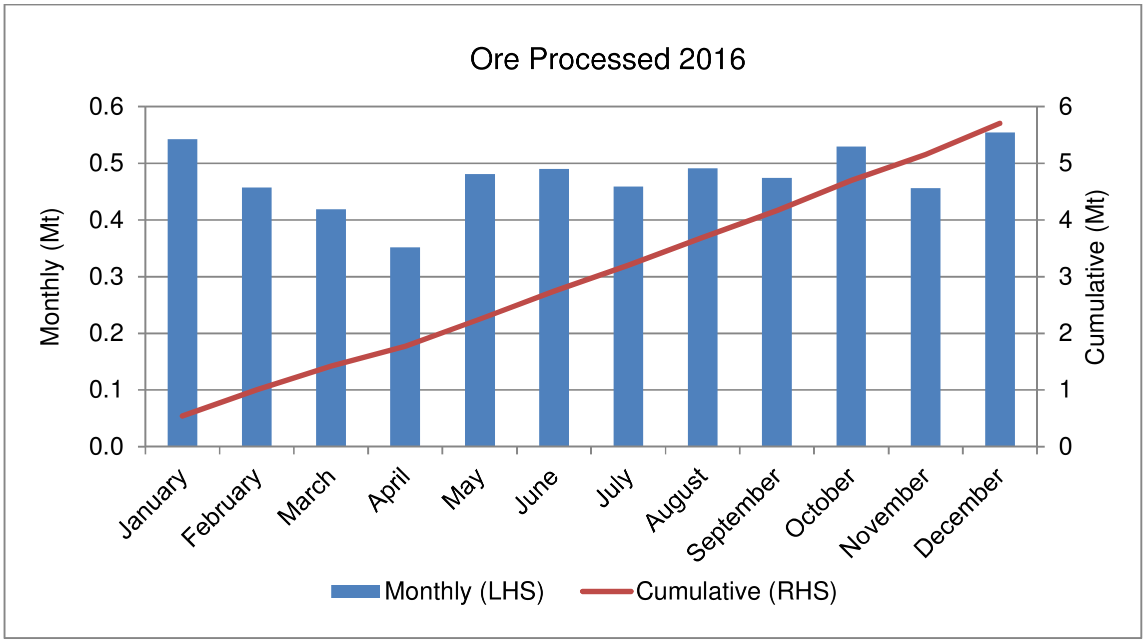
Operational and Environmental Aspects	2016	Life of Mine Total	Comments
Ore processed (Mt)	5.71	125.08	Consistent with recent years.
Gold production (oz)	488,977	19,707,506	Below 2016 guidance.
Competent waste rock produced (Mt)	4.76	423.83	Consistent with previous years.
Incompetent waste rock produced – Anawe (Mt)	4.35	228.40	Consistent with previous years.
Incompetent waste rock produced – Anjolek (Mt)	3.62	225.56	Consistent with previous years.
Tailings to underground paste (% total tailings volume)	12.4	NA	Record volume diverted in 2016.
Tailings discharged (Mt)	5.33	121.97	Consistent with recent years.
Total sediment discharged to river (Mt) (from tailings and erodible dumps)	14.0	NA	Higher than recent years due to higher rainfall increasing erosion of the erodible dumps.
Sewage discharge (m^3)	244,073	NA	Consistent with recent years.
Mine contact rainfall runoff (Mm^3)	7,603,267	NA	Higher than previous years due to higher rainfall.
Greenhouse gas and energy efficiency (kg CO2-e / t processed ore)	78	NA	0.8% reduced emission rate compared to 2015, negative trend maintained.
Water use and efficiency (L / t processed ore)	4,990	NA	3.4% increased efficiency compared to 2015.
Area land disturbed (ha)	2336.6	41% of total leased area is undisturbed.	
Area of disturbed land under rehab (ha)	239.2	10% of total disturbed land.	

4.1 Production

4.1.1 Mining and Processing Operations

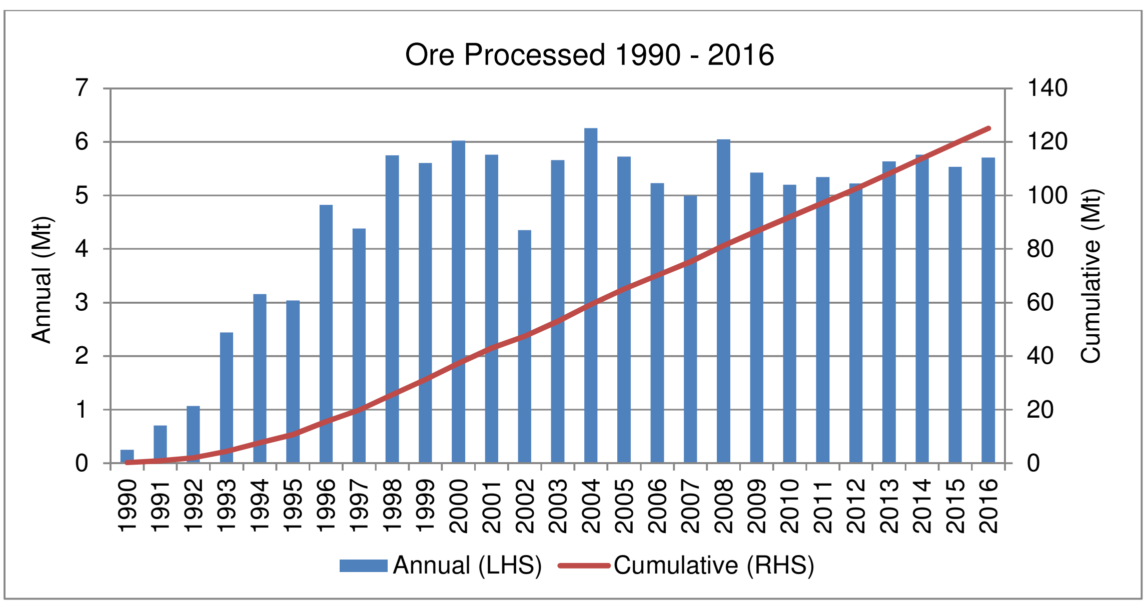
4.1.1.1 Total ore processed

The total quantity of ore processed in 2016 was 5.71 million tonnes (Mt). Figure 4-1 shows the monthly and cumulative quantities of ore processed in 2016. The cumulative quantity of ore processed from 1990 to 2016 was 125.1 Mt. Figure 4-2 shows annual and cumulative quantities of processed ore since production began in 1990.



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

Figure 4-1 Monthly and cumulative ore processed in 2016

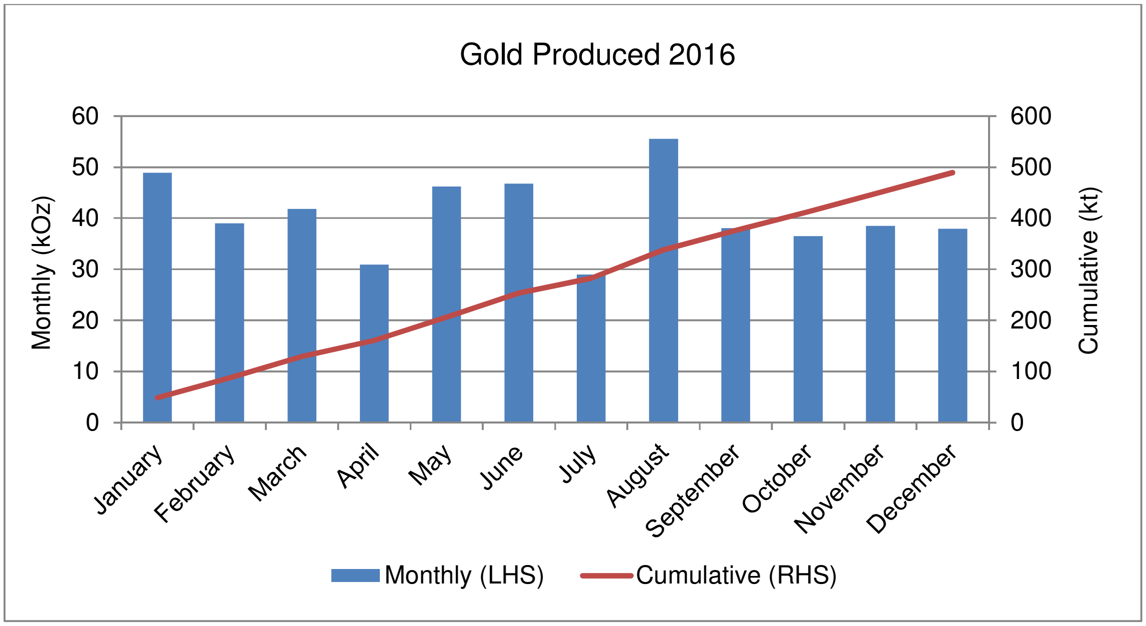


LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-2 Yearly and cumulative ore processed 1990 - 2016

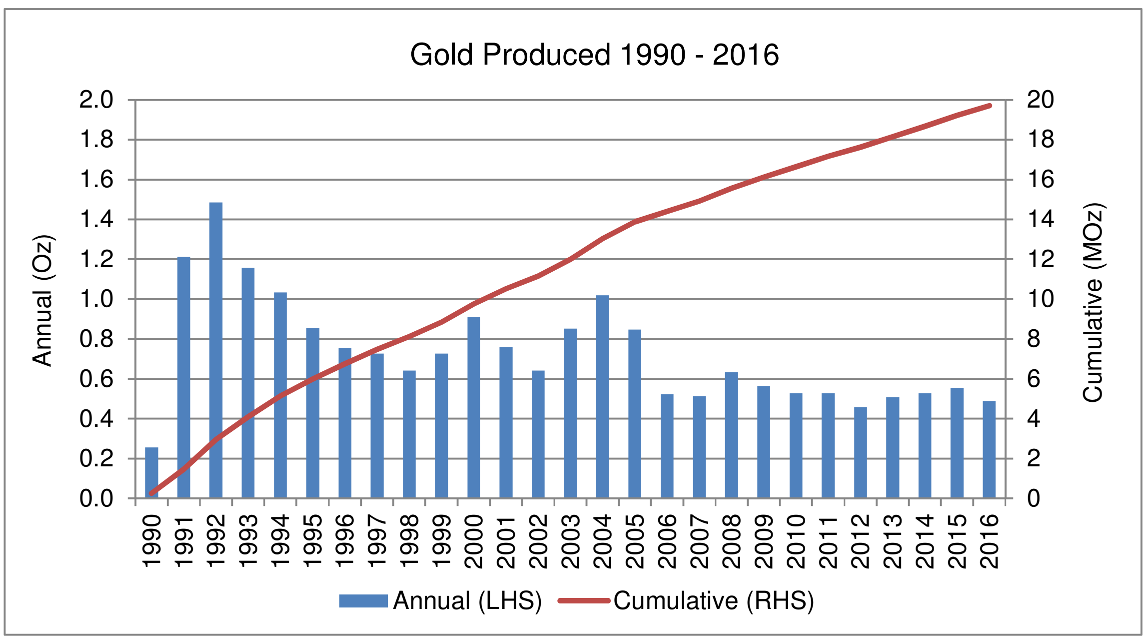
4.1.1.2 Gold production

Total gold production in 2016 was 489 koz. Figure 4-3 shows monthly and cumulative gold production during 2016. Total gold production from 1990 to 2016 was 19.7 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 2016



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

Figure 4-4 Yearly and cumulative gold production 1990 – 2016

4.2 Water Use

Figure 4-5 shows the annual average water use rate per tonne of ore processed. The pressure oxidation of pyrite ore in autoclaves produces sulfuric acid liquor as a by-product which requires significant quantities of water for washing the acidic liquor from the oxidised solids.

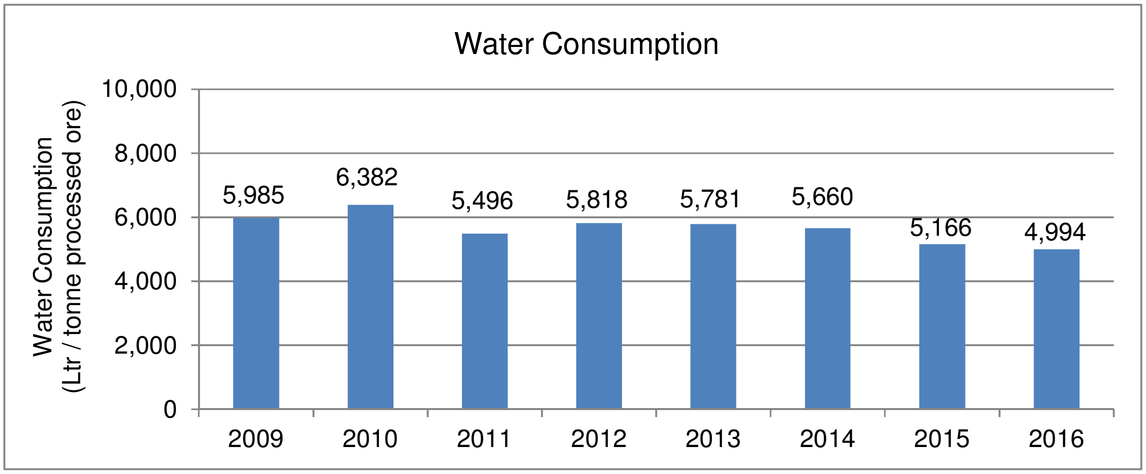


Figure 4-5 Water use efficiency 2009 - 2016

4.3 Land Disturbance

4.3.1 Land Disturbance

Porgera mine holds eight leases with a total area of 3,926.79 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 surrounds 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 2016 was 2,336.6 ha, equating to approximately 59% of the total leased areas. The total area of disturbance increased by 14.3 ha during 2016, comprising: 6.3 ha due to expansion of the erodible dumps; 4.9 ha due to expansion of the Kogai competent dump; 2.0 ha due to mining expansion at the Open pit, and 1.0 ha due to expansion of the Pangalita limestone quarry.

Table 4-2 Areas of cumulative land disturbance and reclamation to December 2016

Lease	Total Lease Area (ha)	Disturbed (ha)	Undisturbed (ha)	Under Progressive Reclamation (ha)
SML	2106.85	1360.10	746.75	239.19
Kogai LMP	424.42	178.91	245.51	0
Kaiya LMP	601.98	345.19	256.79	0
Anawe North LMP 72	219.48	116.91	102.57	0
Anawe South LMP 77	203.87	132.30	71.57	0
Anawe LMP3	80.83	80.83	0.00	0
Suyan LMP	69.43	44.60	24.83	0

Lease	Total Lease Area (ha)	Disturbed (ha)	Undisturbed (ha)	Under Progressive Reclamation (ha)
Pangalita LMP	134.91	62.06	72.85	0
Waile LMP	85	15.70	69.30	0
TOTAL	**3,926.77**	**2,336.60**	**1,590.17**	**239.19** (10.2% of disturbed)

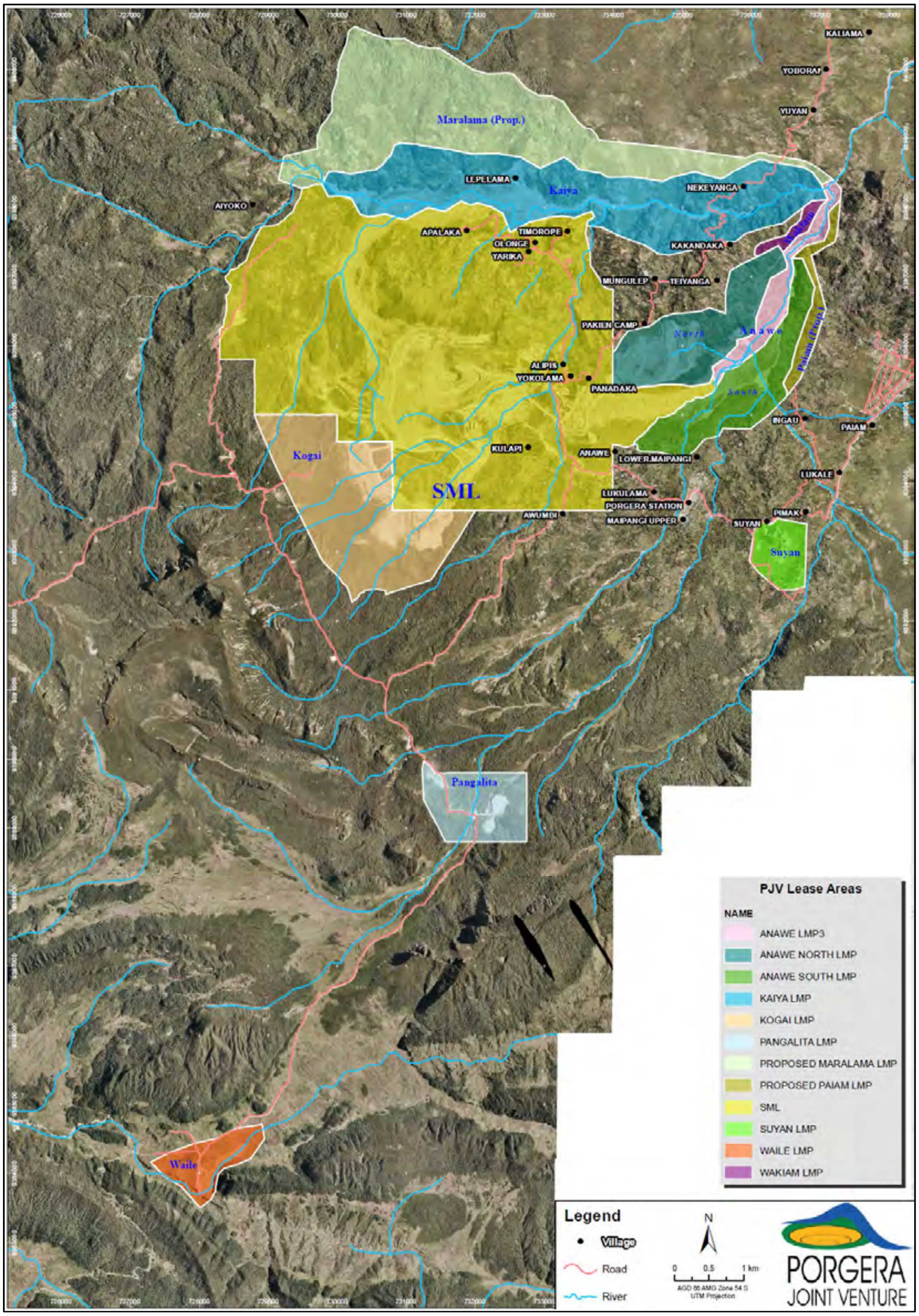


Figure 4-6 Special mining lease and leases for mining purposes boundaries

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 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.

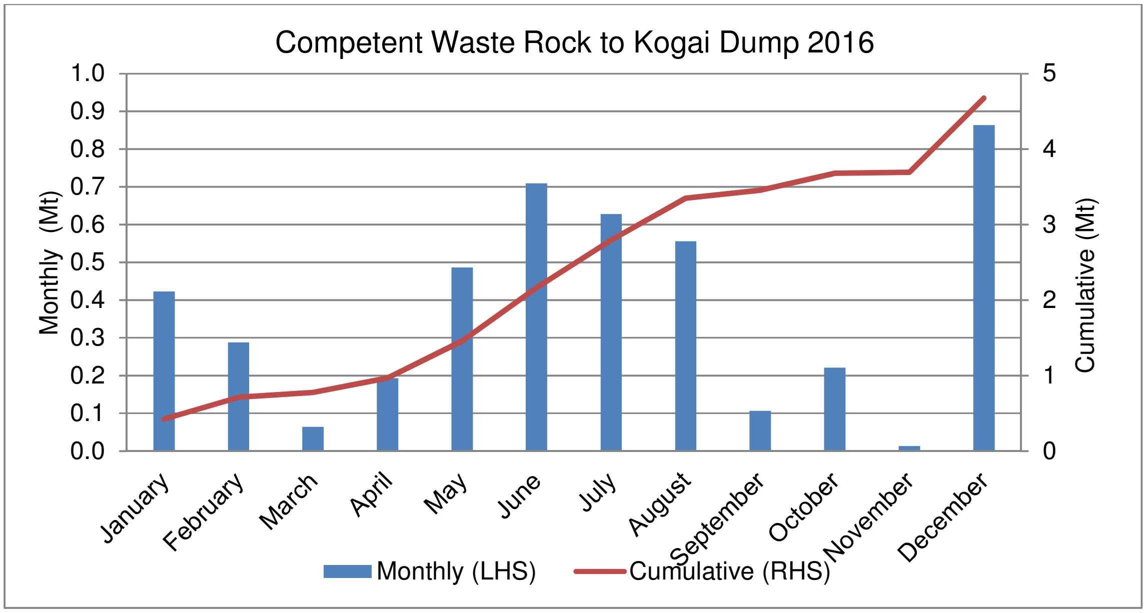
The mass of competent and incompetent waste rock produced and its disposal location between 1989 and 2016 are presented in Table 4-3. The data show that to date, the quantity of competent waste rock placed at Kogai dump is approximately twice the total amount placed at Anawe North competent dump since 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 – 2016

Waste Dump	Total Volume (Mt)
Anawe North Competent	134.31
Kogai Competent	289.52
Competent Sub-Total	***423.83***
Anawe Erodible	228.40
Anjolek Erodible	225.56
Erodible Sub-Total	***453.96***
TOTAL	**877.79**

4.4.1 Kogai Competent Dump

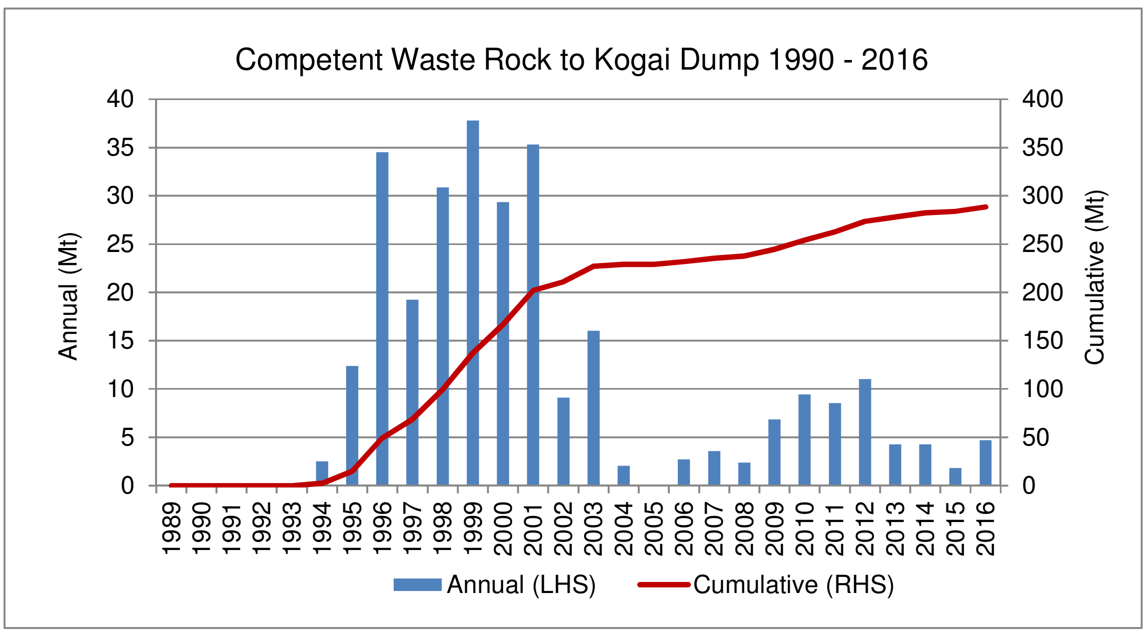
The total quantity of competent waste rock placed at the Kogai dump in 2016 was 4.68 million tonnes. Figure 4-7 shows the monthly and cumulative quantities placed at Kogai dump during 2016. The dump received the competent waste rock mined from Stage 5C of the Open Pit during the year.



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 2016

The total quantity of competent waste rock placed at Kogai dump since 1992 was 289 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 levels of the open pit.

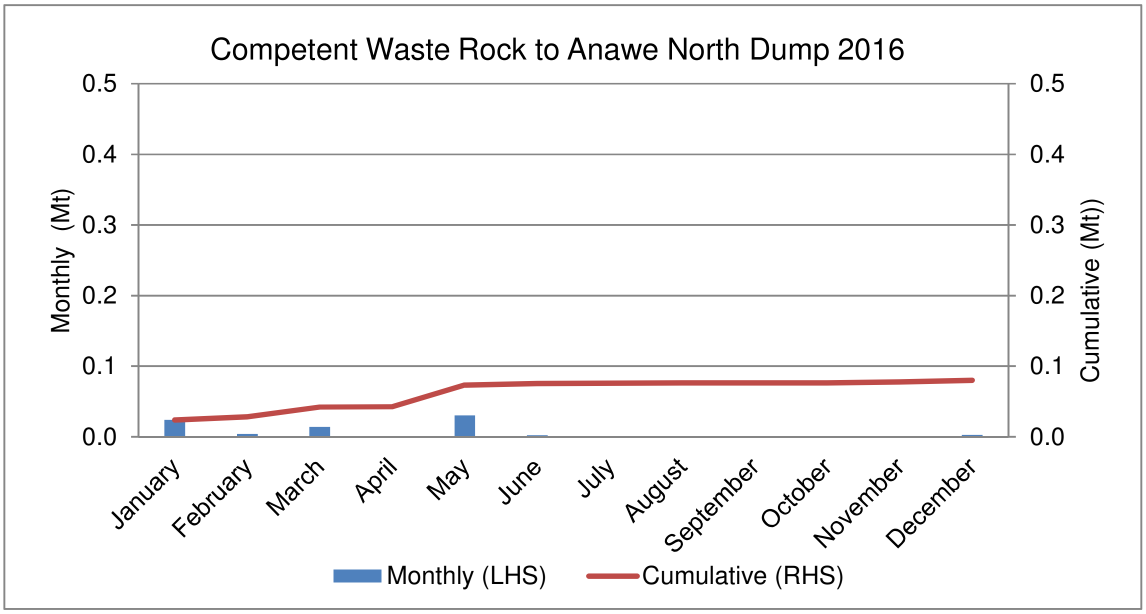


LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-8 Yearly tonnages of competent waste rock placed at Kogai Dump 1989 - 2016

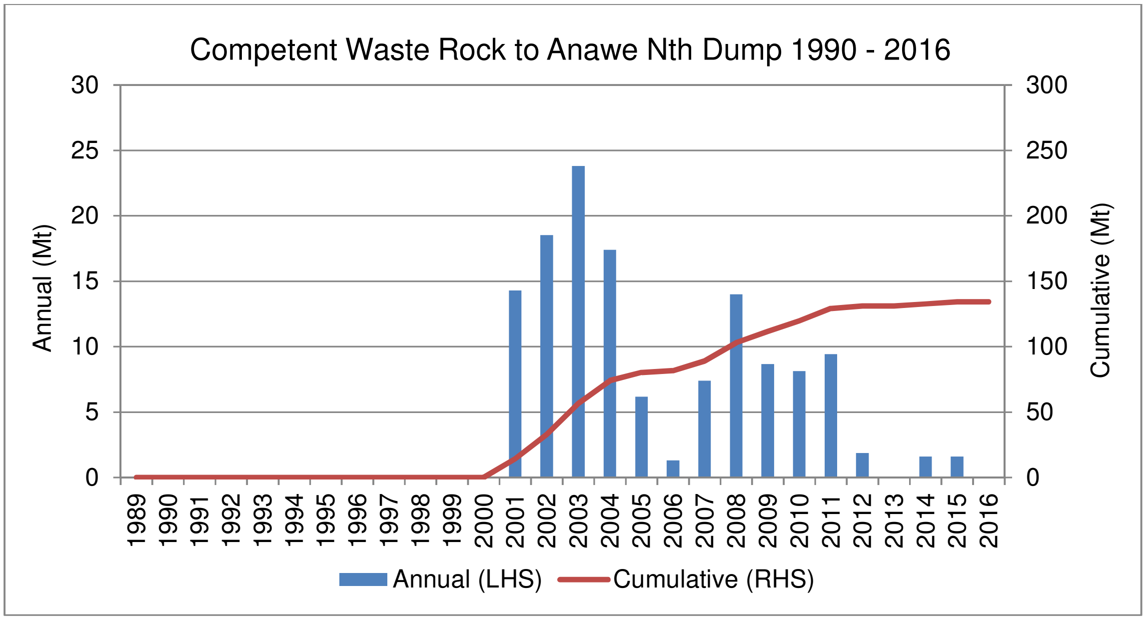
4.4.2 Anawe North Competent Dump

Anawe North received 0.08 Mt of competent waste rock in 2016. Figure 4-9 shows the monthly and cumulative quantities of competent rock placed at Anawe North during 2016. The total quantity of competent waste rock placed at Anawe North dump since construction began in 2001 was 134.3 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 2016



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

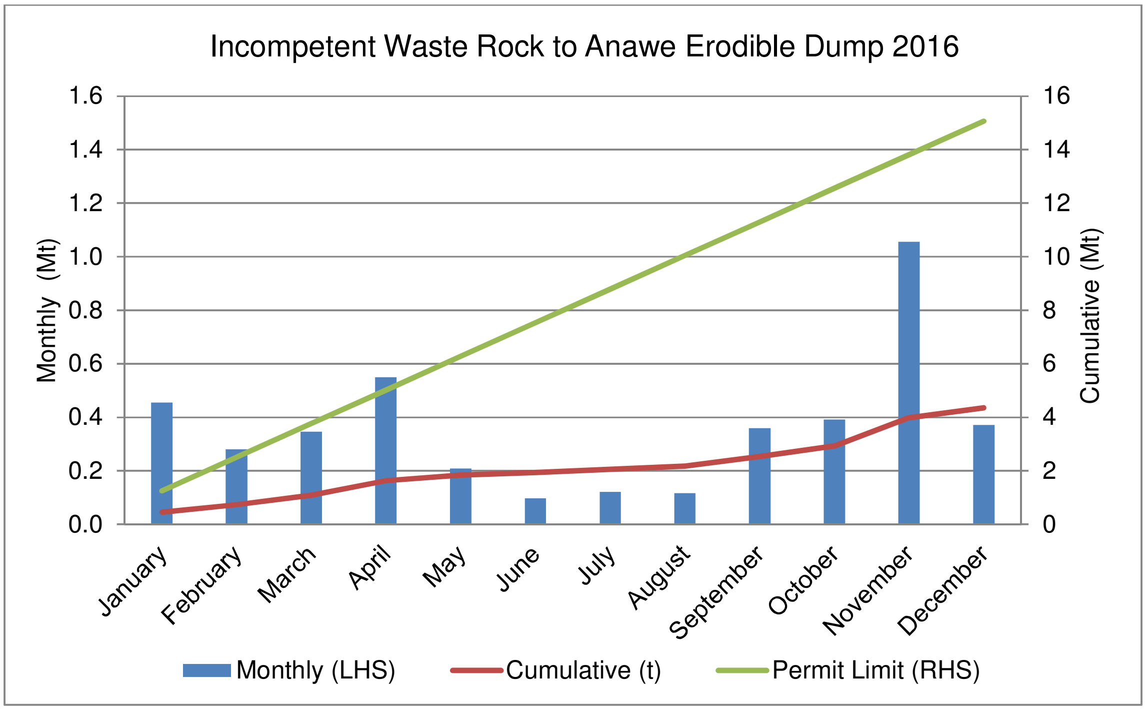
Figure 4-10 Yearly tonnages of competent waste rock placed at Anawe North Dump 2001-2016

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 2016 were slightly less than previous years due to decreased mining of incompetent material from the bottom of the open pit.

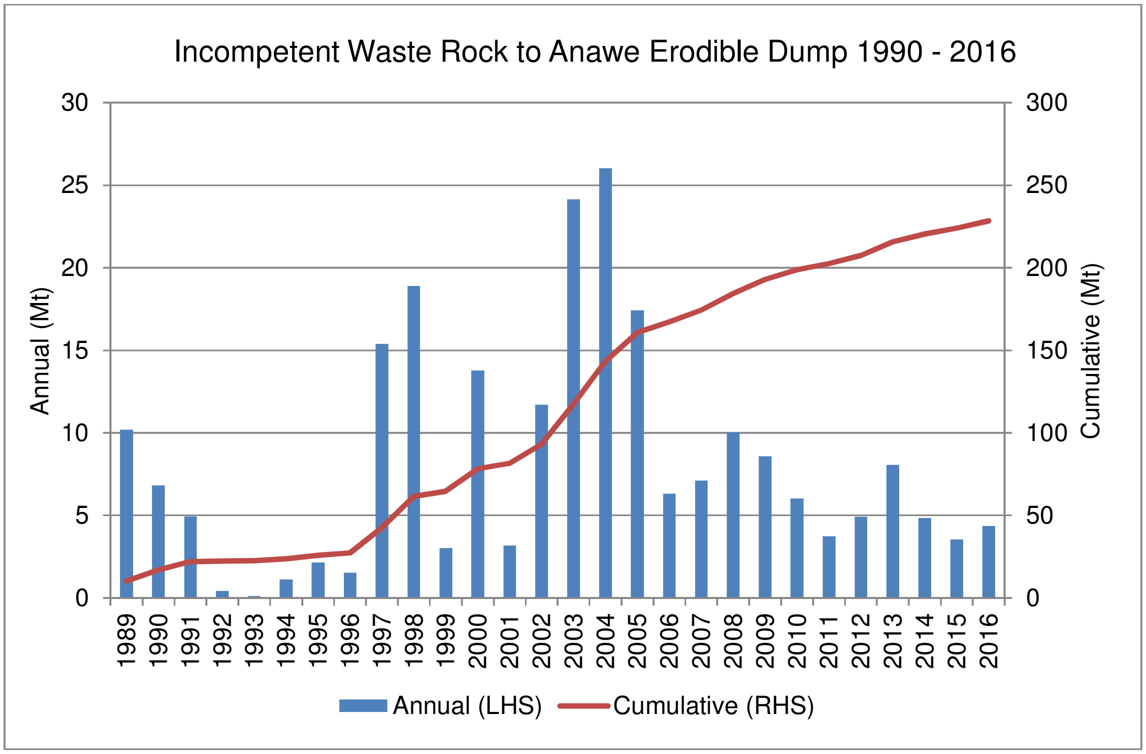
4.5.1.1 Anawe Erodible Dump

Monthly tonnages of incompetent waste rock disposed to Anawe erodible dump in 2016 are shown in Figure 4-11. A total of 4.4 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 29% 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 2016



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 July 1989-2016

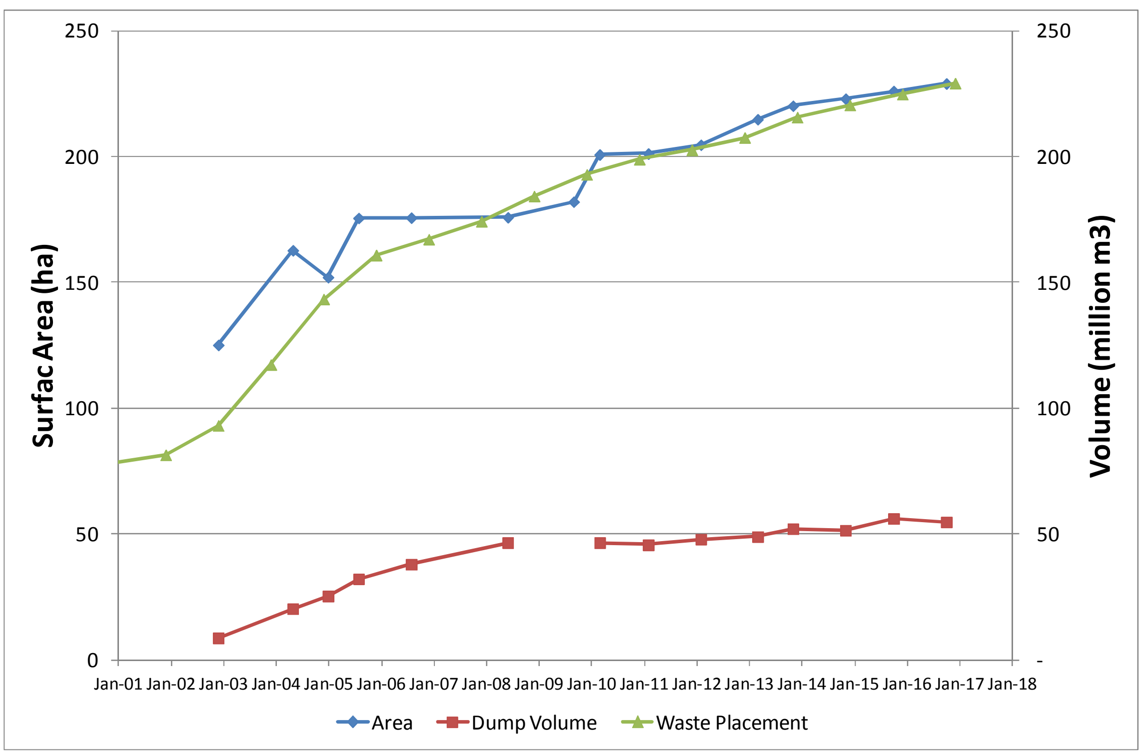
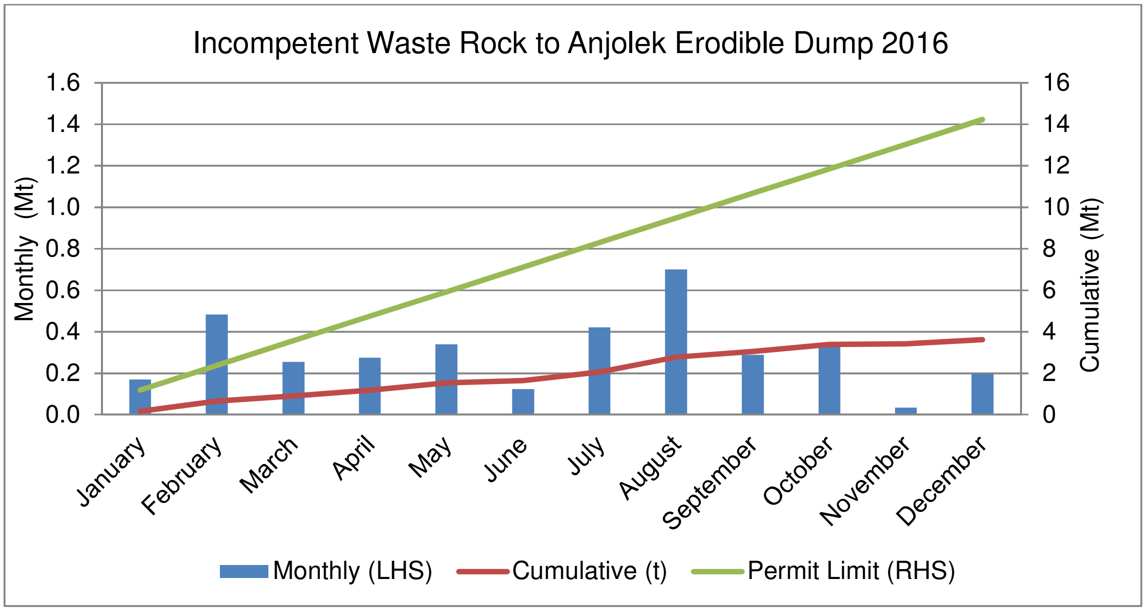


Figure 4-13 Area and volume of Anawe Erodible Dump based on LiDAR survey 2001-2016

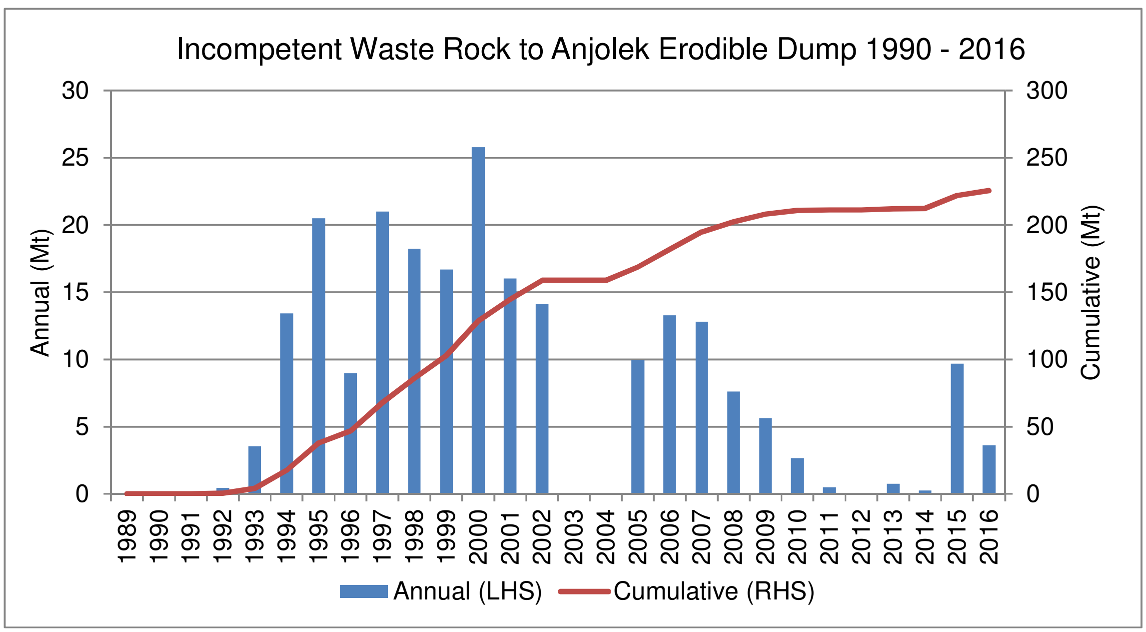
4.5.1.2 *Anjolek Erodible Dump*

Figure 4-14 shows monthly tonnages of incompetent waste rock disposed to Anjolek dump during 2016. A total of 3.6 Mt was placed during the year, the majority of which was mudstone from a cut-back of the west wall of the open pit. This was equivalent to 25% of the annual permit limit of 14.23 Mt. The quantity dumped in 2016 was significantly less than in 2015 due to a decrease in mining of the west wall cut-back during 2016. Figure 4-15 shows the tonnage of incompetent waste rock placed in the Anjolek 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 2016



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 1992-2016

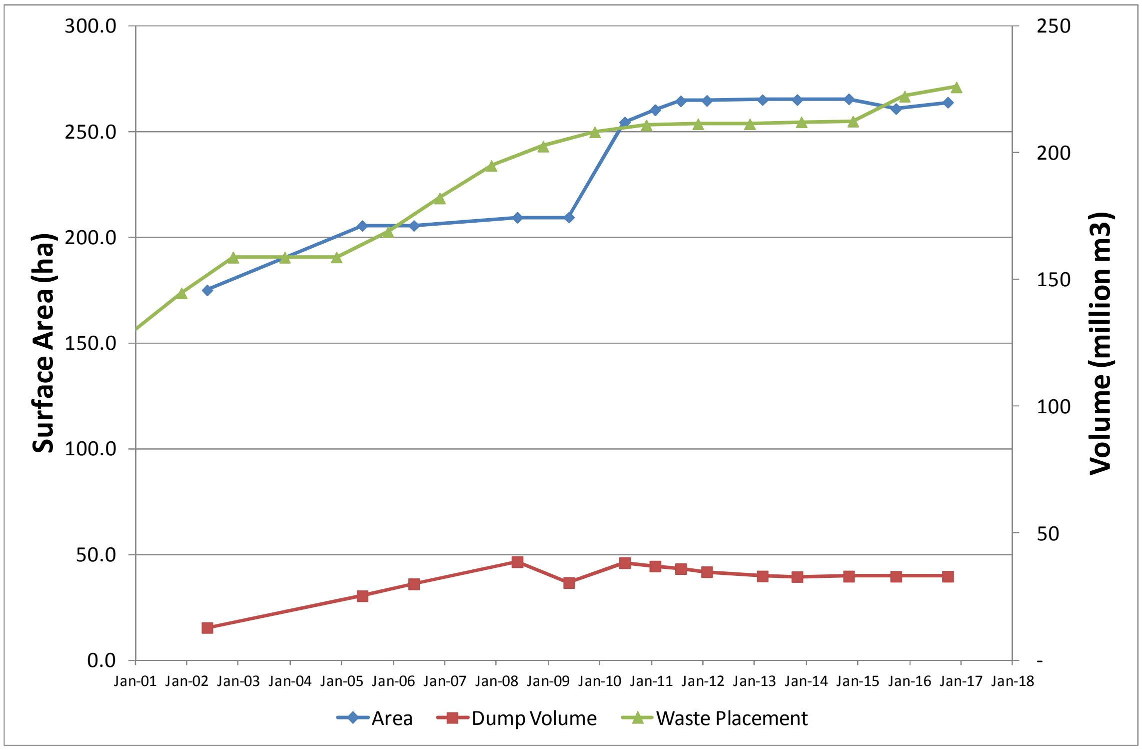


Figure 4-16 Area and volume of Anjolek Erodible Dump based on LiDAR survey 2001-2016

4.6 Status of the Erodible Dumps in 2016

4.6.1 Anawe Erodible Dump

An aerial inspection and review of survey data for 2016 showed that there had been little change in the morphology of the dump since 2015. Survey data showed that:

- In the upper tract (between the tip-heads and the Maiapam area) (Figure 4-17), the dump surface was well below historic higher levels and close to the original topographic surface. The elevation was similar to the 2015 surface.
- From about the Maiapam area to the toe area, the dump thickens considerably and recent surfaces are higher than historic levels (Figure 4-18). The 2016 surface was similar to the 2015 surface. Accelerated thickening in this area has been occurring since about 2014.
- Survey data indicate that the location of the toe has progressed downstream about 200 m since 2009, but the current location is stable compared with the 2015 survey.
- The most notable thickening has occurred in areas adjacent to the Pongema River between the Pongema Fan and the Toe. In some areas the 2016 surface was higher than all previous surfaces.
- Survey data indicated a modest increase of dump surface area (3.3 ha), and a minor reduction in overall volume (1.4 Mm^3).
- There were no significant changes to the areas of previous concern, notably the Maiapam slide toe complex and the Maiapam overspill area.

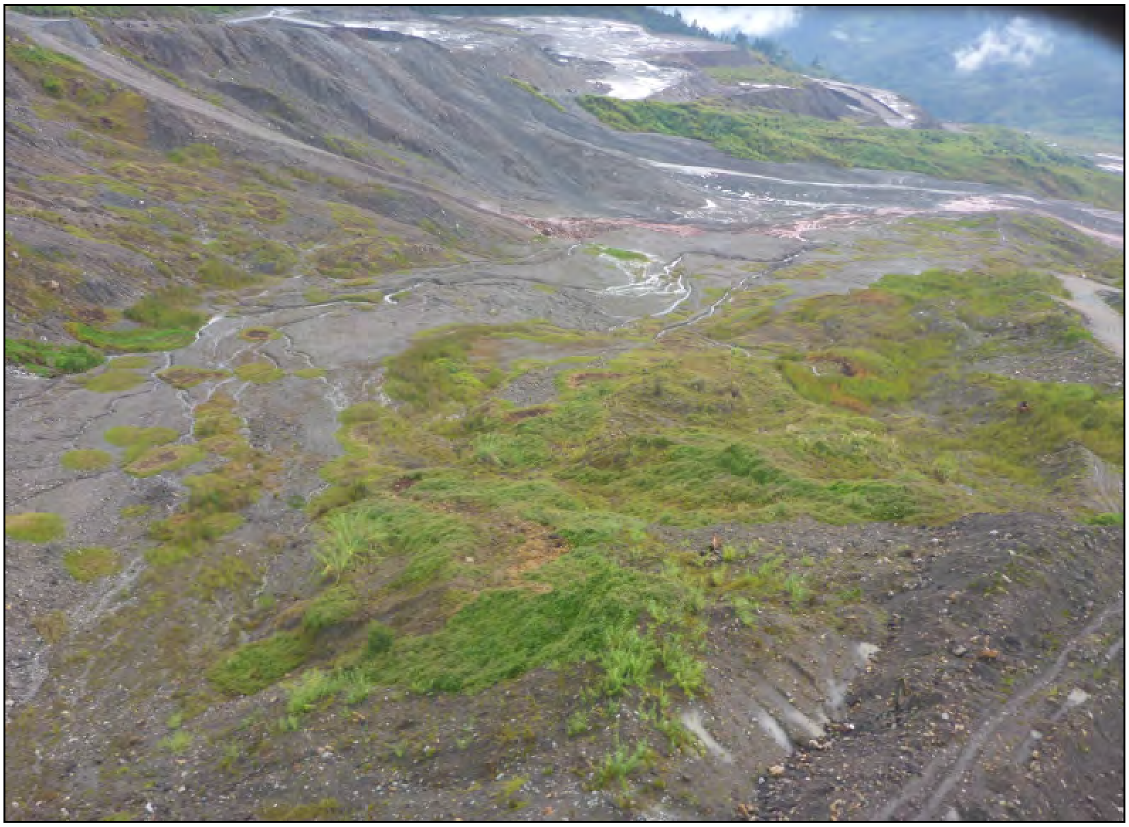


Figure 4-17 Anawe looking downstream from tip-head showing eroded and concave surface profile

Figure 4-18 Anawe looking downstream over Pongema Fan showing area of thickening

4.6.2 Anjolek Erodible Dump

Similar to Anawe, the overall morphology of Anjolek Dump appeared relatively unchanged compared with the 2015 survey. Data showed that:

- Below the tip-heads, the 2016 surface was similar to the 2015 surface, well below the 2009 surface but above the surfaces between 2011 and 2013.
- In the area adjacent to Kaiya River Fan where the dump turns to the right (east), the 2015 and 2016 surfaces are at a similar elevation and close to the base topography level.
- In the Kaiya River Valley, the 2016 surface is similar to the 2015 surface, below the level of previous higher surfaces. However in the lower part of the Kaiya River Valley near the toe, the dump surface has continually eroded down since about 2012, following the rapid forward surge and thickening at the toe that occurred during 2011.
- In about 2010, there was thickening in the upper Kaiya River Valley, and at the same time thickening near the toe as the dump material advanced. The surface in this area has remained relatively steady since 2010.
- Notable erosion of the toe area occurred after 2013. Since then the toe has remained relatively static although the surface is eroding back and there is a more gentle transition between the toe area and Kaiya River, making the identification of the exact location of the toe more difficult.
- Survey data indicated a minor increase in dump volume (0.02 Mm^3) and a minor increase in surface area of 3 ha.
- The most significant change to the dump was an avulsion of the Kaiya River (Figure 4-19) that had reverted back to a former course adjacent to the northern slopes, from its most recent position that occupied a central course through the dump. It is thought that this avulsion occurred in late 2016 after the 2016 survey had been completed. This may result in increased rates of fluvial erosion of the base of the northern slopes (Figure 4-20).
- Inspection of the confluence of Kaiya River and Kogai Creek showed that there was no apparent sediment-related impact from upstream earthworks at Yarik Portal. Localised aggradation may have occurred and on-ground survey would be required to confirm this.

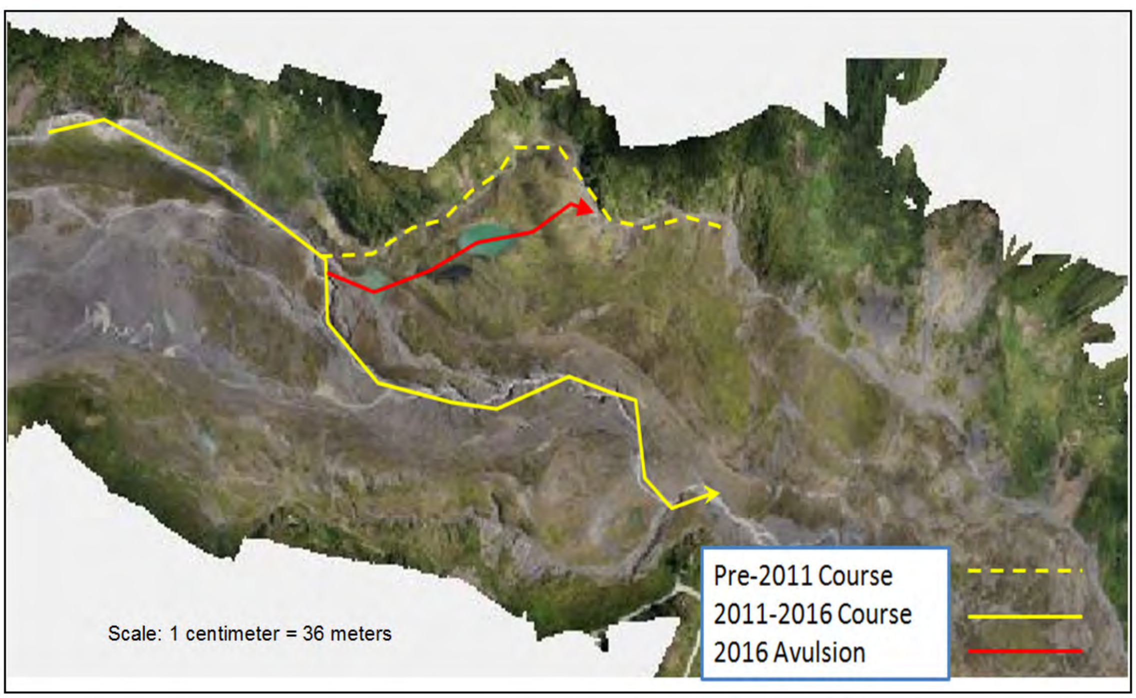


Figure 4-19 Preliminary assessment of Kaiya River avulsion

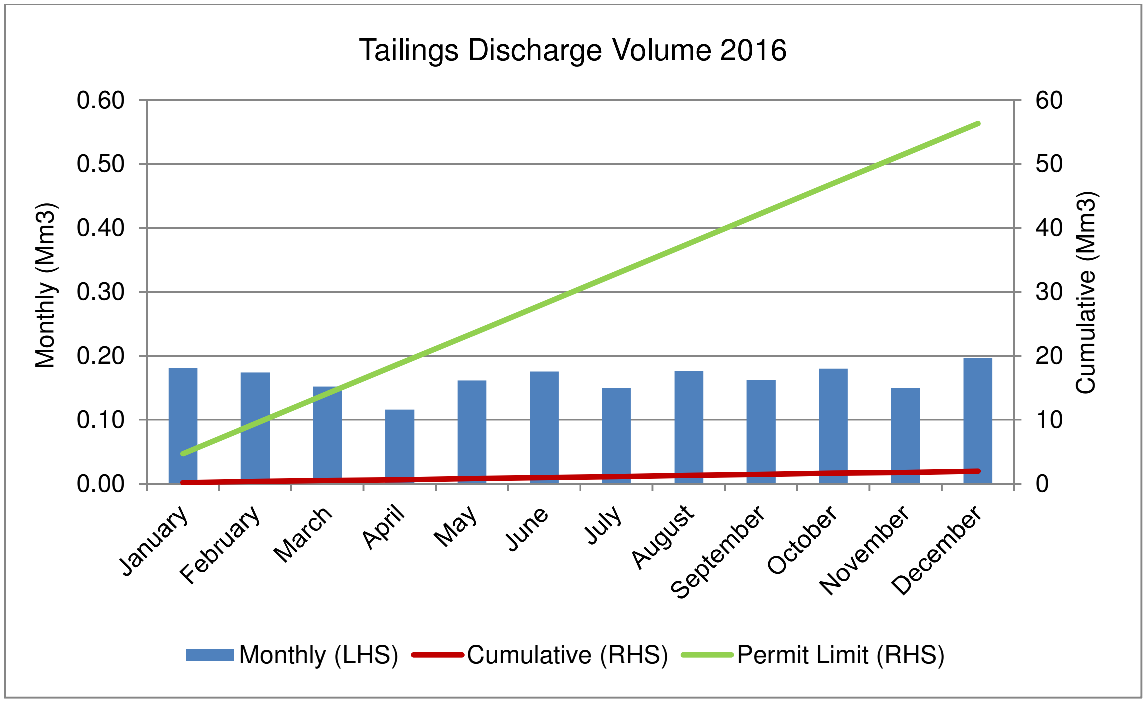
Figure 4-20 New course of Kaiya River adjacent to northern slopes

4.7 Tailings Disposal

4.7.1 Riverine Tailings Disposal

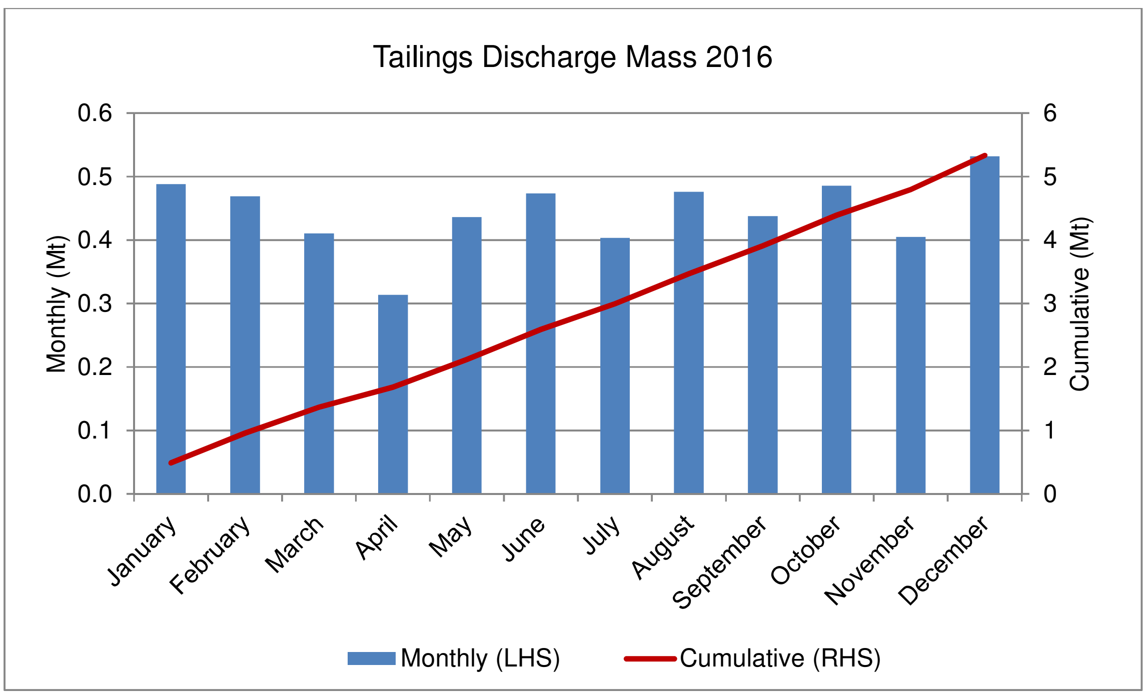
Monthly and cumulative volumes (m^3) of tailings solids discharged in 2016 are shown in Figure 4-21 and are reported in m^3 for comparison with the permit limits which are applied in m^3. The total volume of tailings solids discharged in 2016 was 1.97 Mm^3 and is compliant with the environmental permit discharge limits of 56.35 m^3.

The yearly and cumulative mass (t) of tailings solids discharged over the life of the mine are shown in Figure 4-23, and show the mass discharged in 2016 was consistent with historical volumes. Discharge mass (t) is reported to allow comparison with erodible waste rock discharge mass.



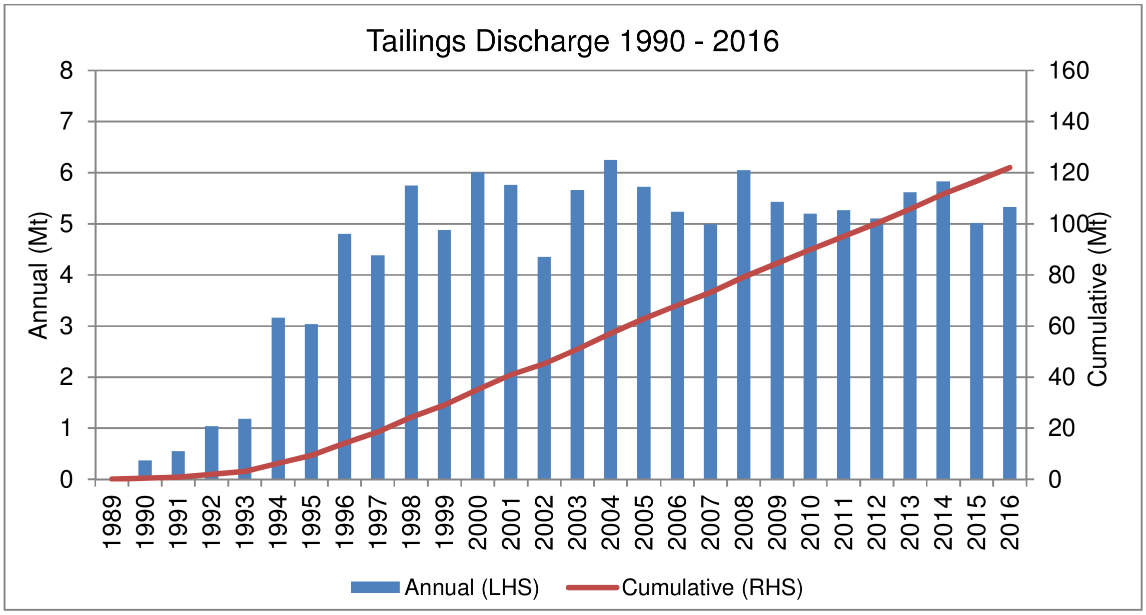
LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-21 2016 Monthly and cumulative tailings discharge volumes (Mm^3)



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

Figure 4-22 2016 Monthly and cumulative tailings discharge mass (Mt)

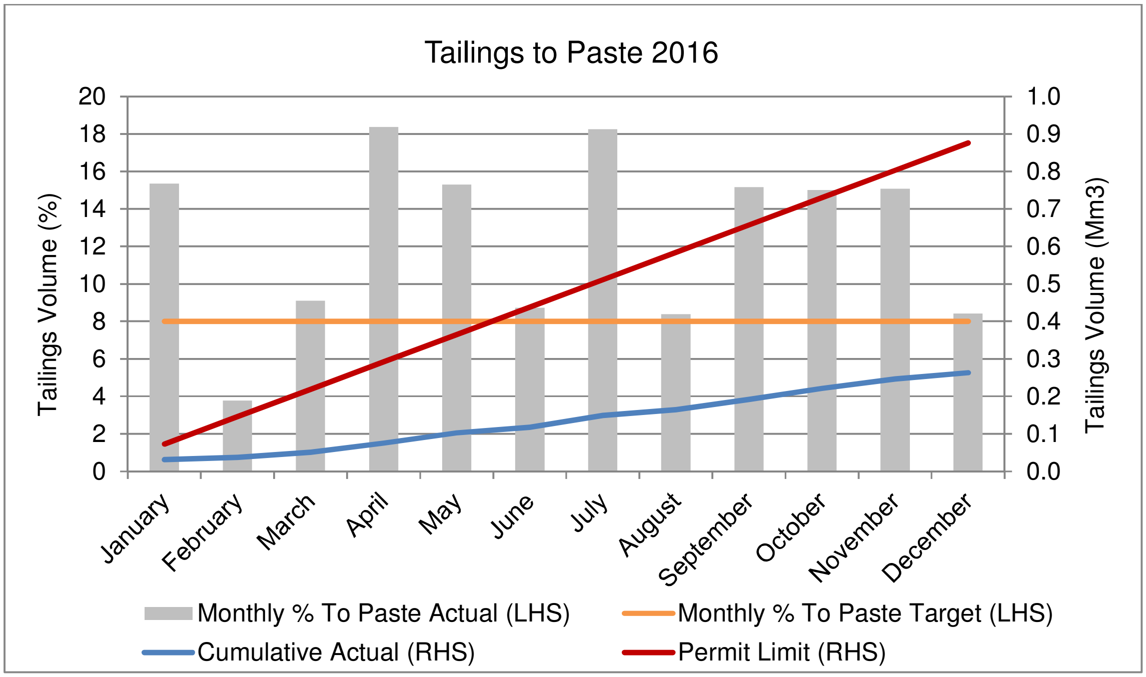


LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-23 Annual and cumulative tailings discharge mass (Mt) (dry solids) (1989-2016)

4.7.2 Tailings used as Underground Mine Backfill

The paste plant operated consistently throughout 2016. The monthly and cumulative volumes diverted to the underground mine are shown in Figure 4-24. A total of 262,870 m^3 of the coarse fraction of tailings were diverted to paste in 2016, which is approximately 12.5 % of the total tailings volume produced. The volume of tailings diverted in 2016 was the highest in the sites history and is attributed to the high rates of availability of the paste plant and increased underground mining.



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

Figure 4-24 Tailings diverted to underground backfill in 2016

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. A summary of 2016 tailings quality is shown in Table 4-4.

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 TSS concentration of the tailings, and the rate of discharge have remained relatively consistent throughout the history of the operation. Discharge volumes and TSS concentrations in 2016 were consistent with historical levels. Monthly and annual TSS concentrations in the tailings discharge are shown in Figure 4-25 and Figure 4-26. The Figures use box plots to present the full data sets within each period, box plots are explained in Appendix B.

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 into solution during the oxidation process, which reaches 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.

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 expert advice in 2012 the criterion has been set between pH 6.3 and pH 7.0.

Discharge during 2016 achieved 99% compliance with the internal site-developed end-of-pipe criteria for pH. The results for 2016 are shown in Figure 4-27. Variation from the target occurred as a result of a high pH event in November due to an operational requirement to divert flotation tailings directly into the final neutralization tank during a major shut-down of the autoclaves and the leach circuit. Results from 2007 – 2016 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 2016 were low and in full compliance with the site-developed end of pipe criterion. The monthly WAD-CN results for 2016 are shown in Figure 4-30. The performance achieved during 2016 has continued the trend of low WAD-CN concentrations demonstrated since the commissioning of the CN 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 Trigger Action Response Plan (TARP) for managing the operation of the treatment circuit.

The 20%ile, median and 80%ile concentrations of total and dissolved metals in the tailings slurry (water/solids mixture) during 2016 are shown in Table 4-4. Monthly concentrations for 2016 and annual concentrations between 2007 and 2016 are shown as box plots in Figure 4-33 to Figure 4-54 for all metals. An explanation of box plots is given at Appendix B.

In 2016, the tailings exhibited elevated concentrations of total silver, arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead and zinc, compared with upper river reference conditions and low concentrations of total selenium.

Median concentrations of dissolved cadmium, copper, nickel and zinc in tailings slurry were elevated in 2016. Moderate proportions of cadmium (6.1%), nickel (24%) and zinc (9.4%) were present in dissolved forms throughout 2016 as shown in Table 4-5.

Metals concentrations in tailings solids are presented in Table 4-6 and show that concentrations of WAE arsenic, WAE cadmium, WAE copper, WAE mercury, WAE lead and WAE zinc were higher than the upper river trigger values and therefore pose a potential risk to the receiving environment.

Statistical analysis of the trends of parameters in tailings discharge between 2007 and 2017 was performed using the Spearman Rank Test. The results are presented in Table 4-7. The results show a statistically significant increase in the concentrations of alkalinity, dissolved and total cadmium, total chromium, dissolved copper, dissolved and total nickel and dissolved zinc between 2007 and 2017. 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 4-4 Tailings slurry discharge quality 2016 (µg/L except where shown)

Parameter	20%ile	Median	80%ile
pH	6.4	6.4	6.6
WAD-CN*	0.20	0.20	0.20
Sulfate*	1,840	2,450	3,319

Parameter	20%ile	Median	80%ile
ALK-T*	204	242	282
TSS*	120,700	171,150	222,660
Hardness*	3,220	3,470	3,940
Ag-D	0.010	0.050	0.50
Ag-T	39	65	301
As-D	0.50	0.85	1.6
As-T	6,482	11,350	19,040
Cd-D	82	124	173
Cd-T	1,274	2,230	2,636
Cr-D	0.20	0.20	0.50
Cr-T	2,148	4,075	7,666
Cu-D	15	44	81
Cu-T	9,278	16,450	23,480
Fe-D	6.4	21	111
Fe-T	950,000	2,680,000	4,804,000
Hg-D	0.060	0.14	0.62
Hg-T	13	54	129
Ni-D	1,302	1,625	1,896
Ni-T	3,328	4,935	7,288
Pb-D	0.10	0.10	0.80
Pb-T	7,122	15,000	46,260
Se-D	1.3	1.7	2.2
Se-T	25	33	57
Zn-D	26,000	41,600	60,620
Zn-T	233,400	343,000	473,000
	> UpRiv TV = Potential Risk		

^ std units, * mg/L, D - Dissolved fraction, T – Total

Table 4-5 Percentage of total metals in tailings in dissolved form in 2016 (µg/L)

	% Total in Dissolved Form 2016		
Parameter	**20%ile**	**Median**	**80%ile**
Ag-D	0.05	0.19	0.41
As-D	0.01	0.01	0.01
Cd-D	5.0	6.0	8.1
Cr-D	0.01	0.01	0.01
Cu-D	0.27	0.39	0.51
Fe-D	0.00	0.00	0.01
Hg-D	0.41	1.27	2.91
Ni-D	27	30	34
Pb-D	0.00	0.00	0.00
Se-D	2.6	3.4	5.5
Zn-D	11	13	15

D – Dissolved fraction

Table 4-6 Tailings solids discharge quality 2016 (mg/kg whole sediment)

Parameter	20%ile	Median	80%ile
Ag-TD	11	16	22

Parameter	20%ile	Median	80%ile
Ag-WAE	0.18	0.33	0.51
As-TD	275	335	388
As-WAE	36	47	60
Cd-TD	14	17	19
Cd-WAE	7.2	9.0	10.5
Cr-TD	74	81	99
Cr-WAE	18	21	22
Cu-TD	118	137	153
Cu-WAE	78	90	109
Fe-TD	49,900	55,950	64,500
Fe-WAE	11,300	12,900	14,700
Hg-TD	1.1	1.4	1.9
Hg-WAE	0.16	0.30	0.44
Ni-TD	38	45	54
Ni-WAE	17	22	25
Pb-TD	868	1,080	1,450
Pb-WAE	131	178	229
Se-TD	0.60	0.80	1.0
Se-WAE	0.10	0.10	0.20
Zn-TD	2,300	2,730	3,200
Zn-WAE	1,100	1,500	1,780
	> UpRiv TV = Potential Risk		

WAE – Weak-acid extractable, TD - Total digest

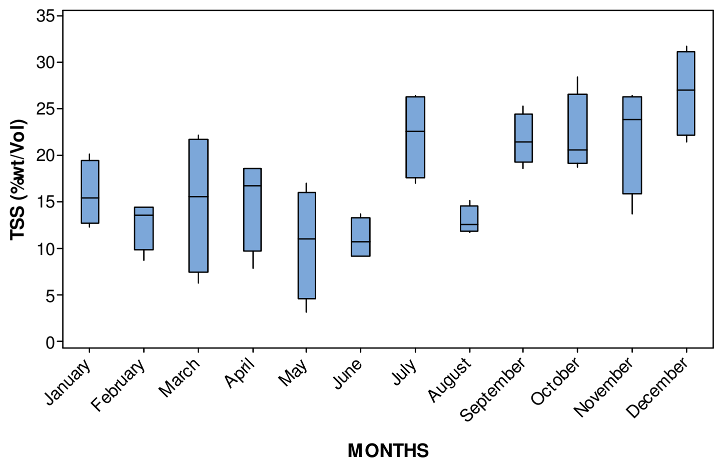


Figure 4-25 Monthly TSS in tailings discharge in 2016

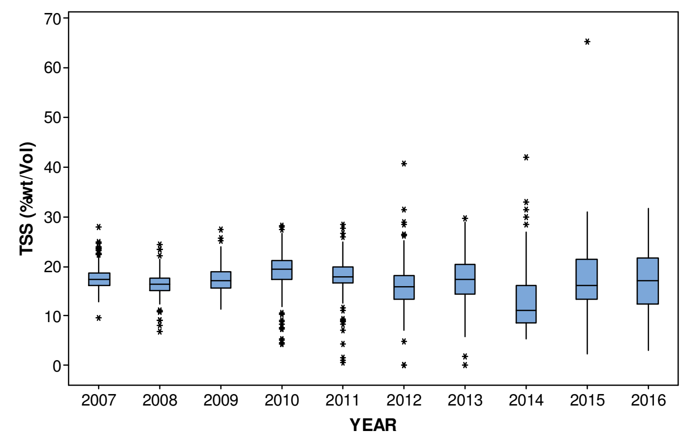


Figure 4-26 Annual TSS in tailings discharge 2007-2016

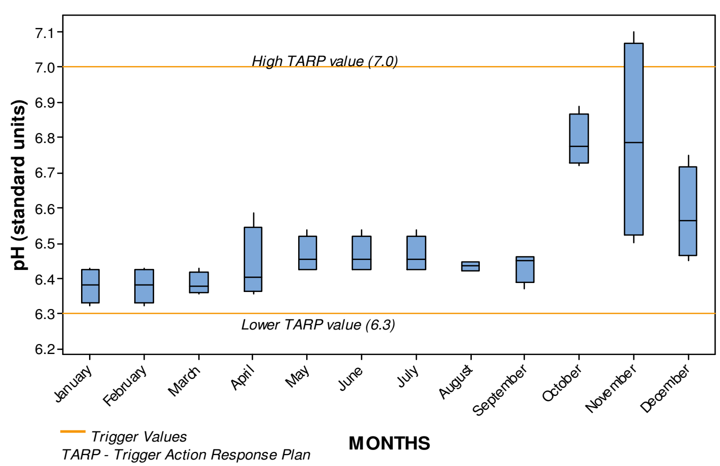


Figure 4-27 Monthly pH in tailings discharge in 2016

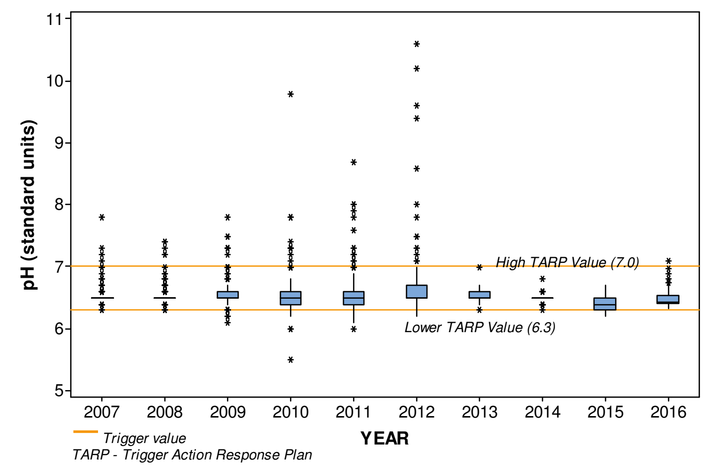


Figure 4-28 Annual pH in tailings discharge 2007-2016

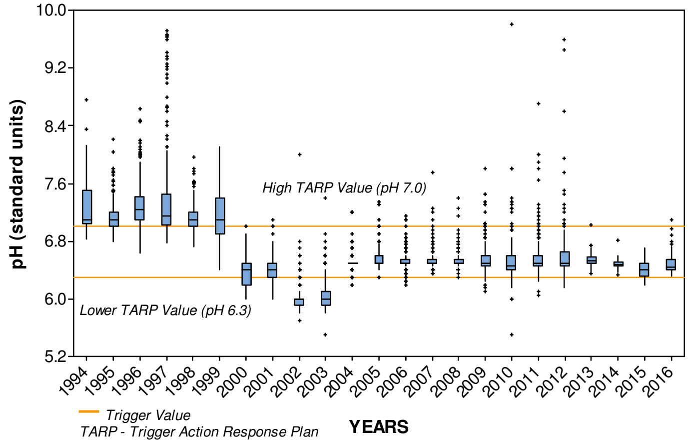


Figure 4-29 pH in tailings discharge 1994-2016

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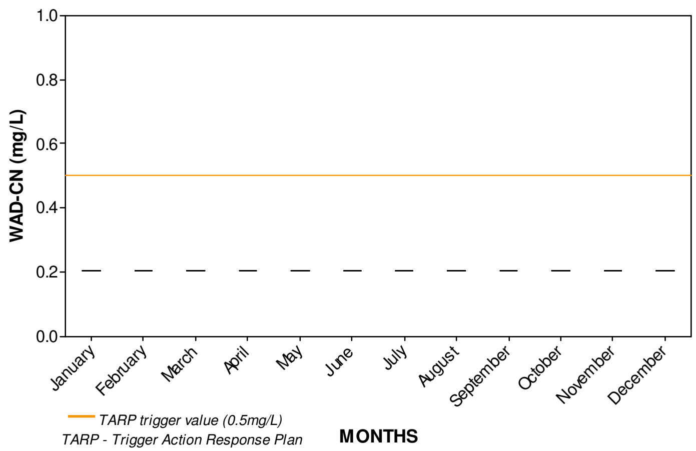

Figure 4-30 Monthly WAD-CN concentration in tailings discharge in 2016 (mg/L)

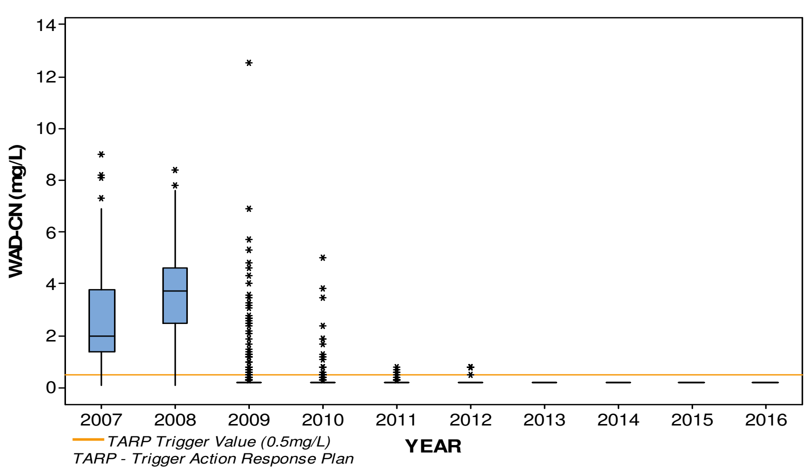

Figure 4-31 Annual WAD-CN concentration in tailings discharge 2007-016 (mg/L)

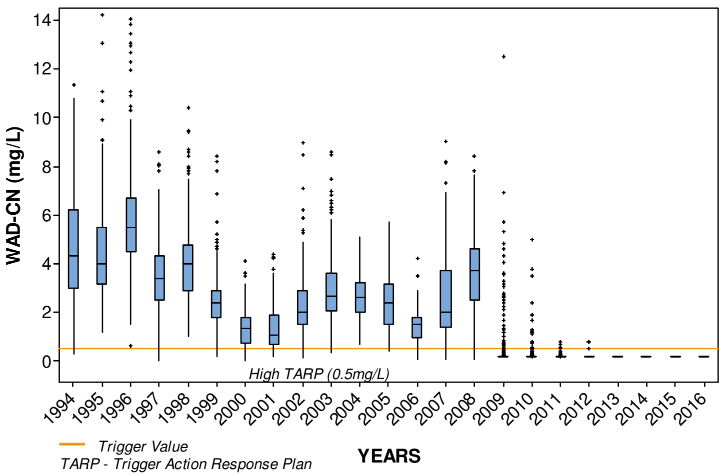

Figure 4-32 WAD-CN in tailings discharge 1994-2016

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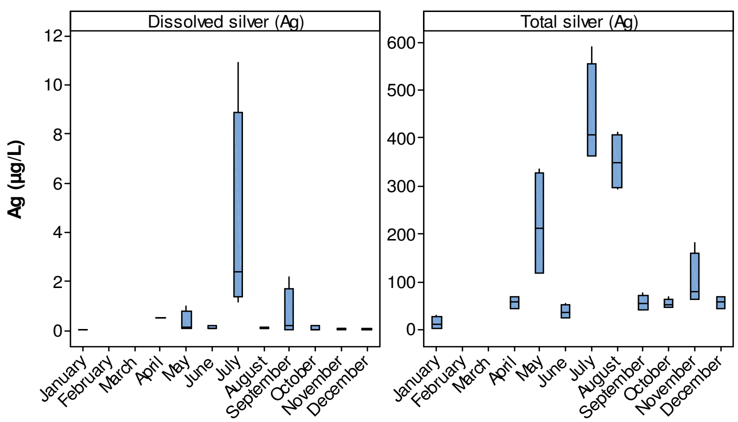


Figure 4-33 Monthly dissolved and total silver concentrations in tailings 2016 (µg/L)

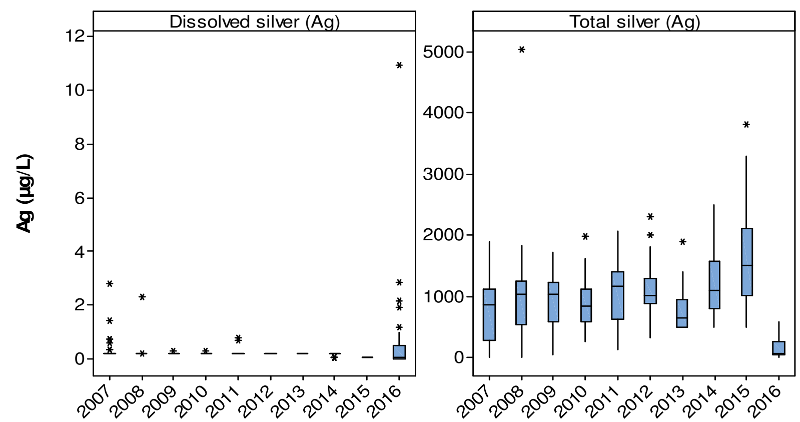


Figure 4-34 Annual dissolved and total silver concentrations in tailings 2007-2016 (µg/L)

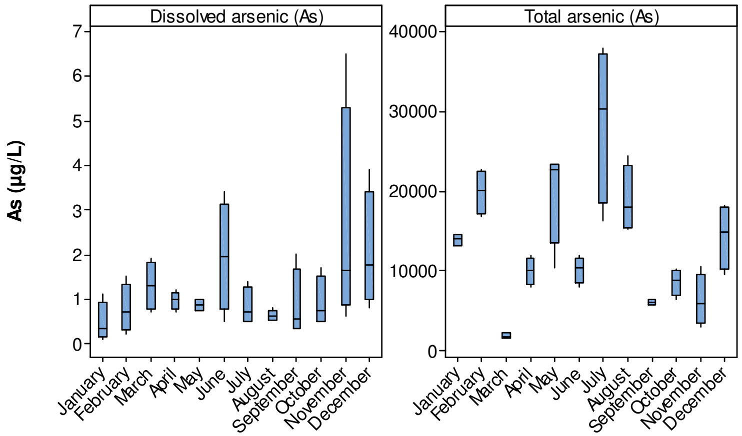


Figure 4-35 Monthly dissolved and total arsenic concentrations in tailings 2016 (µg/L)

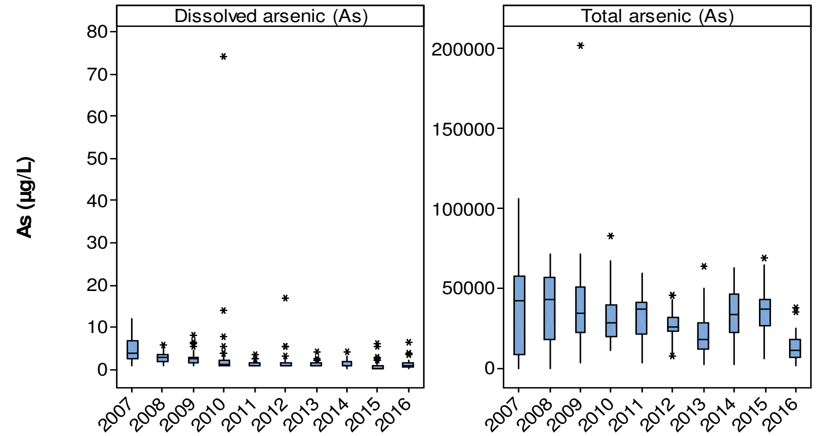


Figure 4-36 Annual dissolved and total arsenic concentrations in tailings 2007-2016 (µg/L)

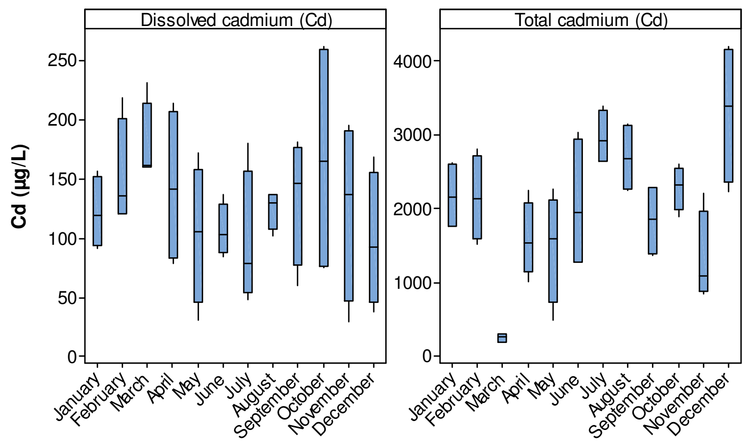


Figure 4-37 Monthly dissolved and total cadmium concentrations in tailings 2016 (µg/L)

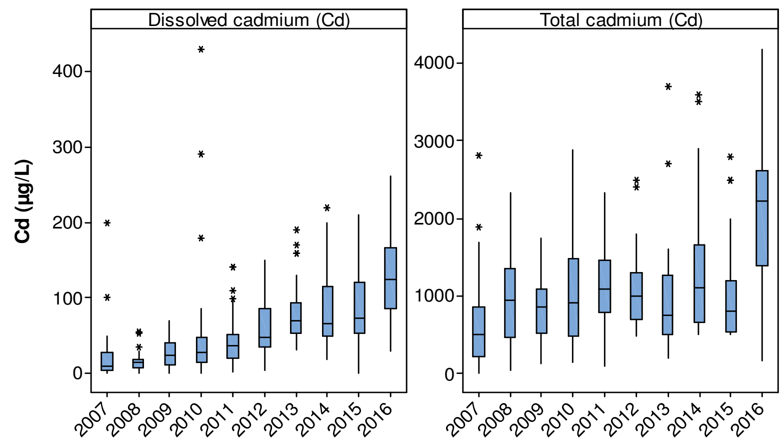


Figure 4-38 Annual dissolved and total cadmium concentrations in tailings 2007-2016 (µg/L)

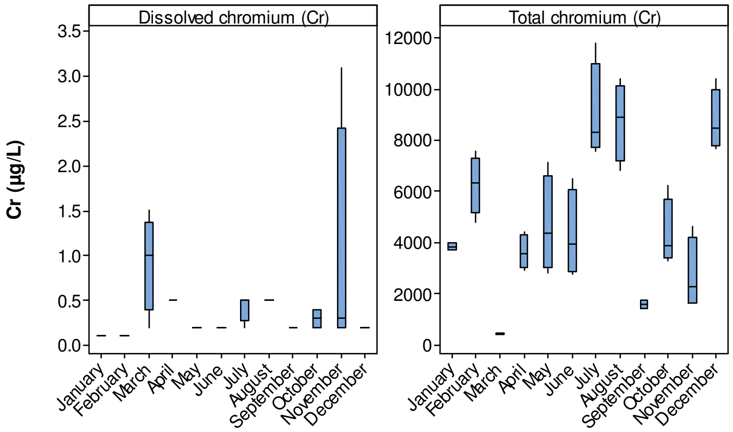


Figure 4-39 Monthly dissolved and total chromium concentrations in tailings 2016 (µg/L)

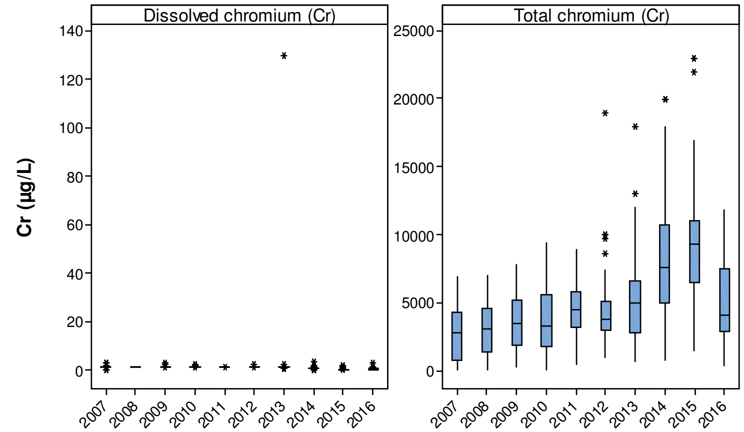


Figure 4-40 Annual dissolved and total chromium concentrations in tailings 2007- 016 (µg/L)

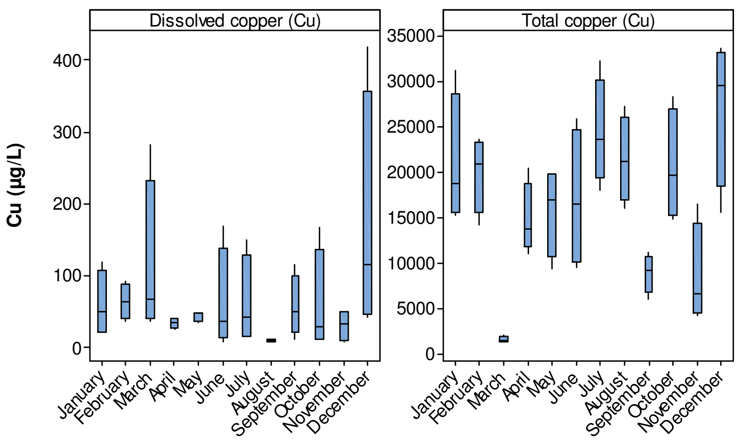


Figure 4-41 Monthly dissolved and total copper concentrations in tailings 2016 (µg/L)

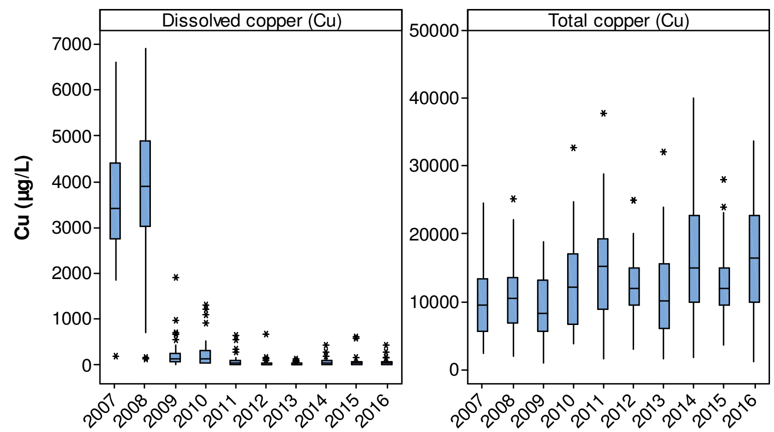


Figure 4-42 Annual dissolved and total copper concentrations in tailings 2007-2016 (µg/L)

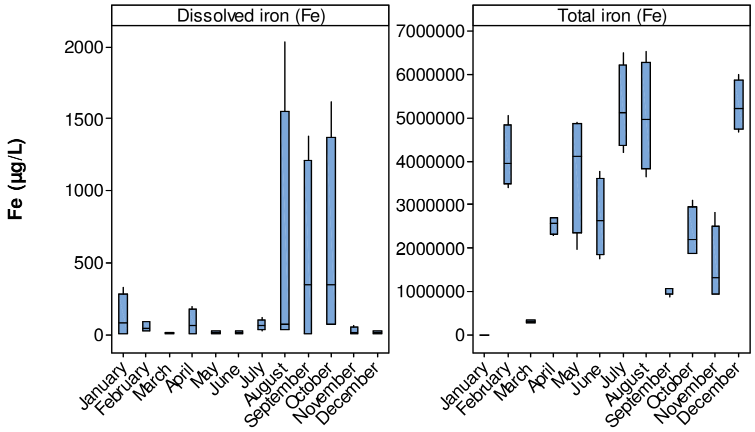


Figure 4-43 Monthly dissolved and total iron concentrations in tailings 2016 (µg/L)

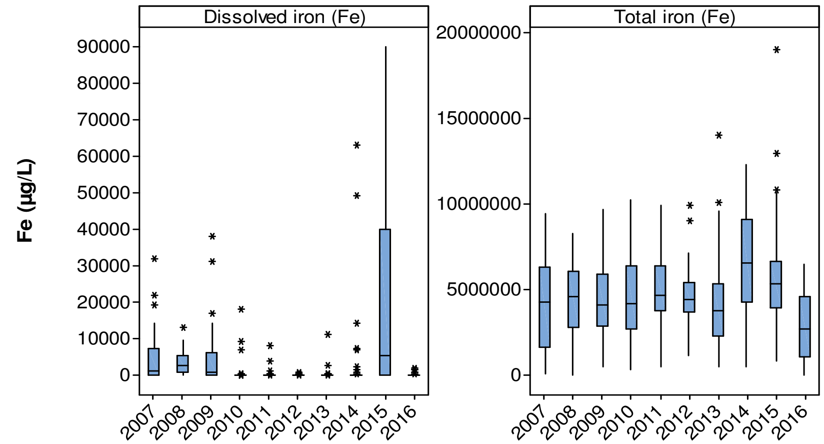


Figure 4-44 Annual dissolved and total iron concentrations in tailings 2007-2016 (µg/L)

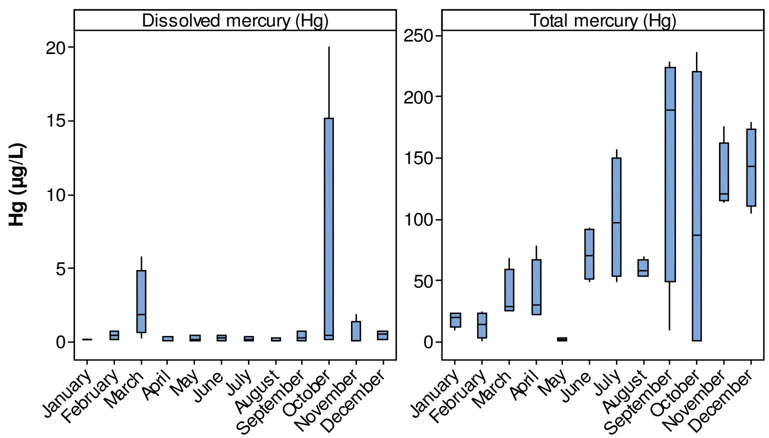


Figure 4-45 Monthly dissolved and total mercury concentrations in tailings 2016 (µg/L)

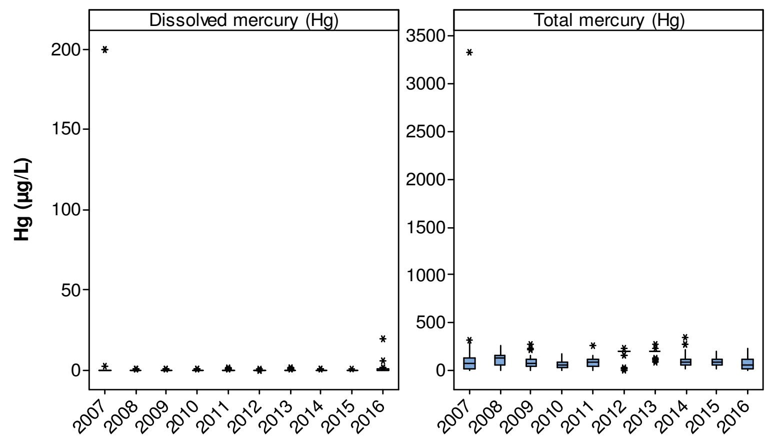


Figure 4-46 Annual dissolved and total mercury concentrations in tailings 2007-2016 (µg/L)

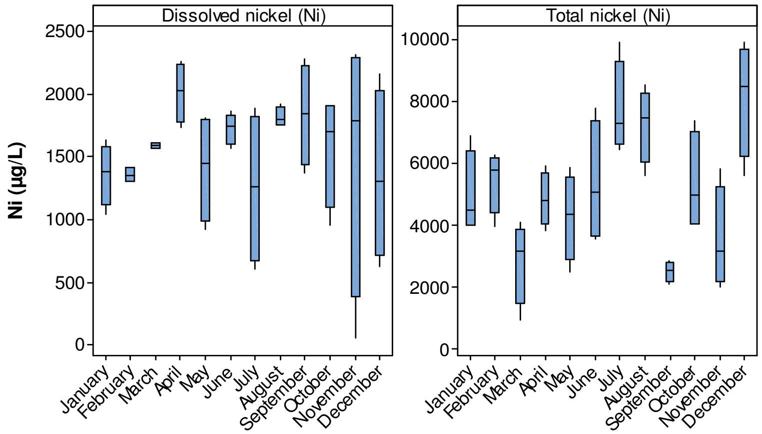


Figure 4-47 Monthly dissolved and total nickel concentrations in tailings 2016 (µg/L)

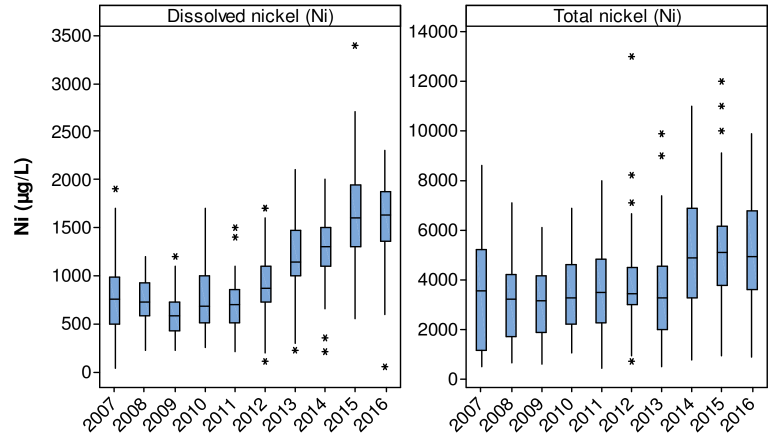


Figure 4-48 Annual dissolved and total nickel concentrations in tailings 2007-2016 (µg/L)

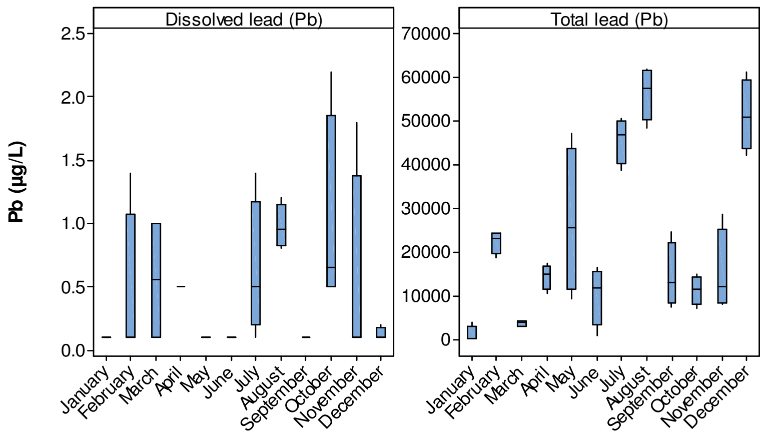


Figure 4-49 Monthly dissolved and total lead concentrations in tailings 2016 (µg/L)

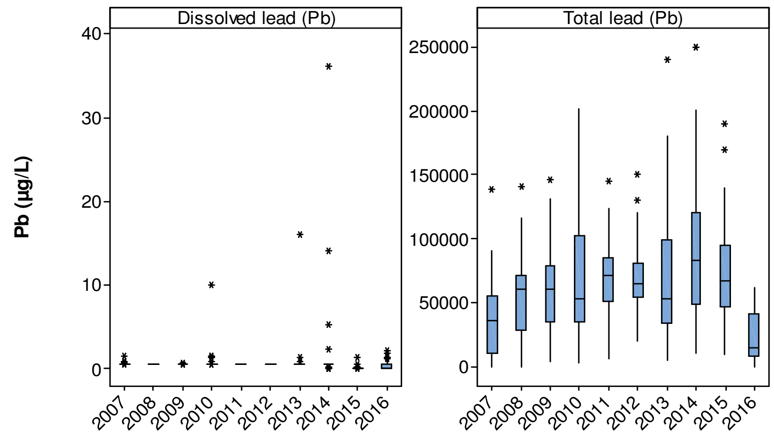


Figure 4-50 Annual dissolved and total lead concentrations in tailings 2007-2016 (µg/L)

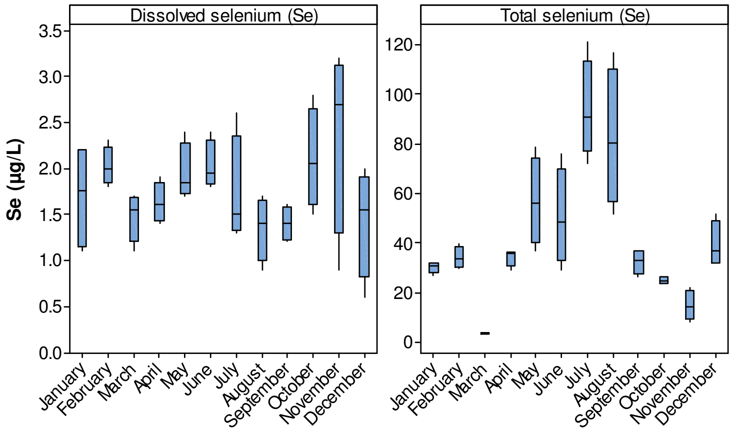


Figure 4-51 Monthly dissolved and total selenium concentration in tailings 2016 (µg/L)

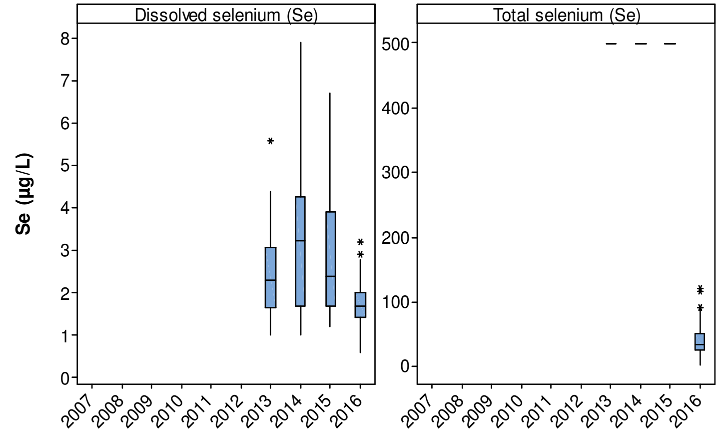


Figure 4-52 Annual dissolved and total selenium concentrations in tailings discharge 2007-2016 (µg/L)

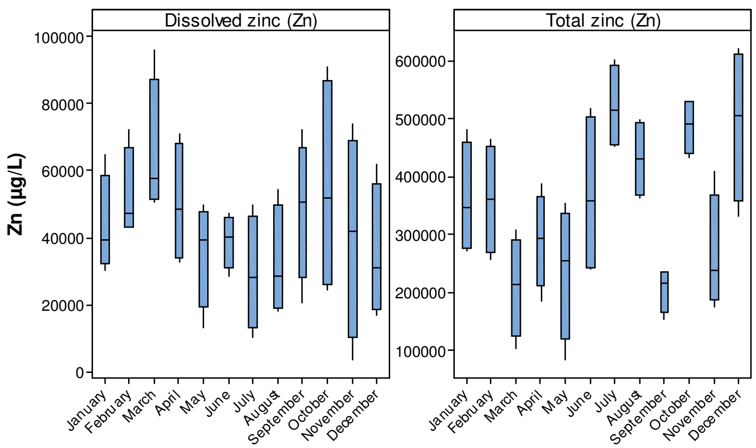


Figure 4-53 Monthly dissolved and total zinc concentrations in tailings 2016 (µg/L)

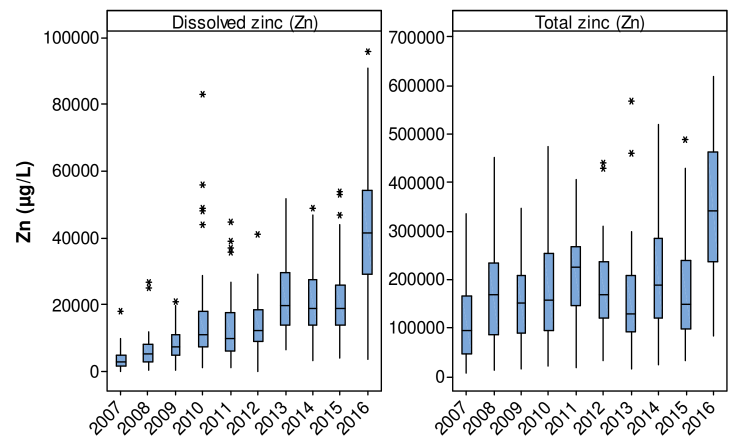


Figure 4-54 Annual dissolved and total zinc concentrations in tailings 2007-2016 (µg/L)

Table 4-7 Trends of tailings quality 2007 - 2016

Indicator	Spearman's rho	p-Value (p=0.05)	Trend (2007 – 2016)
pH	-0.026	0.222	No change over time
WAD-CN*	-0.735	<0.001	Decreased over time
Sulfate	-0.054	0.012	Decreased over time
ALK-T	0.497	<0.001	Increased over time
TSS	-0.023	0.273	No change over time
Hardness	-0.070	0.342	No change over time
Ag-D*	-0.519	<0.001	No change over time
Ag-T	-0.027	0.559	No change over time
As-D*	-0.621	<0.001	No change over time
As-T	-0.261	<0.001	Decreased over time
Cd-D	0.705	<0.001	Increased over time
Cd-T	0.295	<0.001	Increased over time
Cr-D*	-0.653	<0.001	No change over time
Cr-T	0.436	<0.001	Increased over time
Cu-D	-0.643	<0.001	Decreased over time
Cu-T	0.243	<0.001	Increased over time
Fe-D	-0.214	<0.001	Decreased over time
Fe-T	-0.006	0.891	No change over time
Hg-D	-0.149	0.001	Decreased over time
Hg-T	0.046	0.319	No change over time
Ni-D	0.633	<0.001	Increased over time
Ni-T	0.319	<0.001	Increased over time
Pb-D*	-0.458	<0.001	No change over time
Pb-T	0.006	0.901	No change over time
Se-D	-0.229	0.002	Decreased over time
Se-T	-0.770	<0.001	Decreased over time
Zn-D	0.711	<0.001	Increased over time
Zn-T	0.280	0.222	No change over time

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

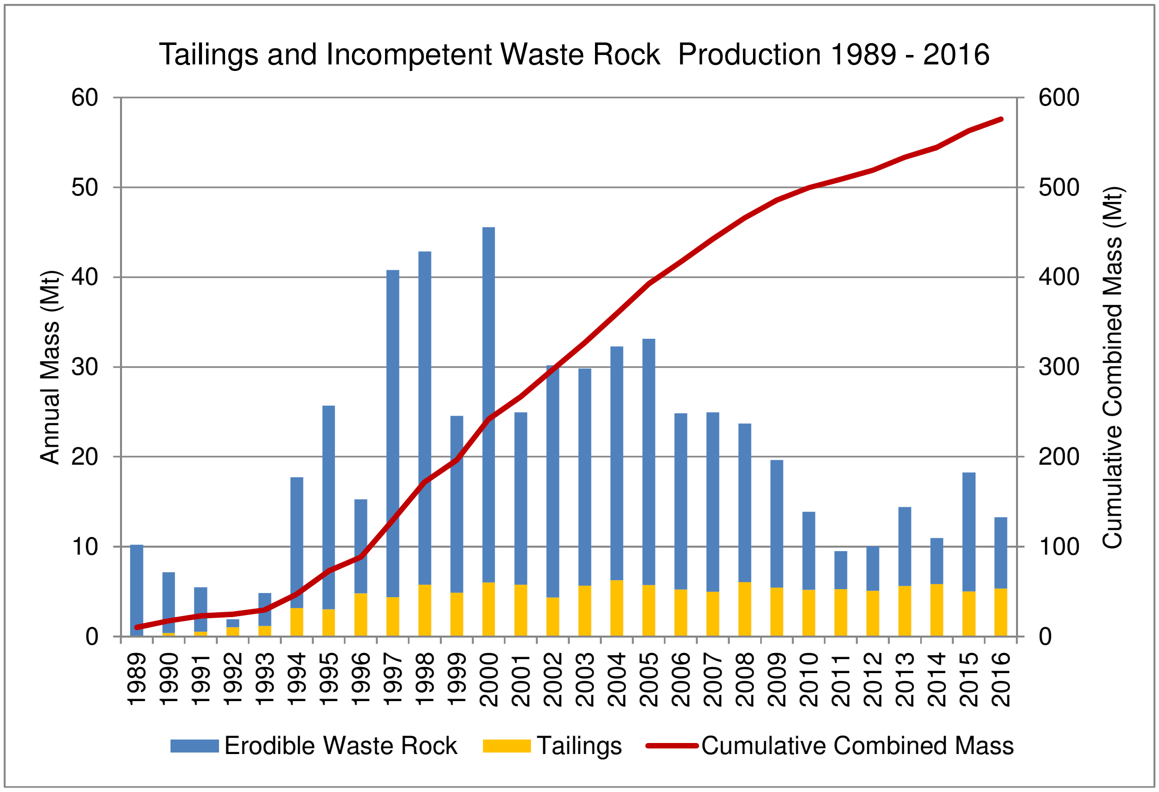
D – Dissolved fraction, T – Total, LOR - Limit of Reporting

4.9 Sediment Contributions to the River System

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 2016 and 1989 - 2016

Discharge Location	Total for 2016 (Mt)	Total 1989 – 2016 (Mt)
Anawe Erodible Dump	4.35	228.4
Anjolek Erodible Dump	3.62	225.6
Tailings Discharge (dry solids)	5.33	122.0
TOTAL	**13.30**	**575.9**



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

Figure 4-55 Production of incompetent rock and tailings 1989-2016

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 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 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 the toe of dumps where the dumps are intersected by higher flowing rivers. The dominant factors for each of these mechanisms are rainfall 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 particle size distribution analysis 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, bars and overbank) 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
Median (1, 2, 4 and 5)	**59**	**22**	**19**

Long-term survey data (2002-2016) and mass-balance calculations for the dumps are 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 indicate that the amount of material exported downstream since 2010 expressed as a percentage of the amount of material dumped was higher at approximately 73% for Anawe and 145% for Anjolek. This partly reflects the lower rates of dumping in recent years, particularly to Anjolek dump, while there has been consistent erosion of material from the dumps by river flows. The data also indicate that there has been a net reduction in dump volume and surface area for Anjolek as erosion exceeds the low rates of dump input.

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 Anjolek appears to be receding.

Estimates of the rates of sediment loss from the dumps are summarised in Table 4-10 which also shows that the estimated average annual load of sediment that is transported downstream is 9.1 Mt/y based on survey data since 2010. This appears a reasonable estimate and compares well with the estimated suspended load at SG1 of approximately 10 Mt/y, based on historic 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	63	3.6	4.1 (145%)
Anawe	49	4.8	5.0 (73%)
Total	**NA**	**8.4**	**9.1**

Based on the figures above, Table 4-11 presents estimates of suspended sediment discharge from the SML for both tailings and waste rock. 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.

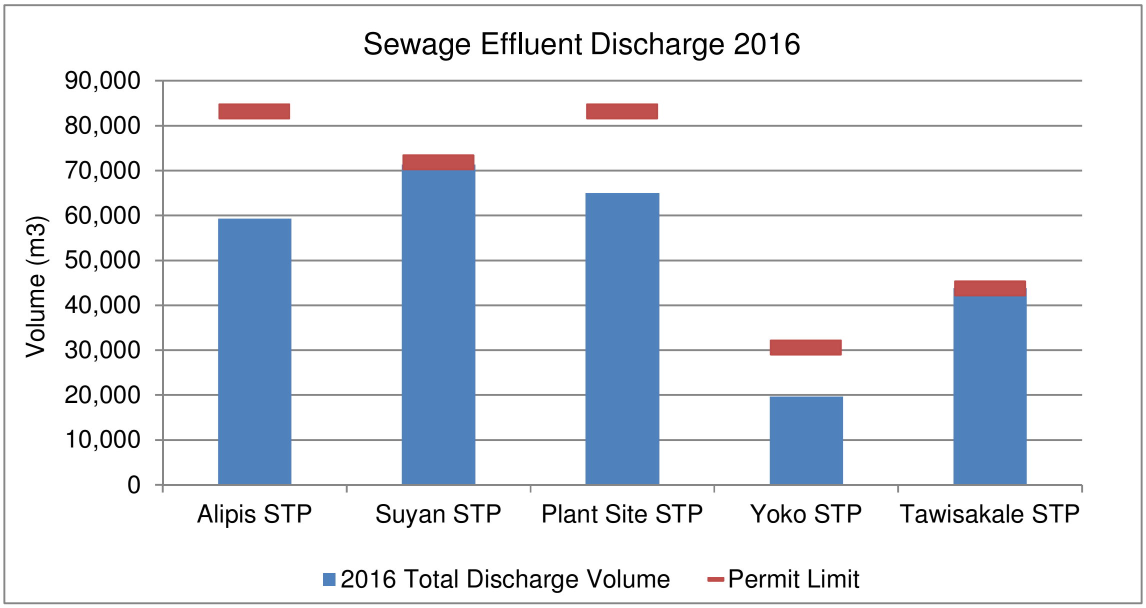
Table 4-11 Estimate of sediment discharge from erodible dumps and tailings during 2016

Source	Total Sediment Discharged from Dumps (Mt/y)	Suspended Sediment Component (Mt/y)	Comments
Erodible Dumps	9.1	5.4	Assumes 59% (silt fraction) travels as suspended load
Tailings	5.1 (5.3 x 0.95)	4.8 (5.1 x 0.95)	Assumes 95% of tailings is transported to the river system and 5% remains stored in Anawe dump
TOTAL 2016	**14**	**10**	

4.10 Other Discharges to Water

4.10.1 Treated Sewage Effluent

The total volume of treated sewage effluent discharged from the 5 treatment plants that service the mine site and accommodation camps is shown in Figure 4-56. The Tawisakale sewage treatment plant (STP) totaliser meter calibration failed during the year and the maximum capacity of the plant



was used to estimate the volume discharged. Discharges from all STPs were within the environment permit limits.

Figure 4-56 Total annual discharge volumes of treated sewage for 2016

The quality of the discharge from each STP is monitored for TSS, BOD_5 and faecal coliforms. The results of monitoring for 2016 are shown in Figure 4-57 to Figure 4-59 respectively. Operation of the sewage treatment plants did not consistently achieve compliance with the TSS criterion of 30 mg/L throughout the year. All plants were effective for achieving compliance with the BOD_5 criterion and chlorination of the treated effluent was effective for achieving compliance with the faecal coliform criterion throughout the year. PJV has developed SOPs for each of the treatment plants and continues to improve the competence of the operators through training. At the same time, higher level supervision and leadership are also being improved. PJV has also engaged an external technical expert to regularly visit the site and provide training, supervision and review the performance of the plants.

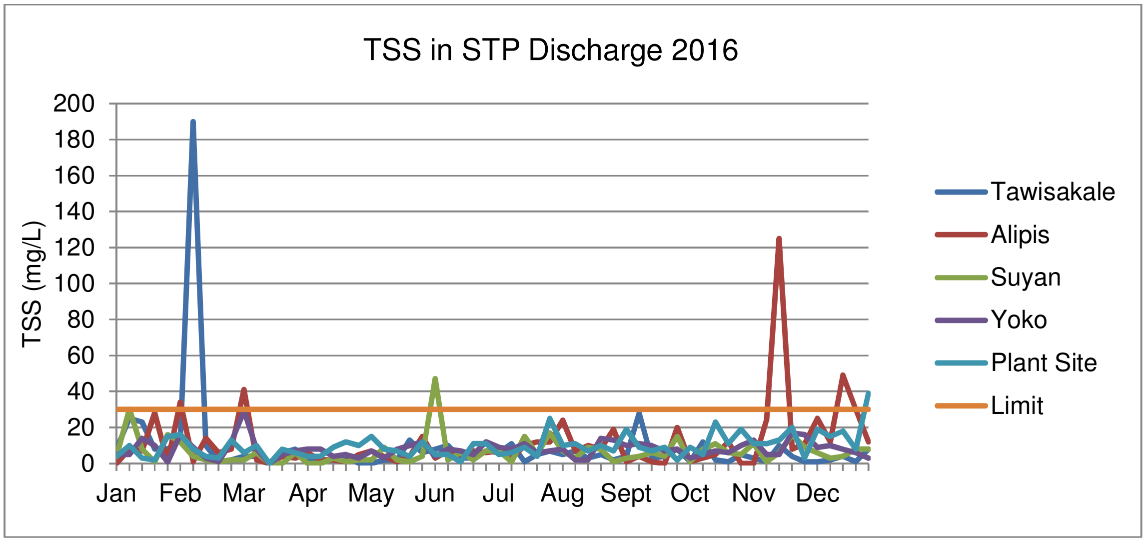


Figure 4-57 Average monthly TSS concentration in treated sewage discharge in 2016

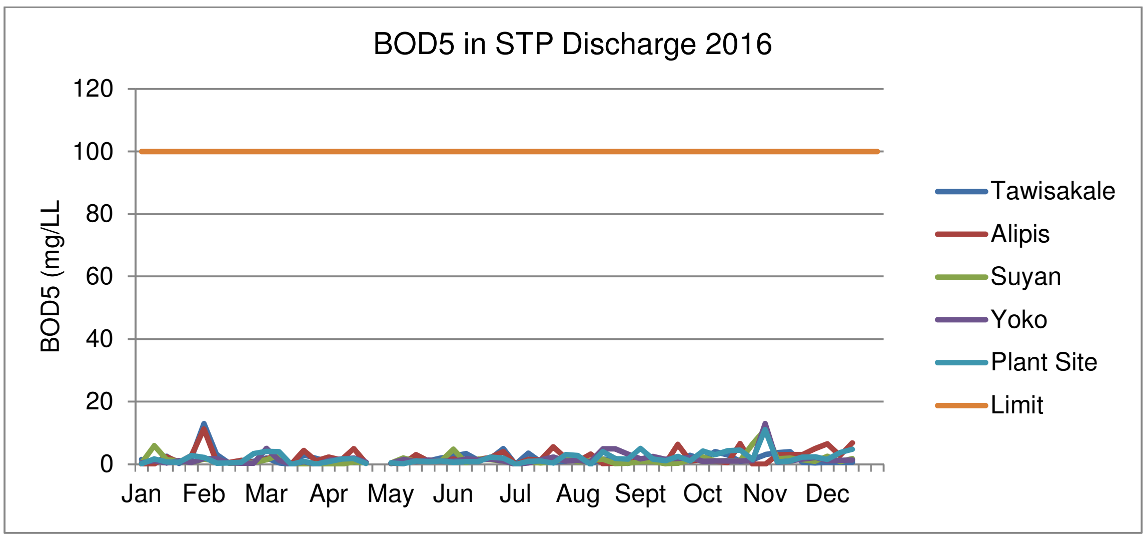


Figure 4-58 Average monthly BOD_5 concentration in treated sewage discharge in 2016

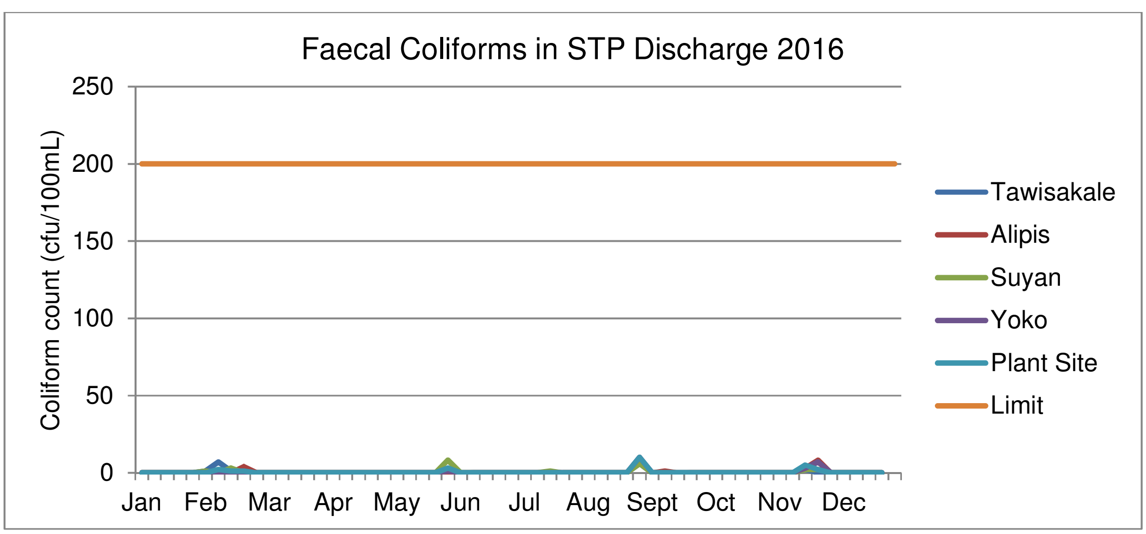


Figure 4-59 Average monthly faecal coliform count in treated sewage discharge 2016

4.10.2 Oil/Water Separator Effluent

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

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

Hydrocarbons were detected in very low concentrations in contact water sampled at the mine site boundary in six months of 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.

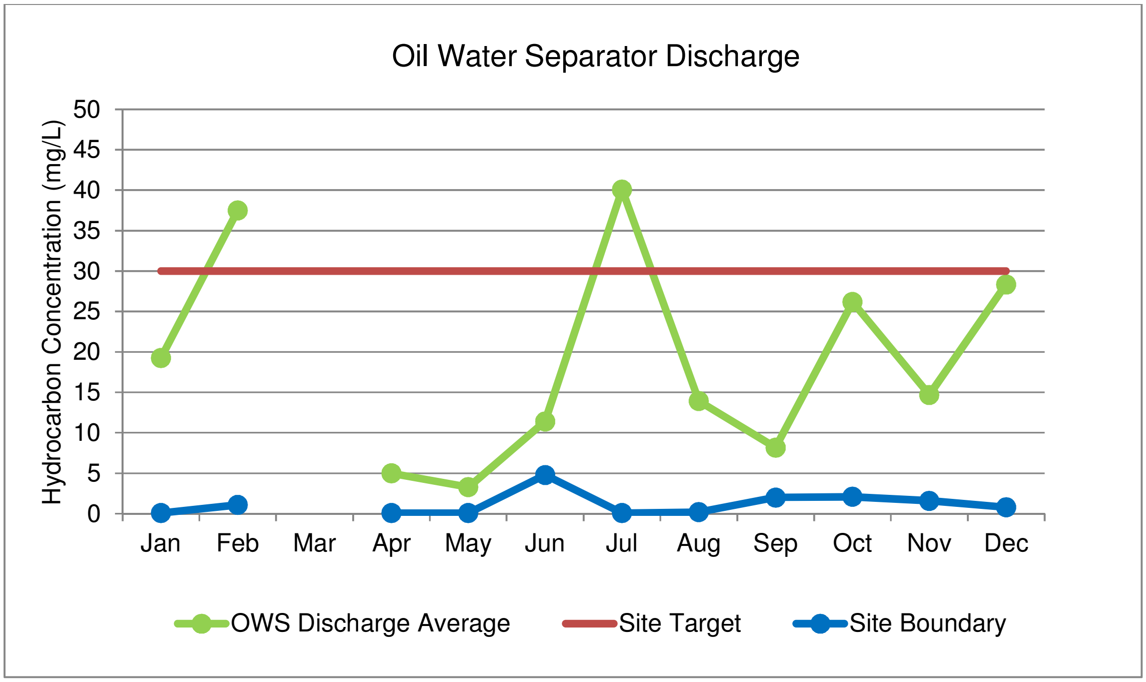


Figure 4-60 Average monthly total hydrocarbon concentrations in oil water separator discharges 2016

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 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. Following the completion of a project to collect contact runoff from the civil crusher area for use in the SAG mill, there is minimal discharge from this area. PJV will apply to remove this discharge point from the environmental permit.

Table 4-12 Estimated volumes of contact runoff from mine lease areas 2016

Location	Total Rainfall run off 2016 (Mm^3)	Permit Limit (Mm^3/y)
Starter Dump A (SDA) (DP3)	0.3	1.8
Civil crusher to Kogai Creek (DP4)	0.0	0.1
Kogai Waste Dump to Kogai Creek (DP5)	5.5	1,682
Open Pit and UG Mine drainage tunnel to Kogai Creek (DP6)	1.3	12.1
Anawe stable dump to Wendoko Creek (DP7)	0.4	4.5
Runoff from Hides to a tributary of the Tagari River (DP16)	0.002	0.1
TOTAL	**7.5**	**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	Lime processing
Wendoko Crk downstream of Anawe Nth stable dump	Competent waste rock dump
Yakatabari Creek downstream of 28 Level discharge	Underground mine Workshops Sewage treatment plant Hazardous substance storage
Yunarilama/Yarik portal	Open cut mine Underground mine

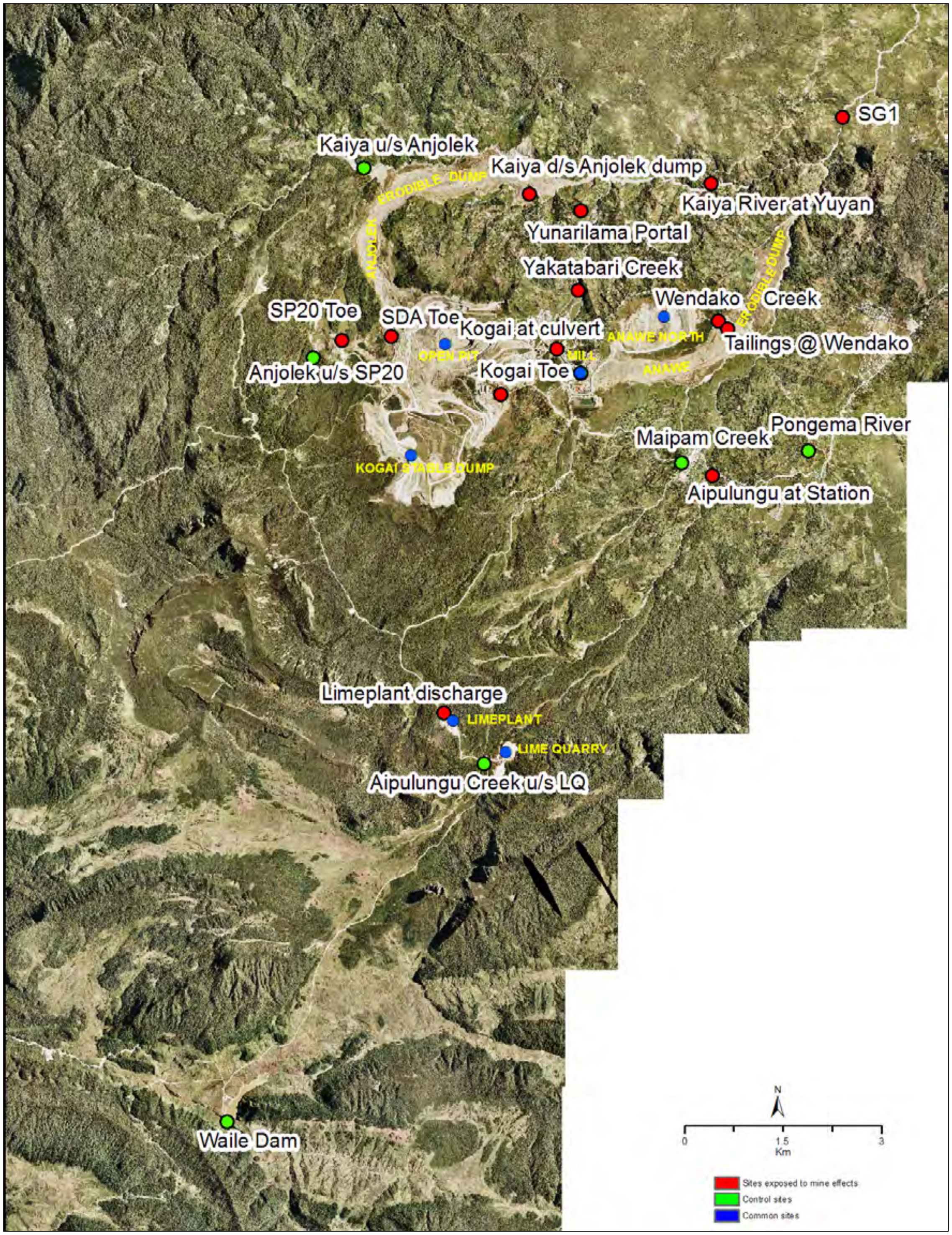


Figure 4-61 Mine contact runoff sampling location

Annual median values from monthly monitoring conducted in 2016 at mine contact runoff sites are shown in Table 4-14. An amber highlight indicates values that exceed the upper river TV. The results indicate that Kogai Stable Dump Toe and Wendoko Crk d/s Anawe Nth, which both receive runoff from competent waste rock dumps, exhibited elevated concentrations of dissolved cadmium and zinc and were slightly above neutral pH. 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 indicate, however that there is insufficient alkalinity to precipitate and adsorb cadmium and zinc, which typically require higher pH ranges than other metals to achieve complete removal from solution via precipitation and adsorption onto particulate material. SDA toe and Kogai Culvert exhibit elevated dissolved zinc. Discharge from the lime plant exhibits elevated pH and dissolved chromium. Runoff from Yakatabari Crk DS 28 Level, Yunarilama at Portal and Kaiya River downstream Anjolek erodible dump exhibited elevated TSS.

A summary of trends of water quality parameters between 2007 and 2016 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 increasing concentrations of sulfate, dissolved cadmium and dissolved zinc at Kogai Toe, which is indicative of drainage from the Kogai competent waste rock dump. The median concentration of these metals exceeded the upper river trigger value in 2016, indicating potential risk. The increasing trend suggests the potential to continue to pose a risk to the receiving environment. Also of note is the increasing total concentration of a number of metals at Yarik Portal, this is indicative of increased sediment discharge associated with remedial works carried out throughout 2016, although the bioavailable dissolved fractions are below the upper river TV and are not increasing, indicating low risk to the receiving environment.

The median concentrations of WAE and total metals in sediment in runoff from the mine areas are shown in Table 4-16. The results show elevated WAE silver in sediment discharged from 28 level, WAE arsenic in sediment discharged from 28 level, WAE cadmium in sediment discharged from 28 level, Kogai Dump Toe and Wendoko Crk DS Anawe Nth, the latter reflecting drainage from the Kogai and Anawe Nth competent waste rock dumps respectively. Elevated WAE lead in sediment discharged from all sites except the lime plant and elevated WAE zinc in sediment discharged from 28 Level, Kogai Dump Toe, Wendoko Crk DS Anawe Nth and Yakatabari Crk DS 29 Level. Elevated lead and zinc in sediment is a reflection of the geology of the Porgera ore body which contains sphalerite, which is a zinc mineral, and galena which is a lead mineral.

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 be done in future years once a multi-year data set has been established.

Table 4-14 Contact Water Quality 2016 median values (µg/L except where shown)

Parameter	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 / Yarik @ Portal
pH^	7.6	7.6	7.6	7.8	7.7	11	7.7	7.5	7.4
WAD-CN*	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Sulfate*	198	419	50	143	681	2.0	1160	539	564
ALK-T*	97	146	103	135	243	524	156	141	157
TSS*	496	229	3,823	440	130	561	25	4,528	7,368
Hardness*	353	602	94	253	916	142	1,325	519	498
Ag-D	0.01	0.02	0.05	0.01	0.01	0.01	0.01	0.01	0.02
Ag-T	1.0	0.42	1.8	0.65	0.5	0.14	0.52	18	19
As-D	2.8	0.9	1.1	1.1	0.85	0.20	1.1	6.7	1.7
As-T	35	7.2	79	17	10	2.5	4.3	362	425
Cd-D	0.08	0.06	0.05	0.12	2.2	0.05	0.78	0.07	0.12
Cd-T	2.5	1.5	5.5	1.9	4.1	0.56	1.8	32	25
Cr-D	0.20	0.20	0.20	0.20	0.20	4.6	0.20	0.20	0.20
Cr-T	11	11	107	12	6	48	1.4	101	314
Cu-D	0.50	0.55	0.75	0.90	0.70	0.56	0.50	0.65	0.50
Cu-T	21,450	13,900	96,850	17,300	9,100	26,550	2,200	290,000	422,500
Fe-D	3.0	2.0	4.5	7.5	2.9	2.5	3.0	3.3	5.5
Fe-T	19,050	12,300	183,000	19,750	6,730	11,040	1,330	216,000	502,000
Hg-D	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.06
Hg-T	0.11	0.04	0.16	0.13	0.06	0.06	0.04	0.34	0.40
Ni-D	2.9	1.4	0.65	0.69	2.7	0.50	1.9	1.8	1.8
Ni-T	28	12	103	14	7	15	3.2	138	322
Pb-D	0.10	0.20	0.20	0.40	0.90	0.10	0.20	1.0	0.30
Pb-T	157	51	539	127	70	8.3	8.4	2,320	1,910
Se-D	0.20	0.6	0.50	0.20	0.20	0.20	0.60	0.50	1.2
Se-T	0.35	0.9	3.7	0.40	0.35	0.40	0.60	4.0	11
Zn-D	19	26	11	21	411	4.5	355	20	18
Zn-T	544	276	1,075	488	849	67	596	5,490	4,675
	> UpRiv TV = Potential Risk								

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

Table 4-15 Trends of water quality contact runoff 2007 - 2016 (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 Crk D/S Anawe Nth	Yakatabari Crk D/S 28 Level	Yunarilama / Yarik @ Portal
pH	(green)	(green)	(green)	(green)	(orange)	(green)	(green)	(green)	(green)
WAD-CN	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)
Sulfate	(green)	(green)	(green)	(green)	(orange)	(green)	(green)	(green)	(green)
ALK-T	(green)	(green)	(orange)	(green)	(orange)	(green)	(green)	(green)	(orange)
TSS	(green)	(orange)	(green)	(green)	(green)	(green)	(green)	(green)	(green)
Hardness	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)
Ag-D	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)
Ag-T	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(orange)
As-D	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)
As-T	(green)	(green)	(orange)	(green)	(orange)	(green)	(green)	(green)	(green)
Cd-D	(green)	(green)	(green)	(green)	(orange)	(green)	(green)	(green)	(green)
Cd-T	(green)	(green)	(orange)	(green)	(orange)	(green)	(green)	(green)	(orange)
Cr-D	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)
Cr-T	(green)	(orange)	(orange)	(orange)	(orange)	(orange)	(green)	(green)	(orange)
Cu-D	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)
Cu-T	(green)	(orange)	(orange)	(orange)	(orange)	(orange)	(green)	(orange)	(orange)
Fe-D	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)
Fe-T	(green)	(orange)	(orange)	(orange)	(orange)	(orange)	(green)	(green)	(orange)
Hg-D	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)
Hg-T	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)
Ni-D	(orange)	(green)	(green)	(green)	(orange)	(green)	(green)	(green)	(green)
Ni-T	(green)	(green)	(green)	(orange)	(orange)	(orange)	(green)	(green)	(orange)
Pb-D	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(orange)	(green)
Pb-T	(green)	(orange)	(orange)	(green)	(orange)	(orange)	(green)	(green)	(green)
Se-D	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)
Se-T	(green)	(green)	(orange)	(green)	(green)	(green)	(green)	(orange)	(green)
Zn-D	(orange)	(green)	(green)	(green)	(orange)	(green)	(green)	(orange)	(green)
Zn-T	(green)	(green)	(orange)	(green)	(orange)	(orange)	(green)	(green)	(orange)

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

D - Dissolved fraction, T - Total

Table 4-16 Contact Sediment Quality 2016 median values (mg/kg whole fraction)

Parameter	28 Level	Anjolek SDA	Kaiya R DS Anj dump	Kogai Culvert	Kogai Dump Toe	Lime Plant	Wendoko Crk DS Anawe Nth	Yakatabari Crk DS 28 Level	Yunarilama @ Portal
Ag-WAE	1.7	0.06	0.05	0.37	0.53	0.17	0.18	1.0	0.05
Ag-TD	31	3.1	0.60	3.6	6.1	0.30	4.9	3.8	2.0
As-WAE	21	5.4	4.3	8.5	17	0.82	15	17	4.2
As-TD	403	127	57	134	175	3.2	116	97	69
Cd-WAE	1.7	1.0	0.42	0.75	2.1	0.39	2.1	1.1	0.22
Cd-TD	15	10	2.5	7.4	13	0.46	7.0	4.0	2.5
Cr-WAE	14	4.4	4.8	4.1	4.8	7.1	4.6	4.3	5.1
Cr-TD	77	35	29	29	39	18	26	30	34
Cu-WAE	24	4.6	3.8	5.1	11	2.8	10	11	5.1
Cu-TD	146	54	38	50	86	8.8	57	42	30
Hg-WAE	0.11	0.05	0.03	0.03	0.04	0.02	0.06	0.06	0.07
Hg-TD	1.3	0.29	0.27	0.47	0.46	0.03	0.29	0.37	0.17
Ni-WAE	19	4.4	5.9	4.7	6.2	2.1	6.1	7.7	5.7
Ni-TD	85	34	35	33	40	6.6	34	36	36
Pb-WAE	697	184	78	142	333	11	199	185	85
Pb-TD	929	334	134	250	613	69	273	237	220
Se-WAE	0.10	0.10	0.10	0.20	0.10	0.30	0.15	0.15	0.10
Se-TD	1.8	1.0	1.0	1.0	1.0	0.15	1.0	0.75	0.90
Zn-WAE	615	155	66	128	346	16	310	237	54
Zn-TD	3,650	1,640	522	1,255	2,150	44	1,245	845	576
	> UpRiv TV = Potential Risk								

WAE – Weak Acid Extractable, TD – Total Digest

4.11 Point Source Emissions to Air

PJV carried out monitoring of concentrations of metals in the emissions from stationary sources at the mine site, the Lime Plant and at Hides Power Station in 2015. Papua New Guinea does not have legislation for controlling emissions to air and PJV has voluntarily set a target of complying with the relevant Australian Standards, which are the NSW Protection of the Environment Operations (Clean Air) Regulation 2010 and the Victoria State Environment Protection Policy (Air Quality Management) 2001. A comparison of results against the standards is presented in Section 7.8. PJV plans to conduct monitoring of emissions from stationary sources again in 2017.

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 efficiency improved by 1.3% in 2016 compared to 2015, and the decreasing trend since 2010 has been maintained.

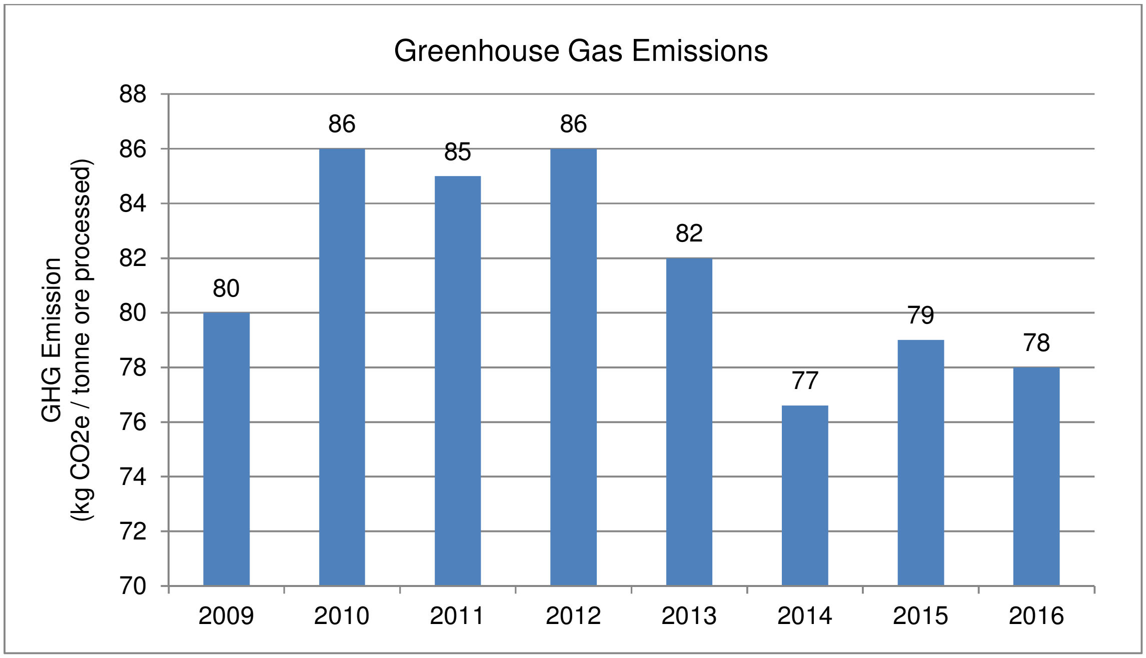


Figure 4-62 Energy efficiency 2009 - 2016

4.13 Closure Planning and Reclamation

4.13.1 Mine Closure Plan

In 2016, Porgera mine revised the draft Mine Closure Plan in line with the Barrick Closure Standard and Guidelines. This plan was based on the content from previous draft closure 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. The plan also includes estimates of closure costs.

4.13.2 Life of Mine

The Life of Mine (LOM) for Porgera mine was reviewed and revised in 2016, following the revision of the geological model reserves. Ore production and processing are expected to cease in 2028. The closure period will begin in 2028 with decommissioning and dismantling of plant and infrastructure which is expected to take approximately three years. The establishment of a stable vegetation cover across the plant site and related infrastructure will take approximately two years while the post-closure period including monitoring and maintenance will be eight years, inclusive of the time required for revegetation.

4.13.3 Mine Closure Vision and Objectives

Porgera's vision for mine closure is "leaving behind a better future". This vision will be achieved through Porgera's specific objectives for mine closure:

- Integrate mine closure planning with operational mine planning during the life of the project ensuring orderly, cost-effective and timely mine completion.
- Ensure the safety and health of workers during site closure activities (decommissioning and rehabilitation).
- Retain transport facilities considered of value to the local community in an operational condition for transfer to local and regional authorities. Ongoing maintenance and liability for such structures will be passed to the local authority.
- Monitor rehabilitation performance during all phases of the project and implement appropriate actions where observed trends do not reflect agreed closure criteria.
- Ensure that adequate financial provision is made to cover all agreed closure commitments until such time as final lease relinquishment.
- Comply with mine closure permitting and regulatory requirements and at all times obtain documented confirmation of compliance.

4.13.4 Key Closure Environmental and Social Issues

Some of the key environmental issues identified affecting closure include waste rock dump stability, water quality and final void management, while social considerations at mine closure include loss of employment, livelihood, artisanal mining and facilities and social services. These issues and the associated risks will be looked at closely and measures highlighted in the plan will be implemented to mitigate closure liability.

4.13.5 Mine Closure Consultation and Stakeholder Identification

The mine closure and stakeholder consultation will be critical in ensuring a safe and successful exit from the operation. Stakeholders' views and expectations will be discussed during the consultation process to achieve balanced, realistic and achievable outcomes during closure.

Porgera closure stakeholders will be listed in the closure plan. Key people will be nominated by respective stakeholder groups to represent their interests to the closure committee group. The closure committee group's primary role will be to identify issues of concern, look at ways to address those issues and to monitor their projected outcomes during the closure process.

4.13.1 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 239.19 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 2016 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.

A total of 5,870 tree seedlings were planted on the Kogai dump. 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 2016

Type	Scientific Name	Local Name	Number Planted 2016
Hardwood	*Castanopsis acuminatissima*	Pai	144
	Dacrydilium nidilium	Pawa	106
	Elaeocarpus polydactylus Schltr	Yano	58
	Nothofagus sp.	Taro	725
	Pinus Wallichiana	Tai	2
	Podocarpus Neriifolius	Kaipu	980
	Syzgium richardsonianum	Pip	1,265
Softwood	*Daphniphllum* sp.	Yongena	68
	Cordyline sp.	Tanget	23
	Dodonea viscosa	Lokai	59
	Eurya pluriflora (kobuski) Baker	Nekeya	38
	Ficus aurantiacafoldia	Marakombi	5
	Ilex arnhemensis	Muli	178
	Libocedrus papuanus	Pulapia	71
	Litsea timorauna	Mara	120
	Pentaphylaceae adinandra	Kapano	87
	Perrotteia aipestris Blume	Epulaumbe	565
	Sarananga sp.	Tendaka	50
	Saurauia alitterra Royen	Sanakango	25
	Saurauia benguetensis Merr	Kuaro	176
	Acalypha villosa	Souk	205
Mixed	Mixed species	Mixed	920
		TOTAL	**5,870**

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 2016, 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.

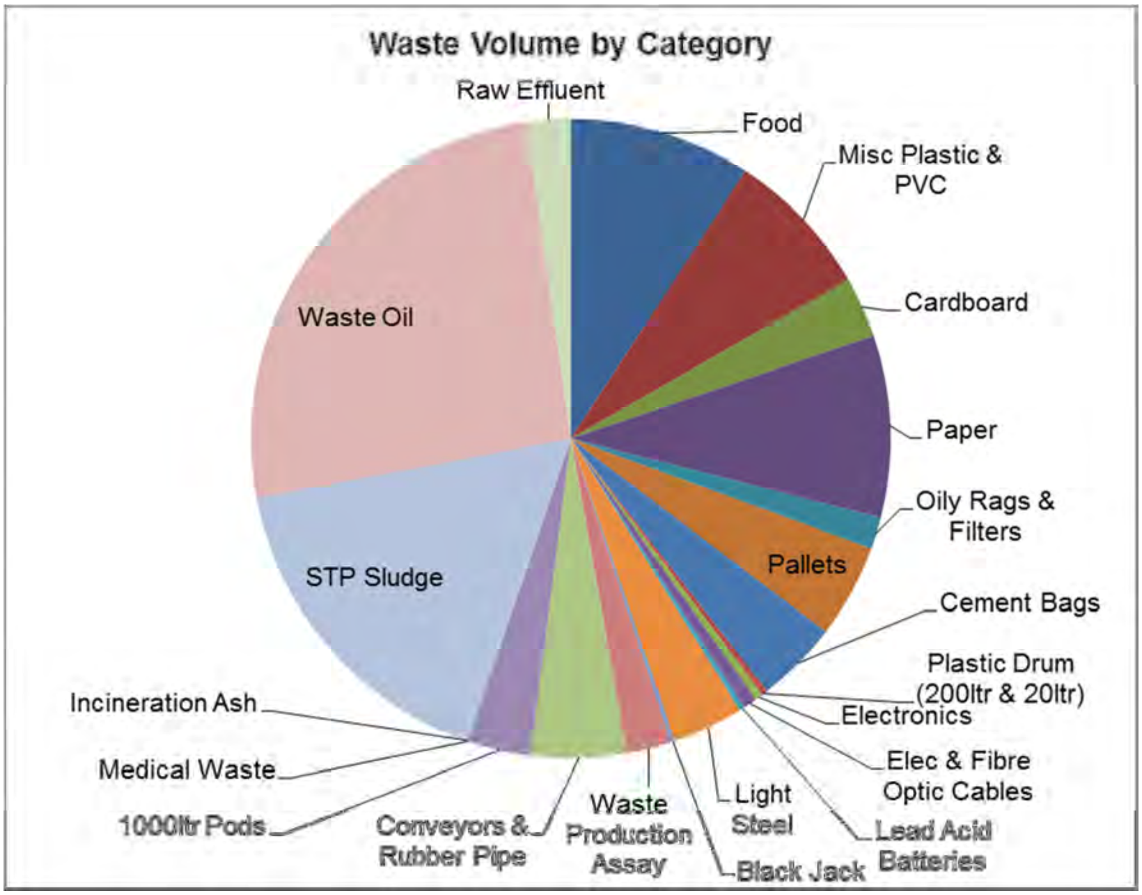


Figure 4-63 Non-mineralised waste production proportions by volume

5 BACKGROUND ENVIRONMENTAL CONDITIONS AND TVs

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 adjacent to and downstream of the Porgera Mine, how much of that change is caused by factors not related to the mining operation, and how much of that change is caused by factors that are related to the mining operation.

Aspects 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 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:

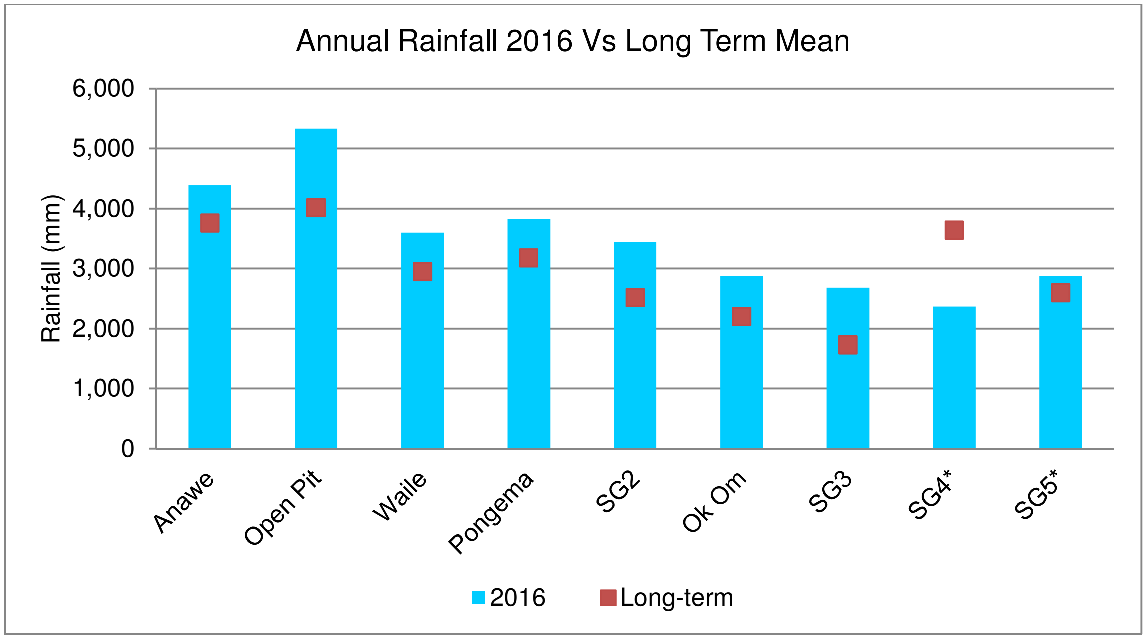
1. Quantify the climatic condition, meteorological and hydrological conditions at the mine site and within the receiving environment during 2016;
2. Describe the background environmental physical, chemical and biological conditions of aquatic ecosystems not influenced by the operation (i.e. reference site condition) and identify and quantify the natural changes at those sites during 2016 and over the history of mine 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 conducted in Section 6 and Section 7.

5.1 Climate

5.1.1 2016 Rainfall in Strickland River Catchment

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 to SG5 (near Lake Murray) and beyond to the Fly River.

In general terms, rainfall in 2016 was approximately 23% above the long term mean in the upper reach. In the middle reach (SG2, Ok Om, SG3) rainfall was about 29% above average. Rainfall records for the lower reach (SG4, SG5) were incomplete due to data loss caused by vandalism to the stations.



*Incomplete data record for SG4/SG5 due to equipment vandalism. There were 86 days lost at SG4 and 28 days lost at SG5.

Figure 5-1 Comparison of annual rainfall (2016 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 Pacific Decadal Oscillation (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. 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 2016 was 5.7, indicating a La Nina event, which typically exhibits above average rainfall.

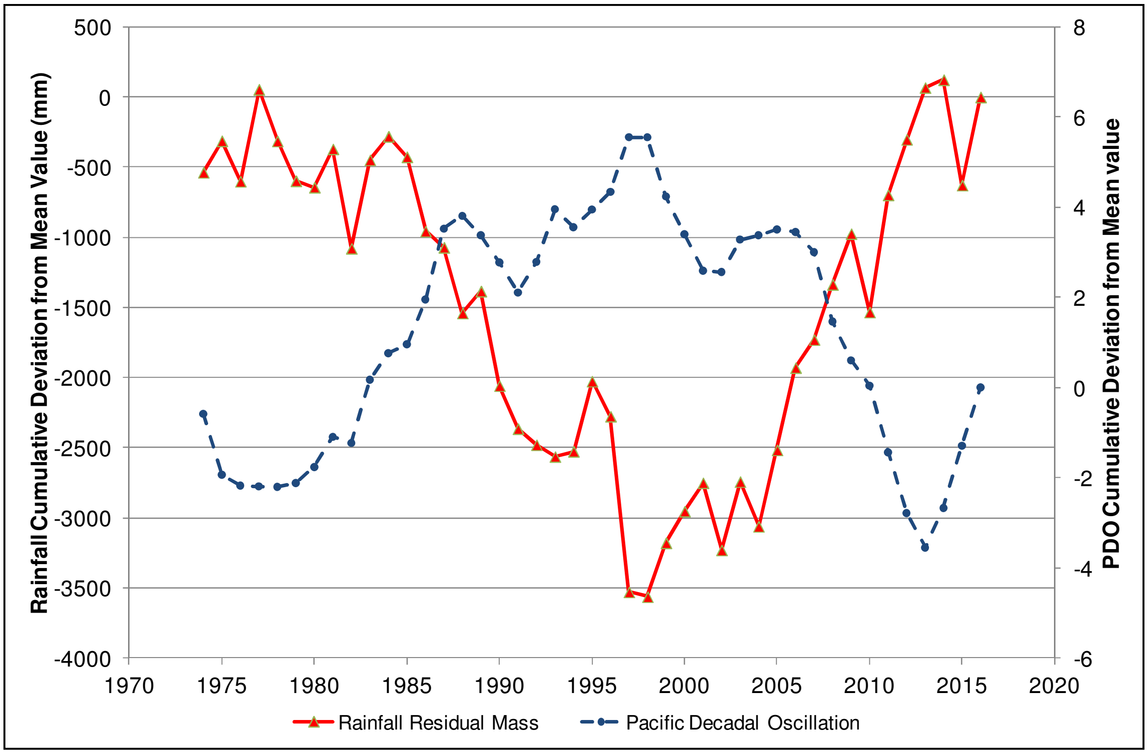


Figure 5-2 Residual mass plots Anawe rainfall station data

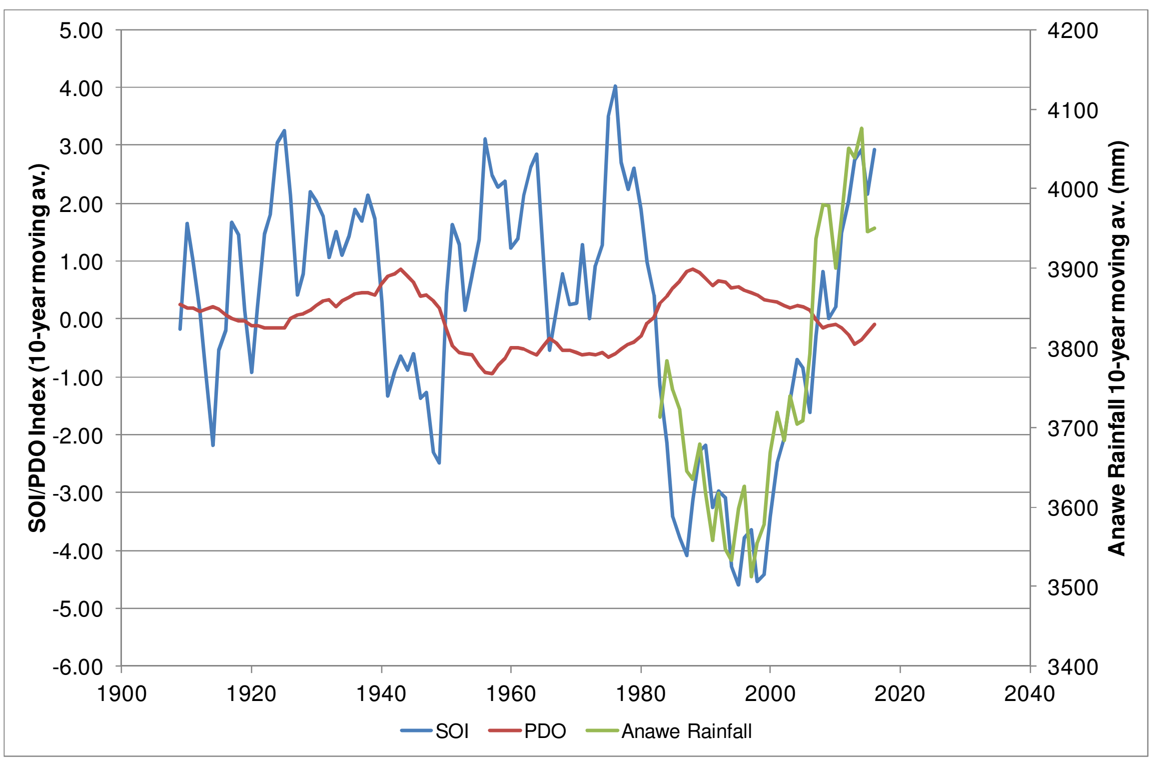


Figure 5-3 Anawe rainfall, SOI and PDO indices on 10-y moving average

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. Winds are katabatic (down-slope) in nature and generally tend from the east. Table 5-1 provides a summary of the meteorology data collected during the year.

Table 5-1 Summary of meteorological data recorded at Anawe plant site during 2016

Parameter	Yearly total	Daily max	Daily min	Daily mean	Long-term daily mean
Rainfall (mm)	4387	71	0.0	12	10.3
Max/Min Temp. (^{o}C)	-	23	8.9	-	-
Mean Daily Temp.(^{o}C)	-	19.2	12.0	16.2	16.1
Sunshine (h)	1287	10	0.0	3.6	4.1
Evaporation (mm)	968	7.4	0.0	2.7	2.8
Wind Run (km)	11488	73.0	0.0	32	47

The historical rainfall at Anawe is shown in Figure 5-4 and Figure 5-5. The highest annual rainfall recorded at Anawe was 4,594 mm in 2011. Figure 5-4 shows monthly total rainfall at Anawe in 2016 against long-term monthly means. Annual rainfall was 4,387 mm on 338 wet days in 2016. The long-term mean annual total was 3,758 mm.

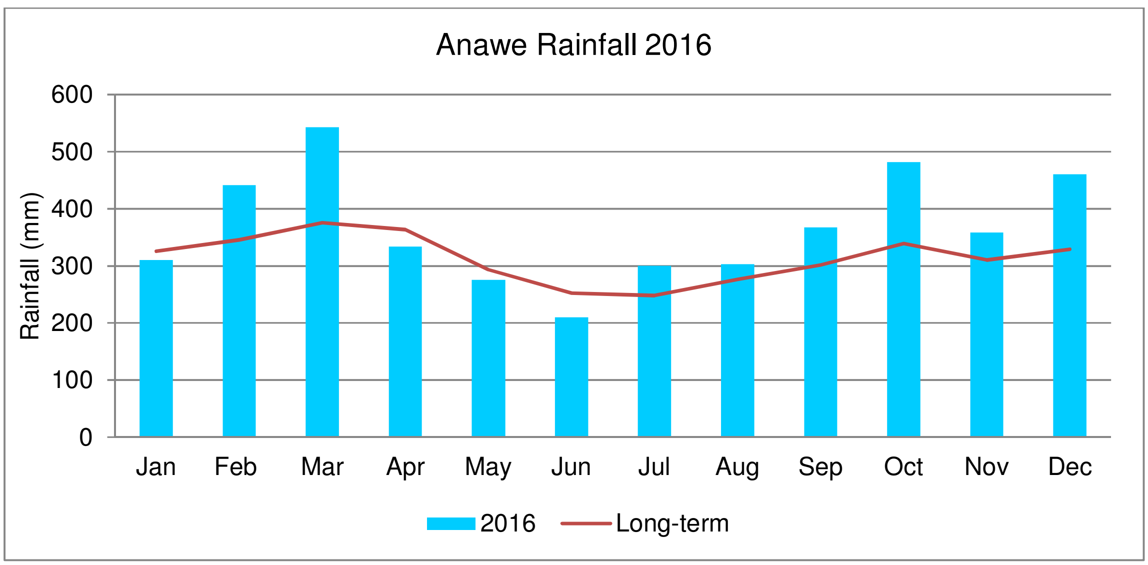


Figure 5-4 Monthly rainfall at Anawe Plant Site during 2016 compared to long-term monthly means

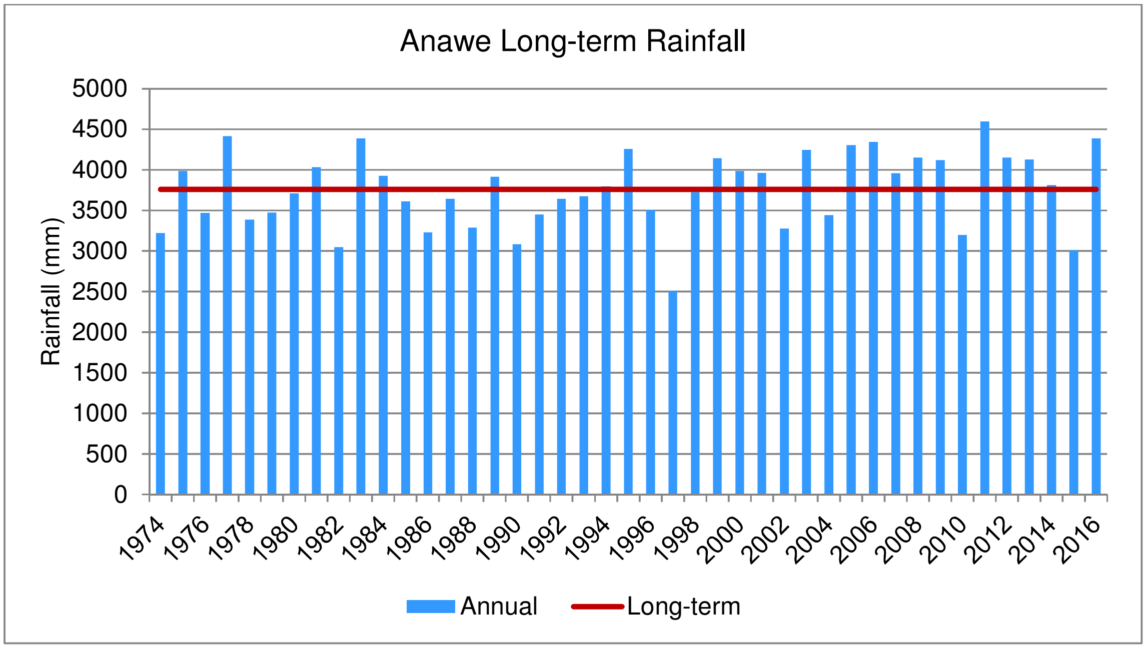


Figure 5-5 Comparison of annual rainfall at Anawe Plant Site with long-term mean 1974 - 2016

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 5,331 mm which was the highest on record. Rainfall occurred on 342 wet days. The long-term mean annual total was 3,922 mm. Figure 5-7 shows the historical annual totals.

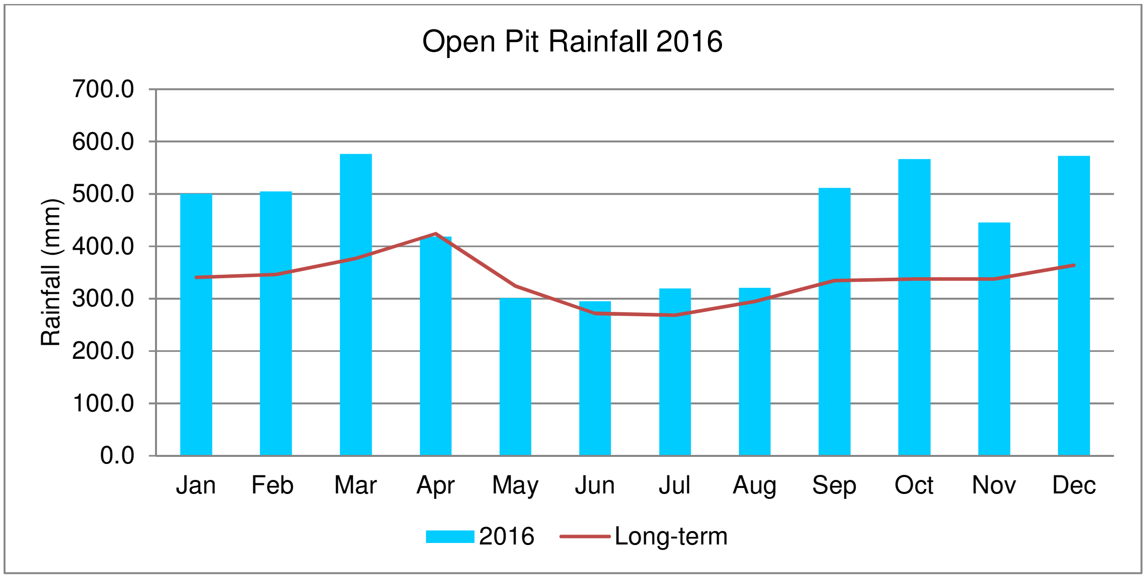


Figure 5-6 Rainfall at Open Pit during 2016 compared to long-term monthly means

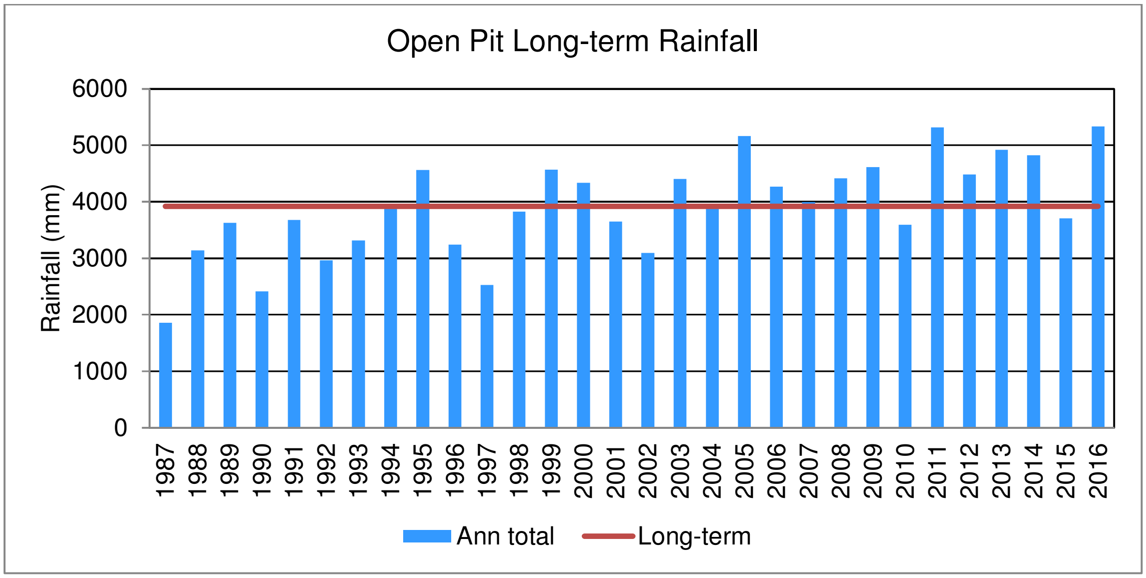


Figure 5-7 Annual rainfall at Open Pit 1988–2016

5.1.3.3 Waile Creek

Figure 5-8 shows rainfall at Waile Dam during 2016 compared to long-term monthly means. Annual rainfall was 3,598 mm which occurred on 337 wet days. The long-term mean annual total was 2,929mm.

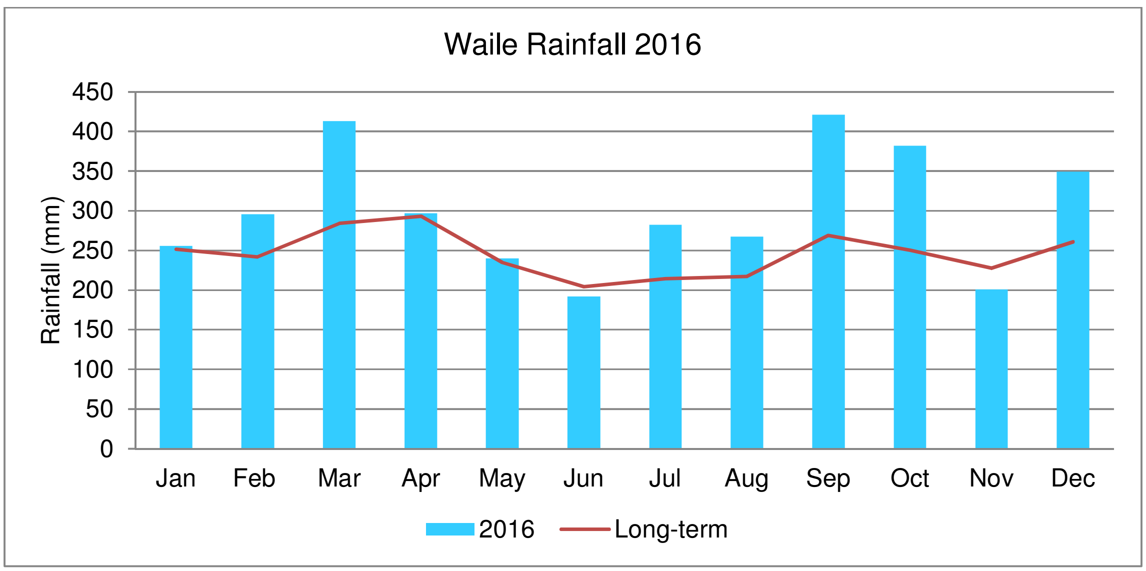


Figure 5-8 Rainfall at Waile Dam during 2016 compared to long-term monthly means

5.1.3.4 Pongema

Figure 5-9 shows rainfall recorded at Suyan Camp during 2016 against long-term monthly means. Annual rainfall was 3,831 mm which occurred on 336 wet days. The long-term mean annual total was 2,971.2 mm.

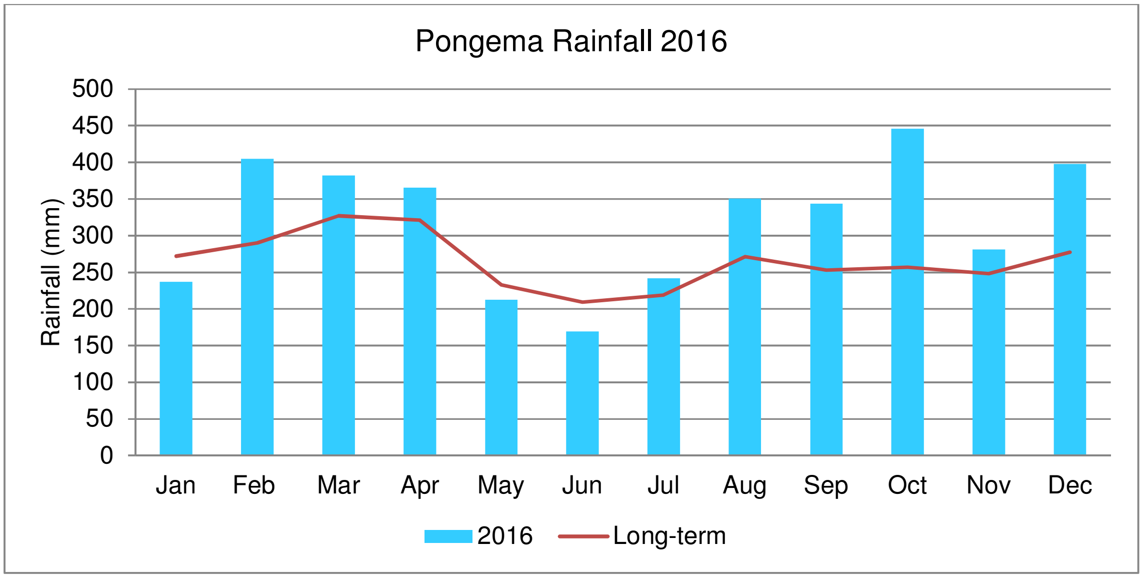


Figure 5-9 Rainfall at Suyan Camp during 2016 compared to long-term monthly means

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 3,440 mm on 308 wet days. The long-term mean annual total was 2,082 mm.

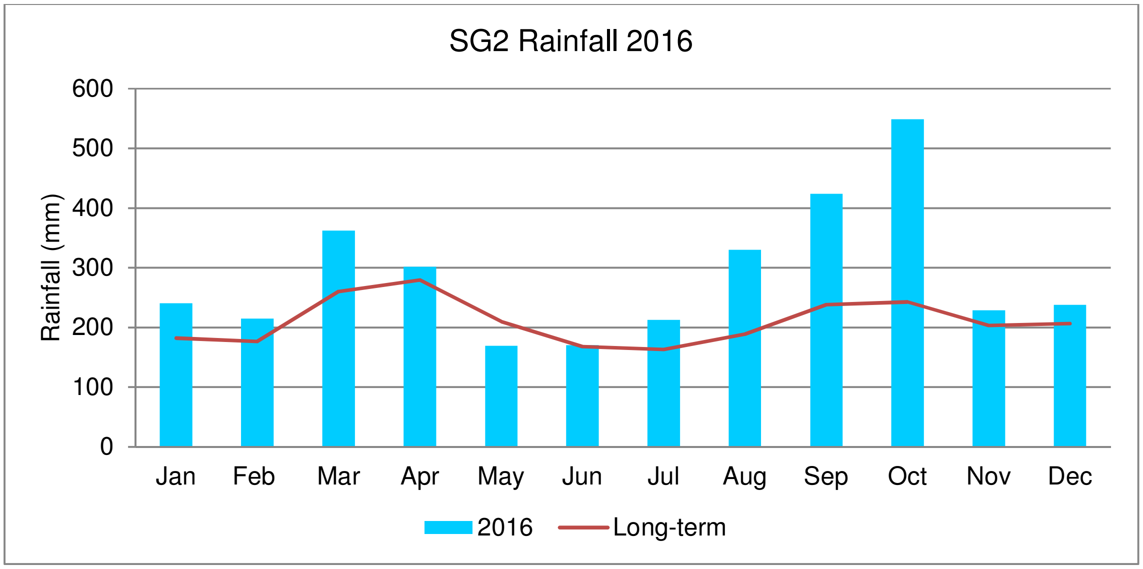


Figure 5-10 Rainfall at SG2 during 2016 compared to long-term monthly means

5.1.3.6 Ok Om

Figure 5-11 shows rainfall at Ok Om during 2016 against long-term monthly means. Annual rainfall of 2,872 mm fell on 276 wet days. The long-term mean annual total was 2,130 mm.

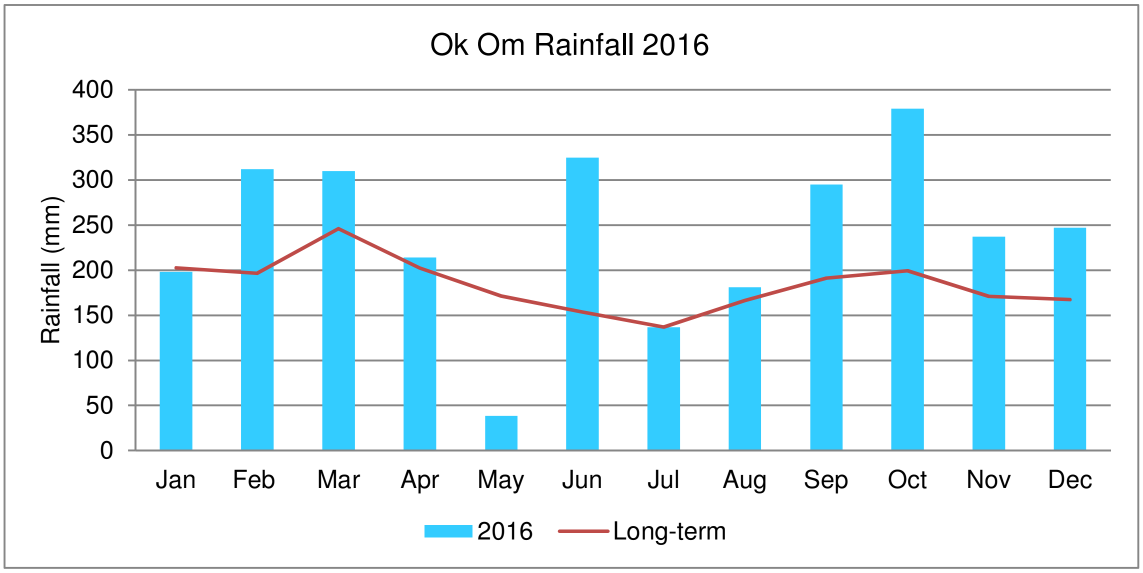


Figure 5-11 Rainfall at Ok Om during 2016 compared to long-term monthly means

5.1.3.7 SG3 (Compliance site)

Figure 5-12 shows rainfall at the SG3 compliance site during 2016 against long-term monthly means. Annual rainfall of 2,679 mm fell on 268 wet days. The long-term mean annual total was 1,758 mm.

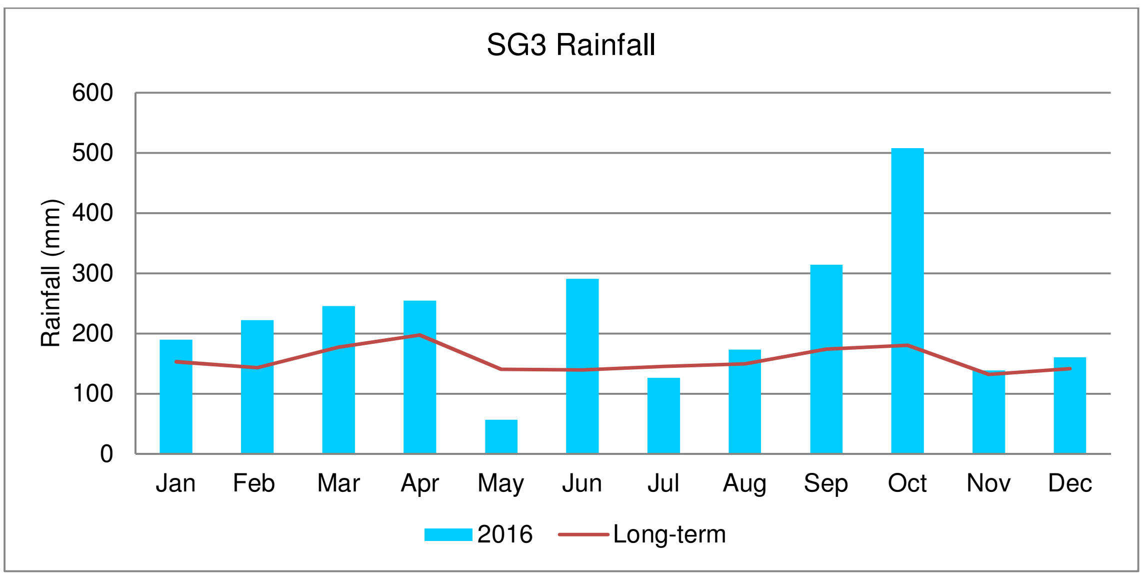
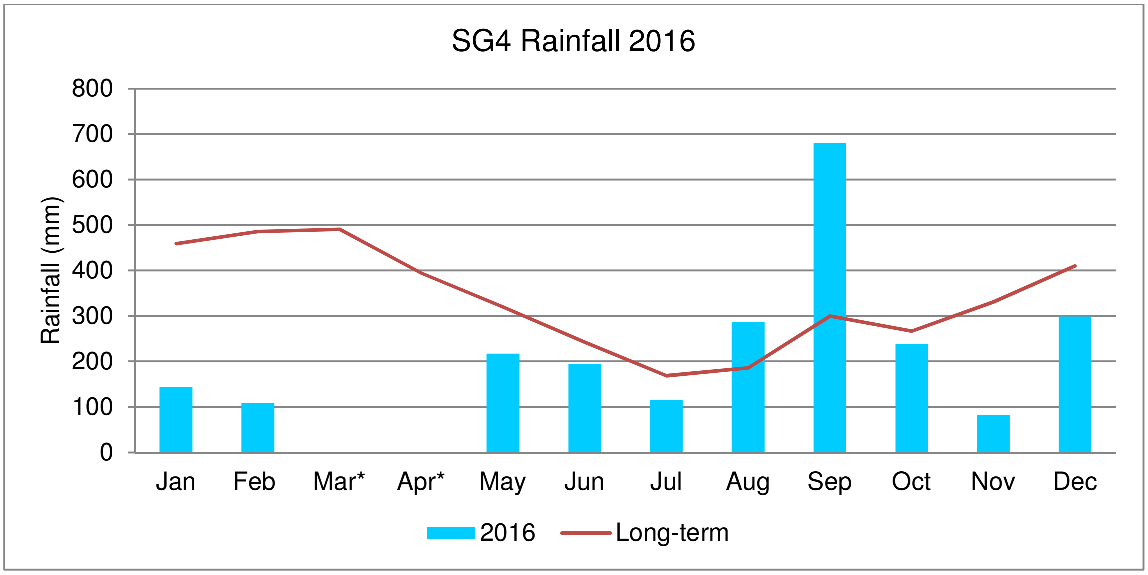


Figure 5-12 Rainfall at SG3 during 2016 compared to long-term monthly means

5.1.3.8 SG4

Figure 5-13 shows rainfall at SG4 in 2016 against long-term monthly means. The annual rainfall total was not calculated due to loss of data for 86 days caused by vandalism of the equipment. The long-term mean annual total is 3,596 mm.

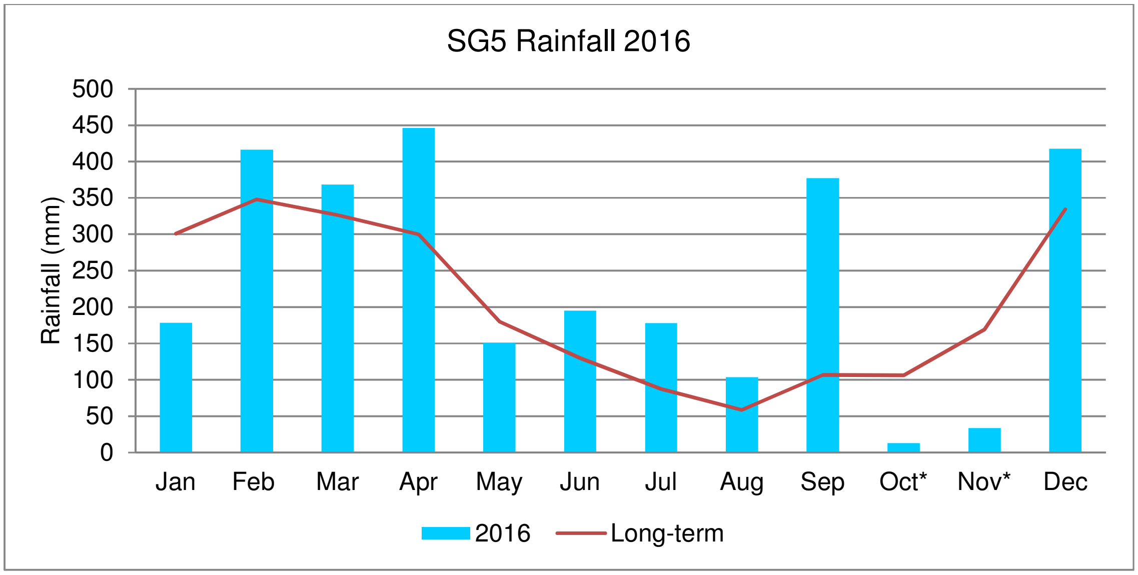


*Incomplete data record due to equipment vandalism (86 days)

Figure 5-13 Rainfall at SG4 during 2016 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 was not reported due to loss of data records for 28 days. The long-term mean annual total was 2,288 mm.



*Incomplete data record due to equipment vandalism (28 days)

Figure 5-14 Rainfall at SG5 during 2016 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 region sites of Kogai at SAG Mill and Kogai at culvert because of the higher than average rainfall recorded around mine site. Actual values could not be calculated due to loss of data by siltation at Kogai Sag mill and vandalism at the other sites. The portal at Yunarilama was not operational due to reconstruction of the site. About 25% above-average flows were recorded in the middle region, at SG3. Flows at SG4 were 14% below average and 7% above average for SG5 due to variations in rainfall distribution at the lower regions. The tributaries downstream of SG4 are another contributing factor to the flow differences in the lower regions.

A summary of river flow data collected at the operational stations during the year is given in Table 5-2, while plots of yield and total flow for the main stations are provided in Figure 5-15 and 5-16 respectively.

Table 5-2 Summary of flows in m^3/s for riverine stations in 2016

Station	Days lost 2016	Max	Mean	Min	Long-term Mean
Kogai @ SAG Mill	63	3.6	NA	0.0	0.9
Kogai @ Culvert	147	4.2	NA	0.1	1.6
Portal @ Yunarilama	-	-	-	-	-
Lagaip @ SG2	264	739	NA	170	216
Ok Om	0	625	171	51	137
Strickland @ SG3	0	3,304	974	258	749
Strickland @ SG4	0	8,113	2,169	545	2,531
Strickland @ SG5	0	4,350	3,434	1,273	3,207

NA – Mean not valid due to the amount of data loss throughout the year at these sites

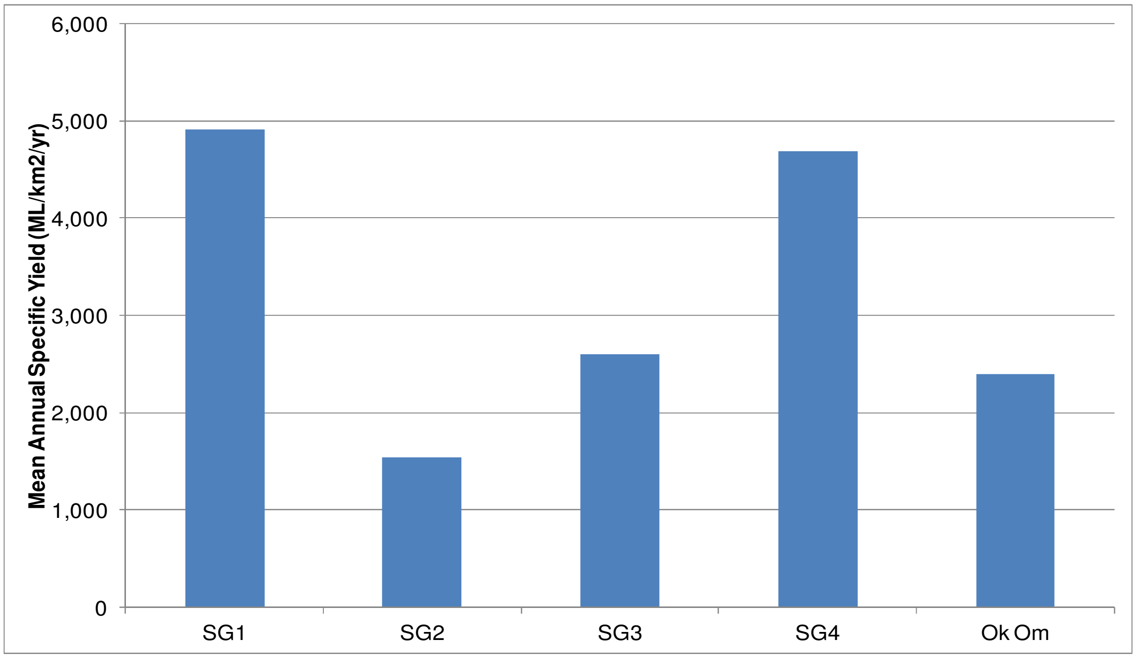
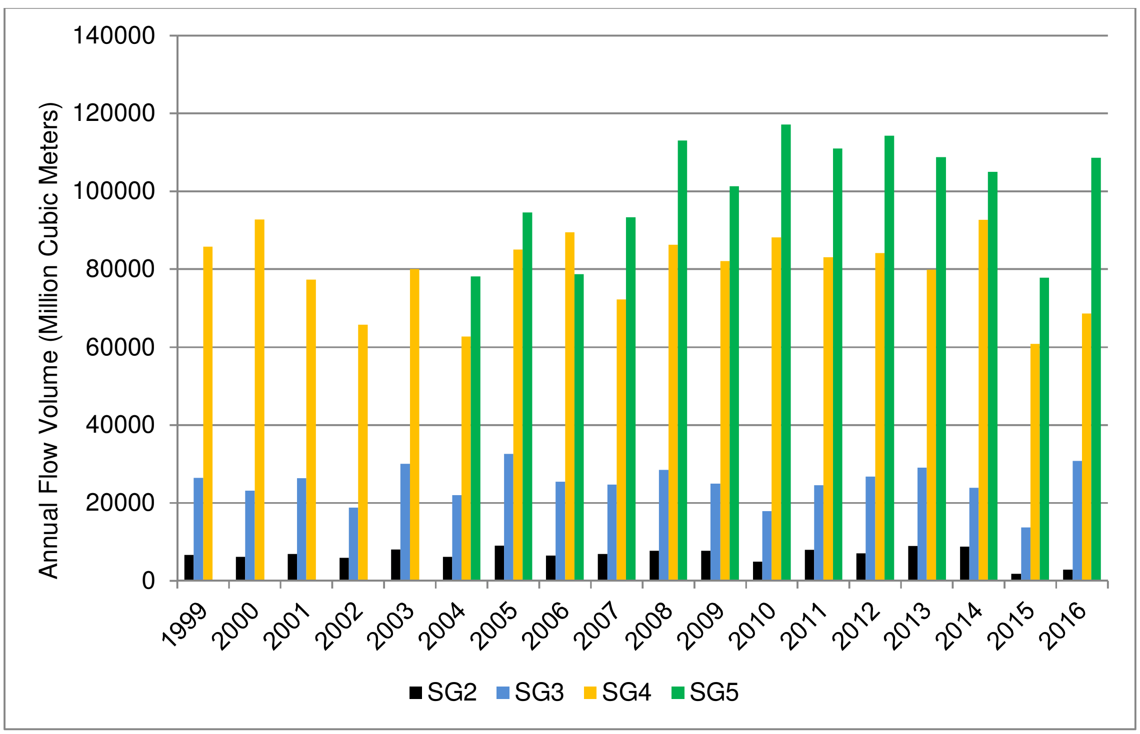


Figure 5-15 Comparison of annual specific yield for main river gauging stations



Note that the rainfall total and flow data for SG2 in 2016 were affected by the station being non-operational for almost a year (264 days) due to landowner issues. The station resumed in mid-September after the land-owner issues had been resolved.

Figure 5-16 Mean annual flow volumes for the main river gauging stations in 2016

5.2.2 SG3 (Compliance site)

The total flow for the year at SG3 of 30,810 GL was approximately 46% above the long-term average of 21,080 GL. October had the highest monthly flow with 4,833 GL while July had the least with 1,155 GL. Figure 5-17 shows the daily total flows for the year at SG3 while Figure 5-18 shows total monthly flows compared to long-term monthly averages.

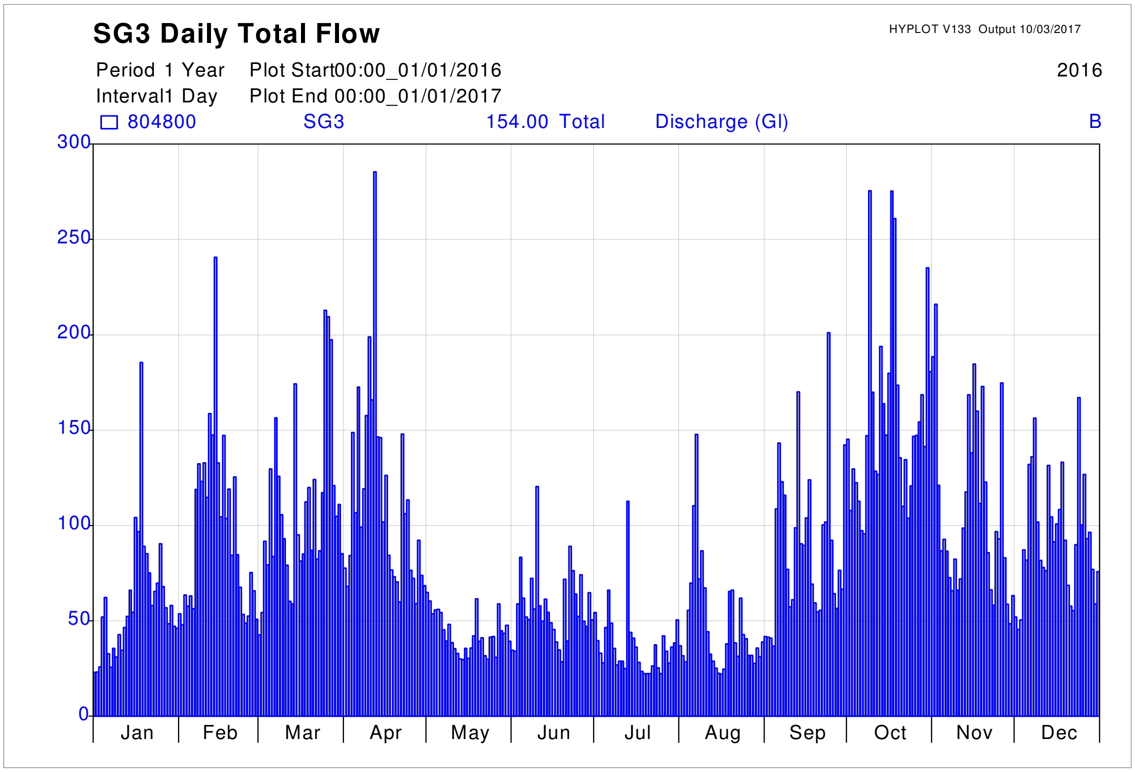


Figure 5-17 Total daily flow (GL) at SG3 for 2016

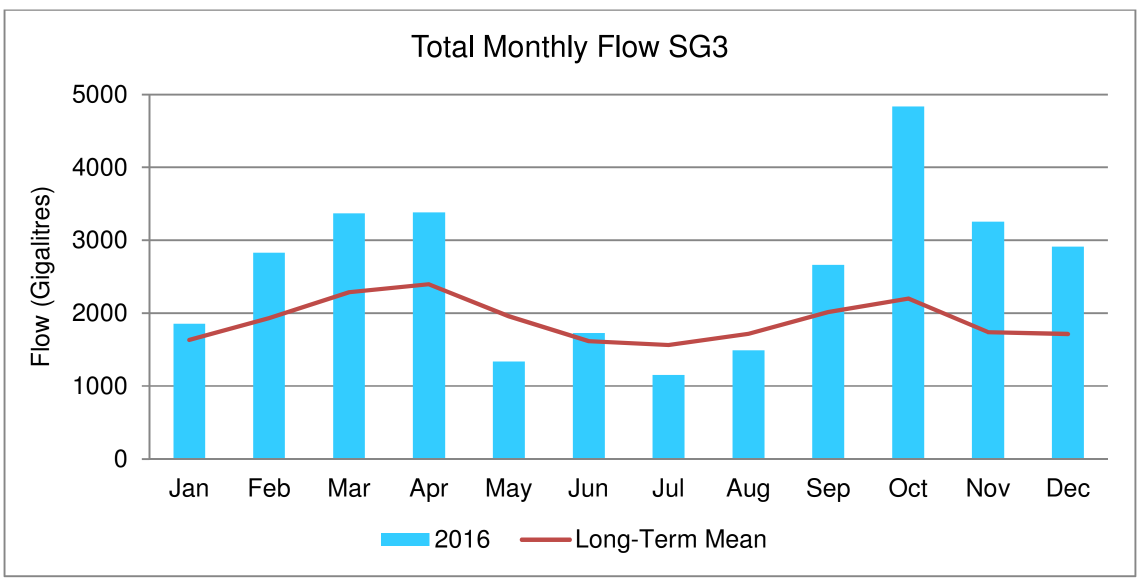


Figure 5-18 Total monthly flow (GL) at SG3 during 2016 compared to long-term monthly means

5.3 Background Water Quality and TVs

This section presents the water quality data collected from reference sites throughout the history of the operation and establishes TVs for use in the risk assessment in Section 7. The sites are grouped into Local Sites, Upper River, Lower River and Lake Murray and Off-River Water Bodies (ORWBs).

Data from all groups except local creeks are used to develop risk assessment criteria for water quality indicators in each of the respective groups. Risk assessment TVs are derived from the reference site monitoring data from the previous 24 months and describe the current non-mine related conditions of the receiving environment.

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

5.3.1 Local Sites

Local Sites comprise the small highland creeks within the Porgera River catchment that are not affected by the mining operation. Water from these creeks joins with discharge from the mine to form the Porgera River, and so the quality of water within 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 2016 are presented in Table 5-4 and shown in Figure 5-19 to Figure 5-48, with trends from 2007-2016 shown in Table 5-5.

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 within 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 reach elevated levels particularly under high rainfall periods due to landslides and erosion within the steep valley catchment, and particularly in the Kaiya River catchment (Kaiya US Anjolek) and Aipulungu River. Concentrations of dissolved metals generally were low, however, background concentrations of mercury and selenium were at detectable levels throughout the historical record, although none of the concentrations exceeded the upper river TV. Additionally, high concentrations of some total metals are present throughout the record at some sites.

A summary of the trends between 2007 and 2016 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 alkalinity at Aipulungu US Lime Quarry and dissolved zinc at Waile Creek had increased over time, while all other elements at all sites had either reduced or remained constant over the period.

Table 5-4 Local Reference Site water quality 2016 median values (µg/L except where shown)

Parameter	Aipulungu U/S Lime Plant	Waile Dam	Kaiya Riv U/S Anj Dump	Pongema
pH^	7.9	8.0	7.6	8.1
WAD-CN*	0.20	0.20	0.20	0.20
Sulfate*	2.5	1.5	20	4.0
ALK-T*	91	76	64	123
Hardness*	84	72	61	129
TSS*	25	5.8	108	37
Ag-D	0.01	0.01	0.05	0.01
Ag-T	0.05	0.01	0.05	0.05
As-D	0.20	0.20	0.30	0.20
As-T	0.30	0.25	1.0	0.60
Cd-D	0.05	0.05	0.05	0.05
Cd-T	0.05	0.05	0.05	0.06
Cr-D	0.20	0.20	0.15	0.20
Cr-T	0.90	0.45	4.1	1.7
Cu-D	0.50	0.50	0.50	0.50
Cu-T	1.6	0.60	3.5	1.9
Fe-D	24	56	21	8.0
Fe-T	748	272	6,300	1,980
Hg-D	0.04	0.04	0.04	0.04
Hg-T	0.04	0.04	0.04	0.04
Ni-D	0.50	0.50	0.50	0.50
Ni-T	1.0	0.50	4.4	1.7
Pb-D	0.10	0.10	0.10	0.10
Pb-T	0.40	0.25	1.7	1.2
Se-D	0.20	0.20	0.20	0.20
Se-T	0.20	0.20	0.20	0.20
Zn-D	10	9.0	10	11
Zn-T	5.4	3.3	16	8.0
	> UpRiv TV			

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

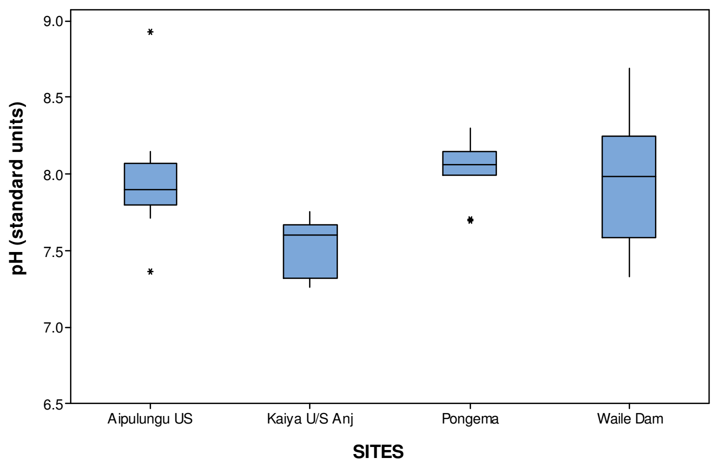


Figure 5-19 pH in local creek runoff 2016

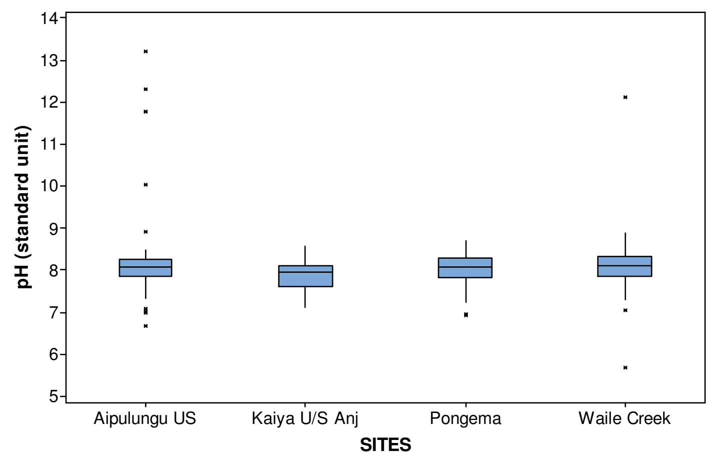


Figure 5-20 pH in local creek runoff 2007-2016

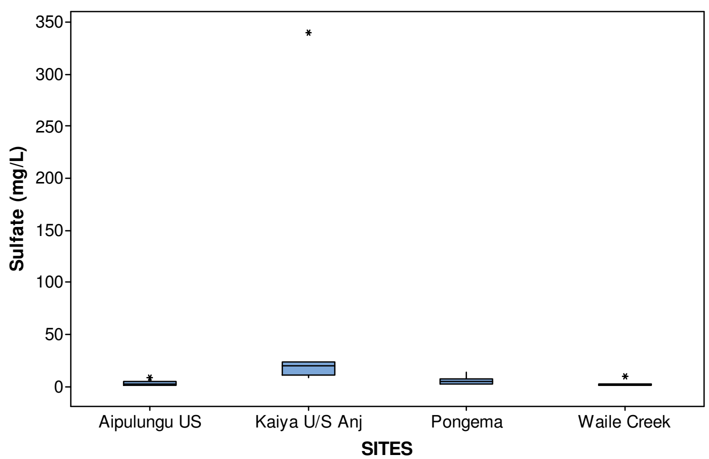


Figure 5-21 Sulfate in local creek runoff 2016

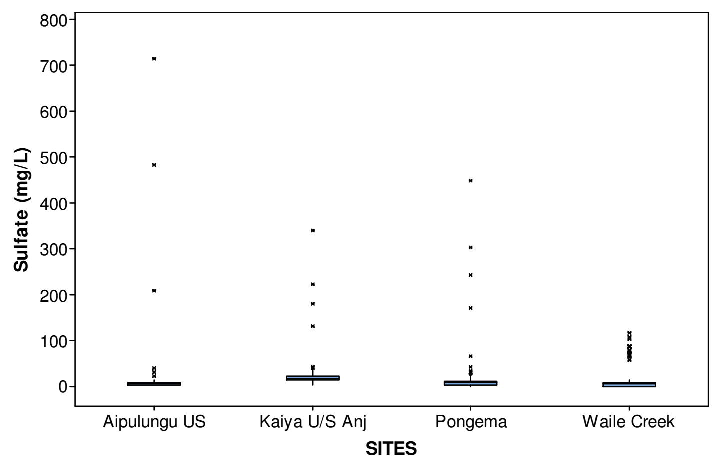


Figure 5-22 Sulfate in local creek runoff 2007-2016

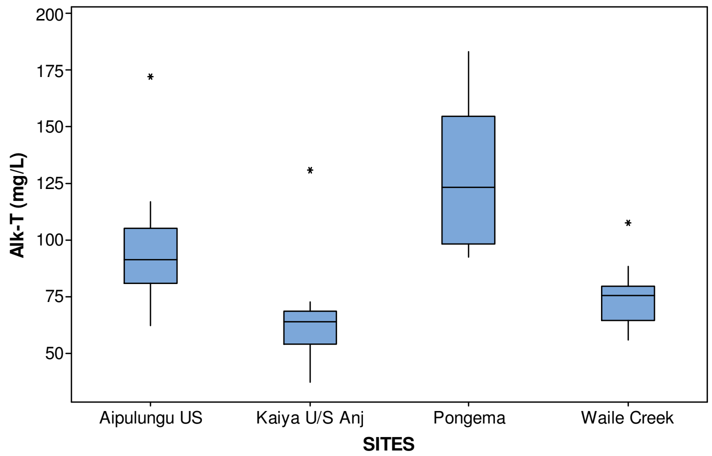


Figure 5-23 Alkalinity in local creek runoff 2016

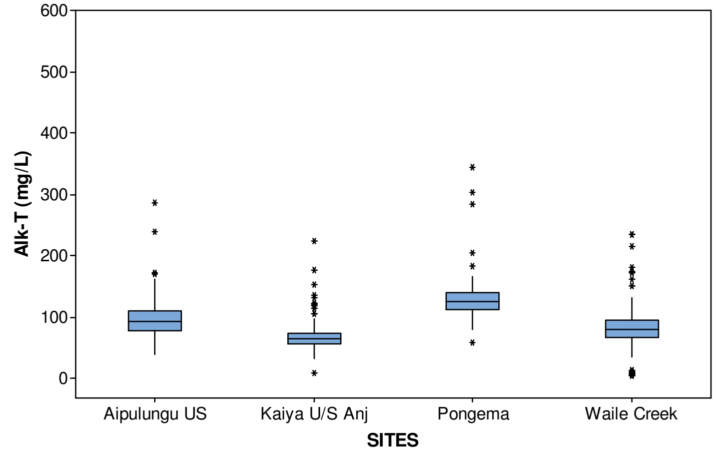


Figure 5-24 Alkalinity in local creek runoff 2007-2016

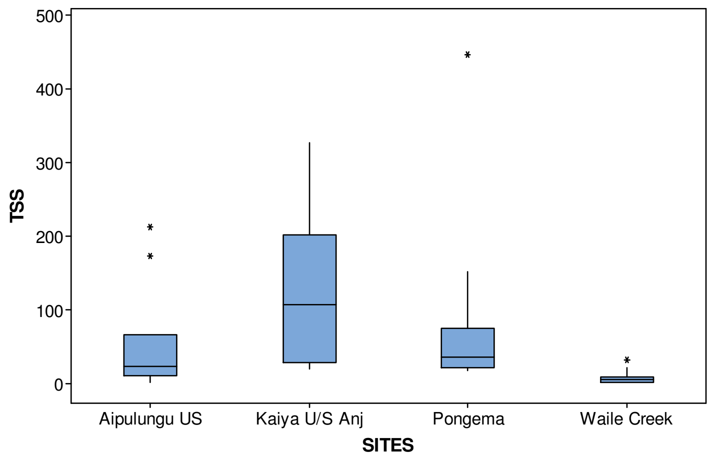


Figure 5-25 TSS in local creek runoff 2016

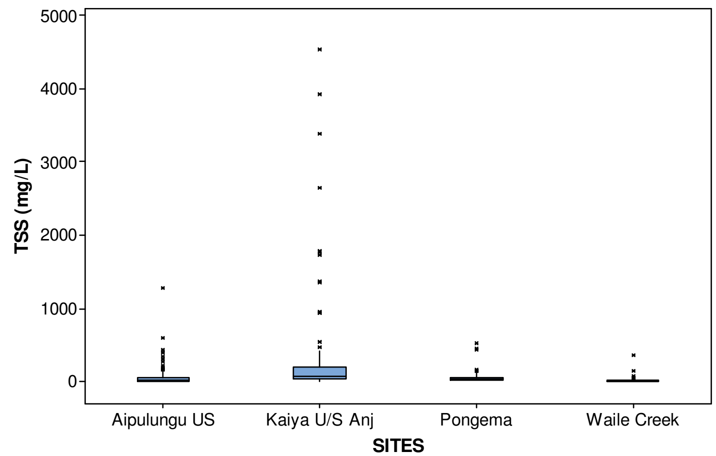


Figure 5-26 TSS in local creek runoff 2007-2016

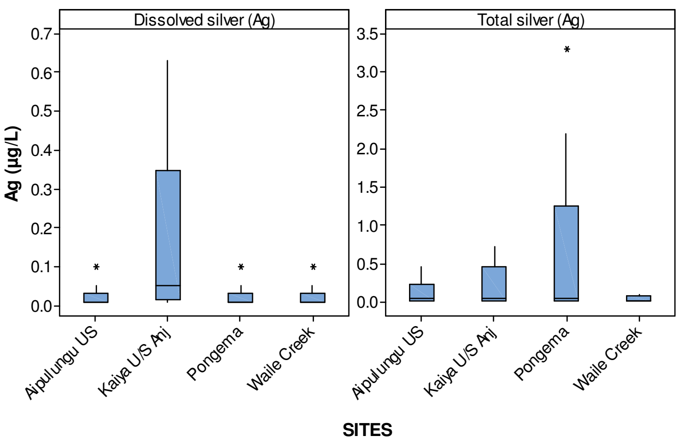


Figure 5-27 Dissolved and total silver in local creek runoff 2016

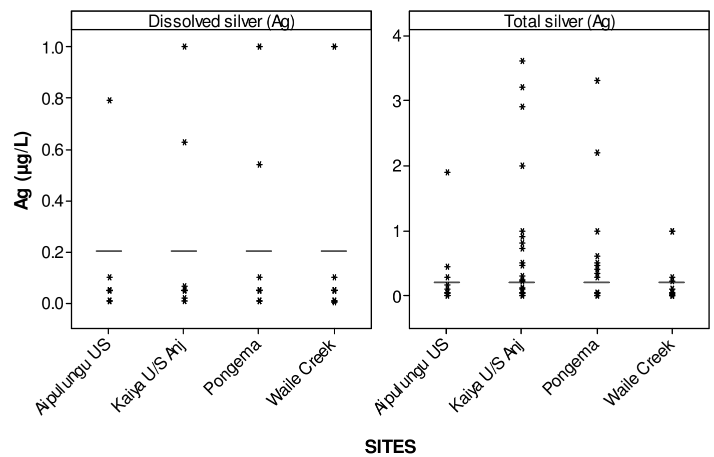


Figure 5-28 Dissolved and total silver in local creek runoff 2007-2016

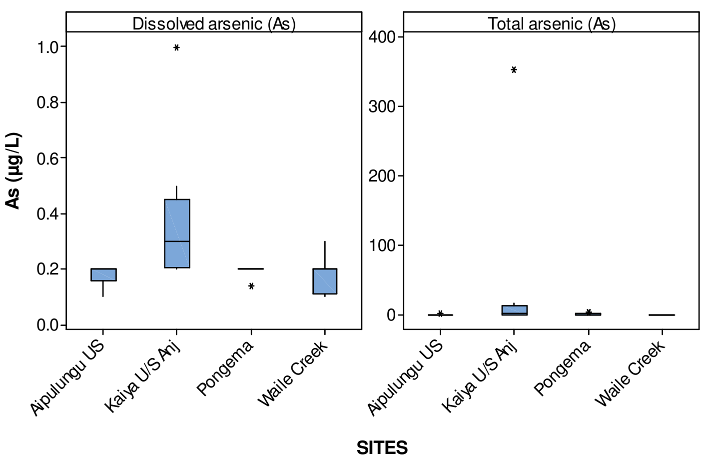


Figure 5-29 Dissolved and total arsenic in local creek runoff 2016

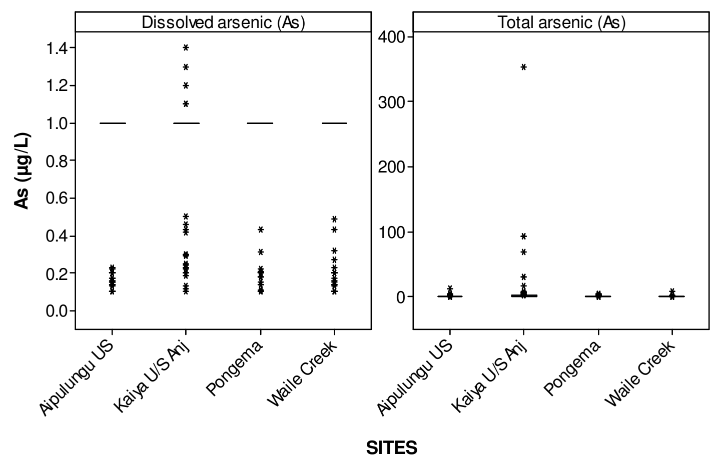


Figure 5-30 Dissolved and total arsenic in local creek runoff 2007-2016

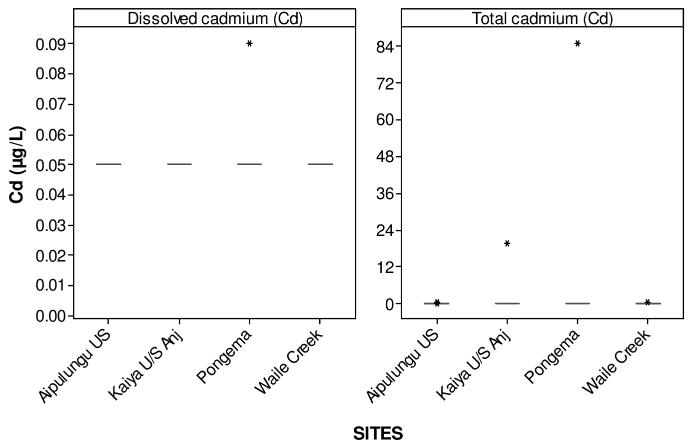


Figure 5-31 Dissolved and total cadmium in local creek runoff 2016

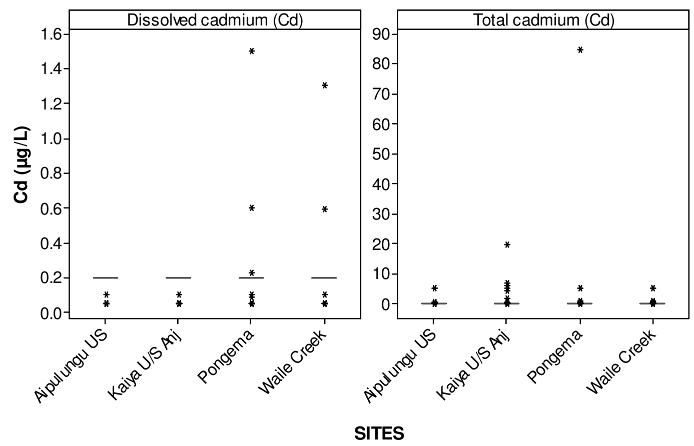


Figure 5-32 Dissolved and total cadmium in local creek runoff 2007-2016

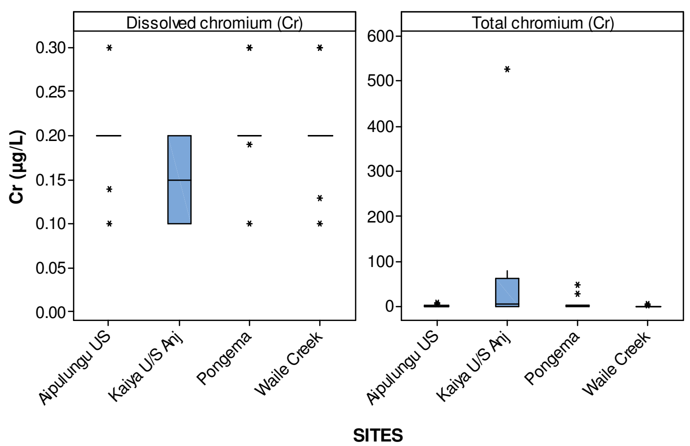


Figure 5-33 Dissolved and total chromium in local creek runoff 2016

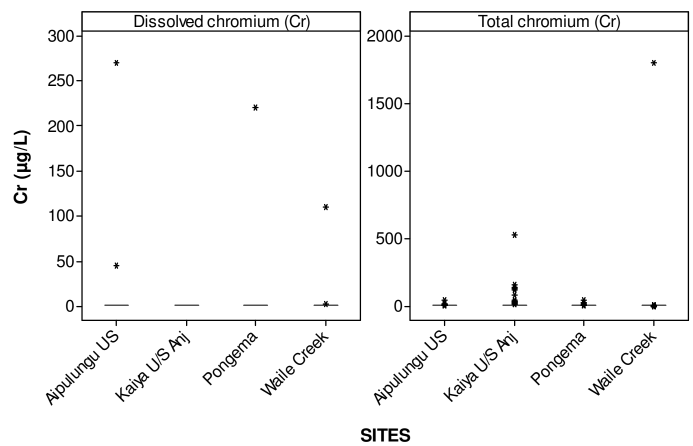


Figure 5-34 Dissolved and total chromium in local creek runoff 2007-2016

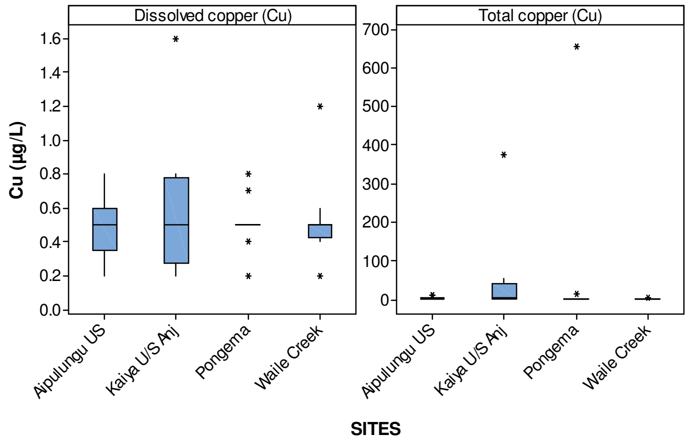


Figure 5-35 Dissolved and total copper in local creek runoff 2016

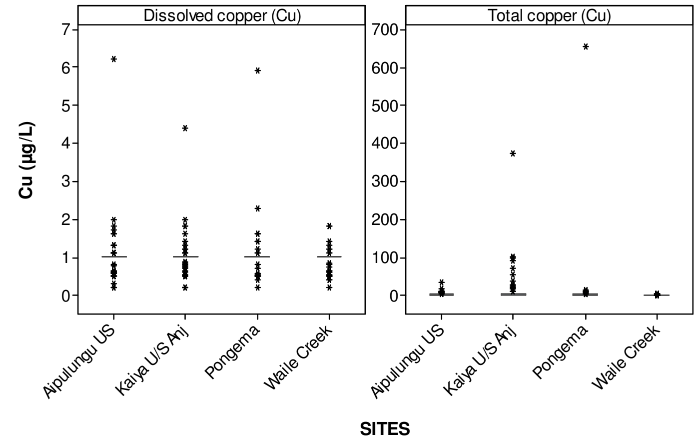


Figure 5-36 Dissolved and total copper in local creek runoff 2007-2016

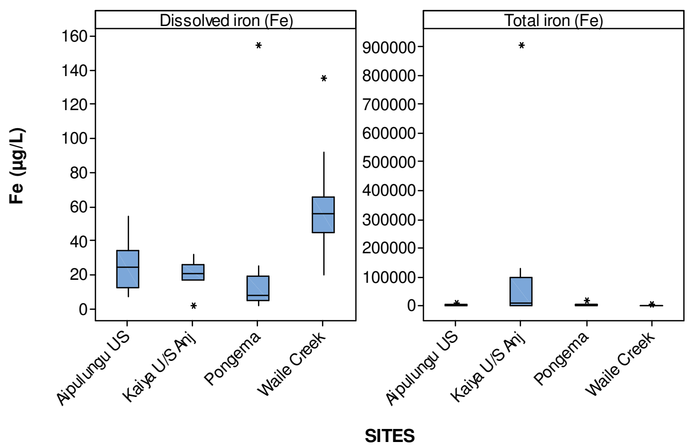


Figure 5-37 Dissolved and total iron in local creek runoff 2016

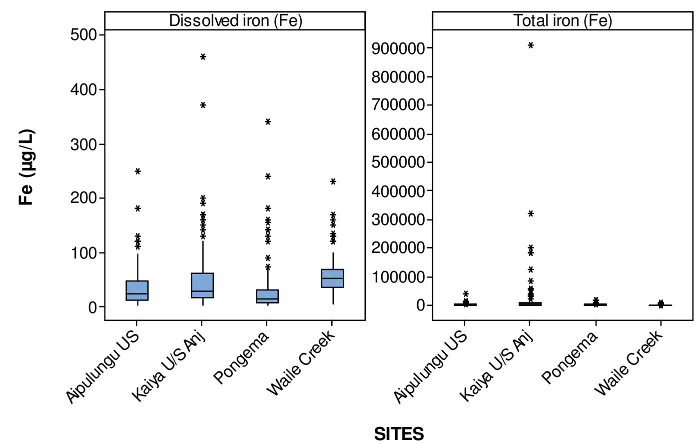


Figure 5-38 Dissolved and total iron in local creek runoff 2007- 2016

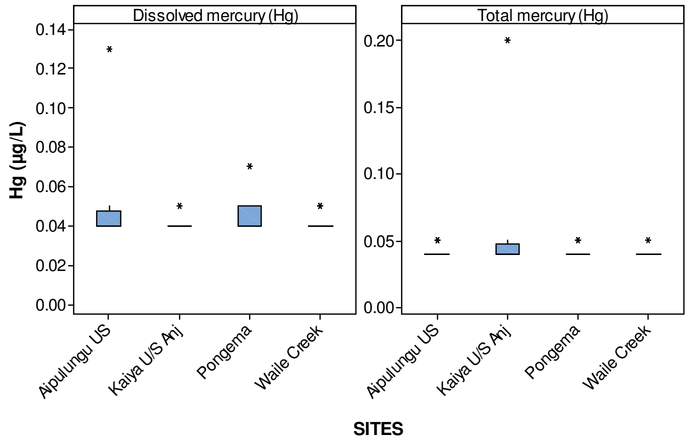


Figure 5-39 Dissolved and total mercury in local creek runoff 2016

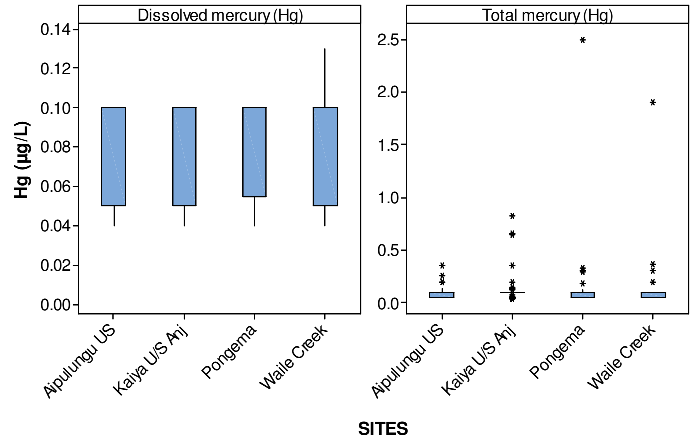


Figure 5-40 Dissolved and total mercury in local creek runoff 2007-2016

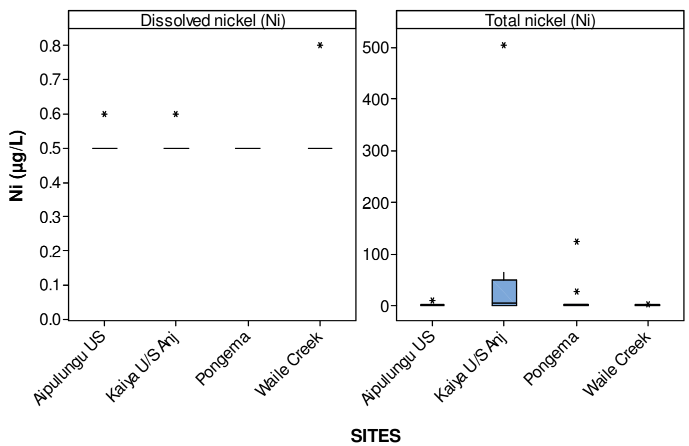


Figure 5-41 Dissolved and total nickel in local creek runoff 2016

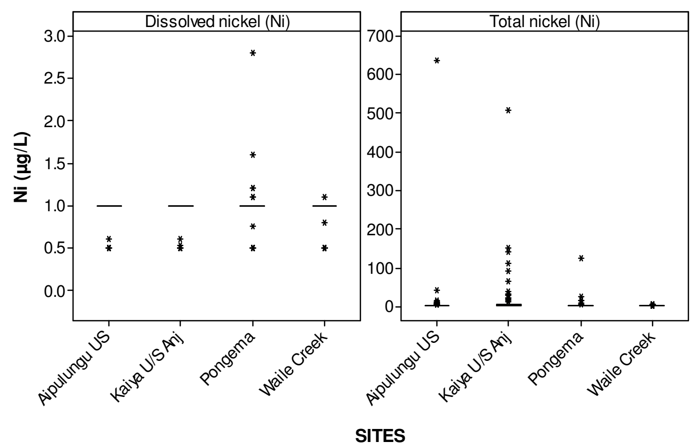


Figure 5-42 Dissolved and total nickel in local creek runoff 2007-2016

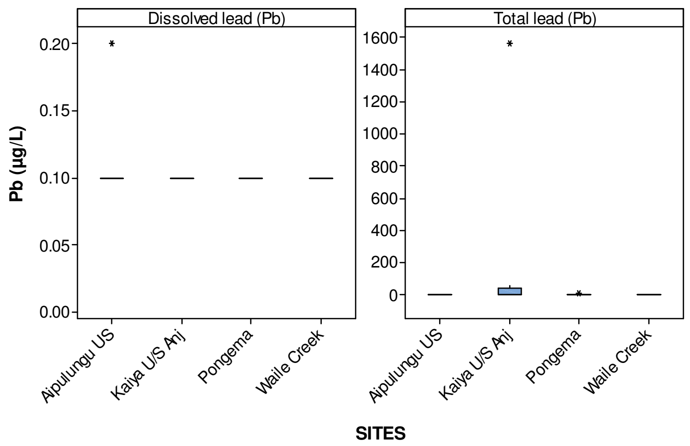


Figure 5-43 Dissolved and total lead in local creek runoff 2016

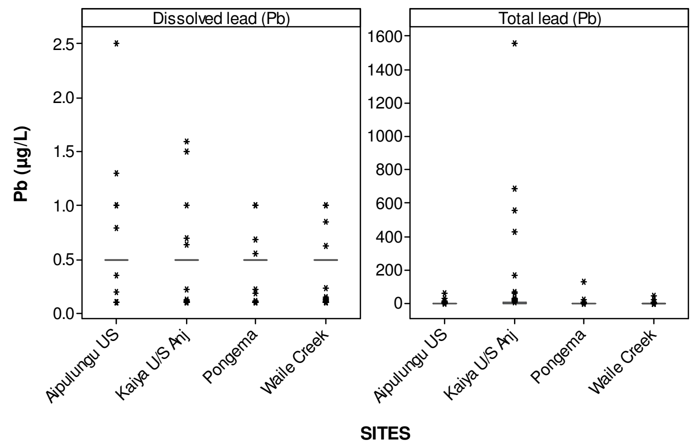


Figure 5-44 Dissolved and total lead in local creek runoff 2007-2016

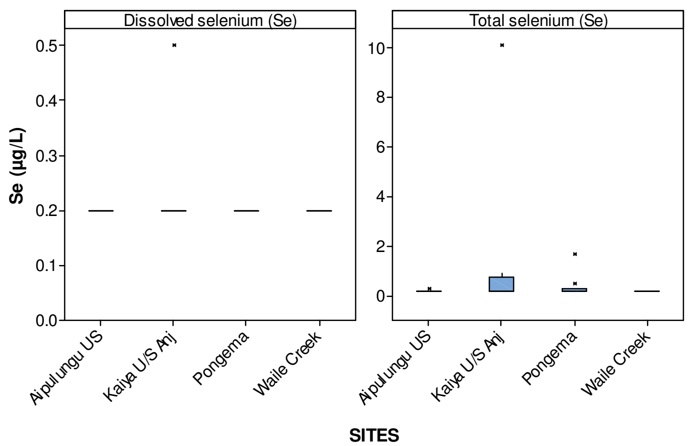


Figure 5-45 Dissolved and total selenium in local creek runoff 2016

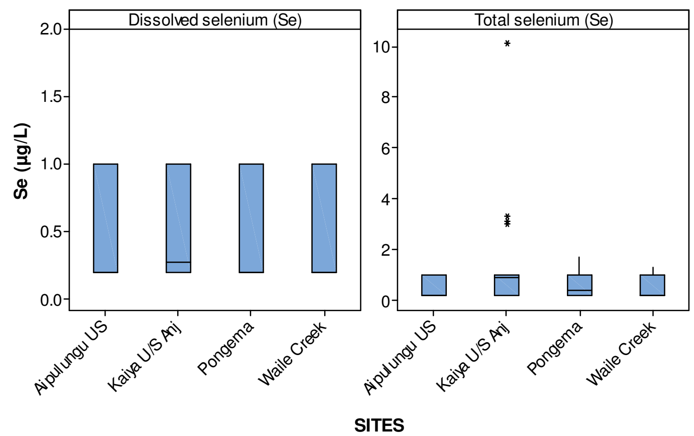


Figure 5-46 Dissolved and total selenium in local creek runoff 2007-2016

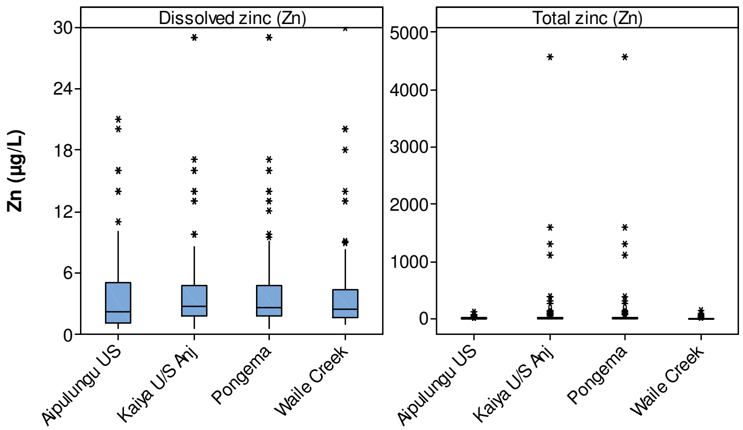


Figure 5-47 Dissolved and total zinc in local creek runoff 2016

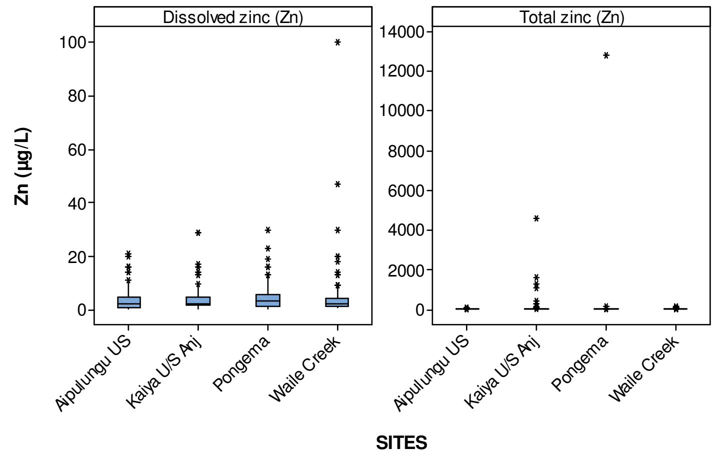


Figure 5-48 Dissolved and total zinc in local creek runoff 2007-2016

Table 5-5 Trends of water quality in mine area runoff reference sites 2007-2016 as tested by Spearman Rank Correlation

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

	Decreased or no change over time
	Increased over time

^ std units, * mg/L, D - Dissolved fraction, T - Total

5.3.2 Upper and Lower River – Background Water Quality and TVs

This section presents pre-mine baseline water quality data at upper and lower river test sites and data from the most recent 24 months from upper and lower river reference sites. Baseline data were collected from the test sites prior to the commencement of mining.

The purpose of this section is to establish TVs for supporting the risk assessment stage by describing the water quality conditions at sites that are not influenced by the mining operation and comparing them against relevant guidelines for protection of environmental values.

Water quality TVs for the upper and lower river reference sites are presented in Table 5-6 and Table 5-7 respectively. In accordance with the methodology outlined in Section 2, the TVs are derived by comparing the 80%ile of the baseline data at test sites, the 80%ile of the most recent 24-month data from all of the reference sites, and the ANZECC/ARMCANZ (2000) default guideline for 95% species protection, and then adopting the highest of the three values for each analyte.

Baseline data in the upper river exhibited elevated pH, sulfate, alkalinity, concentrations of TSS, total and dissolved arsenic, copper, iron, mercury, lead and zinc compared to the upper river reference sites. This indicates that the catchment which hosts the Porgera deposit, and in which the test sites are located, has naturally elevated pre-mine concentrations of dissolved and total metals compared to the regional reference sites. The reference site 80%ile is equal to the ANZECC/ARMCANZ (2000) guideline for dissolved silver and was adopted as the TV as no baseline data for silver were available. The ANZECC/ARMCANZ (2000) guideline values were higher than the baseline and reference 80%iles for dissolved arsenic, cadmium, chromium, mercury, lead and selenium. The baseline 80%iles were higher than the reference 80%iles and ANZECC/ARMCANZ (2000) guideline values for TSS, dissolved copper, nickel and zinc.

In the lower river, baseline data exhibited higher pH, and concentrations of sulfate, TSS, total and dissolved arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead and total zinc than the lower river reference sites. This also indicates that the catchment which hosts the Porgera deposit, in which the lower river test sites are located, has naturally elevated pre-mine concentrations of dissolved and total metals compared to the regional reference sites. The lower river reference 80%iles were equal to the respective ANZECC/ARMCANZ (2000) guideline values for dissolved silver and copper. No baseline data for silver are available. The lower river reference 80%ile for dissolved zinc was higher than the baseline 80%ile and the ANZECC/ARMCANZ (2000) guideline value. The ANZECC/ARMCANZ (2000) guideline values were higher than the baseline or reference 80%iles for dissolved arsenic, cadmium, chromium, mercury, lead and selenium. The baseline 80%iles were higher than the upper river reference 80%iles and the ANZECC/ARMCANZ (2000) guideline values for dissolved iron and nickel.

Table 5-6 Summarised water quality for upper river test sites for baseline and reference sites for previous 24 months, presenting 20%ile, median and 80%ile of data for each site. ANZECC/ARMCANZ (2000) default TV for 95% species protection provided for comparison (µg/L except where indicated)

	UpRiv Ref 24 month (n=132)			SG1 Baseline (n=15)			SG2 Baseline (n=24)			SG3 Baseline (n=25)			Baseline SG1,SG2 & SG3 (n=64)			ANZECC / ARMCANZ 95%	UpRiv TV
Parameter	20%ile	Median	80%ile	20%ile	Median	80%ile	20%ile	Median	80%ile	20%ile	Median	80%ile	20%ile	Median	80%ile		
pH*	7.3	7.5	7.7	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
Sulfate*	5	12	24	10	12	16	18	21	31	28	30	34	14.84	22.2	32.12		
Alk-T*	54	75	116	110	117	122	110	150	263	96	106	124	106.4	117	169		
TSS*	38	267	977	222	401	2,496	258	1,462	4,874	743	1,428	2,663	258	1,188	2,837	NA	2,837
Hardness*	61	86	121	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
Ag-D	0.01	0.05	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05	0.05
Ag-T	0.05	0.05	0.12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
As-D	0.4	0.5	0.6	ND	ND	ND	1.7	1.7	1.7	0.5	0.5	1.2	0.5	0.5	1.7	24	24
As-T	0.7	2.0	8.8	1.8	3.5	11	2.0	3.7	10	4.2	9	15	2	5.5	13		
Cd-D	0.1	0.05	0.05	ND	ND	ND	0.05	0.05	0.05	ND	ND	ND	0.05	0.05	0.05	0.4	0.4
Cd-T	0.1	0.05	0.10	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	0.1	0.2	0.4	ND	ND	ND	133	133	133	ND	ND	ND	0.5	0.5	0.5	1.0	1.0
Cr-T	1.2	10.0	43	ND	ND	ND	0.5	0.5	0.5	ND	ND	ND	133	133	133		
Cu-D	0.5	0.5	0.8	1.1	1.2	1.4	0.56	0.9	7.2	1	1.7	4.3	0.98	1.4	4.14	1.4	4.1
Cu-T	0.9	6.2	40	5.2	15	66	8.8	41	146	7.4	36	68	7	29.4	81.8		
Fe-D	5.1	8.6	21	75	75	75	57	75	75	75	75	75	75	75	75	NA	75
Fe-T*	0.9	9.0	50	14	17	104	13	40	203	23	64	118	13	44	148		
Hg-D	0.04	0.05	0.05	ND	ND	ND	0.2	0.2	0.2	0.05	0.05	0.05	0.08	0.13	0.17	0.06	0.06
Hg-T	0.04	0.05	0.08	0.10	0.10	0.16	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1		
Ni-D	0.5	0.5	0.5	13	15	15	5.7	9.1	15	11	16	23	10	15	21	20**	21
Ni-T	1.1	11.0	48	16	16	16	20	20	179	10	12	94	12	20	90		
Pb-D	0.1	0.1	0.1	0.30	0.30	0.64	0.26	0.30	0.38	0.3	0.3	1.3	0.3	0.3	1	8.4**	8.4
Pb-T	0.4	3.0	17	4.36	12	160	6.1	18	139	3.6	23	59	4.4	18.8	82		
Se-D	0.2	0.2	0.2	ND	ND	ND	0.07	0.07	0.07	ND	ND	ND	0.07	0.07	0.07	11	11
Se-T	0.2	0.2	0.6	ND	ND	ND	0.25	0.25	0.25	ND	ND	ND	0.25	0.25	0.25		
Zn-D	1.2	2.3	10	0.18	0.2	0.42	0.28	0.40	0.64	0.8	4.3	25	0.48	1.4	20	15**	20
Zn-T	3.1	19	110	25	77	374	30	79	623	45	131	249	26	103	376		

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

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

Table 5-7 Summarised water quality for lower river test sites for baseline and reference sites for previous 24 months, presenting 20%ile, median and 80%ile of data for each site. ANZECC/ARMCANZ (2000) default TV for 95% species protection provided for comparison (µg/L except where indicated)

	LwRiv Ref 24 Month (n=30)			Baseline SG4 (n=36)			ANZECC/ ARMCANZ 95%	LwRiv TV
Parameter	20%ile	Median	80%ile	20%ile	Median	80%ile		
pH^	7.0	7.3	7.7	7.8	8.0	8.1	6.0-8.0	6.0-8.1
Sulfate*	2.0	5.0	12	10	15	18		
ALK-T*	44	71	107	83	93	101		
TSS*	2.6	23	80	326	638	983	NA	983
Hardness*	24	48	71	ND	ND	ND		
Ag-D	0.03	0.05	0.05	ND	ND	ND	0.05	0.05
Ag-T	0.05	0.05	0.20	ND	ND	ND		
As-D	0.18	0.37	0.56	0.60	0.70	0.80	24	24
As-T	0.20	0.44	1.0	3.5	5.5	8.0		
Cd-D	0.05	0.05	0.05	0.07	0.08	0.09	0.2	0.2
Cd-T	0.05	0.05	0.05	0.60	0.90	1.0		
Cr-D	0.10	0.20	0.21	0.50	0.50	0.50	1.0	1.0
Cr-T	0.29	1.0	2.9	18	34	46		
Cu-D	0.50	0.51	0.74	0.50	0.85	1.4	1.4	1.4
Cu-T	0.52	1.2	2.7	8.0	18	26		
Fe-D	16	30	55	0.64	75	75	NA	75
Fe-T*	0.24	0.89	3.0	17	37	49		
Hg-D	0.04	0.05	0.05	ND	ND	ND	0.60	0.60
Hg-T	0.04	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	0.50	1.3	4.4	10	23	24		
Pb-D	0.10	0.10	0.10	0.30	0.50	0.70	3.4	3.4
Pb-T	0.10	0.31	1.2	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	0.20	0.20	0.20	0.50		
Zn-D	1.7	3.1	10.0	0.50	1.0	2.9	8.0	10
Zn-T	1.0	2.2	9.0	28	68	94		

^ std units, * mg/L, D - Dissolved fraction, T - Total, NA - Not applicable, ND - Not determined

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

An analysis of the trend of median values for pH, TSS and total and dissolved metals at upper and lower river reference sites from 2007 to 2016 is presented in Table 5-8 and Table 5-9 respectively and shows that, with the exception of dissolved zinc at lower river reference sites, all parameters either decreased or did not change over that time period.

Table 5-8 Trends for water quality at upper river reference sites 2007-2016 as determined by Spearman Rank correlation against time

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2007 – 2016)
Upper River Ref (Trend of all data from 2007 - 2016)	pH	-0.430	<0.001	Decreased over time
	TSS	-0.008	0.870	No change over time
	Ag-D*	-0.708	<0.001	No change over time
	Ag-T*	-0.415	<0.001	No change over time
	As-D*	-0.760	<0.001	No change over time
	As-T	-0.034	0.468	No change over time
	Cd-D*	-0.776	<0.001	No change over time
	Cd-T*	-0.613	<0.001	No change over time
	Cr-D*	-0.845	<0.001	No change over time
	Cr-T*	0.013	0.783	No change over time
	Cu-D*	-0.602	<0.001	No change over time
	Cu-T	-0.025	0.592	No change over time
	Fe-D	-0.286	<0.001	Decreased over time
	Fe-T	0.004	0.937	No change over time
	Hg-D*	-0.800	<0.001	No change over time
	Hg-T*	-0.596	<0.001	No change over time
	Ni-D*	-0.740	<0.001	No change over time
	Ni-T	-0.014	0.772	No change over time
	Pb-D*	-0.733	<0.001	No change over time
	Pb-T	-0.033	0.484	No change over time
	Se-D*	-0.813	<0.001	No change over time
	Se-T*	-0.555	<0.001	No change over time
	Zn-D	0.043	0.364	No change over time
	Zn-T	-0.006	0.895	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.

Table 5-9 Trends for water quality at lower river reference sites 2007-2016 as determined by Spearman Rank correlation against time

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2007 – 2016)
Lower River Ref (Trend of all data from 2007 - 2016)	pH	-0.040	0.604	No change over time
	TSS	0.077	0.319	No change over time
	Ag-D*	-0.602	<0.001	No change over time
	Ag-T*	-0.335	<0.001	No change over time
	As-D*	-0.456	<0.001	No change over time
	As-T	-0.112	0.130	No change over time
	Cd-D*	-0.602	<0.001	No change over time
	Cd-T*	-0.450	<0.001	No change over time
	Cr-D*	-0.637	<0.001	No change over time
	Cr-T	-0.023	0.753	No change over time
	Cu-D*	-0.409	<0.001	No change over time
	Cu-T	0.018	0.806	No change over time
	Fe-D	-0.265	<0.001	Decreased over time
	Fe-T	0.008	0.918	No change over time
	Hg-D*	-0.626	<0.001	No change over time
	Hg-T*	-0.484	<0.001	No change over time
	Ni-D*	-0.559	<0.001	No change over time
	Ni-T	0.034	0.649	No change over time
	Pb-D*	-0.544	<0.001	No change over time
	Pb-T	-0.071	0.336	No change over time
	Se-D*	-0.863	<0.001	No change over time
	Se-T*	-0.817	<0.001	No change over time
	Zn-D	0.293	<0.001	Increased over time
	Zn-T	0.006	0.932	No change over time

D - Dissolved fraction, T - Total fraction

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

5.3.3 Lake Murray and ORWBs – Background Water Quality and TVs

The North Lake Murray sampling sites were selected as the most appropriate reference sites for all indicators at the central and southern end of the lake, and for all parameters at the ORWBs except TSS. The ORWBs are located adjacent to the main Strickland River channel, and so TSS in these locations is potentially influenced by inflow from the river via the connecting tie-channel on a rising river level.

The 80%ile value from North Lake Murray site data set and the 80%ile value from the whole of Lake Murray baseline data set have been compared with the ANZECC/ARMCANZ (2000) default guideline for 95% species protection, and the highest of the three values adopted for each analyte. The results are presented in Table 5-10. Reference site 80%iles were higher than the baseline 80%iles and ANZECC/ARMCANZ (2000) guideline values for TSS and dissolved silver. The baseline 80%iles were higher than the reference 80%iles and the ANZECC/ARMCANZ (2000) guideline values for dissolved cadmium and dissolved iron. The ANZECC/ARMCANZ (2000) guideline values were higher than the baseline 80%iles and the reference 80%iles for dissolved arsenic, chromium, copper, mercury, nickel, lead, selenium and zinc.

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 20%ile, median and 80%ile of data for each site. ANZECC/ARMCANZ (2000) default TV for 95% species protection provided for comparison (µg/L except where indicated)

	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)			LMY ORWBs REF	LMY ORWBs Baseline	ANZECC / ARMCANZ 95%	LMY ORWBs TV
Parameter	20%ile	Median	80%ile	20%ile	Median	80%ile	20%ile	Median	80% ile	20%ile	Median	80%ile				
pH^	5.6	6.0	6.5	6.3	6.4	6.4	6.3	6.4	6.6	6.3	6.4	6.6	5.3-5.7	6.3-6.6	6.0-8.0	5.3-8.0
Sulfate*	1.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0				
ALK-T*	5.6	7.1	8.3	7.7	8.1	8.8	7.9	8.1	8.5	7.8	8.1	8.7				
TSS* #	5.0	16	24	6.0	7.0	9.0	4.6	6.0	8.2	5.4	6.5	9.0	24	9.0	NA	24
Hardness*	2.0	5.0	7.0	ND	ND	ND	ND	ND	ND	ND	ND	ND				
Ag-D	0.01	0.03	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05	ND	0.05	0.05
Ag-T	0.01	0.03	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND				
As-D	0.19	0.20	0.20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.2	0.5	24	24
As-T	0.20	0.26	0.31	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	0.8	0.1	0.1	0.64	0.1	0.1	0.72	0.05	0.72	0.20	0.72
Cd-T	0.05	0.05	0.05	2.0	4.1	5.1	0.4	1.1	1.3	0.7	1.4	4.8				
Cr-D	0.18	0.27	0.30	0.1	0.1	0.44	0.1	0.1	0.2	0.1	0.1	0.4	0.30	0.4	1.0	1.0
Cr-T	0.40	0.77	1.3	0.1	0.1	0.4	0.1	0.25	1.3	0.1	0.15	0.6				
Cu-D	0.50	0.51	0.83	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.8	0.1	1.4	1.4
Cu-T	0.50	1.0	1.4	0.26	0.4	0.8	0.1	0.3	0.52	0.1	0.3	0.7				
Fe-D	107	120	166	138	255	342	166	230	324	148	250	340	166	340	NA	340
Fe-T	876	1175	2076	762	1005	1072	898	945	102	898	980	1072				
Hg-D	0.04	0.05	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05	ND	0.60	0.60
Hg-T	0.04	0.05	0.05	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3				
Ni-D	0.50	0.59	0.76	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8	1.0	11	11
Ni-T	0.50	0.84	1.3	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	0.1	0.7	3.4	3.4
Pb-T	0.10	0.25	0.54	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	0.2	0.9	11	11
Se-T	0.20	0.20	0.20	0.9	0.9	0.9	0.7	0.8	1.0	0.7	0.9	1.0				
Zn-D	2.6	5.0	9.4	0.05	0.05	0.14	0.05	0.5	1.0	0.05	0.08	0.8	9.4	0.8	8.0	9.4
Zn-T	3.3	4.5	9.2	1.2	2	2.7	1.3	2	2.88	1.3	2	2.8				

^ std units, * mg/L, D - Dissolved fraction, T - Total, NA - Not applicable, ND - Not determined

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

An analysis of the trend of median values for pH, TSS and total and dissolved metals at Lake Murray and ORWB reference sites from 2007 to 2016 is presented in Table 5-11. The concentrations of all parameters either decreased or did not change over that time period.

Table 5-11 Trends for water quality in Lake Murray and ORWBs 2007 - 2016 as determined using Spearman Rank Correlation against time

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2007 – 2016)
Lake Murray and ORWB Ref (Trend of all data from 2007 - 2016)	pH	-0.635	<0.001	Decreased over time
	TSS	0.225	0.070	No change over time
	Ag-D*	-0.896	<0.001	No change over time
	Ag-T*	-0.551	<0.001	No change over time
	As-D*	-0.751	<0.001	No change over time
	As-T	0.035	0.779	No change over time
	Cd-D*	-0.864	<0.001	No change over time
	Cd-T*	-0.782	<0.001	No change over time
	Cr-D*	-0.735	<0.001	No change over time
	Cr-T*	-0.429	<0.001	No change over time
	Cu-D*	-0.628	<0.001	No change over time
	Cu-T*	-0.480	<0.001	No change over time
	Fe-D	-0.393	0.001	Decreased over time
	Fe-T	0.119	0.334	No change over time
	Hg-D*	-0.605	<0.001	No change over time
	Hg-T*	-0.601	<0.001	No change over time
	Ni-D*	-0.771	<0.001	No change over time
	Ni-T	0.112	0.363	No change over time
	Pb-D*	-0.807	<0.001	No change over time
	Pb-T*	-0.683	<0.001	No change over time
	Se-D*	-0.433	0.013	No change over time
	Se-T	-0.076	0.549	No change over time
	Zn-D	0.233	0.055	No change over time
	Zn-T	-0.229	0.060	No change over time

D - Dissolved fraction, T - Total fraction

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

5.4 Background Benthic Sediment Quality and TVs

This section presents the sediment quality data from local sites, and reference data for upper rivers, lower river and Lake Murray and ORWBs.

Data from all groups except local creeks were used to develop the risk assessment criteria for sediment quality indicators in each of the respective groups. Data from local reference sites are presented only to describe the quality of non-mine related contributions to the receiving environment, they 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. No baseline data exist for WAE metals in whole sediment. The WAE concentrations are intended to better mimic the ability of an organism's digestive system to liberate metals from sediment, and therefore the WAE concentration represents the bioavailable fraction of metals within the sediment which have the potential to cause toxicity. The total digest (TD) method uses a much stronger acid to liberate metals from the sediment and is likely to overestimate the concentration of metals to which an organism would be exposed from digesting the sediment, but TD metals are presented here for comparison with WAE metals.

5.4.1 Local 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 providing the full context of inputs that influence downstream environmental conditions. Sediment monitoring began at local sites in 2016, 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 of all metals are comparable to other regional reference sites, indicating that the local creeks do not contribute significant metals in sediment to the river system downstream of the mine.

Table 5-12 Local sites sediment quality 2016 (mg/kg whole sediment)

	Aipulungu US			Kaiya US Anj			Pongema		
Parameter	20%ile	Median	80%ile	20%ile	Median	80%ile	20%ile	Median	80%ile
Ag-WAE	0.05	0.05	0.23	0.05	0.05	0.23	0.05	0.05	0.32
Ag-TD	0.16	0.20	0.32	0.10	0.15	0.32	0.14	0.20	0.38
As-WAE	1.0	1.2	1.3	1.8	2.0	2.2	1.3	1.5	1.5
As-TD	2.9	3.0	3.0	6.6	7.0	8.7	4.2	5.4	6.3
Cd-WAE	0.11	0.12	0.27	0.05	0.05	0.23	0.09	0.10	0.34
Cd-TD	0.10	0.15	0.32	0.10	0.10	0.26	0.20	0.20	0.38
Cr-WAE	4.2	5.4	6.1	1.8	2.4	3.1	3.0	3.5	5.0
Cr-TD	24	26	26	25	25	25	20	22	23
Cu-WAE	7.4	8.0	8.7	5.6	6.1	6.7	2.3	2.8	2.9
Cu-TD	13	15	18	28	28	32	7.5	8.8	11
Hg-WAE	0.01	0.01	0.05	0.01	0.02	0.05	0.01	0.01	0.01
Hg-TD	0.02	0.03	0.04	0.06	0.07	0.07	0.01	0.02	0.02
Ni-WAE	6.6	7.3	8.3	4.9	5.0	5.1	2.9	3.1	3.2
Ni-TD	21	23	25	27	29	31	13	15	17
Pb-WAE	4.7	4.8	5.0	10	11	11	4.0	4.1	4.4
Pb-TD	6.1	7.7	9	16	17	19	5.3	6.4	9.4
Se-WAE	0.10	0.15	0.32	0.10	0.15	0.32	0.10	0.10	0.34
Se-TD	0.56	0.65	0.70	0.50	0.55	0.72	0.38	0.50	0.56
Zn-WAE	28	32	34	23	25	28	13	14	17
Zn-TD	71	76	87	106	111	118	48	61	79

WAE - Weak acid extractable, TD - Total digest

5.4.2 Upper and Lower River – Background Sediment Quality and TVs

This section presents a comparison of the benthic sediment quality data collected from upper and lower river reference sites over the past 24 months and the ANZECC/ARMCANZ (2000) interim sediment quality guidelines (ISQG) for aquatic ecosystem protection. Baseline TD metals on the

<63µm fraction are not directly comparable to the WAE metals in whole sediment, but are presented for comparison. TD metals in the <63 µm fraction typically exhibit higher concentrations of metals than the WAE metals in whole sediment fraction as the <63 µm fraction has a larger relative surface area than the coarser whole sediment fraction, which creates a larger number of adsorption sites per unit mass of sediment. In addition, the TD method uses a much stronger acid than the WAE method to digest the metals from the particles during analysis, thereby resulting in a higher concentration of extractable metals.

The purpose of this section is to establish TVs for supporting the risk assessment stage by describing the sediment quality conditions at sites that are not influenced by the mining operation and comparing them against relevant guidelines for protection of environmental values.

In accordance with the methodology outlined in Section 2, the TVs are derived by comparing the 80%ile of the most recent 24-months' data from all of the reference sites and the ANZECC/ARMCANZ (2000) ISQG-low, and then adopting the higher of the two values for each analyte. Sediment quality risk assessment TVs from the upper and lower river reference sites are presented in Table 5-13 and Table 5-14 respectively.

With the exception of nickel in the upper rivers, the ANZECC ISQG-low values were higher than the reference 80%iles for all metals within the upper and lower rivers. ANZECC/ARMCANZ (2000) does not provide a guideline value for selenium, so the reference 80%iles for selenium have been adopted for the upper and lower rivers TVs.

Table 5-13 Summarised sediment quality data for upper river reference sites for previous 24 months. (mg/kg whole sediment)

	UpRivs Ref 24 month (n = 107)			UpRivs Baseline (<63µm)			ANZECC / ARMCANZ ISQG-Low	Porgera UpRivs SED TV
Parameter	20%ile	Median	80%ile	20%ile	Median	80%ile		
Ag-WAE	0.05	0.5	0.5	0.05	0.5	0.5	1	1
Ag-TD	0.10	0.5	0.5	0.10	0.5	0.5		
As-WAE	1.4	2.0	2.4	1.4	2.0	2.4	20	20
As-TD	8.4	11	13	8.4	11	13		
Cd-WAE	0.05	0.5	0.5	0.05	0.5	0.5	1.5	1.5
Cd-TD	0.10	0.5	0.5	0.10	0.5	0.5		
Cr-WAE	1.6	3.2	6.0	1.6	3.2	6.0	80	80
Cr-TD	21	30	114	21	30	114		
Cu-WAE	3.6	7.0	11	3.6	7.0	11	65	65
Cu-TD	14	29	46	14	29	46		
Hg-WAE	0.01	0.01	0.02	0.01	0.01	0.02	0.15	0.15
Hg-TD	0.03	0.04	0.06	0.03	0.04	0.06		
Ni-WAE	4.0	6.2	26	4.0	6.2	26	21	26
Ni-TD	25	39	130	25	39	130		
Pb-WAE	6.0	7.5	9.3	6.0	7.5	9.3	50	50
Pb-TD	11	15	18	11	15	18		
Se-WAE	0.10	0.50	0.50	0.10	0.50	0.50	NA	0.50
Se-TD	0.40	0.50	0.50	0.40	0.50	0.50		
Zn-WAE	11	14	20	11	14	20	200	200
Zn-TD	70	90	100	70	90	100		

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 Summarised sediment quality data for lower river reference sites for previous 24 months. ANZECC/ARMCANZ (2000) ISQG-Low values are provided for comparison (mg/kg whole sediment)

	LwRivs REF			LwRivs Baseline (<63µm)			ANZECC / ARMCANZ ISQG-Low	Porgera LwRivs Sed TV
Parameter	20%ile	Median	80%ile	20%ile	Median	80%ile		
Ag-WAE	0.05	0.5	0.5	ND	ND	ND	1.0	1.0
Ag-TD	0.1	0.5	0.5	ND	ND	ND		
As-WAE	0.5	1.2	1.7	ND	ND	ND	20	20
As-TD	2.2	3.7	5.6	2.8	10	14		
Cd-WAE	0.08	0.5	0.5	ND	ND	ND	1.5	1.5
Cd-TD	0.1	0.5	0.5	2.4	2.4	2.4		
Cr-WAE	3.0	6.1	8.6	ND	ND	ND	80	80
Cr-TD	48	51	56	12	12	12		
Cu-WAE	3.4	3.8	4.5	ND	ND	ND	65	65
Cu-TD	10	14	18	24	24	24		
Hg-WAE	0.01	0.01	0.01	ND	ND	ND	0.15	0.15
Hg-TD	0.01	0.01	0.06	0.3	0.6	0.9		
Ni-WAE	4.5	11	19	ND	ND	ND	21	21
Ni-TD	54	65	70	38	38	38		
Pb-WAE	3.2	3.6	5.3	ND	ND	ND	50	50
Pb-TD	5.3	6.2	6.8	22	22	22		
Se-WAE	0.16	0.5	0.5	ND	ND	ND	NA	0.5
Se-TD	0.2	0.5	0.5	0.2	0.2	0.2		
Zn-WAE	19	21	25	ND	ND	ND	200	200
Zn-TD	80	100	116	105	138	190		

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

An analysis of the trends of total and WAE metals at the upper river reference sites from 2013 to 2016 is presented in Table 5-15 and shows that the concentrations of WAE arsenic, WAE chromium, WAE copper, WAE nickel, WAE lead and WAE zinc increased over the time period, all other parameters either decreased or did not change over that time period. Table 5-16 presents the trends for the lower rivers and shows that the concentrations of TD arsenic, WAE chromium, TD copper, WAE nickel, TD nickel, WAE lead, TD lead and WAE zinc increased over the time period, all other parameters either decreased or did not change over that time period.

Table 5-15 Trends for sediment quality for upper river determined by Spearman Rank correlation against time (2013-2016)

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013 – 2016)
UpRivs Ref (Trend of all data WAE from 2013–2016 TD from 2007-2016)	Ag-WAE*	-0.717	<0.001	No change over time
	Ag-TD	-0.530	<0.001	Decreased over time
	As-WAE	0.405	<0.001	Increased over time
	As-TD	0.042	0.410	No change over time
	Cd-WAE*	-0.715	<0.001	No change over time
	Cd-TD*	-0.507	<0.001	No change over time
	Cr-WAE	0.309	<0.001	Increased over time
	Cr-TD	0.085	0.094	No change over time

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013 – 2016)
	Cu-WAE	0.222	0.003	Increased over time
	Cu-TD	-0.009	0.855	No change over time
	Hg-WAE	-0.127	0.091	No change over time
	Hg-TD*	-0.798	<0.001	No change over time
	Ni-WAE	0.281	<0.001	Increased over time
	Ni-TD	-0.007	0.890	No change over time
	Pb-WAE	0.462	<0.001	Increased over time
	Pb-TD	0.014	0.783	No change over time
	Se-WAE*	-0.732	<0.001	Decreased over time
	Se-TD*	-0.226	<0.001	Decreased over time
	Zn-WAE	0.313	<0.001	Increased over time
	Zn-TD	-0.021	0.686	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.

Table 5-16 Trends for sediment quality for lower river determined by Spearman Rank correlation against time (2013 - 2016)

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013 – 2016)
LwRivs Ref (Trend of all data WAE from 2013–2016 TD from 2007-2016)	Ag-WAE*	-0.677	<0.001	No change over time
	Ag-TD*	-0.307	<0.001	No change over time
	As-WAE	0.259	0.152	No change over time
	As-TD	0.314	<0.001	Increased over time
	Cd-WAE*	-0.569	0.001	No change over time
	Cd-TD*	-0.181	0.038	No change over time
	Cr-WAE	0.361	0.043	Increased over time
	Cr-TD	-0.102	0.244	No change over time
	Cu-WAE	0.256	0.158	No change over time
	Cu-TD	-0.181	0.037	Increased over time
	Hg-WAE*	-0.346	0.052	No change over time
	Hg-TD*	-0.673	<0.001	No change over time
	Ni-WAE	0.358	0.044	Increased over time
	Ni-TD	0.221	0.011	Increased over time
	Pb-WAE	0.404	0.022	Increased over time
	Pb-TD	0.195	0.025	Increased over time
	Se-WAE*	-0.673	<0.001	No change over time
	Se-TD	-0.359	<0.001	No change over time
	Zn-WAE	0.612	<0.001	Increased over time
	Zn-TD	-0.090	0.306	No change over time

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

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

5.4.3 Lake Murray and ORWBs – Background Sediment Quality and TVs

Sediment quality TVs for Lake Murray and ORWBs are presented in Table 5-17. TD metals in the <63 µm fraction were measured in the baseline samples and are included for reference purposes. TVs were derived by comparing the reference site 80%ile from the previous 24-month WAE data set against the ANZECC/ARMCANZ (2000) ISQG-low and adopting the higher of the two values.

For all metals the ANZECC/ARMCANZ (2000) ISQG-low values were higher than the reference 80%iles. ANZECC/ARMCANZ (2000) does not provide a guideline value for selenium, so the reference 80%ile for selenium has been adopted for the TV.

Table 5-17 Summarised sediment quality data for Lake Murray and ORWBs reference sites for previous 24 months, presenting 20%ile, median and 80%ile of data for each site. ANZECC/ARMCANZ (2000) ISQG-Low values are provided for comparison (mg/kg whole sediment)

	Northern Lake Murray (n=13)			LMY Baseline (<63µm)			ANZECC / ARMCANZ ISQG-Low	LMY and ORWBs TV
Parameter	20%ile	Median	80%ile	20%ile	Median	80%ile		
Ag-WAE	0.06	0.12	0.27	ND	ND	ND	1.0	1.0
Ag-TD	0.10	0.20	0.38	ND	ND	ND		
As-WAE	0.64	0.96	1.08	ND	ND	ND	20	20
As-TD	5.0	5.4	5.9	2.8	10	14		
Cd-WAE	0.10	0.12	0.28	ND	ND	ND	1.5	1.5
Cd-TD	0.10	0.20	0.38	2.4	2.4	2.4		
Cr-WAE	6.0	6.9	10.7	ND	ND	ND	80	80
Cr-TD	40	43	45	12	12	12		
Cu-WAE	11	12	13	ND	ND	ND	65	65
Cu-TD	22	23	25	24	24	24		
Hg-WAE	0.03	0.04	0.06	ND	ND	ND	0.15	0.15
Hg-TD	0.11	0.13	0.14	0.3	0.6	0.9		
Ni-WAE	8	10	12	ND	ND	ND	21	21
Ni-TD	27	32	34	38	38	38		
Pb-WAE	8	9	11	ND	ND	ND	50	50
Pb-TD	14	16	16	22	22	22		
Se-WAE	0.10	0.15	0.32	ND	ND	ND	NA	0.32
Se-TD	0.76	0.90	1.04	0.2	0.2	0.2		
Zn-WAE	41	45	55	ND	ND	ND	200	200
Zn-TD	103	110	119	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

An analysis of the trends of total and WAE metals at the Lake Murray and ORWB reference sites from 2013 to 2016 is presented in Table 5-18 and shows that the concentrations of WAE arsenic, WAE chromium, TD copper, WAE nickel, WAE lead and WAE zinc increased over the time period, all other parameters did not change over that time period.

Table 5-18 Trends for sediment quality Lake Murray and ORWBs determined by Spearman Rank correlation against time (2013 - 2016)

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013 – 2016)
Lake Murray and ORWB Ref (Trend of all data WAE from 2013 – 2016 TD from 2007 - 2016)	Ag-WAE*	-0.857	<0.001	No change over time
	Ag-TD*	-0.666	<0.001	No change over time
	As-WAE	0.529	0.005	Increased over time
	As-TD	-0.031	0.814	No change over time
	Cd-WAE*	-0.855	<0.001	No change over time
	Cd-TD*	-0.687	<0.001	No change over time
	Cr-WAE	0.517	0.007	Increased over time
	Cr-TD	0.031	0.811	No change over time
	Cu-WAE	0.167	0.416	No change over time
	Cu-TD	-0.150	0.248	No change over time
	Hg-WAE	-0.022	0.916	No change over time
	Hg-TD*	-0.716	<0.001	No change over time
	Ni-WAE	0.473	0.015	Increased over time
	Ni-TD	-0.220	0.916	No change over time
	Pb-WAE	0.770	<0.001	Increased over time
	Pb-TD	0.155	0.232	No change over time
	Se-WAE*	-0.806	<0.001	No change over time
	Se-TD	-0.129	0.322	No change over time
	Zn-WAE	0.470	0.015	Increased over time
	Zn-TD	-0.286	0.026	Decreased 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.

5.5 Background Tissue Metal Concentrations and TVs

This section presents the tissue metal concentration data collected from baseline sampling at test sites pre-mine and from reference sites over the past 24 months. The baseline data are limited to tissue metal concentrations in fish muscle. The reference site data include tissue metal concentrations in fish muscle and prawn abdomen.

Risk assessment TVs for metal concentrations in the tissue of fish and prawns were established by comparing the 80%ile value from the baseline data set, the 80%ile value from the combined reference site data over the most recent 24-month period and US EPA guidelines values where applicable, and then selecting the highest value as the TV.

5.5.1 Upper and Lower River – Background Tissue Metal Concentrations and TVs

In the upper river, baseline concentrations of arsenic, cadmium, copper, nickel, lead and zinc in fish flesh all were higher than the respective reference 80%iles. The USEPA guideline for selenium in fish flesh was higher than the reference or baseline 80%ile. As no baseline or guideline values exist for chromium in fish flesh or for all metals in prawn abdomen, the reference 80%ile values in these cases have been adopted as the TV, acknowledging the potential for concentrations at reference sites to be influenced by migration of specimens from adjacent exposed sites.

For the lower river, baseline concentrations of arsenic, chromium, nickel and lead in fish flesh all were higher than the reference 80%iles. The USEPA guideline for selenium in fish flesh was higher than the reference or baseline 80%iles. As no baseline or guideline values exist for cadmium in fish flesh or for any metals in prawn abdomen, the reference 80%ile values in these cases have been adopted as the TV, acknowledging the potential for concentrations at reference sites to be influenced by migration of specimens from adjacent exposed sites.

Tissue metal TVs for the upper and lower river are presented in Table 5-19 to Table 5-22.

Table 5-19 Summarised tissue metal data for upper river reference sites for previous 24 months (As-Cu), presenting median and 80%ile of data for each site (mg/kg wet wt.)

Site	Sample	n	As		Cd		Cr		Cu	
			Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile
Pori	Fish Flesh	31	0.01	0.02	0.003	0.003	0.01	0.01	0.15	0.22
	Prawn Ab	38	0.06	0.07	0.003	0.003	0.06	0.09	5.9	8.06
Ok Om	Fish Flesh	35	0.01	0.02	0.003	0.005	0.01	0.02	0.18	0.23
	Prawn Ab	37	0.04	0.05	0.003	0.003	0.02	0.03	5.2	7.72
Kuru	Fish Flesh	35	0.01	0.02	0.003	0.004	0.01	0.01	0.17	0.24
	Prawn Ab	38	0.05	0.06	0.003	0.003	0.09	0.11	4.85	8.2
Upper River Ref	Fish Flesh	101	0.01	0.02	0.003	0.004	0.01	0.02	0.16	0.23
	Prawn Ab	113	0.04	0.06	0.003	0.003	0.06	0.09	5.2	8.08
Wankipe baseline	Fish Flesh	28	0.20	0.20	0.01	0.02	ND	ND	0.21	0.48
Trigger Value	Fish Flesh	-	-	0.20	-	0.02	-	0.02	-	0.48
	Prawn Ab	-	-	0.06	-	0.01	-	0.11	-	9.8

ND - Not Determined

Table 5-20 Summarised tissue metal data for upper river reference sites for previous 24 months (Hg-Zn), presenting median and 80%ile of data for each site (mg/kg wet wt.)

Site	Sample	n	Hg		Ni		Pb		Se		Zn	
			Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile
Pori	Fish Flesh	31	0.08	0.11	0.01	0.01	0.01	0.01	0.23	0.27	5.6	6.9
	Prawn Ab	38	0.01	0.01	0.01	0.01	0.01	0.01	0.27	0.33	14	16
Ok Om	Fish Flesh	35	0.04	0.07	0.01	0.01	0.01	0.01	0.21	0.28	5.7	7.24
	Prawn Ab	37	0.01	0.01	0.01	0.03	0.01	0.01	0.39	0.48	14	16
Kuru	Fish Flesh	35	0.07	0.09	0.01	0.02	0.01	0.01	0.24	0.27	7	8.84
	Prawn Ab	38	0.01	0.01	0.01	0.02	0.01	0.01	0.34	0.38	13	15.6
Upper River Ref	Fish Flesh	101	0.07	0.09	0.01	0.02	0.01	0.01	0.23	0.27	6.1	8
	Prawn Ab	113	0.01	0.01	0.01	0.02	0.01	0.01	0.34	0.39	14	16
Wankipe baseline	Fish Flesh	28	0.07	0.08	0.10	0.10	0.7	0.17	0.20	0.20	8.9	10.4
USEPA (2014)	Fish Flesh	NA	NA	NA	NA	NA	NA	NA	2.26 (11.3 dry wt.)		NA	NA
Trigger Value	Fish Flesh	-	-	0.09	-	0.10	-	0.17	-	2.26	-	10.4
	Prawn Ab	-	-	0.01	-	0.02	-	0.01	-	0.43	-	16

NA - Not Applicable, dry wt. - dry weight

Table 5-21 Summarised tissue metal data for lower river reference sites for previous 24 months (As-Cu), presenting median and 80%ile of data for each site (mg/kg wet wt.)

Site	Sample	n	As		Cd		Cr		Cu	
			Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile
Baia	Fish Flesh	1	0.01	0.01	0.003	0.003	0.01	0.01	0.19	0.19
	Prawn Ab	28	0.07	0.11	0.003	0.003	0.04	0.05	5.7	8.28
Tomu	Fish Flesh	19	0.01	0.01	0.003	0.003	0.01	0.01	0.1	0.15
	Prawn Ab	32	0.06	0.10	0.003	0.006	0.03	0.04	7.6	9.54
Lower River Ref	Fish Flesh	20	0.01	0.01	0.003	0.003	0.01	0.01	0.1	0.16
	Prawn Ab	60	0.07	0.11	0.003	0.004	0.03	0.04	6.2	9.3
SG4 baseline	Fish Flesh	19	0.04	0.07	0.003	0.003	0.02	0.03	0.13	0.17
Trigger Value	Fish Flesh	-	-	0.07	-	0.003	-	0.03	-	0.17
	Prawn Ab	-	-	0.01	-	0.01	-	0.06	-	11.6

Table 5-22 Summarised tissue metal data for lower river reference sites for previous 24 months (Hg-Zn), presenting median and 80%ile of data for each site (mg/kg wet wt.)

Site	Sample	n	Hg		Ni		Pb		Se		Zn	
			Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile
Baia	Fish Flesh	1	0.01	0.01	0.01	0.01	0.01	0.01	0.16	0.16	3.5	3.5
	Prawn Ab	54	0.01	0.01	0.01	0.02	0.01	0.01	0.25	0.28	13	14
Tomu	Fish Flesh	31	0.07	0.09	0.01	0.01	0.01	0.01	0.15	0.23	3.1	4.8
	Prawn Ab	44	0.01	0.01	0.01	0.01	0.01	0.01	0.27	0.33	14	16
Lower River Ref	Fish Flesh	32	0.07	0.09	0.01	0.01	0.01	0.01	0.16	0.22	3.2	4.8
	Prawn Ab	98	0.01	0.01	0.01	0.01	0.01	0.01	0.26	0.31	13	16
SG4 baseline	Fish Flesh	19	0.06	0.12	0.026	0.03	0.076	0.17	0.13	0.17	3.33	4.6
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	-	0.03	-	0.17	-	2.26	-	4.8
	Prawn Ab	-	-	0.01	-	0.01	-	0.01	-	0.31	-	16

NA - Not Applicable,

An analysis of the trends of values for metals in fish flesh and prawn abdomen between 2007 and 2016 are shown in Table 5-23 to Table 5-26 and shows that the concentrations of chromium, copper and nickel in prawn abdomen in the upper river reference sites and arsenic, chromium, copper and mercury in prawn abdomen at the lower river reference sites have increased over the time period. All other metals in fish flesh and prawn abdomen in the upper and lower river reference sites have either decreased or did not change over that time period.

Table 5-23 Trends of metals in fish flesh for upper river reference sites 2007 - 2016 determined by Spearman Rank correlation against time

Fish flesh Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2007–2016)
UpRivs Ref (Trend of all data 2007-2016)	As	-0.125	0.001	Reduced over time
	Cd	-0.567	<0.001	Reduced over time
	Cr	0.001	0.985	No change over time
	Cu	-0.125	0.001	Reduced over time
	Hg	0.001	0.975	No change over time
	Ni	-0.056	0.129	No change over time
	Pb	-0.058	0.112	No change over time
	Se	-0.256	<0.001	Reduced over time
	Zn	-0.066	0.072	No change over time

Table 5-24 Trends of metals in prawn abdomen for upper river reference site 2007 - 2016 determined by Spearman Rank correlation against time

Prawn Abdomen Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2007–2016)
UpRivs Ref (Trend of all data 2007-2016)	As	-0.148	<0.001	Reduced over time
	Cd	-0.630	<0.001	Reduced over time
	Cr	0.101	0.005	Increased over time
	Cu	0.142	<0.001	Increased over time
	Hg	0.031	0.397	No change over time
	Ni	0.127	<0.001	Increased over time
	Pb	-0.044	0.220	No change over time
	Se	-0.237	<0.001	Reduced over time
	Zn	-0.121	0.001	Reduced over time

Table 5-25 Trends of metals in fish flesh at lower river reference site 2007 - 2016 determined by Spearman Rank correlation against time

Fish flesh Site	Element	Spearman's rho	p-Value (p=0.05)	Trend (2007–2016)
LwRivs Ref (Trend of all data 2007-2016)	As	-0.381	<0.001	Reduced over time
	Cd	-0.610	<0.001	Reduced over time
	Cr	0.014	0.848	No change over time
	Cu	-0.215	0.002	Reduced over time
	Hg	-0.092	0.193	No change over time
	Ni	-0.069	0.332	No change over time
	Pb	0.000	1.000	No change over time
	Se	-0.329	<0.001	Reduced over time
	Zn	-0.152	0.031	Reduced over time

Table 5-26 Trends of metals in prawn abdomen at lower river reference sites 2007-2016 determined by Spearman Rank correlation against time

Prawn Abdomen Site	Element	Spearman's rho	p-Value (p=0.05)	Trend (2007–2016)
LwRivs Ref (Trend of all data 2007-2016)	As	0.105	0.021	Increased over time
	Cd	-0.496	<0.001	Reduced over time
	Cr	0.175	<0.001	Increased over time
	Cu	0.175	<0.001	Increased over time
	Hg	0.142	0.002	Increased over time
	Ni	-0.013	0.770	No change over time
	Pb	-0.050	0.276	No change over time
	Se	-0.140	0.002	Reduced over time
	Zn	0.029	0.525	No change over time

5.5.2 Lake Murray and ORWBs – Background Tissue Metal

A lack of community support for the monitoring program has prevented access to sites in Lake Murray for the purposes of fish sampling. Tissue metal risk assessment TVs for the Lake Murray and ORWBs therefore could not be developed due to a lack of tissue metal data from the North Lake Murray reference site locations within the past 24 months.

An analysis of the trends of median values for metals in fish flesh and fish liver between 1999 and 2009 are shown in Table 5-27 and Table 5-28 and show that the concentration of copper and selenium in fish flesh and mercury and zinc in fish liver increased over that time period, while all other metals in fish flesh and fish liver in the Lake Murray and ORWBs reference sites have either decreased or did not change over that time period.

Table 5-27 Trends of metals in fish flesh at Lake Murray and ORWB reference sites 1999-2009 determined by Spearman Rank correlation against time

Fish Flesh Site	Element	Spearman's rho	p-Value (p=0.05)	Trend (1999–2009)
LMY Ref Site (Maka) (Trend of Annual Median)	As	-0.286	0.322	No change over time
	Cd	<LOR	<LOR	No change over time
	Cr	-0.800	0.001	Decreased over time
	Cu	0.553	0.040	Increased over time
	Hg	0.254	0.382	No change over time
	Ni	0.034	0.907	No change over time
	Pb	ND	ND	No change over time
	Se	0.771	0.010	Increased over time
	Zn	0.094	0.750	No change over time

LOR - Limit of Reporting, ND – No data

Table 5-28 Trends of metals in fish liver at Lake Murray and ORWB reference sites 1997 2009 determined by Spearman Rank correlation against time

Fish Liver Site	Element	Spearman's rho	p-Value (p=0.05)	Trend (1999–2009)
LMY Ref Site (Maka) (Trend of Annual Median)	As	-0.670	0.012	Decreased over time
	Cd	0.426	0.146	No change over time
	Cr	-0.761	0.003	Decreased over time
	Cu	0.259	0.393	No change over time
	Hg	0.711	0.006	Increased over time
	Ni	0.222	0.466	No change over time
	Pb	<LOR	<LOR	No change over time
	Se	0.303	0.314	No change over time
	Zn	0.648	0.017	Increased over time

LOR - Limit of Reporting

5.6 Background Aquatic Biology and Impact Assessment Criteria

5.6.1 Upper and Lower River – Background Abundance and TVs

Impact assessment of aquatic biology based on fish and prawn populations is performed by comparing the mean abundance of indicator species from 2016 at test sites against the mean abundance at paired reference sites using the two-sample t-test statistical analysis.

Abundance is measured as the total number of indicator fish and prawn species recorded at a particular site during each sampling day (n), during which five (5) replicates of the standard catch method are performed. The standard catch method for fish in the upper rivers is hook and line fishing, while gill netting is used in the lower rivers. The standard method for catching prawns in the upper river is backpack electro-fishing, and fyke netting is used in the lower rivers. It is assumed that by applying a standard method at each site, the sampling effort is the same at each site on each sampling day.

The mean abundance of indicator fish and prawn species at the upper river reference site is shown in Table 5-29, and the lower river reference sites in Table 5-30.

Table 5-29 Fish and prawn abundance at the Upper River reference site during 2016 (number of individuals per sampling day)

Reference Site	Species	Scientific Name	n	Mean
Ok Om	Fish	*Neosilurus equinus*	8	14.9
	Prawn	*Macrobrachium handschini*	8	9.6
		Macrobrachium lorentzi	8	41.3

Table 5-30 Fish and prawn abundance at the Lower River reference sites during 2016 (number of individuals per sampling day)

Site	Species	Scientific Name	n	Mean
Baia	Fish	*Potamosilurus latirostris*	8	3.4
		Potamosilurus macrorhynchus	8	0.25
	Prawn	*Macrobrachium rosenbergii*	8	8.5
Tomu	Fish	*Potamosilurus latirostris*	8	10.4
		Potamosilurus macrorhynchus	8	4.8
	Prawn	*Macrobrachium rosenbergii*	8	7.4

As the new standard methods for measuring fish and prawn abundance were only commenced in 2016, it is not yet possible to analyse trends based on this data. Analysis based on historical data compiled from a range of different sampling methods and sampling effort is not capable of supporting reliable results, as the data is strongly influenced by the type of method and amount of effort applied each year, and is therefore not presented.

5.6.1.1 Lake Murray

Biological performance assessment criteria for Lake Murray are presented in Table 5-31.

Monitoring has not been conducted within Lake Murray since 2009 due to a lack of community support for the monitoring program. The results show no change in any of the indicators throughout the period 1993 – 2009.

Table 5-31 Trends for fish at Lake Murray reference site 1993 - 2009 determined by Spearman Rank correlation against time

Indicator	Spearman's rho	p-Value	Trends (1993 – 2009)
Fish Abundance	-0.164	0.558	No change over time
Fish Richness	0.087	0.759	No change over time
Fish Biomass	0.111	0.694	No change over time
Fish Condition	-0.446	0.095	No change over time

5.6.2 Macroinvertebrate Populations

The trigger values established during the 2016 macroinvertebrate campaign for the four (4) indices used to assess macroinvertebrate populations are shown in Table 5-32 and are used to support the impact assessment in Section 8.2.

Table 5-32 2016 TVs for indices of macroinvertebrate communities

Site	Indices	2016 TV
Mine site - Kogai	*S*	13
	EPT	5
	SIGNAL 2	76
	%Similarity	40
Upper Rivers - SG2 - Wasiba - Wankipe - Ambi	*S*	25
	EPT	8
	SIGNAL 2	152
	%Similarity	49

6 COMPLIANCE

This Section provides a summary of the operation's compliance with environmental legal requirements. Table 6-1 is a summary of compliance with the operation's environmental permit conditions and Table 6-2 is a summary of water quality results at the SG3 compliance point and other monitoring stations between the discharge point and SG3. It should be noted that SG3 is the only mandatory compliance point. The results from other monitoring stations within the mixing zone are reported for information purposes only.

Table 6-1 Compliance Summary 2016

Permit	% Compliance	Comments
Waste Discharge Permit WD – L3 (121)	98%	Averaged 98% compliance throughout 2016. Non-compliance related to short duration events where TSS concentrations exceeded the permit limit in discharge from four (4) of the five (5) sewage treatment plants.
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 2016 (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	6	7.5	0.01	1.1	0.24	0.20	2.2	0.90	0.10	19.5
Wasiba	22	7.7	0.01	1.2	0.15	0.20	1.0	0.65	0.10	15.0
Wankipe	21	7.6	0.01	1.1	0.08	0.20	1.4	0.50	0.10	14.0
SG3	192	7.7	0.01	1.1	0.05	0.20	1.1	0.50	0.10	11.6
SG3 Permit Criteria		**6 - 9**	**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 2016, 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, although some flow occurs downstream of the dam wall when the dam is not overflowing due to leakage from the dam. During 2016, there were 11 occurrences when the dam did not overflow (for one or more days) with the longest period being 6 days.

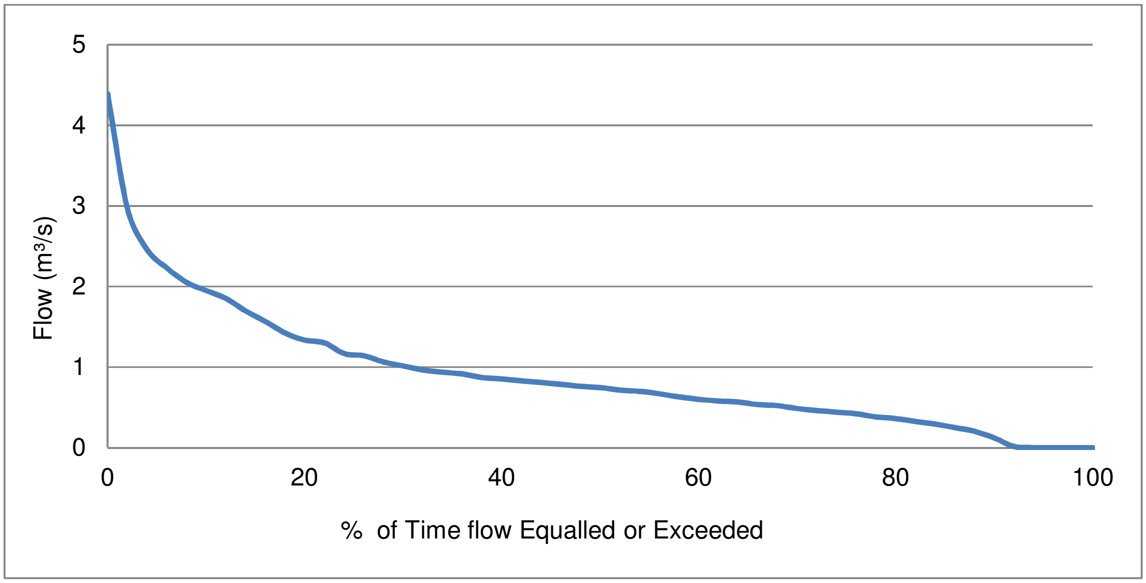


Figure 7-1 Daily flow duration curve (estimated) for Waile Creek Dam overtopping

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). 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.

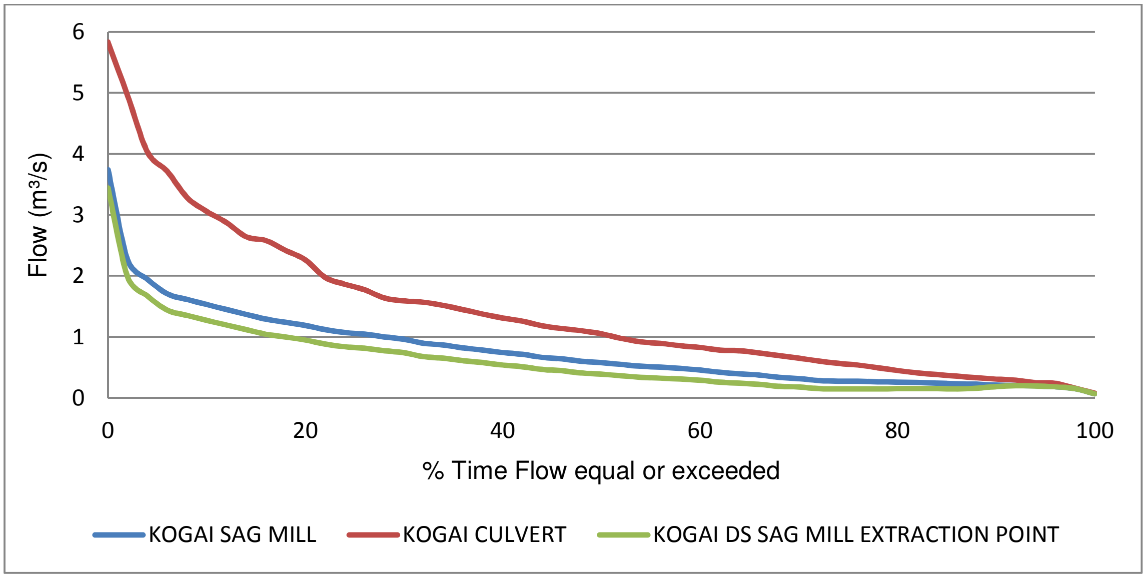


Figure 7-2 Daily flow duration curves for Kogai Creek

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.

Estimating the volumes of sediment that actually reaches the river system each year, and the relative contributions of natural sediment, waste rock and tailings are made using: 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 2016 are shown in Figure 7-3, 2016 monthly TSS loads are shown in Figure 7-4 and historical annual TSS loads are shown in Figure 7-5.

The annual suspended sediment load at SG3 is 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 2016 was estimated by Gumleaf to be 76.0 Mt, this compares to the long term median since 1990 of approximately 44 Mt/a, and an annual load in 2015 of 20.3 Mt.

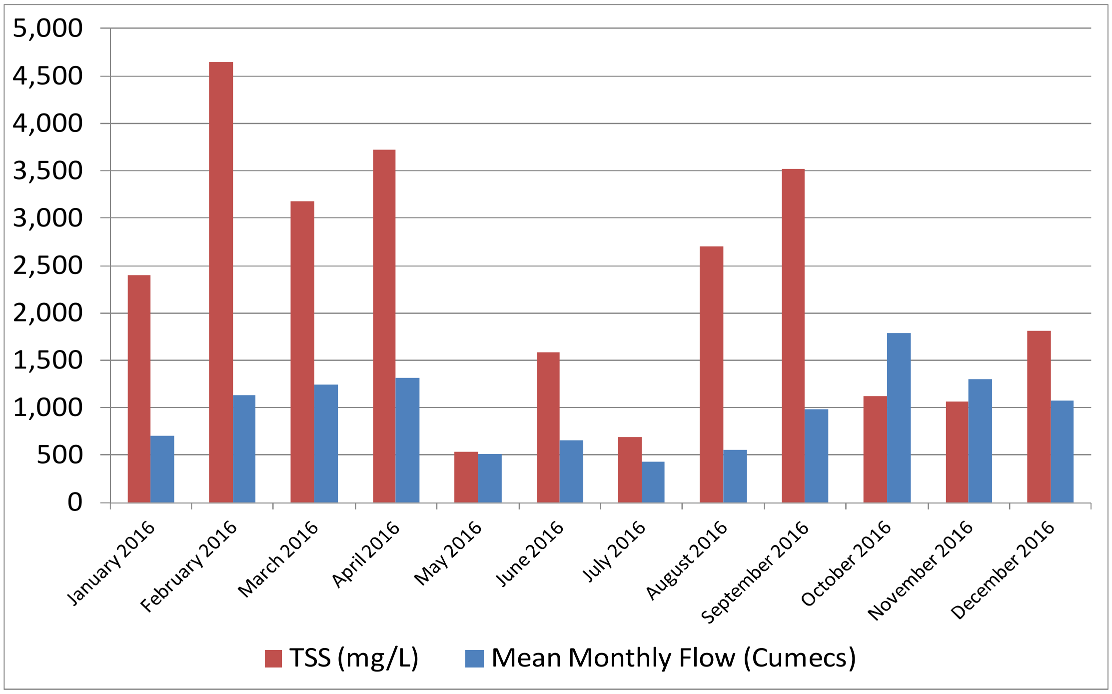


Figure 7-3 Mean monthly TSS and flow at SG3 for 2016

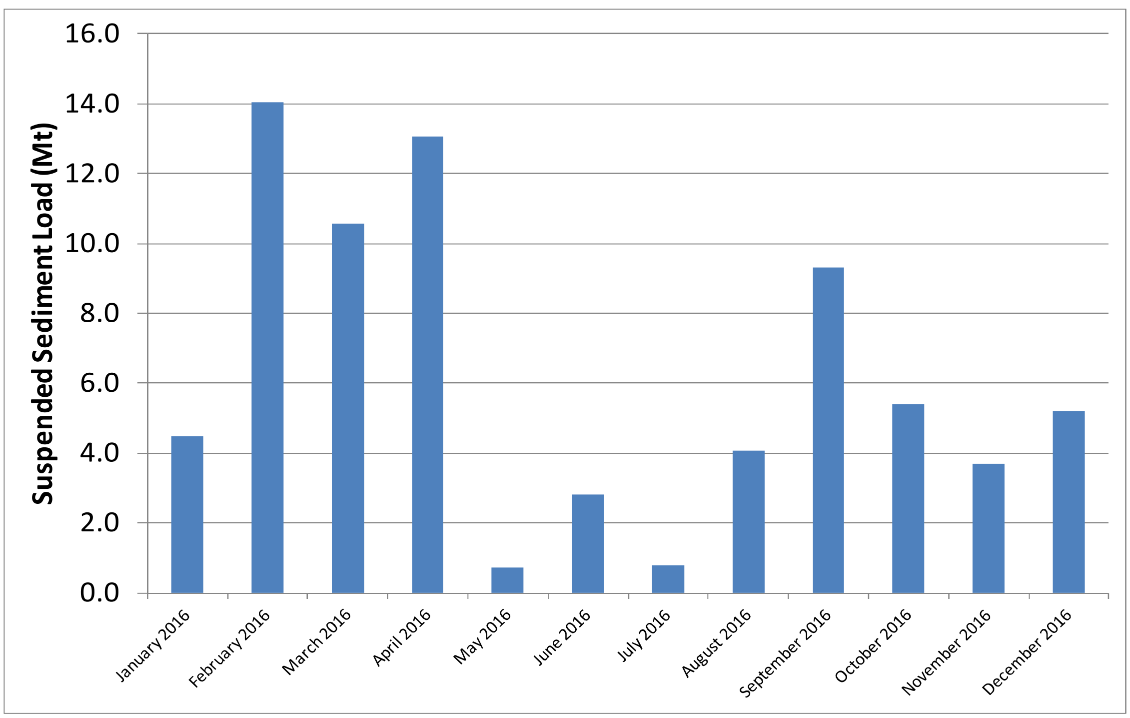


Figure 7-4 Estimated mean monthly suspended sediment loads for SG3 (Mt)

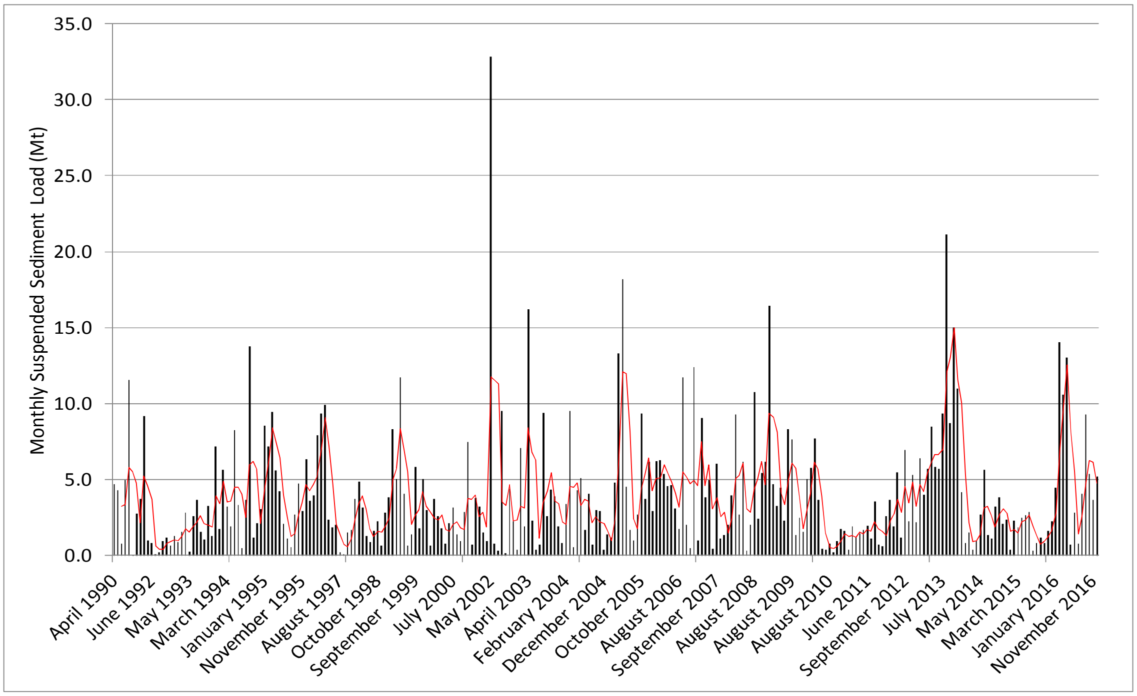
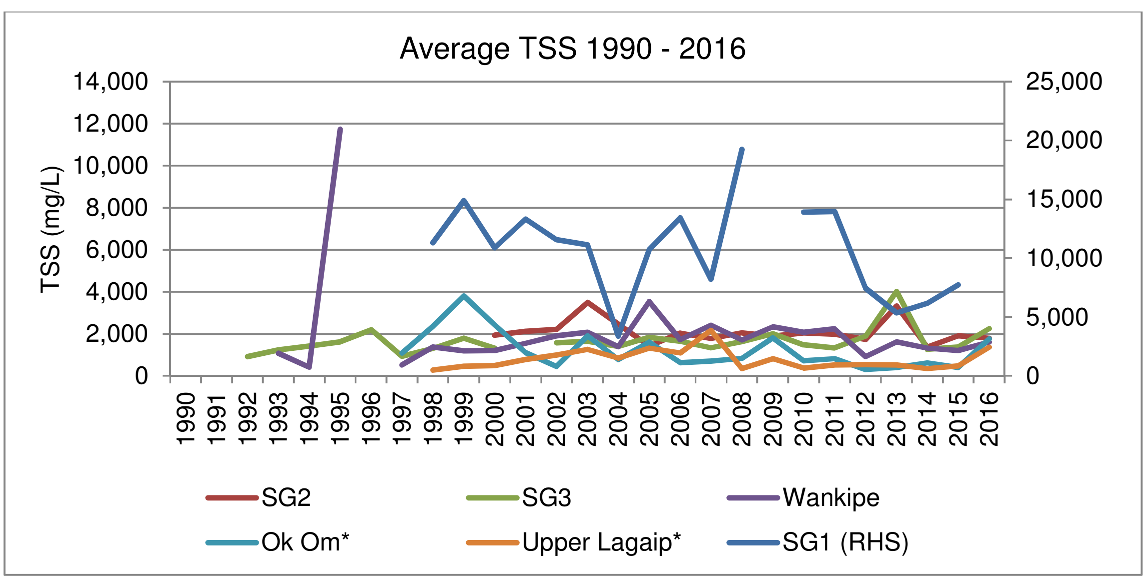


Figure 7-5 Estimated monthly suspended sediment load (black bars) with 3-month moving average at SG3 for full record (red solid line)

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 survey analysis and tailings data.

Figure 7-6 shows historical average TSS concentrations at river monitoring stations upstream of SG3. In 2016 all reference and test sites showed an increase in TSS concentrations compared with 2015 concentrations, with the exception of SG2 where the 2016 concentration was 94% of that for 2015. The most significant increase in TSS was for the reference sites Ok Om and Upper Lagaip, indicating that significant increases in natural sediment load had occurred from 2015 to 2016. No data were collected from SG1 for 2016 due to security concerns.



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

Figure 7-6 Historical average TSS 1990-2016

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 2016 were consistent with historical rates, and also that the natural sediment load was notably high in the context of historical loads.

As a result of consistent mine-derived load and an increase in natural load, the proportion of total suspended sediment load that was mine-derived during 2016 at SG3 was estimated to be approximately 13% which compares to 49% in 2015 and the long term median value 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 proportion of mine-derived sediment was 29% for SG3 and 12-13% for SG4 (Swanson et al. 2008).

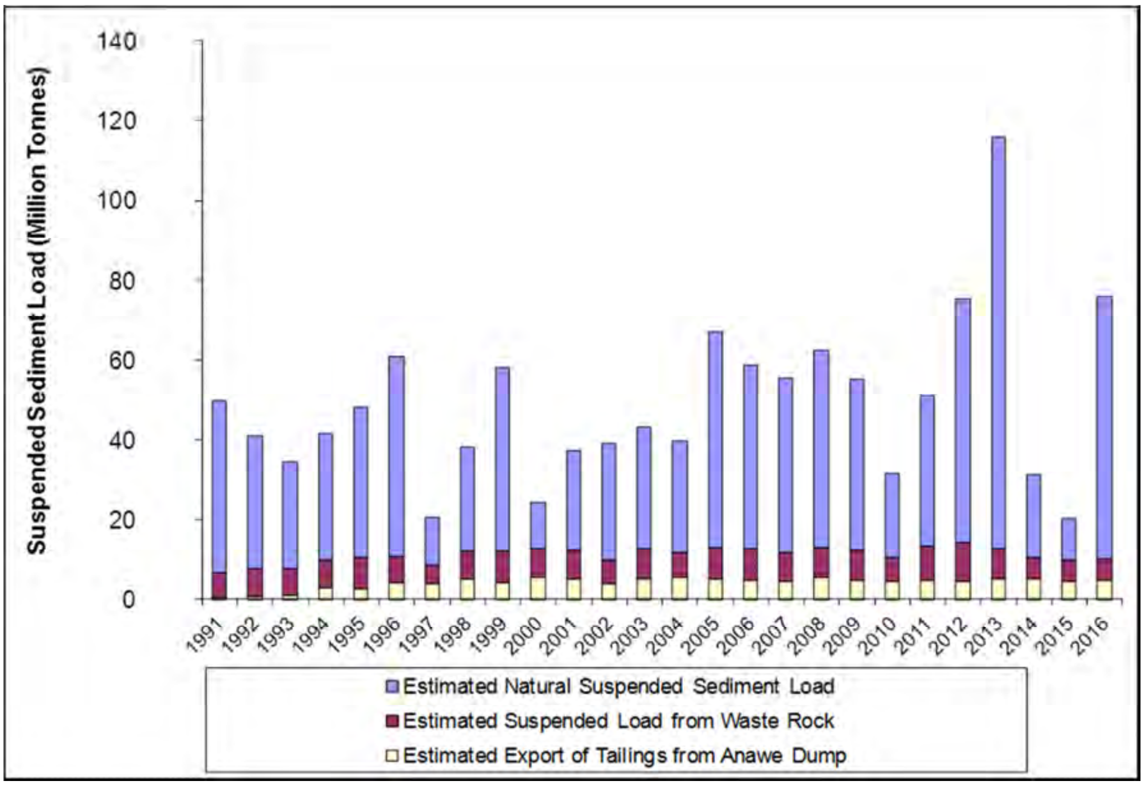


Figure 7-7 Suspended sediment budget at SG3 1991-2016

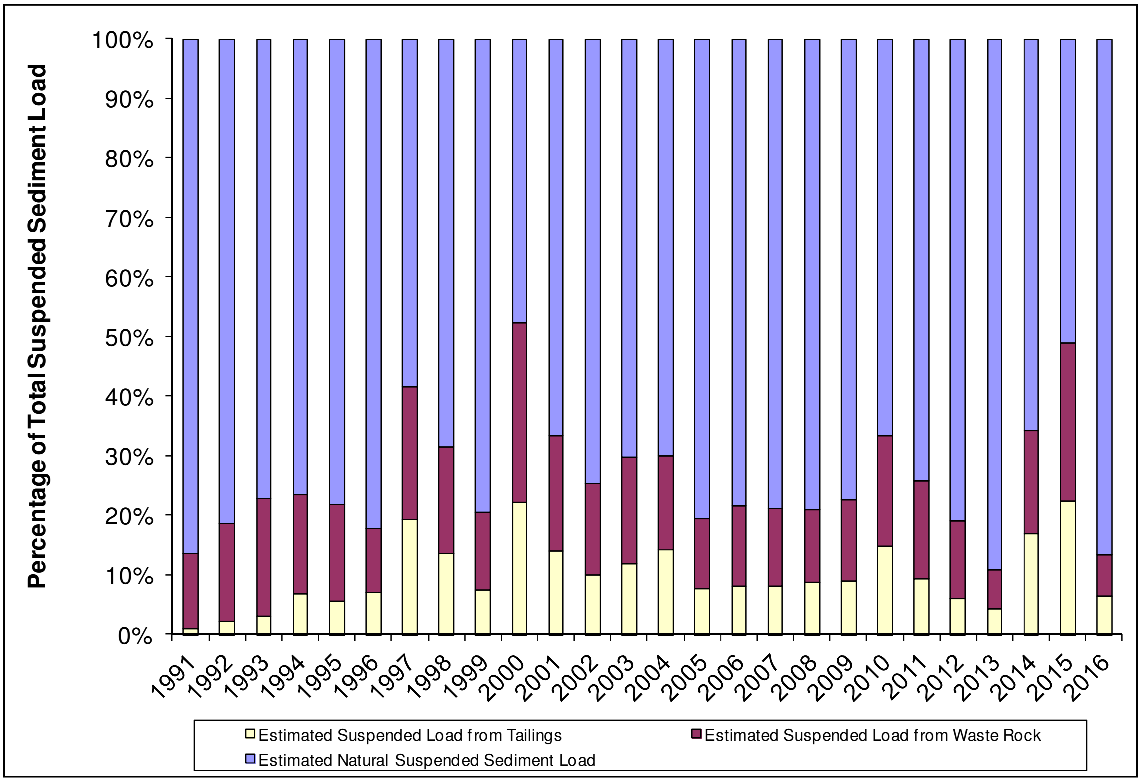


Figure 7-8 Relative contribution of natural and mine-derived suspended sediment at SG3 (%) 1991-2016

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 few 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 community unrest. Profiling sites 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 – 2016
Lower Rivers	Strickland River at PF10	2000 – 2016

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 m 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 to Figure 7-11 illustrate the current situation within the Kaiya

Valley, compared with past surveys. The profiles show that the 2016 bed levels are 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 2012 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. However, 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.

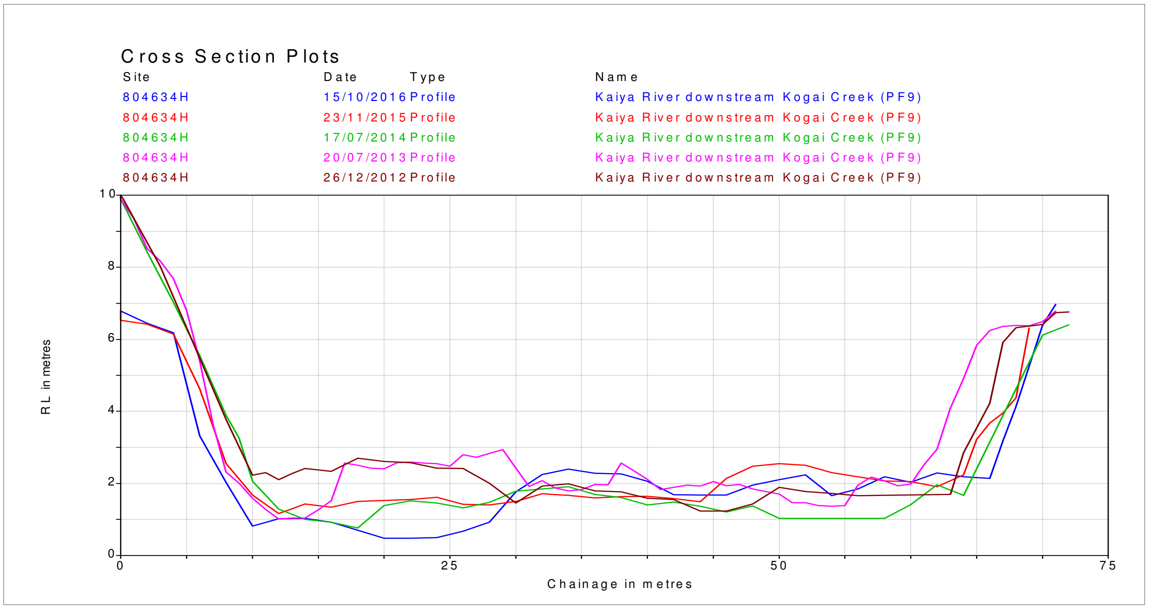


Figure 7-9 Profile comparison (2012-2016) at Kaiya River downstream of Kogai Creek Confluence

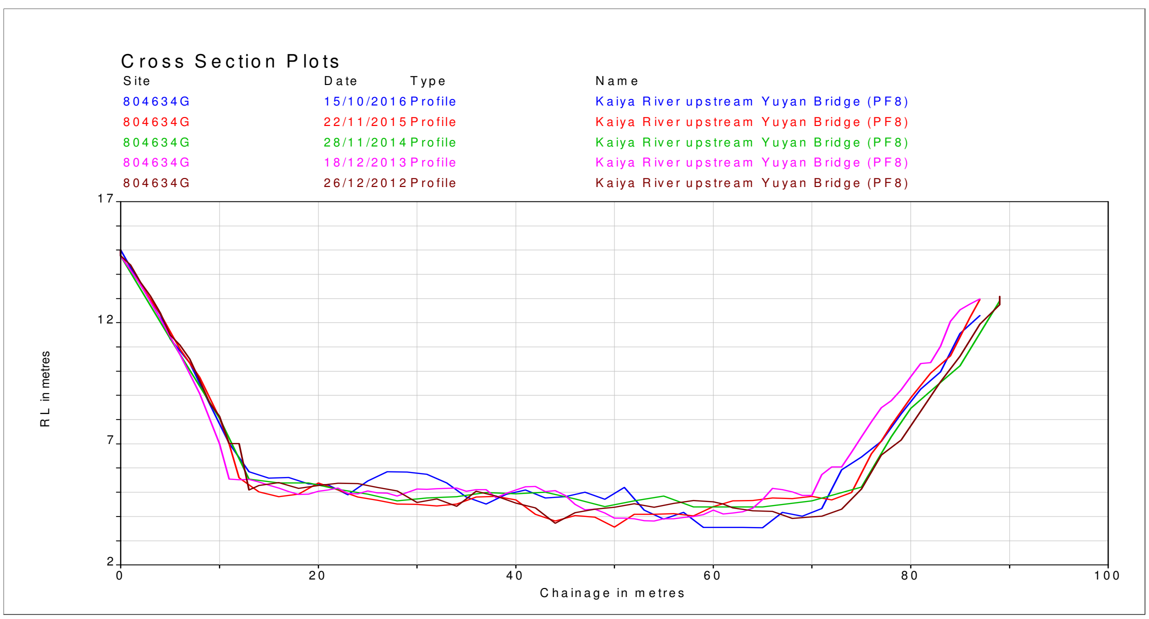


Figure 7-10 Profile comparison (2012- 016) for Kaiya River upstream of Yuyan Bridge

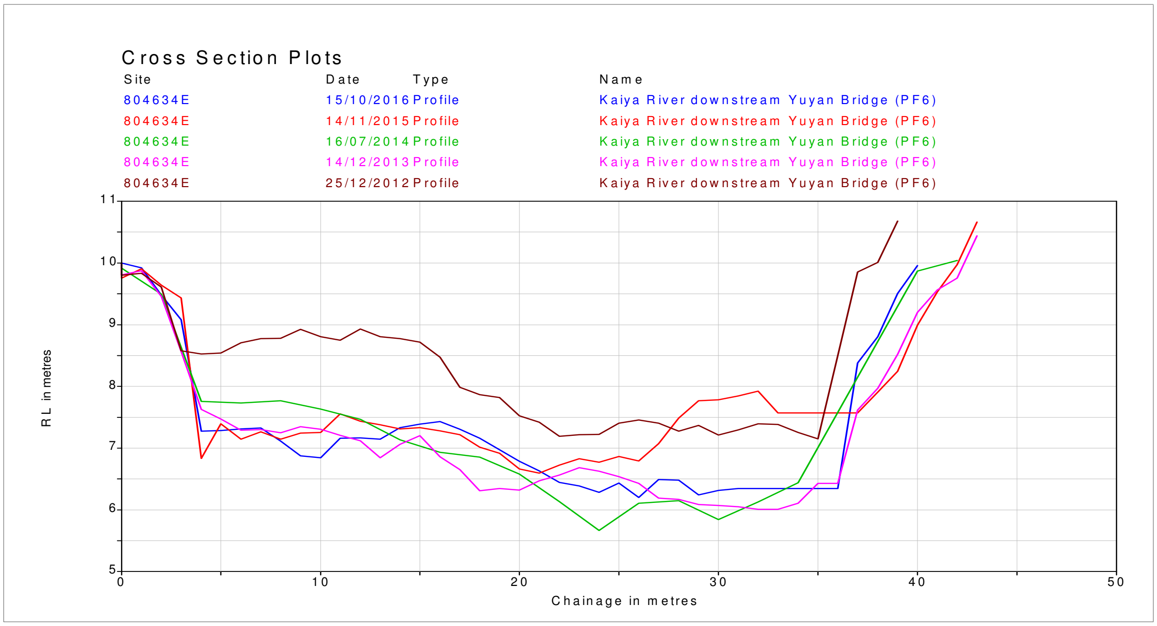


Figure 7-11 Profile comparison (2012-2016) for Kaiya River downstream of Yuyan Bridge

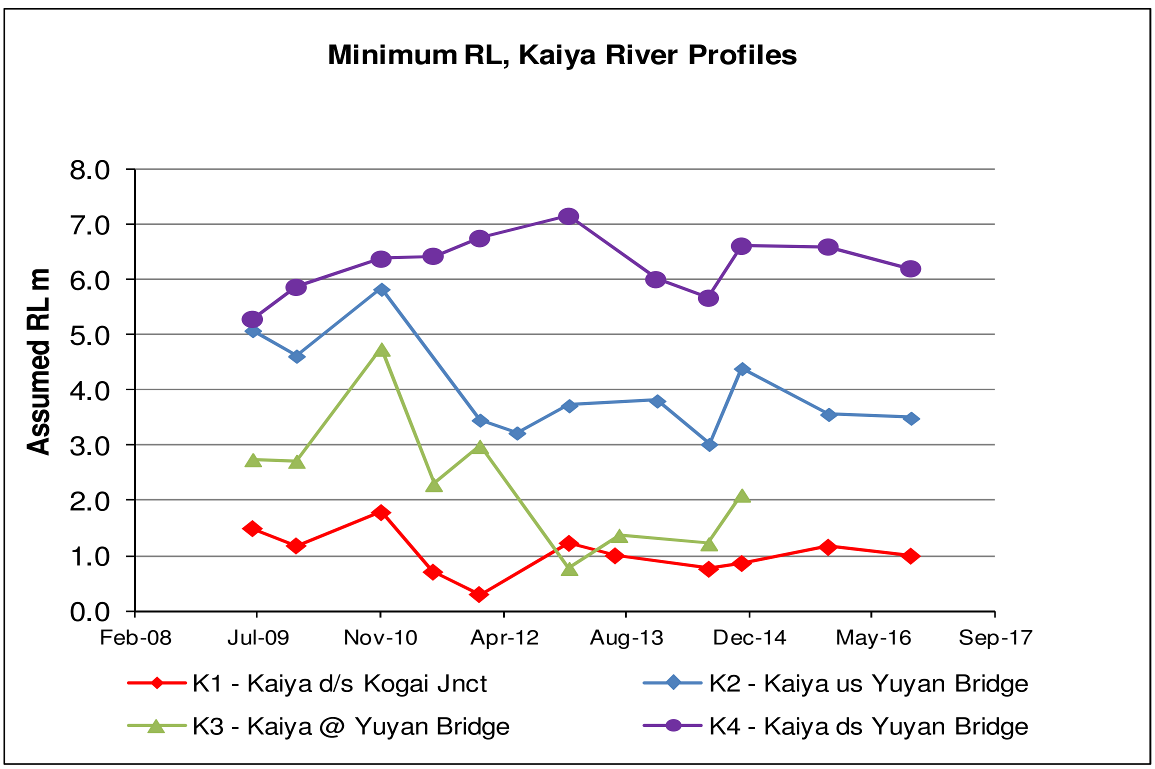


Figure 7-12 Time series of minimum bed elevations along the Kaiya River 2008-2016

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. Degradation appears to have occurred in 2016, however, in the longer term there appears to be no long term aggradation or degradation.

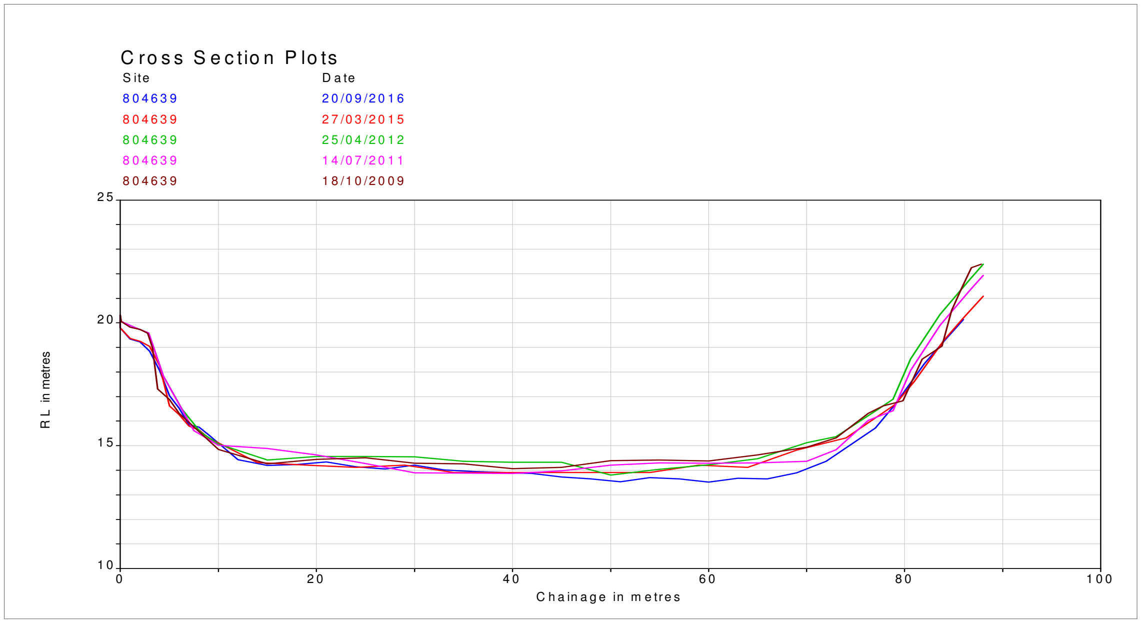


Figure 7-13 Profile comparison (2009-2016) at Lagaip River at SG2

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 becomes 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). There is no discernible change or evidence of sediment aggradation at PF10 aside from the isolated spatial redistribution throughout the cross section which is indicative of natural behaviour in a meandering lowland river. 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. The 2016 survey shows that no significant change has occurred since the last survey.

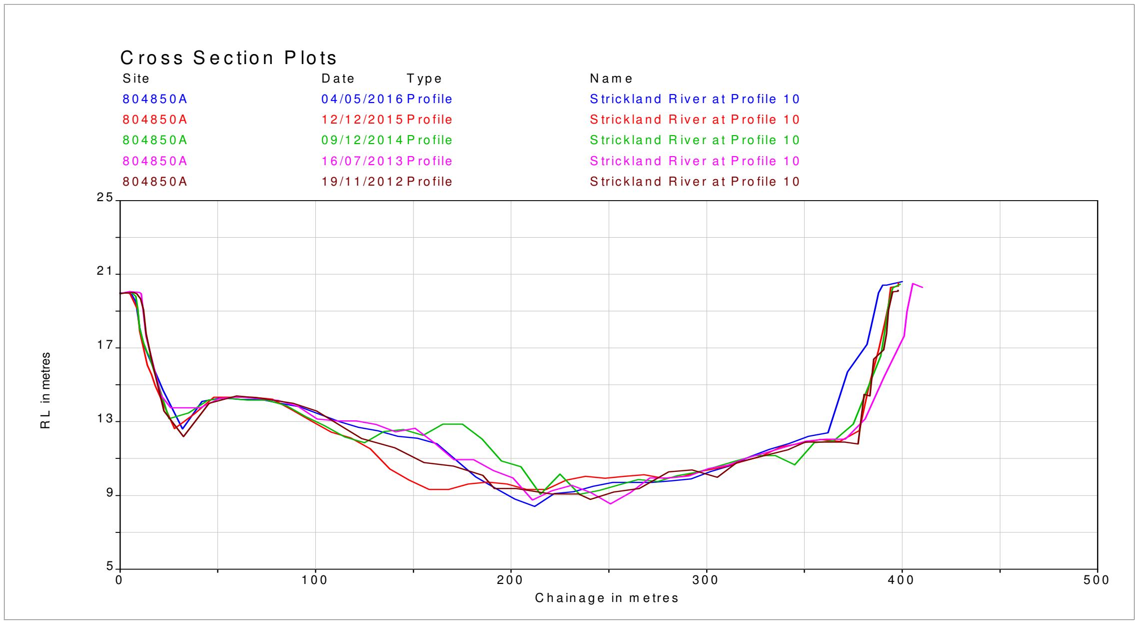


Figure 7-14 Profile comparison (2012-2016) at Profile 10

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 tissue metals. The risk assessment is performed in accordance with the methodology outlined in Section 2.1. Each risk matrix is 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 behavior 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 river test sites involves comparing the 2016 median value at each test site (i.e. 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 either from the most recent 12-month data set or 24-month data set, depending on the number of samples collected during the time period, in order to provide the appropriate level of statistical power.

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 in these cases the risk assessment is made based on a direct comparison of the TV and TSM.

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, Table D-3 to Table D-10 and figures showing comparisons of the historical data against the TVs are shown in Appendix D, Figure 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 reflect periods of high rainfall with a prevalence of large scale erosion and landslides, and periods of low TSS reflect periods of low rainfall with reduced erosion and sediment transport.

In addition to receiving fluctuating loads of natural sediment, rivers downstream of the mine also receive a constant input of sediment from the mine, predominantly from the tailings discharge and to a lesser extent from the erodible waste rock dumps. Therefore, it is possible that the potential risk to rivers downstream of the mine is caused through both significant increases in maximum TSS concentrations compared to reference conditions and also the constant nature of the mine tailings contribution. The tailings discharge causes average TSS concentrations to be elevated throughout the year, when compared to reference conditions, which prevents or reduces episodes of low TSS from occurring as they would in a natural system.

The assessment showed that TSS concentrations at all upper river and lower river test sites were significantly less than the respective TSS TVs and therefore do not pose a risk to aquatic ecosystem health. It is worth noting that in both the upper and lower rivers, the TSS TV is derived from baseline data, meaning that the median TSS concentrations at the upper and lower river test sites during 2016 were significantly below the baseline 80%ile for TSS.

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.

The risk assessment results show that, in the upper river at SG2, the median concentration of dissolved zinc was not significantly different from the TV, and in the lower river at Bebelubi and SG4, the median concentration of dissolved zinc was greater than the TV. Dissolved zinc concentrations at SG4 and Bebelubi also exceed the TV. The behaviour of zinc within the receiving environment is discussed further in Section 7.4.4.12.

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 2016.

Table 7-2 Risk assessment – median water quality results at upper river test sites in 2016 compared against UpRivs TVs showing which indicators pose low and potential risk (µg/L except where shown)

Site	n	pH^	TSS*	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
SG2	6	7.5	1,880	0.01	1.1	0.24	0.20	2.2	3.0	0.04	0.90	0.10	0.20	19.5[1]
Wasiba	22	7.7	1,385	0.01	1.2	0.15	0.20	1.0	4.0	0.04	0.65	0.10	0.20	15.0
Wankipe	21	7.6	920	0.01	1.1	0.08	0.20	1.4	4.0	0.04	0.50	0.10	0.20	14.0
SG3	192	7.7	1,775	0.01	1.1	0.05	0.20	1.1	6.0	0.04	0.50	0.10	0.20	11.6
UpRivs WQ TV		**6.0-8.1**	**2,837**	**0.05**	**24**	**0.40**	**1.0**	**4.1**	**75**	**0.60**	**21**	**8.4**	**11**	**20**

(green)	Low risk = significantly < TV
(orange)	Potential risk = not significantly different from TV OR significantly > TV

D - Dissolved fraction, ^ std units, * mg/L, NS – Not sampled due to security concerns

[1] Although TSM falls below the TV, the 2016 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 7-3 Risk assessment – Median water quality results at lower river test sites in 2016 compared against LwRiv TVs showing which indicators pose low and potential risk (µg/L except where shown)

Site	n	pH^	TSS*	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
Bebelubi	5	7.4	528	0.02	1.0	0.05	0.20	1.1	9.0	0.04	0.50	0.10	0.20	13
SG4	5	7.6	364	0.01	0.80	0.05	0.20	1.0	15	0.04	0.50	0.10	0.20	13
SG5	3	7.5	486	0.01	1.0	0.05	0.20	1.0	30	0.04	0.50	0.20	0.20	7.0
LwRivs WQ TV		**6.0-8.2**	**983**	**0.05**	**24**	**0.20**	**1.0**	**1.4**	**75**	**0.6**	**15**	**3.4**	**11**	**10**
	Low risk = significantly < TV													
	Potential risk = significantly > TV OR not significantly different from TV													

D - Dissolved fraction, ^ std units, * mg/L

Trends of water quality in the upper river and the lower river test sites over the period 2007-2016 are summarised in Table 7-4 and Table 7-5 respectively. Detailed results are shown in Appendix D, Tables D-11 and D-12 respectively. The results show: pH at Wasiba, TSS at SG3 and SG5 and dissolved zinc at Wasiba, Wankipe, SG3 and Bebelubi, increased over the period. All other parameters have either remained unchanged or have reduced.

Table 7-4 Comparison of trends of water quality at the upper river reference and test sites 2007-2016

Site	pH	TSS	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
UpRivs Ref													
SG1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SG2													
Wasiba													
Wankipe													
SG3													
	Reduced or no change over time												
	Increased over time												

D - Dissolved fraction

Table 7-5 Comparison of trends of water quality at the lower river reference and test sites 2007 - 2016

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

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

D - Dissolved fraction

7.4.1.2 Lake Murray and ORWBs

The water quality risk assessment results for Lake Murray and the ORWBs are shown in Table 7-6. Results of the statistical analysis are shown in Appendix D, Tables D-13 to D-18 and figures showing comparisons of the historical data against the TVs are shown in Appendix D, Figures D-29 to D-43.

The results show that the 2016 median concentrations of dissolved zinc at Central and Southern Lake Murray were not significantly different from the TV and therefore indicate potential risk, and concentrations of dissolved zinc at Avu exceeded the TV, also indicating potential risk. Note that because it is unlikely that all of the dissolved zinc will be bioavailable, the potential risk will be lower than expected. All other parameters posed low risk to aquatic ecosystems during 2016. It should be noted that although the TSMs at Southern and Central Lake Murray fall below the TV, the 2016 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 7-6 Risk Assessment – Median water quality results at Lake Murray & ORWB test sites in 2016 compared against LMY and ORWB TVs showing which indicators pose low and potential risk (µg/L except where shown)

Site	n	pH	TSS*	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
Central Lake	11	6.6	5.0	0.01	0.20	0.05	0.30	0.50	137	0.04	0.50	0.10	0.20	6.0[2]
Southern Lake	10	6.9	5.0	0.01	0.20	0.05	0.20	0.50	101	0.04	0.50	0.10	0.20	6.0[2]
SG6	2	6.9	86[1]	0.01	0.55	0.05	0.20	0.55	140	0.06	0.55	0.15	0.20	2.5
Kuku-fionga	1	7.5	5.0	0.01	2.6	0.05	0.2	0.5	2.0	0.04	0.50	0.10	0.20	3.0
Zonga-mange	1	7.4	28[1]	0.01	1.0	0.05	0.2	0.7	22	0.04	0.70	0.10	0.20	3.0
Avu	1	6.5	5.0	0.01	0.4	0.05	0.4	0.5	183	0.10	0.60	0.10	0.20	10
Levame	1	7.8	30[1]	0.01	2.9	0.05	0.2	0.5	55	0.04	0.50	0.10	0.20	5.0
LMY and ORWB WQ TV		**5.3-8.0**	**24**	**0.05**	**24**	**0.72**	**1.0**	**1.4**	**340**	**0.60**	**11**	**3.4**	**11**	**9.4**

(green)	Low risk = significantly < TV

	Potential risk = significantly > TV OR not significantly different from TV

D – Dissolved fraction

[1] Shown as low risk even though the TV is exceeded. The TV for TSS is derived from northern Lake Murray data and is not considered applicable to SG6 and off river water bodies which are potentially influenced by overflow from the Strickland River.

[2] Although TSM falls below the TV, the 2016 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.

The long-term trends presented in Appendix D, Table D-19 show the concentrations of dissolved arsenic at Kukufionga and Zongamange, dissolved selenium at Southern Lake and dissolved zinc at Central and Southern Lake increased between 2007 and 2016, while all other parameters either remained unchanged or reduced.

Table 7-7 Comparison of trends of water quality at Lake Murray and ORWB reference and test sites 2007-2016

Site	pH	TSS	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
LMY & ORWBS Ref													
Central Lake													
Southern Lake													
SG6													
Kukufionga													
Zongamange													
Avu													
	Reduced or no change over time												
	Increased over time												

D - Dissolved fraction

7.4.2 Sediment Quality

7.4.2.1 Upper and Lower River

The sediment quality risk assessment results for the upper and lower rivers are presented in Table 7-8 and Table 7-9 respectively. Detailed results of the statistical analysis are shown at Appendix E, Table E-2 to Table E-9 and figures showing comparisons of the historical data against the TVs are shown at Appendix E, Figures E-1 to E-22.

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.

In the upper river, risk to aquatic ecosystems is posed by WAE lead at SG2 and Wasiba and WAE nickel at Wasiba. All other metals in sediments at all other upper and lower river sites were significantly less than the TV and therefore pose a low risk to aquatic ecosystems.

Mine related sources of WAE lead in sediment are tailings, 28 level, SDA toe, Kogai dump toe, Wendoko Crk D/S Anawe Nth and Yunarilama/Yarik @ Portal. WAE lead in sediment shows a trend of decreasing concentration with increasing distance from the mine.

Table 7-8 Risk Assessment – Median sediment quality results at upper river test sites in 2016 compared against UpRivs TVs showing which indicators pose low and potential risk (mg/kg whole sediment)

Site	n	Ag - WAE	As - WAE	Cd - WAE	Cr - WAE	Cu - WAE	Hg - WAE	Ni - WAE	Pb - WAE	Se - WAE	Zn - WAE
SG1	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SG2	8	0.075	6.3	1.1	5.0	10.5	0.025	6.6	152	0.15	152[2]
Wasiba	12	0.05	4.3	0.52	3.5	9.3	0.015	9.8[1]	35[1]	0.10	71
Wankipe	11	0.05	3.6	0.40	3.3	7.6	0.015	9.8	29	0.10	53
SG3	26	0.05	4.0	0.45	3.3	7.6	0.10	9.5	31	0.10	59
UpRivs Sed TV		**1.0**	**20**	**1.5**	**80**	**65**	**0.15**	**26**	**50**	**0.50**	**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 2016 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 2016 compared against LwRivs TVs showing which indicators pose low and potential risk (mg/kg 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	3	0.05	4.0	0.36	4.1	6.8	0.01	16	21	0.10	44
SG4	3	0.05	3.6	0.35	4.4	6.6	0.01	15	17	0.20	49
SG5	3	0.05	3.2	0.22	2.8	6.3	0.01	8.1	16	0.10	38
LwRivs Sed TV		**1.0**	**20**	**1.5**	**80**	**65**	**0.15**	**26**	**50**	**0.50**	**200**
(green)	Low risk = significantly < TV										
(orange)	Potential risk = significantly > TV OR not significantly different from TV										

WAE - Weak acid extractable

The trends of WAE metals concentrations in benthic sediments have been assessed between 2013 and 2016, and the results are summarised in Table 7-10 and7.11. Detailed statistical analysis results are presented in Appendix E Table E-10 for the upper and Table E-11 for lower river test sites.

In the upper river, increased concentrations over time were observed at the following locations: SG1 WAE chromium and WAE nickel; SG2 WAE arsenic, WAE chromium, WAE nickel, WAE lead and WAE zinc; Wankipe WAE chromium, WAE copper and WAE nickel, and at SG3 WAE arsenic, WAE chromium, WAE copper, WAE nickel, WAE lead and WAE zinc. The concentrations of all other WAE metals at all other sites have either reduced or remained unchanged between 2013 and 2016.

In the lower river, increased concentrations were observed at the following locations: Bebelubi WAE chromium and WAE nickel; SG4 WAE chromium. WAE copper and WAE zinc. The concentration of all other WAE metals in benthic sediment have either reduced or remained unchanged between 2013 and 2016.

Table 7-10 Comparison of trends of sediment quality at upper river reference and test sites 2013-2016 (whole sediment)

Site	Ag - WAE	As - WAE	Cd - WAE	Cr - WAE	Cu - WAE	Hg - WAE	Ni - WAE	Pb - WAE	Se - WAE	Zn - WAE
UpRivs Ref	Green	Orange	Green	Orange	Orange	Green	Orange	Orange	Green	Orange
SG1*	Green	Green	Green	Orange	Green	Green	Orange	Green	Green	Green
SG2	Green	Orange	Green	Orange	Green	Green	Orange	Orange	Green	Orange
Wasiba	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Wankipe	Green	Green	Green	Orange	Orange	Green	Orange	Green	Green	Green
SG3	Green	Orange	Green	Orange	Orange	Green	Orange	Orange	Green	Orange
Green	No change or reduced over time									
Orange	Increased over time									

WAE - Weak acid extractable

* Trend from 2013 – 2015, sampling not conducted during 2016 due to community unrest.

Table 7-11 Comparison of trends of sediment quality at lower river reference and test sites 2013-2016 (whole sediment)

Site	Ag - WAE	As - WAE	Cd - WAE	Cr - WAE	Cu - WAE	Hg - WAE	Ni - WAE	Pb - WAE	Se - WAE	Zn - WAE
LwRiv Ref	Green	Green	Green	Orange	Green	Green	Orange	Orange	Green	Orange
Bebelubi	Green	Green	Green	Orange	Green	Green	Orange	Green	Green	Green
SG4	Green	Green	Green	Orange	Orange	Green	Green	Green	Green	Orange
SG5	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Green	No change or reduced over time									
Orange	Increased over time									

WAE - Weak acid extractable

7.4.2.2 Lake Murray and ORWBs

The results of the risk assessment for WAE metals concentrations in sediment sampled at Lake Murray and the ORWB test sites are presented in Table 7-12. Detailed results of the statistical analysis are shown in Appendix E, Tables E-12 to E-18 and figures showing comparisons of the historical data against the TVs are shown in Appendix E, Figures E-23 to E-32.

The risk assessment shows that risk to aquatic ecosystems is posed by WAE lead at Southern Lake Murray and Kukufionga. The concentrations of all other WAE metals in benthic sediment were less than the respective TVs in 2016. The elevated results at Southern Lake Murray and Kukufionga indicated the possible presence of mine-derived sediment.

Table 7-12 Risk assessment – median sediment quality results at Lake Murray and ORWB test sites in 2016 compared against LMY and ORWB TVs showing which indicators pose low and potential risk (mg/kg WAE 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	15	0.12	2.6	0.13	6.4	13	0.02	11	22	0.10	54
Southern Lake	9	0.06	4.9	0.26	3.9	14	0.01	8.6	42	0.10	65
SG6	2	0.05	4.1	0.19	4.7	12	0.02	6.8	29	0.10	44
Kukufionga	1	0.05	8.2	0.38	4.5	18	0.01	9.2	61	0.10	98
Zongamange	1	0.05	3.7	0.45	3.4	15	0.01	11	30	0.10	73
Avu	1	0.11	1.8	0.24	3.1	24	0.01	11	25	0.20	86
Levame	1	0.05	3.2	0.37	2.9	9	0.01	8.1	20	0.10	59
Lake Murray and ORWBs Sed TV		**1.0**	**20**	**1.5**	**80**	**65**	**0.15**	**21**	**50**	**0.32**	**200**

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

WAE - Weak acid extractable

A summary of analysis of trends of WAE metals concentrations in benthic sediment between 2013 and 2016 is shown in Table 7-13. Results of the statistical analysis are shown in Appendix E, Table E-19.

The assessment shows increased concentrations during the period at the following locations: the Central Lake WAE arsenic, WAE copper, WAE lead; the Southern Lake WAE silver, WAE arsenic, WAE chromium, WAE copper, WAE nickel, WAE lead and WAE zinc and at Avu WAE chromium, WAE copper, WAE nickel and WAE zinc. The concentration of all other WAE metals in benthic sediment have either reduced or remained unchanged between 2013 and 2016.

Table 7-13 Comparison of trends of sediment quality at Lake Murray and ORWB reference and test sites 2013-2016 (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										

	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 risk assessment based on metals in tissue from prawn and fish collected in 2016 from riverine test sites are shown in Table 7-14 and Table 7-15 respectively. Detailed results of the statistical analysis are shown in Appendix F, Tables F-2 to F-5 and figures showing comparisons of the historical data against the TVs are shown in Appendix F, Figures F-1 to F-36.

The assessment shows that in the upper river, elevated cadmium, lead, selenium and zinc in prawn abdomen at Wasiba and cadmium and selenium in prawn abdomen at Wankipe indicated a potential risk to aquatic ecosystem health.

In the lower river, elevated arsenic in prawn abdomen at Bebelubi, mercury in fish flesh at SG4, and arsenic and selenium in prawn abdomen at Bebelubi and SG4 indicated a potential risk to aquatic ecosystem health.

Table 7-14 Risk assessment – median tissue metal results at upper river test sites in 2016 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	22	0.02	0.003	0.01	0.18	0.07	0.01	0.01	0.32	5.6
	Prawn Abdo	26	0.03	0.012	0.02	4.85	0.01	0.01	0.04	0.56	15[1]
Wankipe	Fish Flesh	20	0.02	0.004	0.01	0.19	0.06	0.01	0.01	0.26	4.9
	Prawn Abdo	26	0.04	0.007[1]	0.03	5.95	0.01	0.01	0.01	0.42[1]	14
UpRivs TV	Fish Flesh		0.20	0.020	0.02	0.48	0.09	0.10	0.17	2.26	10.4
	Prawn Abdo		0.06	0.010	0.11	9.8	0.01	0.02	0.01	0.43	16
(green)	Low risk = significantly < TV										
(orange)	Potential risk = significantly > TV OR not significantly different from TV										

[1] Although TSM falls below the TV, the 2016 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 7-15 Risk assessment – median tissue metal results at lower river test sites in 2016 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	1	0.01	0.003	0.01	0.14	0.10	0.01	0.01	0.12	3.9
	Prawn Abdo	12	0.08	0.005	0.02	5.75	0.01	0.01	0.01	0.29[1]	13.5
SG4	Fish Flesh	18	0.01	0.003	0.01	0.09	0.09	0.01	0.01	0.16	3.5
	Prawn Abdo	26	0.06	0.007[1]	0.02	9.15	0.01	0.01	0.01	0.34	13.5
LwRivs TV	Fish Flesh		0.07	0.003	0.03	0.17	0.12	0.03	0.17	2.26	4.8
	Prawn Abdo		0.01	0.01	0.06	11.6	0.01	0.01	0.01	0.31	16
(green)	Low risk = significantly < TV										

Site	Sample	n	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
[orange]	Potential risk = significantly > TV OR not significantly different from TV										

[1] Although TSM falls below the TV, the 2016 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.

Analysis of trends of tissue metals in the upper and lower river between 2007 and 2016 are shown in Table 7-16 and Table 7-17 and detailed results of the statistical analysis are shown in Appendix F and Tables F-6 to F-9.

In the upper river test sites, the analysis shows trends of increasing concentrations between 2007 and 2016 for: lead and selenium in prawn abdomen at Wasiba, nickel and lead in prawn abdomen at Wankipe, copper, selenium and zinc in prawn abdomen at Bebelubi and copper and nickel in prawn abdomen at SG4. All other metals in the upper and lower river have either decreased or remained stable over the period.

Table 7-16 Comparison of tissue metal trends at upper river ref and test sites 2007 - 2016

Site	Sample	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
UpRiv Ref	Fish Flesh	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]
	Prawn Abdo	[green]	[green]	[orange]	[orange]	[green]	[orange]	[green]	[green]	[green]
Wasiba	Fish Flesh	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]
	Prawn Abdo	[green]	[green]	[green]	[green]	[green]	[green]	[orange]	[orange]	[green]
Wankipe	Fish Flesh	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]
	Prawn Abdo	[green]	[green]	[green]	[green]	[green]	[orange]	[orange]	[green]	[green]
[green]	No change or reduced over time									
[orange]	Increased over time									

Table 7-17 Comparison of tissue metal trends at lower river ref and test sites 2007–2016

Site	Sample	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
LwRiv Ref	Fish Flesh	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]
	Prawn Abdo	[orange]	[green]	[orange]	[orange]	[orange]	[green]	[green]	[green]	[green]
Bebelubi	Fish Flesh	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]
	Prawn Abdo	[green]	[green]	[green]	[orange]	[green]	[green]	[green]	[orange]	[orange]
SG4	Fish Flesh	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]
	Prawn Abdo	[green]	[green]	[green]	[orange]	[green]	[orange]	[green]	[green]	[green]
[green]	No change or reduced over time									
[orange]	Increased over time									

7.4.3.2 Lake Murray

Monitoring of prawn tissue metal concentrations at Lake Murray has not formed part of the historical monitoring program, and monitoring of fish tissue at Lake Murray has not been conducted since 2009 due to a lack of community support for the monitoring program. As a consequence, there are no recent data available for conducting a risk assessment of bioaccumulation of metals at Lake Murray.

7.4.4 Summary Physical and Chemical Toxicant Risk Assessment

This section presents a summary of the risk to aquatic ecosystems posed by each physical and chemical toxicant within the discharge and within the receiving environment. Table 7-1818 to Table 7-20 provide risk assessment results for each physical and chemical toxicant in water, benthic sediment and fish tissue and prawn abdomen for the purposes of comparison throughout the receiving environment and between matrices.

7.4.4.1 pH

Discharge from the lime plant exhibited elevated pH as a result of rainfall runoff from the area contacting lime. The discharge flow rate is relatively low compared to flows within the receiving environment, which exhibit alkaline conditions due to the naturally occurring limestone geology in the contributing catchment. Therefore the risk posed by elevated pH in discharge from the lime plant is considered minor and localised, being restricted to the area immediately downstream of the discharge point.

The site achieved 100% compliance with the internal site-developed end of pipe criteria for pH in tailings, which reduces the dissolved/bioavailable concentration of metals in the tailings slurry. Although moderate proportions of cadmium (6.0%), nickel (30%) and zinc (13%) were present in dissolved forms throughout 2016, the pH of receiving river waters is alkaline which reduces the potential for metals to be remobilised within the water column.

7.4.4.2 Total Suspended Solids

The tailings discharge and mine contact runoff water discharged from Yakatabari D/S 28 Level and Yunarilama/Yarik at Portal exhibited elevated TSS at concentrations that posed a potential risk to the receiving environment. The erodible dumps also contributed TSS to the river system.

The concentrations of TSS at all sites within the receiving environment downstream from SG2 were significantly lower than the TV, which indicates that TSS inputs from the mine are not causing elevated median TSS concentrations above reference conditions and therefore posed a low risk to aquatic ecosystems.

In addition to the potential risks that TSS concentrations pose to the receiving environment, the relationship between sediment and metals is also an important factor in determining potential risks.

Factors which influence the relationship between sediment and metals in both the discharge from the mine and within the receiving environment are: TSS concentration; particle size distribution; pH; dissolved organic matter concentration; sediment mineral type and degree of mineralisation; and the concentrations of metals. This relationship is discussed further when assessing risks posed by metals in Sections 7.4.4.3 to 7.4.4.12.

7.4.4.3 Silver (Ag)

Concentrations of dissolved silver in water discharged from the mine were less than the respective upper river TV, indicating low risk to the receiving environment. This is confirmed by low dissolved silver concentrations throughout the receiving environment in 2016.

Concentrations of WAE silver in sediment discharged from 28 level exceeded the upper river TV, which indicates potential risk. However, WAE silver concentrations in benthic sediment at all test sites were below their respective TVs in 2016 indicating low risk within the rivers downstream of SG2 on the Lagaip River.

Overall, the system-wide risk posed by silver to aquatic ecosystems is considered low.

7.4.4.4 Arsenic (As)

Dissolved arsenic concentrations in all discharge sources were below the upper river TV. WAE arsenic concentrations in sediment discharged in tailings and from 28 level exceeded the upper river TV, indicating potential risk.

In the receiving environment, sampling was not able to be carried out at SG1 on the Porgera River, where previous monitoring had shown potential risk to aquatic ecosystems. Concentrations of dissolved arsenic in water and WAE arsenic in benthic sediment were below the respective TVs in all receiving environment test sites, indicating low risk to aquatic ecosystems downstream of the Porgera River.

The median concentrations of arsenic in prawn abdomen at Bebelubi and SG4 exceeded the respective TVs in 2016, indicating potential risk at these sites. Arsenic in prawn abdomen at the upper river test sites fell below the TV, indicating low risk and arsenic in fish flesh was below the TV at the lower river sites, also indicating low risk. It should be noted that the concentrations of all metals within prawn and fish tissue at all sites within the upper and lower rivers were below applicable food standards and therefore do not pose a risk to human health if consumed. A comparison against food standards is provided in Section 7.7.

The exceedance of the TV for arsenic in prawn abdomen at Bebelubi and SG4 in the absence of potential risk through water and benthic sediment indicates the potential for an alternative exposure pathway of arsenic to prawns in the lower river.

Overall, given the low levels of arsenic observed in water, sediment and fish tissue throughout the receiving environment, the system-wide risk posed by arsenic to aquatic ecosystems is considered low.

7.4.4.5 Cadmium (Cd)

Dissolved cadmium concentrations in tailings and mine contact runoff from Kogai dump toe and Wendoko D/S 28 level exceeded the upper river TV, indicating potential risk. WAE cadmium in sediment discharged in tailings and from 28 level, Kogai dump toe and Wendoko Crk D/S Anawe North dump also exceeded the upper river TV, indicating potential risk.

Within the receiving environment downstream of the Porgera River, concentrations of dissolved cadmium in water and WAE cadmium in benthic sediment were below the respective TVs at all sites, indicating low risk.

Cadmium in prawn abdomen at Wasiba, Wankipe and SG4 exceeded their respective TVs indicating potential risk.

Similar to arsenic, the exceedance of the TV for cadmium in prawn abdomen at Wasiba, Wankipe and SG4 in the absence of potential risk through water and benthic sediment indicates the potential for an alternative exposure pathway of arsenic to prawns in the lower river.

Overall, the system-wide risk posed by cadmium to aquatic ecosystems is considered low.

7.4.4.6 Chromium (Cr)

The concentration of dissolved chromium in water discharged from the lime plant exceeded the upper river TV, indicating potential risk. Within the receiving environment, the concentrations of dissolved chromium in water, WAE chromium in benthic sediment and chromium in fish flesh and prawn abdomen were below the respective TVs at all sites, indicating low risk.

Overall, the system-wide risk posed by chromium to aquatic ecosystems is considered low.

7.4.4.7 Copper (Cu)

The concentrations of dissolved copper in tailings and WAE copper in tailings sediment exceeded the respective upper river TVs, indicating potential risk. Within the receiving environment downstream of the Porgera River, the concentrations of dissolved copper in water, WAE copper in benthic sediment and copper in fish flesh and prawn abdomen were below the respective TVs at all sites, indicating low risk.

Overall, the system-wide risk posed by copper to aquatic ecosystems is considered low.

7.4.4.8 Mercury (Hg)

The concentrations of dissolved mercury in waters discharged from the mine were below the upper river TV and therefore pose low risk to the receiving environment. This is reflected by low dissolved mercury concentrations in water throughout the receiving environment.

WAE mercury concentration was elevated in tailings sediment and poses a potential risk to the receiving environment. However, WAE concentrations of mercury in benthic sediment throughout the receiving aquatic ecosystem were low and pose low risk.

The concentration of mercury in fish flesh at SG4 exceeded the TV and therefore indicates potential risk. The concentrations of mercury in fish flesh and prawn abdomen at all other test sites fell below the respective TV and therefore posed a low risk to aquatic ecosystems. Again, it should be noted that the concentrations of all metals within prawn and fish tissue at all sites within the upper and lower rivers were below applicable food standards and therefore do not pose a risk to human health if consumed. A comparison against food standards is provided in Section 7.7.

Overall, the system-wide risk of mercury to aquatic ecosystems is considered low.

7.4.4.9 Nickel (Ni)

The concentration of dissolved nickel in tailings exceeded the upper river TV, indicating potential risk to the receiving aquatic ecosystem. However, the concentrations of dissolved nickel at all receiving environment sites downstream of the Porgera River posed low risk. A combination of dilution and adsorption to particulate matter within the receiving environment rapidly reduces the concentration of dissolved nickel in water.

The WAE nickel concentration in sediment discharged from the site was below the upper river TV and therefore posed a low risk to the receiving aquatic ecosystem. WAE nickel in benthic sediment at Wasiba exceeded the TV, indicating potential risk.

Dissolved nickel in water, WAE nickel in benthic sediment and nickel concentrations in fish flesh and prawn abdomen fell below the respective TVs at all other sites, indicating low risk.

Overall, the system-wide risk of nickel to aquatic ecosystems is considered low.

7.4.4.10 Lead (Pb)

Concentrations of dissolved lead in waters discharged from the site pose low risk, and were reflected by low concentrations of dissolved lead in water throughout the receiving environment.

With the exception of the Lime Plant, WAE lead concentrations in sediment in all discharges from the mine exceeded the upper river TV, indicating potential risk.

In the receiving environment, the concentration of WAE lead in benthic sediment exceeded the respective TVs at SG2, Wasiba, Wankipe, Southern Lake Murray and the off-river water body Kukufionga, indicating the presence of mine-derived sediment.

Lead concentration in prawn abdomen at Wasiba was not significantly different from the TV, indicating potential risk. Lead in fish flesh and prawn abdomen at all other sites fell below the respective TVs, indicating low risk. Again, it should be noted that the concentrations of all metals within prawn and fish tissue at all sites within the upper and lower rivers were below applicable food standards and therefore do not pose a risk to human health if consumed. A comparison against food standards is provided in Section 7.7.

The results of the risk assessment indicate that WAE lead in discharges from the mine led to elevated concentrations in benthic sediment extending downstream to Wasiba in the upper river, and that this in turn is contributing to elevated concentrations of lead in prawn abdomen at Wasiba.

Given the elevated concentrations of WAE lead in sediments discharged from the mine, the potential risk indicated by elevated WAE lead in benthic sediment at SG2 and Wasiba, and lead in prawn abdomen at Wasiba, lead is considered to have posed a potential risk to aquatic ecosystems in the upper river between the mine and Wasiba. Downstream from Wasiba, lead posed a low risk to aquatic ecosystems.

7.4.4.11 Selenium (Se)

Dissolved selenium concentrations in water and WAE selenium concentrations in sediment discharged from the site were below the respective upper river TVs and therefore posed low risk to aquatic ecosystems. This is reflected in the receiving environment by low concentrations of dissolved selenium in water and WAE selenium in benthic sediment at all sites, indicating low risk.

Selenium concentrations fish flesh at Wasiba and in prawn abdomen at Wasiba, Wankipe, Bebelubi and SG4, indicated potential risk to aquatic ecosystems at these locations. Again, it should be noted that the concentrations of all metals within prawn and fish tissue at all sites within the upper and lower rivers were below applicable food standards and therefore do not pose a risk to human health if consumed. A comparison against food standards is provided in Section 7.7.

Similar to arsenic and cadmium, however, the exceedance of the TV for selenium in prawn abdomen at Wasiba, Wankipe, Bebelubi and SG4 in the absence of potential risk through water and benthic sediment indicates the potential for an alternative exposure pathway of selenium to prawns in the lower river.

Overall, given the low concentrations of dissolved selenium in water and WAE selenium in mine-derived sediments and throughout the receiving environment, the system-wide risk of selenium is considered low.

7.4.4.12 Zinc (Zn)

The majority of zinc contributions from the mine are in the form of dissolved zinc from tailings and the competent waste rock dumps, and in particulate form from the tailings, 28 level and the competent waste rock dumps. The concentrations of dissolved zinc in tailings and in water discharged from SDA toe, Kogai dump toe and Wendoko D/S Anawe Nth were greater than the upper river TV and pose potential risk to downstream aquatic ecosystems.

Tailings were the dominant source of zinc, accounting for the highest concentrations and loads. Median concentrations of dissolved and total zinc in tailings slurry more than doubled between 2015 and 2016, as shown in Figure 7-15, as did the concentrations of TD and WAE zinc in sediment within the tailings discharge, shown in Table 7-18.

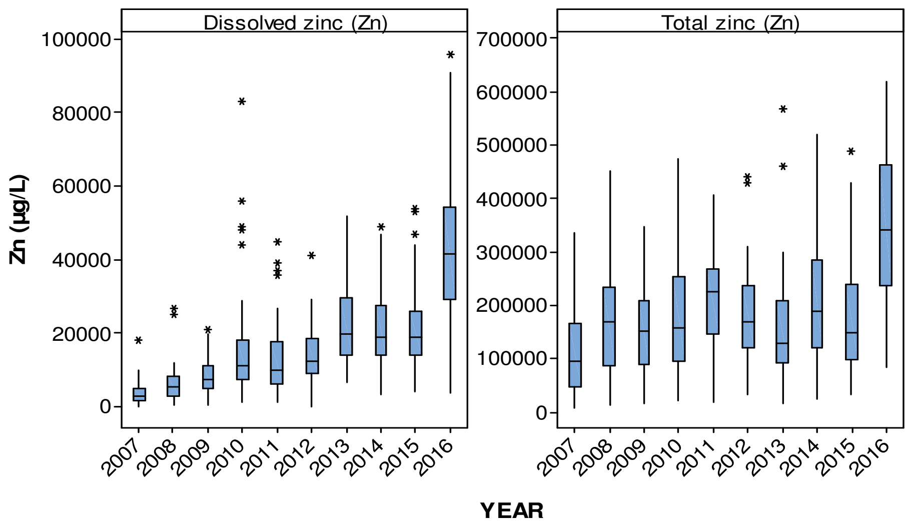


Figure 7-15 Annual dissolved and total zinc concentrations in tailings 2007-2016 (µg/L) (Fig 4-54 reproduced)

Table 7-18 Comparison of zinc concentrations in tailings solids between 2015 and 2016

Year	Parameter	20%ile	Median	80%ile
2015	Zn-TD	742	1,030	1,528
	Zn-WAE	476	680	1,186
2016	Zn-TD	2,300	2,730	3,200
	Zn-WAE	1,100	1,500	1,780
	> UpRiv TV = Potential Risk			

Dissolved zinc concentrations in water exceeded the TV at SG2 in the upper river, at Bebelubi and SG4 in the lower river and at the ORWB Avu. Dissolved zinc concentrations at Central and Southern Lake Murray were not significantly different from the TV. WAE zinc in benthic sediment did not exceed the TV at any of the receiving environment sites. A summary of the results of the risk assessment and trend analysis for zinc in water and sediment throughout the receiving environment is shown in Table 7-19.

Table 7-19 Summary of risk and trend analysis for zinc in water and sediment

Site	Water Zn-D		Sediment WAE Zn	
	Risk	Trend 2007 - 2016	Risk	Trend 2013 - 2016
UpRiv Ref	NA	No change over time	NA	Increased over time
SG2	Potential	No change over time	Low	Increased over time
Wasiba	Low	Increased over time	Low	No change over time
Wankipe	Low	Increased over time	Low	No change over time
SG3	Low	Increased over time	Low	Increased over time
LwRiv Ref	NA	Increased over time	NA	Increased over time
Bebelubi	Potential	Increased over time	Low	No change over time
SG4	Potential	Increased over time	Low	Increased over time
SG5	Low	No change over time	Low	No change over time
Lake Murray ORWB Ref	NA	No change	NA	Increased over time
Central Lake	Potential	Increased over time	Low	No change over time
Southern Lake	Potential	Increased over time	Low	Increased over time
SG6	Low	No change over time	Low	No change over time
Kukufionga	Low	No change over time	Low	No change over time
Zongamange	Low	No change over time	Low	No change over time
Avu	Potential	No change over time	Low	Increased over time

The exceedance of the dissolved zinc TV at SG2 was most likely attributable to the dissolved zinc in tailings discharged from the mine. The trend of increasing dissolved zinc concentrations at Wasiba, Wankipe and SG3 over time also is most likely due to dissolved zinc discharged in tailings, and reflects the increase in dissolved zinc concentrations in tailings between 2015 and 2016.

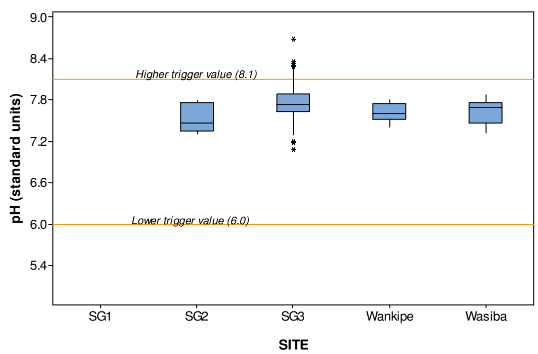
Dissolved zinc at the lower river test sites, Bebelubi and SG4, and at the ORWB Avu also exceeded the respective TV, but was not significantly different from the TV at Central and Southern Lake Murray, indicating potential risk at these sites. There are a number of possible explanations for exceedance of the TVs at these sites.

In order to determine whether, and what degree mine derived zinc is influencing the condition of the receiving aquatic ecosystem, it is important to consider the behavior of zinc discharged from the mine.

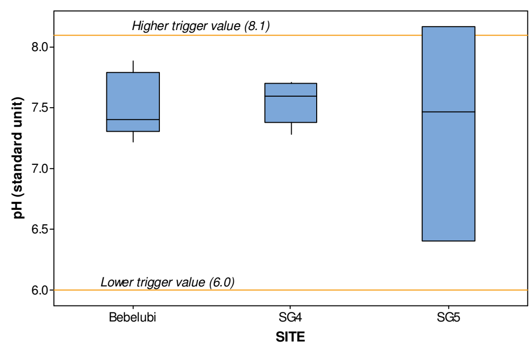
Elevated concentrations of dissolved zinc discharged from the mine decreased rapidly within the receiving environment through the processes of dilution and transfer to the particulate phase by adsorption to particulate matter and complexation with natural organic matter.

WAE metals in sediment are discharged directly from the mine, and also are formed as dissolved zinc becomes adsorbed to natural particulate matter. Particle size of the sediments is an important factor when considering the transport of WAE zinc in particulate form. The majority of the coarser fraction of sediment will settle in the upper rivers, while most of the finer fraction will be transported in suspension to the lower river, Lake Murray and ORWBs during overflow events. The fine sediment possesses a higher specific surface area than coarse sediment, and thereby provides a larger number of available adsorption sites per unit volume. The fine sediment therefore likely contains a higher concentration of adsorbed metals per unit volume than the coarse sediment.

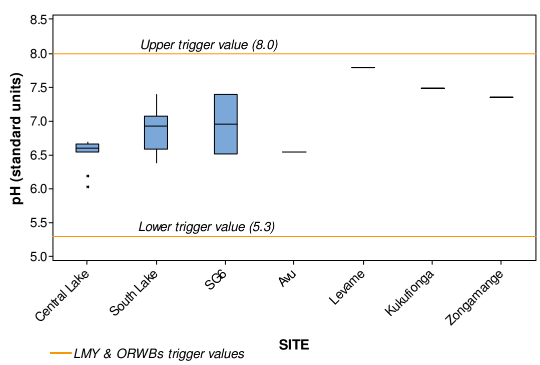
The behavior of zinc in the aquatic ecosystem is influenced by the physico-chemical conditions, such as pH and redox potential within the water column and benthic sediment. The range of pH observed at test sites within the receiving environment during 2016 is presented in Figure 7-16, and shows that median pH in water decreased slightly from the upper river to the lower river, and then decreased further to slightly acidic conditions in Lake Murray and ORWBs. It is possible, that zinc was remobilised from mine-derived and from natural particulates into the dissolved phase under the lower pH conditions of Lake Murray and the ORWBs.



pH range in upper river test sites 2016



pH range in lower river test sites 2016



pH range in Lake Murray and ORWB test sites 2016

Figure 7-16 pH range observed at receiving environment test sites during 2016

At the lower river reference sites, concentrations of dissolved zinc in water increased between 2007 and 2016 and WAE zinc in sediment at the reference sites increased between 2013 and 2016. At the North Lake Murray reference site, the concentration of dissolved zinc in water did not increase between 2007 and 2016, however the concentration of WAE zinc in sediment did increase between 2013 and 2016. It is possible therefore that natural, non-mine related sources of zinc, especially in the particulate phase, may be contributing to the concentrations of dissolved zinc observed at the test sites, through the process of remobilisation from the particulate phase under the lower pH conditions.

Another factor influencing result of the risk assessment, is the risk assessment methodology. This is most applicable to the zinc TV exceedance at the lower river test sites Bebelubi and Tomu. The occurrence of higher dissolved zinc concentrations at the lower river test sites in 2016, also was observed at the lower river reference sites, Baia and Tomu. Figure 7-17 and Figure 7-18 present all data from the lower river reference sites and test sites respectively, between 2007 and 2016. Summary statistics of dissolved zinc concentrations at each site between 2015 and 2016 are presented in Table 7-20. The results show an increase in dissolved zinc concentrations at all reference and test sites between 2015 and 2016.

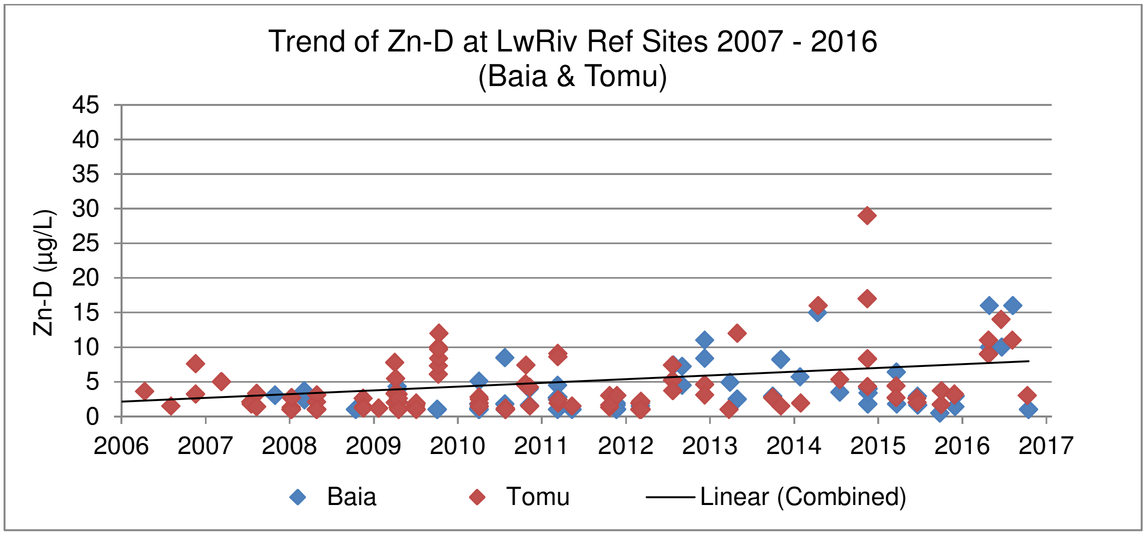


Figure 7-17 Trend of Zn-D at lower river reference sites 2007 – 2016

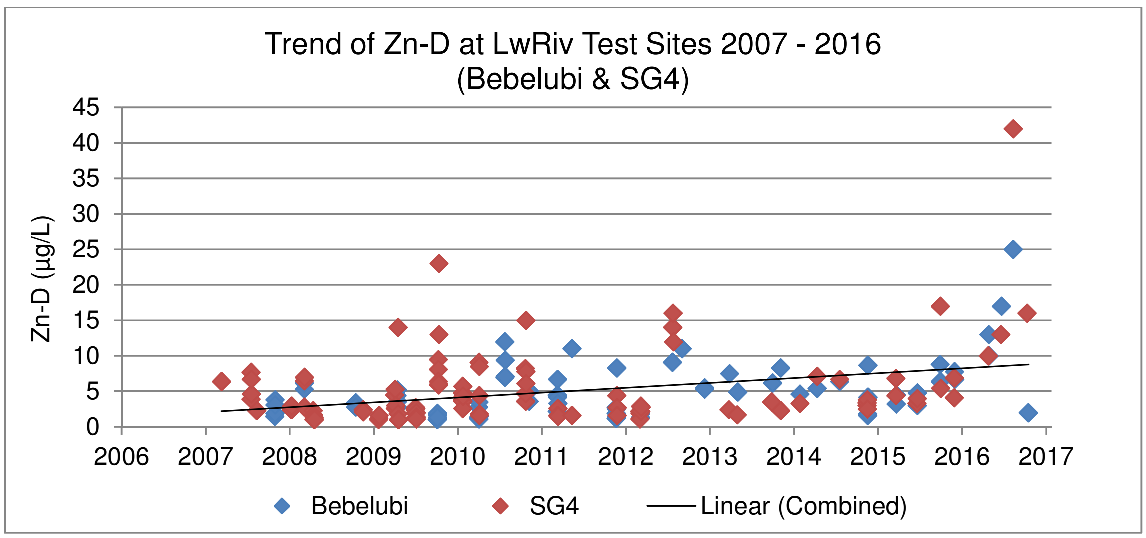


Figure 7-18 Trend of Zn-D at lower river test sites 2007 – 2016

Table 7-20 Summary statistics for Zn-D (µg/L) at lower river reference and test sites 2015 and 2016

Site	20%ile		Median		80%ile		80%ile		TV	
	2015	2016	2015	2016	2015	2016	2014/15	2015/16	2014/15	2015/16
Baia	1.4	8.2	1.8	10	3.6	16	NA	NA	NA	NA
Tomu	1.9	7.8	2.6	11	3.0	11.6	NA	NA	NA	NA
LwRiv Ref (Combined)	1.7	7.8	2.3	10.5	3.2	14.4	5.8	10.0	8.0*	10.0
Bebelubi	3.7	8.4	5.6	13	7.36	18.6	NA	NA	NA	NA
SG4	4.0	10	4.9	13	6.9	21.2	NA	NA	NA	NA

* ANZECC/ARMCANZ 2000 default guideline for 95% species protection

The risk assessment methodology is based on establishing a TV by comparing the 80th %ile of the baseline data, against the 80th %ile of the combined reference site data for the previous 24 months and the ANZECC/ARMCANZ 2000 default guideline for 95% species protection, and adopting whichever is highest. In 2015, the ANZECC/ARMCANZ 2000 guideline value of 8 µg/L was the highest value and subsequently adopted as the lower river TV. In 2016 the 80th %ile value of the combined reference site data for the previous 24 months, (10 µg/L), was the highest and subsequently adopted as the TV. The increase in the TV from 2015 to 2016 reflected the increase in dissolved zinc concentrations at the lower river reference sites, however, as the calculation also included the lower values from 2015, the TV did not fully reflect the magnitude of the increase in dissolved zinc concentrations at the reference sites from 2015 to 2016.

Table 7-21 compares the dissolved zinc TV derived from the previous 24 months data (2015 and 2016) against the previous 12 months data (2016) and shows how the lower dissolved zinc concentrations recorded in 2015 have influenced the 2016 TV. When the 2016 test site medians are compared against the 80th %ile of data from the reference sites in 2016, the 2016 test site medians fall below the 2016 reference site 80th %ile.

Table 7-21 Summary table showing the effect of adopting using the previous 24-months data to develop the TV

Site	TSM 2016	Lower River Ref 80th %ile 2016 only	Lower Ref 80th %ile 2015 & 2016 (i.e. the 2016 TV)
Bebelubi	13.0	14.4	10.0
SG4	13.0	14.4	10.0

ANZECC/ARMCANZ 2000 recommends using the previous 24 months' data to allow for non-mine related variations within the ecosystem condition at the reference site. PJV considers that the risk assessment method is a conservative and prudent approach, which has operated as intended to identify the potential environmental risk posed at the lower river test sites, as a result of the increase in dissolved zinc concentrations at the lower river test sites between 2015 and 2016. It should be noted however, that in this case the use of the previous 24 months' data has contributed to the TV being exceeded.

Finally, it should be noted that PJV had engaged a different external laboratory to perform metals analysis during 2016. This had the potential to influence the results of metals analysis. The external laboratory was NATA certified, and all sample processing procedures and QA&QC applied by PJV remained unchanged from 2015 to 2016. The QA&QC results showed a high level of compliance with applicable targets, therefore, PJV considers it highly unlikely that the use of a different laboratory had influenced zinc results in any way.

Overall, the risk to ecosystem health posed by zinc in 2016 is considered to be low downstream of SG2. At sites between the mine and SG2, zinc poses a potential risk to ecosystem health.

Increasing trends of dissolved and particulate zinc in discharge from the mine, particularly in tailings, and increasing trends of zinc concentrations in water and sediment within the receiving environment, should be noted. These results serve as a cautionary indication that if the 2016 trend continues, zinc has the potential to pose a risk to the receiving environment in future years. This scenario is likely to be exacerbated during lower rainfall years when dilution is reduced.

Table 7-18 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 2016 (µg/L except where indicated)

Region	Site	WATER											
		pH^	TSS*	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
Discharge	Tailings	6.4	171,150	0.05	0.85	124	0.20	44	0.14	1,625	0.10	1.7	41,600
	28 Level	7.6	496	0.01	2.8	0.08	0.20	0.50	0.04	2.9	0.10	0.2	19
	SDA Toe	7.6	229	0.02	0.9	0.06	0.20	0.55	0.04	1.4	0.20	0.6	26
	Kaiya Riv D/S Anj Dump	7.6	3,823	0.05	1.1	0.05	0.20	0.75	0.04	0.65	0.20	0.5	11
	Kogai Culvert	7.8	440	0.01	1.1	0.12	0.20	0.90	0.04	0.69	0.40	0.2	21
	Kogai dump toe	7.7	130	0.01	0.85	2.2	0.20	0.70	0.04	2.7	0.90	0.2	411
	Lime Plant	11	561	0.01	0.20	0.05	4.6	0.56	0.04	0.50	0.10	0.2	4.5
	Wendoko Crk D/S Anawe Nth	7.7	25	0.01	1.1	0.78	0.20	0.50	0.04	1.9	0.20	0.6	355
	Yakatabari D/S 28 Level	7.5	4,528	0.01	6.7	0.07	0.20	0.65	0.04	1.8	1.0	0.5	20
	Yunarilama/Yarik @ Portal	7.4	7,368	0.02	1.7	0.12	0.20	0.50	0.06	1.8	0.30	1.2	18
Upper River	SG1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	SG2	7.5	1,880	0.01	1.1	0.24	0.20	2.2	0.04	0.90	0.10	0.20	19.5
	Wasiba	7.7	1,385	0.01	1.2	0.15	0.20	1.0	0.04	0.65	0.10	0.20	15.0
	Wankipe	7.6	920	0.01	1.1	0.08	0.20	1.4	0.04	0.50	0.10	0.20	14.0
	SG3	7.7	1,775	0.01	1.1	0.05	0.20	1.1	0.04	0.50	0.10	0.20	11.6
Lower River	Bebelubi	7.4	528	0.02	1.0	0.05	0.20	1.1	0.04	0.50	0.10	0.20	13
	SG4	7.6	364	0.01	0.80	0.05	0.20	1.0	0.04	0.50	0.10	0.20	13
	SG5	7.5	486	0.01	1.0	0.05	0.20	1.0	0.04	0.50	0.20	0.20	7.0
Lake Murray and ORWBs	Central Lake	6.6	5.0	0.01	0.20	0.05	0.30	0.50	0.04	0.50	0.10	0.20	6.0
	Southern Lake	6.9	5.0	0.01	0.20	0.05	0.20	0.50	0.04	0.50	0.10	0.20	6.0
	SG6	6.9	86^	0.01	0.55	0.05	0.20	0.55	0.06	0.55	0.15	0.20	2.5
	Kukufionga	7.5	5.0	0.01	2.6	0.05	0.2	0.5	0.04	0.50	0.10	0.20	3.0
	Zongamange	7.4	28^	0.01	1.0	0.05	0.2	0.7	0.04	0.70	0.10	0.20	3.0
	Avu	6.5	5.0	0.01	0.4	0.05	0.4	0.5	0.10	0.60	0.10	0.20	10
	Levame	7.8	30^	0.01	2.9	0.05	0.2	0.5	0.04	0.50	0.10	0.20	5.0

^ std units, * mg/L

Table 7-19 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 2016 (mg/kg whole sediment)

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	0.33	47	9.0	**21**	90	0.30	22	178	0.10	1,500
	28 Level	1.7	21	1.7	14	24	0.11	19	697	0.1	615
	SDA Toe	0.06	5.4	1	4.4	4.6	0.05	4.4	184	0.1	155
	Kaiya Riv D/S Anj Dump	0.05	4.3	0.42	4.8	3.8	0.03	5.9	78	0.1	66
	Kogai Culvert	0.37	8.5	0.75	4.1	5.1	0.03	4.7	142	0.2	128
	Kogai dump toe	0.53	17	2.1	4.8	11	0.04	6.2	333	0.1	346
	Lime Plant	0.17	0.82	0.39	7.1	2.8	0.02	2.1	11	0.3	16
	Wendoko Crk D/S Anawe Nth	0.18	15	2.1	4.6	10	0.06	6.1	199	0.15	310
	Yakatabari DS 28 Level	1	17	1.1	4.3	11	0.06	7.7	185	0.15	237
	Yunarilama/Yarik @ Portal	0.05	4.2	0.22	5.1	5.1	0.07	5.7	85	0.1	54
Upper River	SG1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	SG2	0.075	6.3	1.1	5.0	10.5	0.025	6.6	152	0.15	152
	Wasiba	0.05	4.3	0.52	3.5	9.3	0.015	9.8	35	0.10	71
	Wankipe	0.05	3.6	0.40	3.3	7.6	0.015	9.8	29	0.10	53
	SG3	0.05	4.0	0.45	3.3	7.6	0.10	9.5	31	0.10	59
Lower River	Bebelubi	0.05	4.0	0.36	4.1	6.8	0.01	16	21	0.10	44
	SG4	0.05	3.6	0.35	4.4	6.6	0.01	15	17	0.20	49
	SG5	0.05	3.2	0.22	2.8	6.3	0.01	8.1	16	0.10	38
Lake Murray and ORWBs	Central Lake	0.12	2.6	0.13	6.4	13	0.02	11	22	0.10	54
	Southern Lake	0.06	4.9	0.26	3.9	14	0.01	8.6	42	0.10	65
	SG6	0.05	4.1	0.19	4.7	12	0.02	6.8	29	0.10	44
	Kukufionga	0.05	8.2	0.38	4.5	18	0.01	9.2	61	0.10	98
	Zongamange	0.05	3.7	0.45	3.4	15	0.01	11	30	0.10	73
	Avu	0.11	1.8	0.24	3.1	24	0.01	11	25	0.20	86
	Levame	0.05	3.2	0.37	2.9	9	0.01	8.1	20	0.10	59

WAE – Weak acid extraction

Table 7-20 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 2016

Region	Site	Indicator	Unit	WATER, SEDIMENT, TISSUE METAL COMBINED											
				pH^	TSS*	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Upper River	Wasiba	Water-D	µg/L	7.7	1,385	0.01	1.2	0.15	0.20	1.0	0.04	0.65	0.10	0.20	15
		Sed-WAE	mg/kg	-	-	0.05	4.3	0.52	3.5	9.3	0.015	9.8	35	0.10	71
		Fish Flesh	mg/kg	-	-	-	0.02	0.003	0.01	0.18	0.07	0.01	0.01	0.32	5.6
		Prawn Abdo	mg/kg	-	-	-	0.03	0.012	0.02	4.85	0.01	0.01	0.04	0.56	15
	Wankipe	Water-D	µg/L	7.6	920	0.01	1.1	0.08	0.20	1.4	0.04	0.50	0.10	0.20	14
		Sed-WAE	mg/kg	-	-	0.05	3.6	0.40	3.3	7.6	0.015	9.8	29	0.10	53
		Fish Flesh	mg/kg	-	-	-	0.02	0.004	0.01	0.19	0.06	0.01	0.01	0.26	4.9
		Prawn Abdo	mg/kg	-	-	-	0.04	0.007	0.03	5.95	0.01	0.01	0.01	0.42	14
Lower River	Bebelubi	Water-D	µg/L	7.4	528	0.02	1.0	0.05	0.20	1.1	0.04	0.50	0.10	0.20	13
		Sed-WAE	mg/kg	-	-	0.05	4.0	0.36	4.1	6.8	0.01	16	21	0.10	44
		Fish Flesh	mg/kg	-	-	-	0.01	0.003	0.01	0.14	0.10	0.01	0.01	0.12	3.9
		Prawn Abdo	mg/kg	-	-	-	0.08	0.005	0.02	5.75	0.01	0.01	0.01	0.29	14
	SG4	Water-D	µg/L	7.6	364	0.01	0.80	0.05	0.20	1.0	0.04	0.50	0.10	0.20	13
		Sed-WAE	mg/kg	-	-	0.05	3.6	0.35	4.4	6.6	0.01	15	17	0.20	49
		Fish Flesh	mg/kg	-	-	-	0.01	0.003	0.01	0.09	0.09	0.01	0.01	0.16	3.5
		Prawn Abdo	mg/kg	-	-	-	0.06	0.007	0.02	9.15	0.01	0.01	0.01	0.34	13.5

* std units; * mg/L

7.5 Local Water Supplies

Participatory sampling of local village water supplies was carried out in May 2016 at six Special Mining Lease Villages (Yarik, Apalaka, Timorope, Panadaka, Pakien Camp and Kulapi) to assess suitability of water for domestic use. 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 from tanks and two springs that were identified by PLOA representatives, as well as creeks that are commonly used by local villagers for laundry, bathing, panning for gold or other water-based activities. Sampling sites and details are listed in Table 7-22 and locations are shown in Figure 7-19.

The samples were prepared at the PJV onsite laboratory for dispatch to external laboratories. Samples for bacterial analysis were sent to SGS laboratory in Port Moresby, Papua New Guinea, while samples requiring trace metals and physico-chemical analyses were sent to the Australian Laboratory Services (ALS) laboratory in Brisbane, Australia.

Table 7-22 Revised sampling sites for Local Village Water Supplies 2016

Village	Site	Name on map	Easting	Northing
Apalaka	Yongone Creek	AP_YC	9397744	731458
	Kendo Spring	AP_KS	9397744	731461
	SDA Church	AP_H1	9397663	731732
	Taro Creek	AP_TC	9397557	732278
Yarik	Yambu Creek	YR_YMC	9397517	732539
	Yarik H1 Tank	YR_H1	9397172	732549
	Kapia Kendo	YR_KS	9397157	732803
	Yawena Creek	YR_YNC	9397345	732975
	Yarik School Tank	YR_YS	9397325	733329
Alipis	Yakatabari Creek	AL_YC	9396361	733410
	Alipis House 3 Tank	AL_H3	9395775	733346
Panadaka	Panadaka 1 Bilip Aile Tank	PA_V1H6	9395507	733671
	Panadaka 2 Timothy Kerene Tank	PA_V2H4	9395780	733845
	Kogai Creek	PA_KC	9395473	733109
Kulapi	Kulapi Creek	KL_KC	9394356	733271
	Kulapi V4 H1 tank	KL_V4H1	9394700	732772
	Yoloyope Creek	KL_YC	9394655	732958
Timorope	Wari Ekale	TI_H1	9397393	733125
	Iso Kulina	TI_H2	9397580	733221
Pakien Camp	Pakien Lutheran Church	PC_LC	9396648	734603
	United Church	PC_UC	9396241	734106

The water quality test results for raw drinking water sites are presented in Table 7-23 and Table 7-24 The following exceedances of the PNG Raw Drinking Water Standard (1984) were recorded: elevated hardness and total solids at Kendo Spring; total and faecal coliforms contamination at Kulapi V4 H1 tank and total coliform contamination at Kapia Spring. With the exception of zinc, dissolved metals were very low in all of the water supplies sampled. The source of the elevated dissolved zinc concentrations is most likely the galvanized iron roof catchments of the water tanks. A repeat sampling conducted at Kulapi V4H1 tank complied with the PNG Raw Drinking Water Standard for total and faecal coliforms. The likely sources of bacterial contamination of the two water sources are unknown.

PJV has implemented a supplementary water project involving the installation of a minimum of 10 tanks at each of six villages to improve the availability and reliability of safe drinking water for local communities. The project has received strong community support and village water committees have been established to carry out maintenance of the infrastructure. PJV plans to develop a communication plan for sharing the water supply sampling results with the local communities in conjunction with the PLOA.

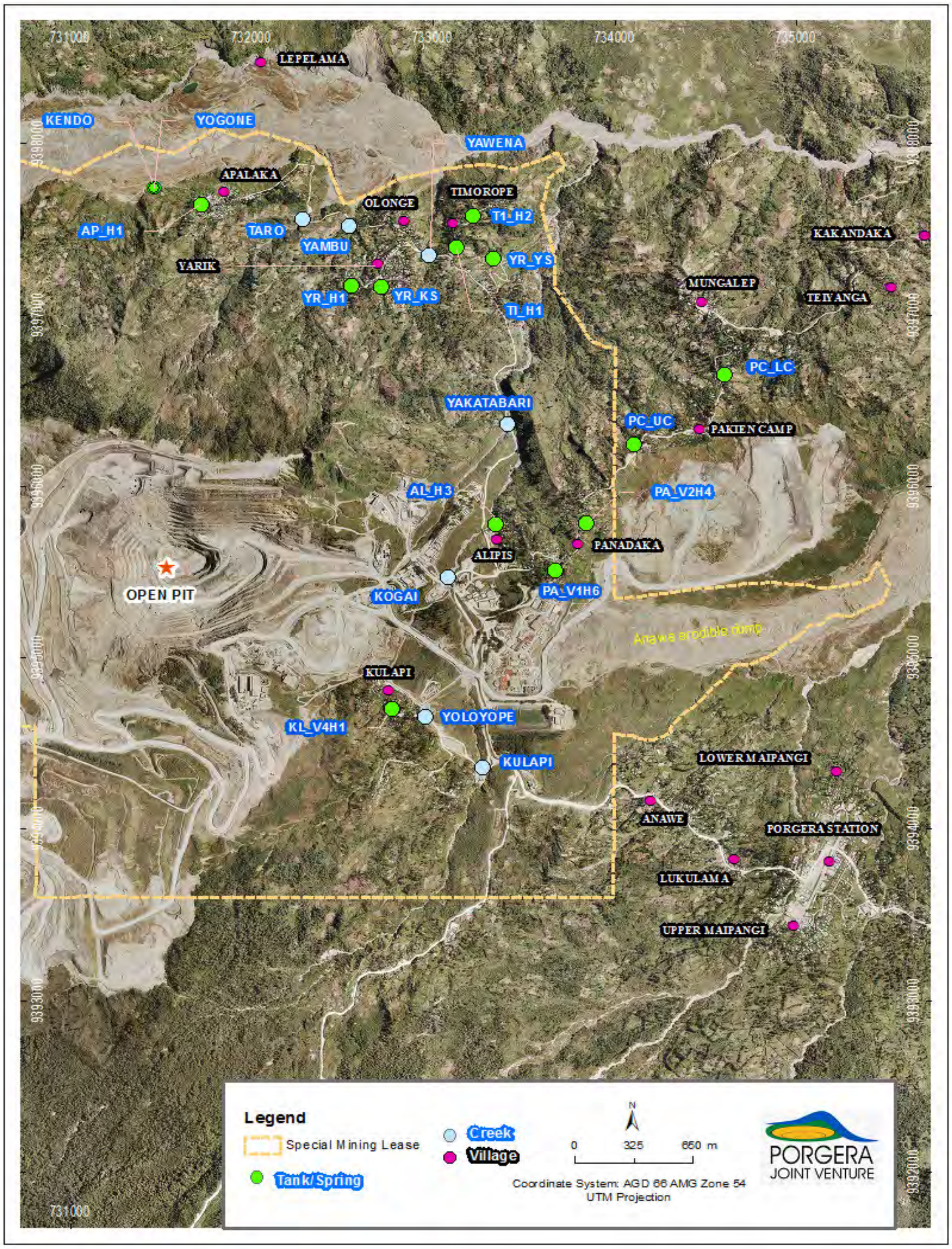


Figure 7-19 Sampling sites for local village water supplies

Table 7-23 Physiochemical and biological water quality 2016 at drinking water sites against Drinking Water Quality Standards

Site / Parameter	pH Value	Electrical Cond. @ 25℃	Total Solids	Colour	Turbidity	Total Hardness	Faecal Coliforms	Total Coliforms
Unit	SU	µS/cm	mg/L	PCU	NTU	mg/L	cfu/100 mL	cfu/100 mL
Kendo Spring	8.2	1340	934	3.0	1.6	461	0	6
Apalaka SDA Church	6.6	3.0	6.0	3.0	1.0	<1	0	0
Yarik H1 Tank	6.7	6.0	12	3.0	3.1	<1	0	4
Kapia Spring	8.3	422	284	6.0	12.5	199	0	91
Yarik School Tank	6.6	4.0	6.0	5.0	1.0	<1	0	0
Panadaka 2 Timothy Kerene	6.8	13	27	25	8.8	<1	0	2
Bilip Aile	6.5	5.0	12	3.0	1.0	<1	0	0
Ailipis Village Tank 3	6.9	13	13	3.0	1.6	2.0	0	1
Kulapi V4 H1 tank	6.8	10	20	7.0	3.4	<1	2	36
Wari Ekale	6.6	6.0	16	10	1.8	<1	0	1
Iso Kulina	6.5	3.0	7.0	3.0	1.9	<1	0	0
Pakien Luthern Church	6.3	2.0	13	13	1.4	<1	0	1
United Church	6.8	7	13	5.0	0.8	2	0	6
PNG (1984)	**6.5 - 9.2**	**NA**	**500**	**15**	**<5**	**200**	**None**	**<10**
WHO (2017)	**6.5 – 8.5**	**NA**		**15**	**<4**	**200**	**None**	**None**

(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

NA - Not Applicable

Cfu – Colony forming units

Table 7-24 Metal concentrations 2016 at drinking water sites against PNG Raw Drinking Water Quality Standard 1984 (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
Kendo Spring	<0.2	<0.2	<0.05	<0.05	<0.5	<0.5	<0.1	<0.1	<0.04	<0.04	<0.5	<0.5	0.5	0.5	6	40
Apalaka SDA Church	<0.2	<0.2	<0.05	<0.05	1.2	11.4	<0.1	0.7	<0.04	<0.04	<0.5	<0.5	<0.2	<0.2	101	143
Yarik H1 Tank	<0.2	<0.2	<0.05	<0.05	0.6	1.3	<0.1	0.2	<0.04	<0.04	<0.5	<0.5	<0.2	<0.2	109	155
Kapia Kendo	1.2	3.0	<0.05	<0.05	<0.5	2.4	<0.1	5.0	<0.04	<0.04	0.7	2.0	<0.2	<0.2	15	11
Yarik School Tank	<0.2	<0.2	<0.05	<0.05	0.7	1.2	<0.1	0.2	<0.04	<0.04	<0.5	<0.5	<0.2	<0.2	117	155
Panadaka 2 Timothy Kerene	0.6	0.9	<0.05	<0.05	8.8	13.3	1.1	2.1	<0.04	<0.04	<0.5	<0.5	<0.2	<0.2	319	454
Bilip Aile	<0.2	<0.2	<0.05	0.06	1.8	3.4	0.1	0.5	<0.04	<0.04	<0.5	<0.5	<0.2	<0.2	171	228
Ailipis Village Tank 3	<0.2	<0.2	<0.05	0.06	1.4	6.0	0.8	2.2	<0.04	<0.04	<0.5	<0.5	<0.2	<0.2	781	1130
Kulapi V4 H1 Tank	<0.2	<0.2	<0.05	0.06	<0.5	0.6	0.2	0.6	<0.04	<0.04	<0.5	<0.5	<0.2	<0.2	169	244
Wari Ekale	<0.2	<0.2	<0.05	<0.05	0.8	2.1	0.2	0.6	<0.04	<0.04	<0.5	<0.5	<0.2	<0.2	306	415
Iso Kulina	<0.2	<0.2	<0.05	<0.05	0.7	1.3	<0.1	0.3	<0.04	<0.04	<0.5	<0.5	<0.2	<0.2	107	147
Pakien Luthern Church	<0.2	<0.2	<0.05	<0.05	2.6	3.6	0.2	0.6	<0.04	<0.04	<0.5	<0.5	<0.2	<0.2	152	188
United Church	<0.2	<0.2	<0.05	<0.05	1.8	0.7	<0.1	0.1	<0.04	<0.04	0.5	<0.5	<0.2	<0.2	47	42
PNG (1984)	**7**	**NA**	**2**	**NA**	**1,000**	**NA**	**10**	**NA**	**1**	**NA**	**20**	**NA**	**10**	**NA**	**3,000**	**NA**
WHO (2017)	**10**	**NA**	**3**	**NA**	**2,000**	**NA**	**10**	**NA**	**6**	**NA**	**70**	**NA**	**40**	**NA**	**NA**	**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, NS – Not Sampled, 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, the median pH and concentration of dissolved metals in the tailings discharge and at test sites within the receiving environment for 2016 were compared against the ANZECC/ARMCANZ (2000) Recreation guideline and the PNG Raw Drinking Water Quality Standard in Table 7-25.

The results show that pH and concentrations of dissolved nickel and dissolved zinc in tailings exceeded the guideline values and therefore indicated potential risk to persons who trespass on the mine lease and are exposed to the undiluted tailings slurry when panning for gold at the tailings discharge.

At all test sites within the upper and lower river there is low risk to human health from exposure to dissolved metals during the various activities that involve contact with water - gold panning, bathing, laundry, fishing and swimming. 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 low risk to human health.

Table 7-25 Comparison of 2016 median receiving water quality values with recreational exposure guidelines (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	6.4	0.05	0.85	124	0.20	44	21	0.14	1,625	0.10	1.7	41,600
SG1	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SG2	6	7.5	0.01	1.1	0.24	0.20	2.2	3.0	0.04	0.90	0.10	0.20	19.5
Wasiba	22	7.7	0.01	1.2	0.15	0.20	1.0	4.0	0.04	0.65	0.10	0.20	15.0
Wankipe	21	7.6	0.01	1.1	0.08	0.20	1.4	4.0	0.04	0.50	0.10	0.20	14.0
SG3	192	7.7	0.01	1.1	0.05	0.20	1.1	6.0	0.04	0.50	0.10	0.20	11.6
ANZECC / ARMCANZ 2000 Recreation		**6.5 – 8.5**	**50**	**50**	**5.0**	**50**	**1,000**	**300**	**1.0**	**100**	**50**	**10**	**5,000**
PNG Raw Drinking Water Quality Standard		**6.5 – 9.2**	**50**	**7.0**	**2.0**	**50**	**1,000**	**1,000**	**1.0**	**20**	**10**	**10**	**3,000**

Green	< Guideline = Low risk
Yellow	≥ Guideline = Potential risk

^ std units

7.7 Fish and Prawn Consumption

Median tissue metal concentrations in fish flesh and prawn abdomen are compared against relevant food standards in Table 7-26. 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 7-26 Risk assessment – median tissue metal results at upper river test sites in 2016 compared against UpRiv 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	22	0.02	0.003	0.01	0.18	0.07	0.01	0.01	0.32	5.6
	Prawn Abdo	26	0.03	0.012	0.02	4.85	0.01	0.01	0.04	0.56	15
Wankipe	Fish Flesh	20	0.02	0.004	0.01	0.19	0.06	0.01	0.01	0.26	4.9
	Prawn Abdo	26	0.04	0.007	0.03	5.95	0.01	0.01	0.01	0.42	15.5
Bebelubi	Fish Flesh	1	0.01	0.003	0.01	0.14	0.10	0.01	0.01	0.12	3.9
	Prawn Abdo	12	0.08	0.005	0.02	5.75	0.01	0.01	0.01	0.29	13.5
Tium-sinawam	Fish Flesh	18	0.01	0.003	0.01	0.09	0.09	0.01	0.01	0.16	3.5
	Prawn Abdo	26	0.06	0.007	0.02	9.15	0.01	0.01	0.01	0.34	13.5
Food Std	**Fish**		**2.0**	**0.05**	**1.0**	**2.0**	**0.50**	**NA**	**0.30**	**2.0**	**15**
	Prawn		**2.0**	**0.50**	**1.0**	**20**	**0.50**	**NA**	**0.50**	**1.0**	**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 90%ile (ANZFA 2001)

NS – Not sampled

7.8 Air Quality

PJV carried out monitoring of concentrations of metals in the emissions from stationary sources at the mine site, the Lime Plant and at Hides Power Station in November/December 2015. Papua New Guinea does not have legislation for controlling emissions to air and 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 Table 7-27. The results show particulate matter in emissions from the Lime Kiln No 2 and NO_x in emissions from the Anawe Diesel Generator exceeded the target. PJV initiated a project in 2016 aimed at reducing the particulate matter emissions from the Lime Kiln.

Table 7-27 Point source emission metal concentrations 2015 (mg/m^3)

Source	Particulate Matter	NO_X	As	Cd	Pb	Ni	Hg	SO_3
Anawe Diesel Generator	14.5	2,201	0.0047	0.00012	0.020	0.0043	0.00071	15.4
Assay Laboratory	6.4	NA	0.0052	0.0014	0.90	0.0095	0.0013	NA
Anawe Autoclaves	57.2	2.1	0.064	0.008	0.12	0.135	0.041	92
Kiln Carbon Regeneration	93	99	0.015	0.10	0.20	0.169	0.038	NA
Gold Room Retort	3.3	2.1	0.0085	0.00090	0.0045	0.00045	0.363	0.24
Lime Kiln No 2	2,339	46	0.012	0.0093	0.029	0.0067	0.0052	NA
Primary Crusher	4.0	NA	0.0044	0.00062	0.027	0.0022	0.00037	NA
Hides Gas Turbine	12	287	0.012	0.00066	0.12	0.0075	0.00079	4.3
Haul Truck 69	29	NA	0.0020	0.009	0.60	0.0059	0.0056	8.2
Criterion	**500**	**1,000**	**10**	**3.0**	**10**	**20**	**3.0**	**200**

(green)	Compliant
(orange)	Non-Compliant

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

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

8 IMPACT ASSESSMENT

8.1 Fish and Prawn Abundance

8.1.1 Upper and Lower River

The results of the impact assessment based on abundance of indicator fish and prawn species in the upper and lower rivers are presented in Table 8-1 to Table 8-4. The results show that the mean abundance of indicator fish and prawn species at the test sites was not significantly different from the mean abundance at the paired reference sites during 2016. It should be noted that the result for *Macrobrachium handschini* at Wankipe and *Potamosilurus latirostris* at Bebelubi were influenced by a large standard deviation within the reference site data sets at each site. This had the effect of reducing the power of the statistical method and contributed to the means being found not significantly different even though by direct comparison the test site mean was lower than the reference site mean.

The results indicate no impact to fish or prawn populations at the test sites within the upper and lower rivers.

Table 8-1 Impact assessment – Mean fish abundance at upper river test sites during 2016 against UpRivs TVs

Test Site				TV (2016 Mean)	Two-sample T-Test	
Site	Species	N	Mean (2016)		p (p=0.05)	Impact Assessment
Wasiba	*Neosilurus equinus*	8	7.6	14.9	0.061	No impact
Wankipe	*Neosilurus equinus*	8	10.6	14.9	0.379	No impact
(green)	No impact = significantly > TV OR not significantly different from TV					
(orange)	Potential impact = significantly < TV					

Table 8-2 Impact assessment – Median prawn abundance at upper river test sites during 2016 against UpRivs TVs

Test Site				TV (2016 Mean)	Two-Sample T-Test	
Site	Species	N	Mean (2016)		p (p=0.05)	Impact Assessment
Wasiba	*Macrobrachium handschini*	8	11.1	9.6	0.745	No impact
	Macrobrachium lorentzi	8	43.6	41.3	0.901	No impact
Wankipe	*Macrobrachium handschini*	8	1.5	9.6	0.073	No impact
	Macrobrachium lorentzi	8	12.6	41.3	0.082	No impact
(green)	No impact = significantly > TV OR not significantly different from TV					
(orange)	Potential impact = significantly < TV					

Table 8-3 Impact assessment – Median fish abundance at lower river test sites during 2016 against LwRivs TVs

Test Site				TV (2016 Mean)	Two-Sample T-Test	
Site	**Species**	**N**	**Mean (2016)**		**p (p=0.05)**	**Impact Assessment**
Bebelubi	*Potamosilurus latirostris*	8	0.75	3.4	0.161	No impact
	Potamosilurus macrorhynchus	8	0.25	0.25	1.000	No impact
SG4	*Potamosilurus latirostris*	8	1.5	10.4	0.086	No impact
	Potamosilurus macrorhynchus	8	5.9	4.8	0.718	No impact
	No impact = significantly > TV OR not significantly different from TV					
	Potential impact = significantly < TV					

Table 8-4 Impact assessment – Median prawn abundance at lower river test sites during 2016 against LwRivs TVs

Test Site				TV (2016 Mean)	Two-Sample T-Test	
Site	**Species**	**N**	**Mean (2016)**		**p (p=0.05)**	**Impact Assessment**
Bebelubi	*Macrobrachium rosenbergii*	8	6.6	8.5	0.793	No impact
SG4	*Macrobrachium rosenbergii*	8	5.3	7.4	0.724	No impact
	No impact = significantly > TV OR not significantly different from TV					
	Potential impact = significantly < TV					

8.1.2 Lake Murray

Monitoring of fish and prawn populations at Lake Murray has not been conducted since 2009 due to a lack of community support for the monitoring program. As a consequence, there are no recent data available for conducting an impact assessment at Lake Murray.

8.2 Macroinvertebrate Populations

Macroinvertebrate monitoring is conducted on an annual campaign basis, by an expert consultant over a two-week period, the 2016 campaign was conducted in July 2016. Indices selected to describe the condition of macroinvertebrate populations are: total species richness (*S*); number of sensitive species of Ephemeroptera and Trichopteran (EPT species richness); the sum of scores assigned to each taxon based on their tolerance/sensitivity to pollution, weighted by abundance (SIGNAL 2 score); and a multivariate measure of percent similarity in assemblage composition between test and reference sites (Bray-Curtis similarity). A "weight of evidence" approach is used to assign a score to each of the indices and thereby establish an overall impact grade for each monitoring site.

The results of the 2016 sampling program are shown in Table 8-5. The results show the overall impact at Kogai Creek was high, indicating that macroinvertebrate populations at these sites were significantly less (worse condition) than the trigger values for each index derived from the reference conditions at the time of sampling. The Kogai sampling point is located on the mine site, within the SML boundary, immediately downstream of the Kogai competent waste rock dump. Water quality at this site is influenced by discharge from the competent dump, which is the driver for reduced macroinvertebrate populations at this site.

The impact grade at SG2 was low, indicating that three of the four indices were comparable to the reference site condition at the time of sampling, with only one index significantly poorer than the reference condition.

The overall impact grade at Wasiba, Wankipe and Ambi (upstream of SG3) was medium, with three of the four indices of macroinvertebrate populations at these sites in worse condition compared to reference conditions at the time of sampling.

Table 8-5 Results of 2016 macroinvertebrate sampling showing weight of evidence scores and overall impact grade for each monitoring site

Site	Indices	2016 TV	2016 Mean	Impact	Score	Total Score	Overall Impact Grade 2016
Kogai	*S*	13	6	Sign Adverse	3	12	High Impact
	EPT	5	1	Sign Adverse	3		
	SIGNAL 2	76	31	Sign Adverse	3		
	%Similarity	40	14	Sign Adverse	3		
SG2	*S*	25	17	Sign Adverse	3	3	Low Impact
	EPT	8	10	No Adverse	0		
	SIGNAL 2	152	135	No Adverse	0		
	%Similarity	49	51	No Adverse	0		
Wasiba	*S*	25	14	Sign Adverse	3	9	Medium Impact
	EPT	8	9	No Adverse	0		
	SIGNAL 2	152	84	Sign Adverse	3		
	%Similarity	49	40	Sign Adverse	3		
Wankipe	*S*	25	18	Sign Adverse	3	9	Medium Impact
	EPT	8	10	No Adverse	0		
	SIGNAL 2	152	98	Sign Adverse	3		
	%Similarity	49	42	Sign Adverse	3		
Ambi (SG3)	*S*	25	16	Sign Adverse	3	9	Medium Impact
	EPT	8	9	No Adverse	0		
	SIGNAL 2	152	99	Sign Adverse	3		
	%Similarity	49	35	Sign Adverse	3		

A comparison of overall impact grades between the 2015 and 2016 macroinvertebrate campaigns is presented in Table 8-6. The results show an increase in impact grade at SG2 from no impact to low impact, and at Wasiba from no impact in 2015 to medium impact in 2016, while the impact levels at all other sites remained unchanged from 2015 to 2016.

Table 8-6 Comparison of results from macroinvertebrate sampling in 2015 and 2016

Site	2015 Total Score	2015 Overall Impact Grade	2016 Total Score	2016 Overall Impact Grade
Kogai	12	High	12	High
SG2	0	No	3	Low
Wasiba	0	No	9	Medium
Wankipe	6	Medium	9	Medium
Ambi (SG3)	9	Medium	9	Medium

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, which is certified to ISO 14001 and has the objectives of consistently and effectively achieving compliance with legal obligations, mitigating risk and continually improving performance.

The PJV environmental monitoring program provides data upon which the operation can assess the effectiveness of the EMS for achieving the stated objectives. The monitoring program has continually evolved over the years with improvements to scientific knowledge and environmental management practices. The 2016 Annual Environment Report continues this tradition by incorporating historical and newly acquired data, information and knowledge within the AER framework.

The purpose of the framework is to assess compliance, risk, impact and performance of the operations environmental aspects. The assessment is based on the comparison of environmental indicators at discharge points within the mine site and potentially impacted (test) sites within the receiving environment downstream of the mine against: compliance limits dictated by the sites environmental permits; trigger values which 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.

Notable changes to the operational and environmental aspects of the mine between 2016 and previous years were related to the record annual rainfall experienced at the site during 2016 and changes to the mineralogy of the ore body. Higher rainfall generated higher rates of rainfall runoff from the site and also resulted in higher volumes of sediment discharged from the site, predominantly from the erodible dumps via increased river flow and erosion. Changes to the mineralogy of the ore body resulted in historically high concentrations of dissolved and particulate zinc and cadmium in tailings discharge. All other operational and environmental aspects of the mine were comparable to previous years.

The site achieved compliance with an average of 99% of the conditions of the environmental permits. Non-compliance related to short duration events where TSS concentrations exceeded the permit limit in discharge from four (4) of the five (5) sewage treatment plants. Water quality at compliance point SG3 on the Strickland River was compliant with all permit requirements throughout 2016.

Background environmental conditions in 2016 were characterised by above average rainfall totals at the mine site and at all other monitoring sites within the receiving environment. The open pit rainfall site recorded the highest ever annual total since monitoring began in 1987. Given that inputs from the mine are relatively consistent from year to year, particularly in recent history, the behavior 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. Higher than average rainfall results in higher natural flows and sediment loads, which provide greater dilution of mine inputs.

Baseline water quality in the upper and lower rivers and in Lake Murray indicated 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 are being contributed from catchments that are not influenced by the PJV mine within the upper and lower rivers and northern Lake Murray.

Similar to water, 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 nickel in benthic sediment is being contributed to the system from the upper river reference sites and low concentrations of all other metals are 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 abdomen in the upper and lower rivers exhibit detectable concentrations of some metals.

Environmental risk assessment was performed by developing 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 concentrations of the same physical and chemical parameters in discharges from the mine and at test sites within the receiving environment that are potentially influenced by mine discharges. Where the concentration of the physical and 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 occurring. It should be noted that the 2016 assessment applies to sites downstream of SG1 on the Porgera River, monitoring was not conducted at SG1 during 2016 due to security concerns, therefore the assessment could not be performed at this location.

The results of the risk assessment show that high rainfall and subsequently high natural river flows during 2016, increased the moderating influence of river flows and natural sediment loads on the operations environmental aspects within the receiving aquatic ecosystem.

High rainfall resulted in sufficient water supply from Waile Creek Dam 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 and Kogai Creeks. This is supported by the results of the macroinvertebrate ecological impact assessment (WRM 2016), which showed there was minimal detectable difference between areas upstream and downstream of the dam.

Inputs from the mine in 2016 were generally consistent with recent years, with the exception of historically high concentrations of dissolved and particulate zinc and cadmium in the tailings discharge and an increase in sediment load from the erodible dumps to the river system, due to greater erosion as a result of higher rainfall. Consistent tailings input from the mine and higher than average natural river flows in the receiving environment resulted in greater dilution of mine inputs by water and natural sediment. This is evidenced by lower TSS concentrations at SG2 compared to previous years and a significant decrease in the proportion of mine derived TSS at SG3 compared to 2015.

TSS concentrations and pH were below the respective TVs throughout the upper rivers, lower river and at Lake Murray and ORWBs. Therefore, the overall risk posed by TSS concentrations and pH in water was considered low.

Metals discharged from the mine site can be categorized into the five forms outlined in Table 9-1, with each form behaving differently within the receiving environment depending on its physical and chemical properties. Table 9-1 provides a description of the physical and chemical behavior of each form in the receiving environment.

Table 9-1 Forms of metals in mine discharges and their behaviour within the receiving environment

Metal form in discharge	Behaviour in receiving environment
Dissolved in water	Becomes diluted or bonded to particulate matter via adsorption, and depending on particle size and bond strength will contribute to one of the particulate forms described below. Potentially bioavailable to aquatic organisms exposed to elevated dissolved concentrations of metals in the water column and in sediment pore water.
Mineralised particulate - strongly bound in coarse fraction (>63 µm)	Particulate matter includes sediment and organic matter. Settle in benthic sediment in the upper river sections of the receiving environment. Low bioavailability to aquatic organisms. Low risk of remobilisation to bioavailable forms within the receiving environment due to alkaline conditions.
Mineralised particulate - strongly bound in fine fraction (<63 µm)	Particulate matter includes sediment and organic matter. Remain suspended within the water column throughout the upper river. A proportion will settle in the lower river, Lake Murray and ORWBs where flow velocities reduce, a proportion will remain suspended. Low bioavailability to aquatic organisms. Low risk of remobilisation to bioavailable forms within the receiving environment due to alkaline conditions.
Particulate - weakly bound/adsorbed to coarse fraction (>63 µm)	Particulate matter includes sediment and organic matter. Settle in benthic sediment in the upper sections of the receiving environment. Potentially bioavailable to aquatic organisms exposed to benthic sediment at discharge points and within the upper river. Low risk of remobilisation to bioavailable forms within the receiving environment due to alkaline conditions.
Particulate - weakly bound/adsorbed to fine fraction (<63 µm)	Remain suspended within the water column throughout the upper river. A proportion will settle in the lower river, Lake Murray and ORWBs where flow velocities reduce, a proportion will remain suspended. Potentially bioavailable to aquatic organisms exposed to suspended sediment in the water column and benthic sediment throughout the entire receiving environment, although the fraction of fine sediment in benthic sediment is higher in the lower river, Lake Murray and ORWBs. Low risk of re-mobilisation to bioavailable forms within the receiving environment due to alkaline conditions.

The three main sources of dissolved metal inputs from the mine were tailings, the Anawe North competent waste rock dump and the Kogai competent waste rock dump. Tailings contained elevated dissolved cadmium, copper, nickel and zinc in water, and elevated arsenic, cadmium, copper, mercury, lead and zinc in sediment. The competent waste rock dumps exhibited elevated dissolved cadmium and zinc in water and elevated cadmium, lead and zinc in sediment.

In 2016, discharges from the mine resulted in potential risk to aquatic ecosystem health that extended between the mine site and Wasiba in the upper rivers, 96km downstream of the mine.

At SG2, 42 km downstream from the mine, concentrations of WAE lead in benthic sediment and dissolved zinc in water exceeded the respective TVs.

At Wasiba, 96kms downstream from the mine, concentrations of WAE lead and nickel in benthic sediment and cadmium, lead, selenium and zinc in prawn tissue exceeded the respective TVs.

These risk assessment results were attributable to mine-related lead in sediment discharged from tailings, waste rock and from the open pit and underground mines, and mine-related zinc in water and sediment discharged from tailings, waste rock and the open pit mine.

Downstream from Wasiba the influence of mine-related inputs was detectable, but did not result in system-wide risk.

In the lower river at Bebelubi and SG4, concentrations of dissolved zinc in water exceeded the TV, which was postulated as due to remobilisation of zinc from mine-derived and from natural particulates, and also that the risk assessment methodology contributed to the use of a conservatively low TV, which in turn resulted in the exceedance. These factors, in addition to the absence of risk posed in benthic sediment, fish tissue and prawn abdomen, indicated that the overall system-wide risk from mine-derived zinc in 2016 downstream of SG2 was low. It should be noted however, that trends of increasing concentrations of dissolved and particulate zinc in discharges from the mine, particularly in tailings, and trends of increasing concentrations of zinc in water and sediment within the receiving environment were observed. These results serve as a cautionary indication that if current trends continue, zinc has the potential to pose a risk to the receiving environment in future years, a scenario which would be exacerbated during lower rainfall years when dilution is reduced.

The influences of mine-derived inputs also were detected within Lake Murray and the ORWBs during 2016. The concentrations of dissolved zinc in water at the Central and Southern Lake and in the ORWB Avu, and the concentrations of lead in benthic sediment at the Southern Lake and in the ORWB Kukufionga exceeded the TV. However the absence of risk in benthic sediment indicated that the overall system-wide risk posed by lead and zinc discharged from the mine in 2016 at Lake Murray and the ORWBs was low.

Additionally, concentrations of arsenic in prawn abdomen at Bebelubi and SG4, concentrations of cadmium in prawn abdomen at Wasiba, Wankipe and SG4, and concentrations of selenium in prawn abdomen at Wasiba, Wankipe, Bebelubi and SG4 exceeded their respective TVs. Arsenic, cadmium and selenium were present in discharges from the mine, however, risk was not indicated by these metals in water or sediment throughout the receiving environment. Therefore while the system-wide risk posed by these metals in discharge from the mine is considered low, elevated concentrations in prawn abdomen indicates the potential for an alternative exposure pathway of arsenic to prawns in the lower river.

Overall, the risk assessment showed that in 2016, as a result of uniform inputs from the mine, consistent application of environmental controls for detoxifying and treating discharges, and dilution by high natural river flows and sediment loads, that risk to aquatic ecosystems downstream of Wasiba was low.

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 within the receiving environment.

Risk assessment showed that the discharges from the mine do not pose a risk to drinking water sources for villages within the SML and LMPs. Risk is posed to people who trespass on the mine lease and are exposed to low pH and elevated concentrations of dissolved nickel and zinc in the undiluted tailings slurry through dermal contact when panning for gold at the tailings discharge. Fish and prawns at Wasiba and Wankipe in the upper river, and Bebelubi and SG4 in the lower river are fit for human consumption.

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

A summary of potential environmental risks and associated environmental aspects is presented in Table 9-2.

Table 9-2 Summary of potential environmental risks

Risk Category	Risk Rating	Associated Environmental Aspect
Hydrology and environmental flows	Low risk	NA
Sediment aggradation and erosion	Low risk	NA
Aquatic ecosystems	Potential risk – within receiving aquatic environment between the mine and Wasiba (approx. 96km downstream of the mine)	Tailings discharge: - Elevated dissolved zinc in slurry - Elevated WAE lead in solids Contact runoff: - Elevated dissolved zinc in water from Kogai and Anawe Nth competent waste rock dumps. - Elevated WAE lead in sediment from 28 level, SDA Toe, Kogai Dump Toe, Wendoko Crk D/S Anawe Nth Dump, Yakatabari D/S 28 level and Yarik Portal.
	Low risk – within the receiving aquatic environment downstream of Wasiba	NA
Local water supplies	Low risk	NA

Risk Category	Risk Rating	Associated Environmental Aspect
Water-based activities	Potential risk – limited to undiluted tailings at discharge point within SML.	Tailings discharge : - Low pH - Elevated dissolved nickel and zinc.
Fish and prawn consumption	Low risk	NA
Air quality	Potential risk – limited to within SML and LMPs.	Stand-by power generation Anawe: - Elevated NO_x emissions from Anawe generator. Lime production: - Elevated particulate matter emissions from lime kiln.

The impact assessment was performed by comparing biological indicators of aquatic ecosystem health between test sites and reference sites to determine whether potential risks were resulting in actual environmental impact. Biological indicators applied in the upper rivers were abundance of indicator fish and prawns species and indices of macroinvertebrate populations, and in the lower rivers abundance of indicator fish and prawn species was applied.

Fish and prawn abundance is defined as the number of individual organisms of each indicator species measured at each site during a sampling day. Sampling was performed by PJV on a quarterly basis throughout the upper and lower rivers. The results showed that the abundance of indicator fish and prawn species at test sites within the upper and lower rivers was not significantly different from the respective TVs derived from the reference sites, indicating no impact on fish and prawn abundance within the upper and lower rivers during 2016. It should be noted however, that the use of abundance as the sole indicator of fish and prawn populations limits the assessment to this aspect of the respective populations. PJV continues to investigate additional impact assessment methods for fish and prawn populations.

Macroinvertebrate monitoring is conducted on an annual campaign basis by an expert consultant over a two-week period. The 2016 campaign was conducted in July 2016. Indicators selected to describe the condition of macroinvertebrate populations were: total species richness (*S*); EPT species richness; SIGNAL 2 score, and multivariate Bray-Curtis similarity. The results of the 2016 campaign showed moderate impact between the site and SG3, except at SG2 where the impact rating was low. The results also showed that the level of impact at SG2 increased from a rating of no impact in 2015 to low impact in 2016, and impact at Wasiba increased from no impact to medium impact. The ratings at Kogai, within the SML boundary, and at Wankipe and SG3 in the upper rivers remained unchanged from 2015 to 2016.

The environmental performance of the operation in 2016 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. A reduction in risk to the receiving environment was noted in 2016, driven by uniform inputs from the mine coupled with high dilution by natural river flows and sediment loading throughout the upper and lower rivers system associated with the historically high annual rainfall within the Porgera Valley and throughout the receiving environment. The results of the macroinvertebrate sampling indicated impact to macroinvertebrate populations between the mine and SG3 in the upper river. Overall, the condition of the receiving aquatic ecosystem remains consistent with predictions made prior to operations commencing in 1990.

10 RECOMMENDATIONS

Recommendations are proposed to improve the certainty of the findings of future reports; the assessment methodology; environmental performance; communication of the findings to the many stakeholders, and to reduce environmental risk and impact.

Note that a number of the recommendations from the 2015 AER are still in progress and appear in the list below in addition to new recommendations raised from this year's AER.

Findings and Assessment Methodology

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. Include EC as indicator parameter, develop an EC TV and include EC in the risk assessment for subsequent Annual Environment Reports.
3. Investigate suitable methods for statistical analysis of fish and prawn population data to improve confidence in the impact assessment results.
4. Reduce the frequency of macroinvertebrate monitoring to every 2 years.
5. Investigate suitable test and reference sites downstream of SG3 for performing macroinvertebrate monitoring.
6. Conduct a study to examine the speciation of dissolved copper, zinc and cadmium in the river system.

Reduce Environmental Risk and Impact and Improve Performance

7. Continue to investigate options for reducing the concentrations of bioavailable metals and mass loads of metals in mine discharges;
8. Continue to implement the Waste Rock Management Plan to minimise the release of metalliferous drainage from the competent waste rock dumps.

Communication and Engagement

9. Continue to develop and apply a communication plan to the AER each year, including a presentation to the PNG Conservation and Environmental Protection Authority (CEPA) and a Report Card on the river system.

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APPENDIX A. QA&QC

Collection of environmental monitoring data is performed by the PJV Environment Department. The team consists of 23 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 2016 was performed by ALS in Brisbane, ALS 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 ±50% aligns with the criteria applied by ALS 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-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)	±50% of primary sample
ALS lab duplicate	Test repeatability of laboratory analytical method.	1 blank per sample batch	±50% of primary sample
ALS lab control sample	Test influence of sample preparation and analysis on recovery.	1 blank per sample batch	80% – 120% recovery
ALS matrix spike	Test influence of sample preparation and analysis on recovery.	1 blank per sample batch	70% – 130% recovery

The results of QA&QC samples from water quality sampling at SG3 in 2016 are shown in Table A-2 and indicate good performance for all of QA&QC samples across the all parameters.

Table A-2 2016 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**	**WAD-CN**
Combined Blank	100	100	100	100	100	100	100	100	100	100	100	100
CRM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	100
Field Duplicate	100	100	100	100	100	100	100	100	100	100	100	100
ALS Duplicate	100	100	100	100	100	100	100	100	100	100	NA	NA
ALS Lab Control Sample	100	100	100	100	100	100	100	100	100	100	NA	NA
ALS Matrix Spike	100	100	100	100	100	100	100	100	100	100	NA	NA

D = Dissolved fraction

The results of QA&QC samples from sediment quality sampling at SG3 in 2016 are shown in Table A-3 and indicate good performance of all samples for all parameters.

Table A-3 2016 Sediment quality QA&QC sample results SG3

	% Within Acceptable Criteria									
Sample Type	**Ag - WAE**	**As - WAE**	**Cd - WAE**	**Cr - WAE**	**Cu - WAE**	**Hg - WAE**	**Ni - WAE**	**Pb - WAE**	**Se - WAE**	**Zn - WAE**
Field Duplicate	100	100	100	100	100	100	100	100	100	100
ALS Duplicate	100	100	100	100	100	100	100	100	100	100
ALS Matrix Spike	100	100	100	100	100	100	100	100	100	100
ALS Blank	100	100	100	100	100	100	100	100	100	100
ALS LCS	100	100	100	100	100	100	100	100	100	100

WAE = Weak-Acid Extractable

In addition to the routine QA&QC samples, PJV also participated in six proficiency test rounds in 2016 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 38% 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 2016

Date	**Analyte**	**Units**	**Lab result**	**MU**	**Median**	**NORM IQR**	**CV (%)**	**n**	**z-score**
Mar 2016	Total Solids	mg/L	619	40	607.5	25.9	4.3	30	0.44
	Total Solids	mg/L	262	40	266.5	20.4	7.6	30	-0.22
	Total Suspended Solids	mg/L	209	15	208	15.6	7.5	42	0.66
	Total Suspended Solids	mg/L	119	15	100	15.5	15.5	43	1.23
	Sulfate	mg/L	41	5	33.65	1.09	3.2	46	6.72
	Sulfate	mg/L	54.3	5	43.2	2.21	5.1	46	5.03
	Conductivity	µS/cm	240	5	252	5.6	2.2	71	-2.16
	Conductivity	µS/cm	374	5	384	8.7	2.3	71	-1.14
	pH - potable	pH units	6.91	0.2	7.3	0.119	1.6	75	-3.29
	pH - potable	pH units	7.58	0.2	7.9	0.159	2	75	-2.01
	Turbidity standard	NTU	3.15	5	3.2	0.267	8.3	45	-0.30
	pH standard	pH units	7.01	0.2	6.97	0.044	0.6	74	0.90
	Colour standard	Pt/Co	18	5	15.5	3.0	19.1	37	0.84

Date	Analyte	Units	Lab result	MU	Median	NORM IQR	CV (%)	n	z-score
Apr 2016	Alkalinity	mg/L	144	NA	154	5.9	3.9	45	-1.69
	Chloride	mg/L	40.2	NA	36.1	1.09	3.0	48	3.75
	Conductivity	µS/cm	432	NA	440.5	8.5	1.9	50	-0.76
	Sulfate	mg/L	13	NA	17.1	0.67	3.9	46	-6.15
	Total Solids	mg/L	497	NA	453	38.5	8.5	33	1.14
Oct 2016	Chloride	mg/L	71.4	NA	60.6	1.93	3.2	25	5.6
Nov 2016	Sulfate	mg/L	28.5	NA	35.85	1.91	5.3	34	-3.85
	Sulfate	mg/L	13	NA	18.15	1.41	7.8	34	-3.66
	Conductivity	µS/cm	262	NA	289	7.4	2.6	44	-3.64
	Conductivity	µS/cm	321	NA	307	6.7	2.2	44	2.10
	pH - potable	pH units	6.55	NA	6.99	0.061	0.9	48	-7.11
	pH - potable	pH units	7.38	NA	7.84	0.069	0.9	48	-6.11
	pH - standard	pH units	7.12	NA	7.15	0.054	0.8	48	-0.56
	Turbidity standard	NTU	1.03	NA	1.07	0.113	10.6	31	-0.35
	Colour standard	Pt/Co	11	NA	13	2.2	17.1	25	-0.9
Dec 2016	Total Solids	mg/L	310	40	273.7	11.6	4.2	28	3.13
	Total Solids	mg/L	335	40	368.5	15.4	4.0	28	-3.35
	Total Suspended Solids	mg/L	60	15	72	3.56	4.9	41	-3.37
	Total Suspended Solids	mg/L	58.8	15	87	7.41	8.5	41	-3.80
(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 Metal

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 2016 are shown in Table A-6 and indicate good performance for the majority of QA&QC samples across the majority of parameters. The exceptions are the performance of arsenic, chromium and copper in the field duplicate and chromium in the field reference 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 2016 Tissue metal QA&QC sample results

	% Within Acceptable Criteria									
	n	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Field Duplicate	28	86	96	79	75	96	93	100	93	96
Field Reference Sample	30	93	100	50	97	100	97	100	97	100
NMI Blank	4	100	100	100	100	100	100	100	100	100
NMI Duplicate	12	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	12	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 2016.

APPENDIX B.   BOX PLOTS EXPLAINED

In a box plot, shown in Figure B-1, the centre horizontal line within the box marks the median value of the sample. The length of the box shows the range within which the central 50% of the values fall, with the box edges (called hinges) at the first and third quartiles (Q1 and Q3).

To describe the information contained in a box plot, a few terms must first be defined. **H-spread** is the inter-quartile range or mid-range (Q3-Q1). **Fences** define outside and far outside values and are defined as follows:

Lower inner fence	=	Q1 - (1.5 x H-spread)
Upper inner fence	=	Q3 + (1.5 x H-spread)
Lower outer fence	=	Q1 - (3 x H-spread)
Upper outer fence	=	Q3 + (3 x H-spread)

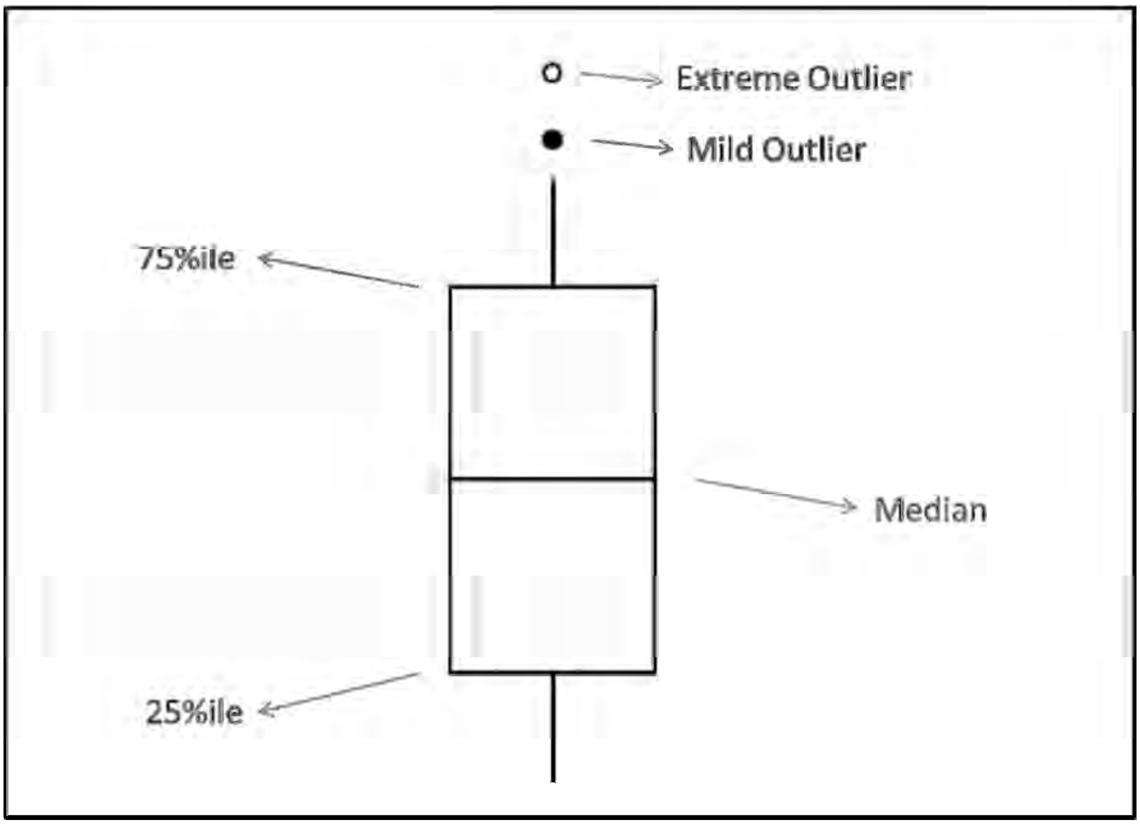

Figure B-1 Box Plot

The whiskers show the range of observed values that fall within the inner fences. In other words, they show the range of values that fall within 1.5 H-spreads of the hinges. Because the whiskers extend to observed values and the fences need not correspond to observed values, the whiskers do not necessarily extend all the way to the inner fences. Values between the inner and outer fences (mild outliers) are plotted with asterisks. Values beyond the outer fences, called extreme outliers, are plotted with empty circles.

APPENDIX C. BOX PLOTS AND TRENDS OF MINE AREA RUNOFF WATER QUALITY 2007–2016

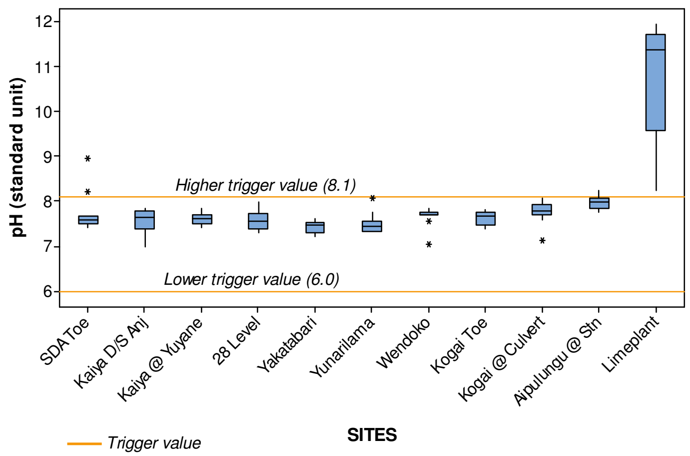

Figure C-1 pH in mine contact runoff 2016

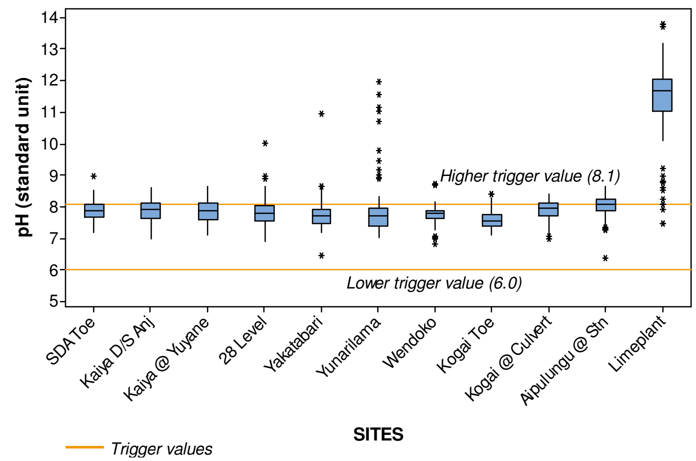

Figure C-2 pH in mine contact runoff 2007-2016

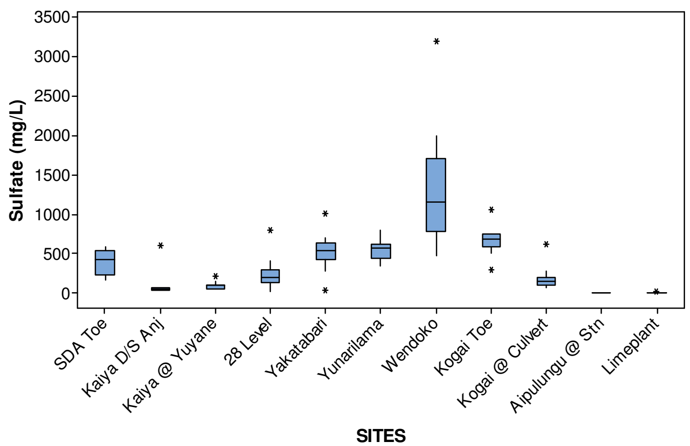

Figure C-3 Sulfate in mine contact runoff 2016

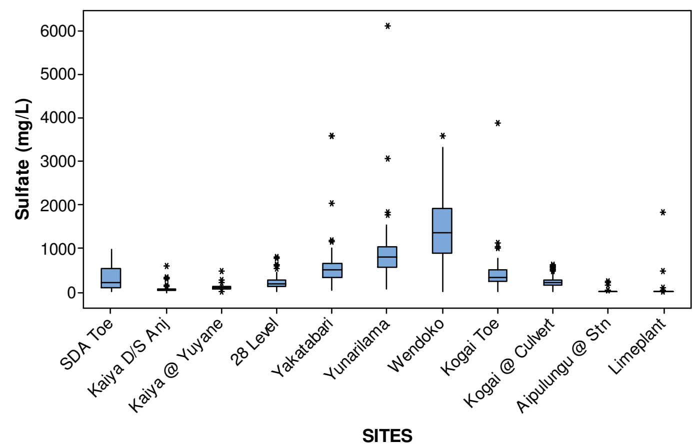

Figure C-4 Sulfate in mine contact runoff 2007-2016

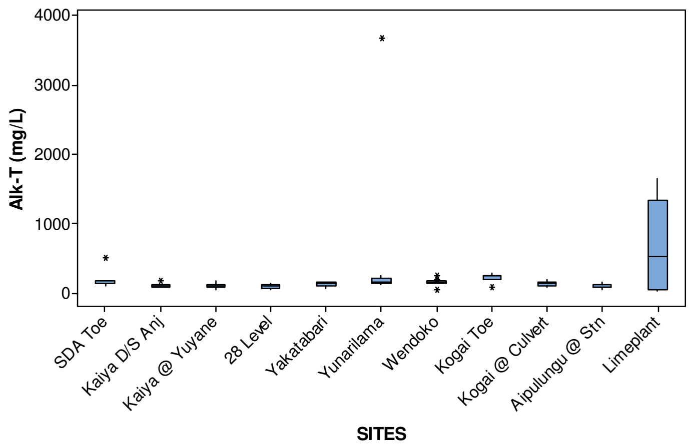

Figure C-5 Alkalinity of contact runoff 2016

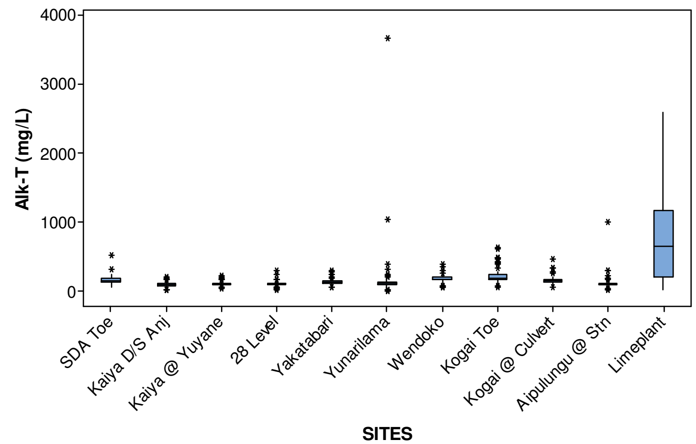

Figure C-6 Alkalinity of contact runoff 2007-2016

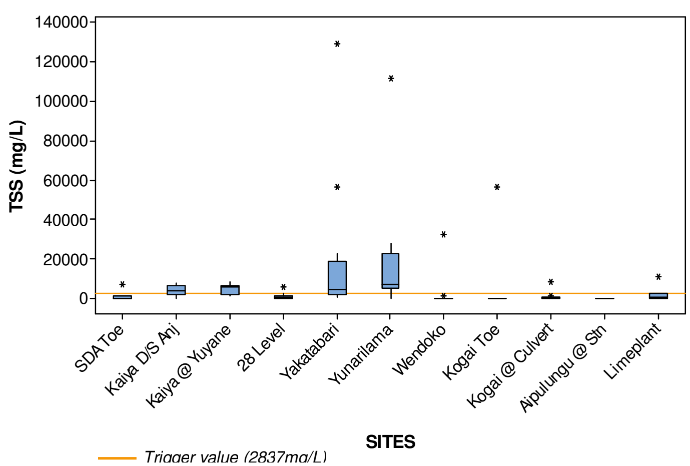

Figure C-7 TSS in contact runoff 2016

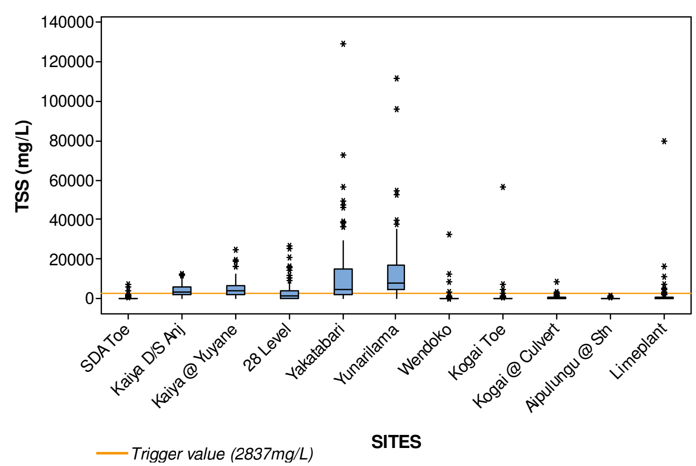

Figure C-8 TSS in contact runoff 2007-2016

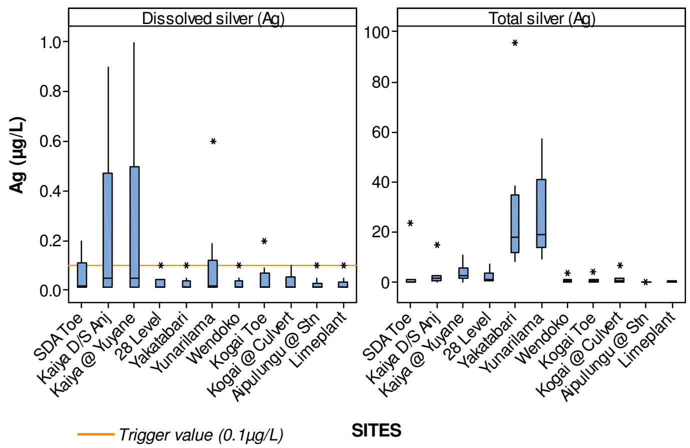

Figure C-9 Dissolved and total silver in contact runoff 2016

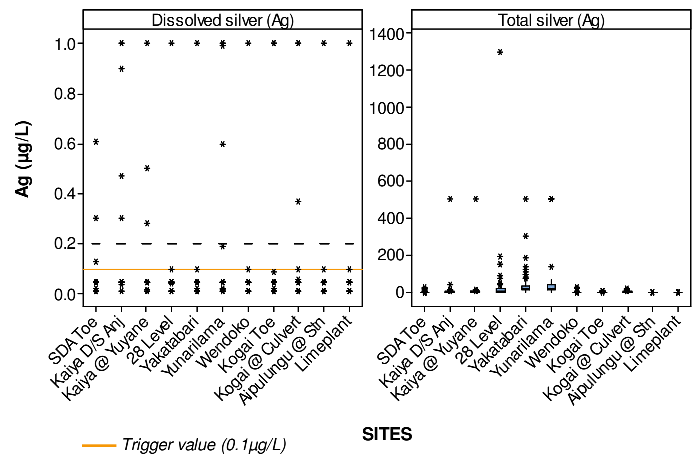

Figure C-10 Dissolved and total silver in contact runoff 20072016

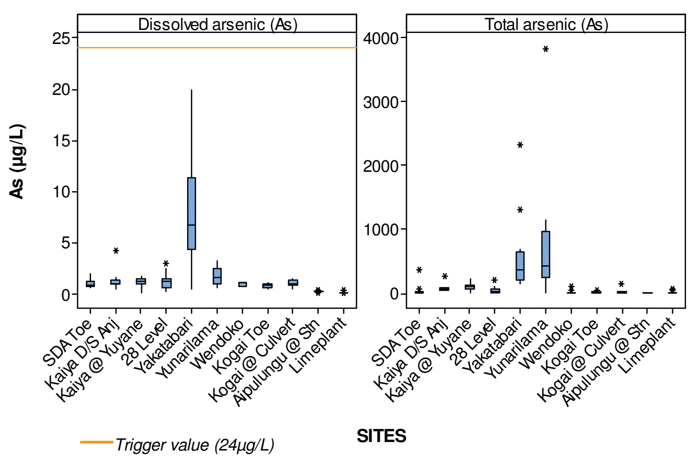

Figure C-11 Dissolved and total arsenic in contact runoff 2016

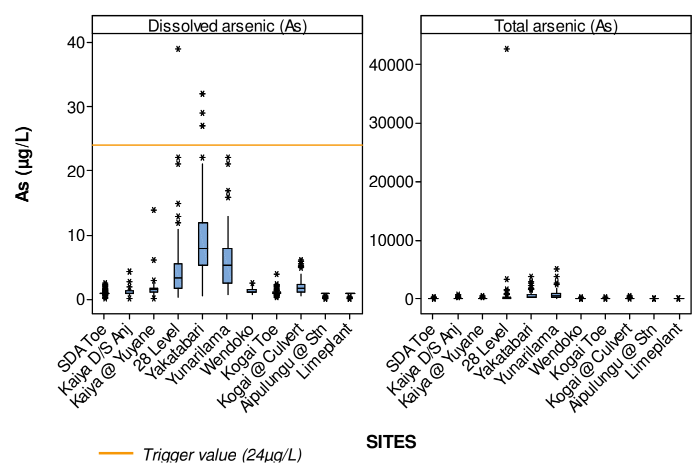

Figure C-12 Dissolved and total arsenic in contact runoff 2007-2016

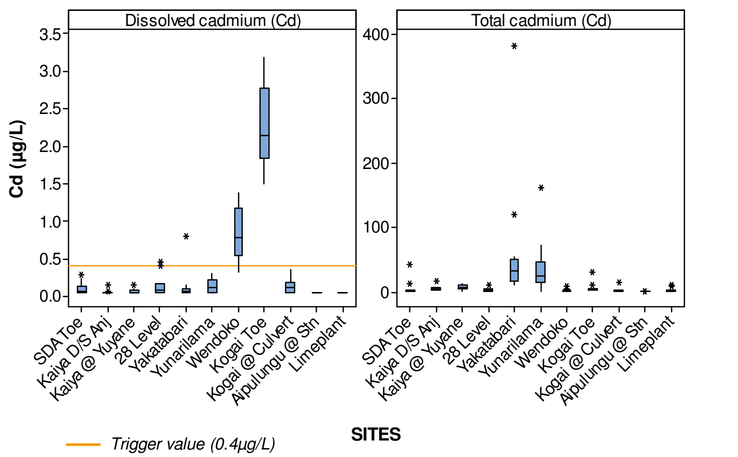

Figure C-13 Dissolved and total cadmium in contact runoff 2016

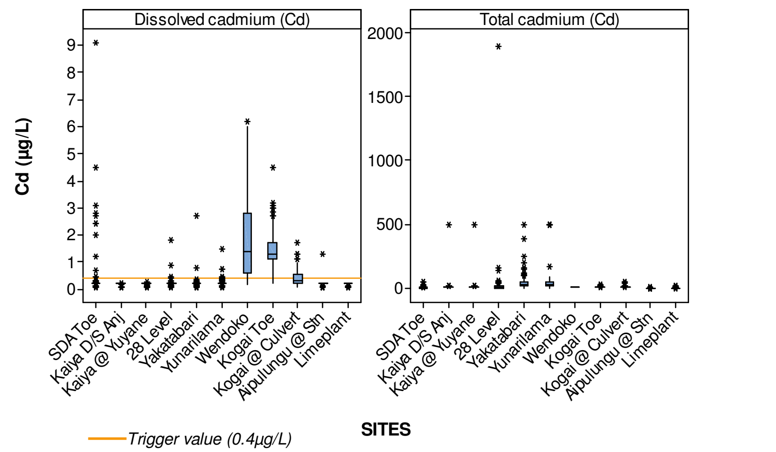

Figure C-14 Dissolved and total cadmium contact runoff 2007-2016

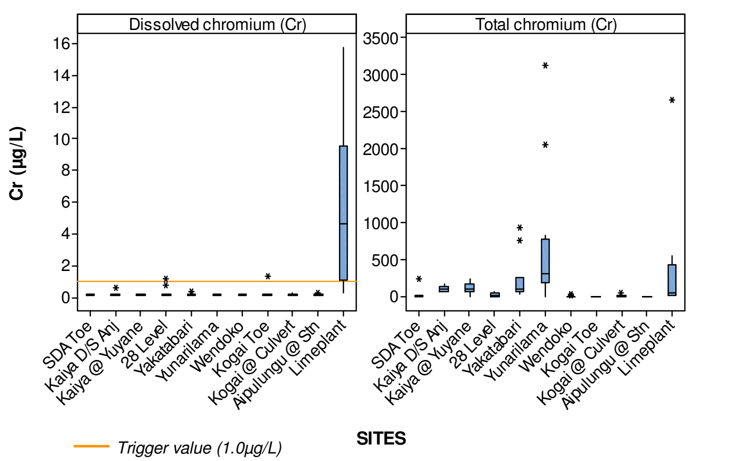

Figure C-15 Dissolved and total chromium in contact runoff 2016

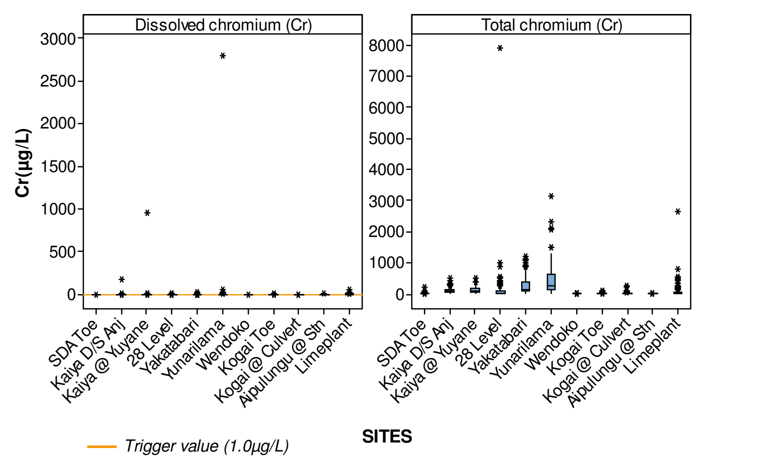

Figure C-16 Dissolved and total chromium in contact runoff 2007-2016

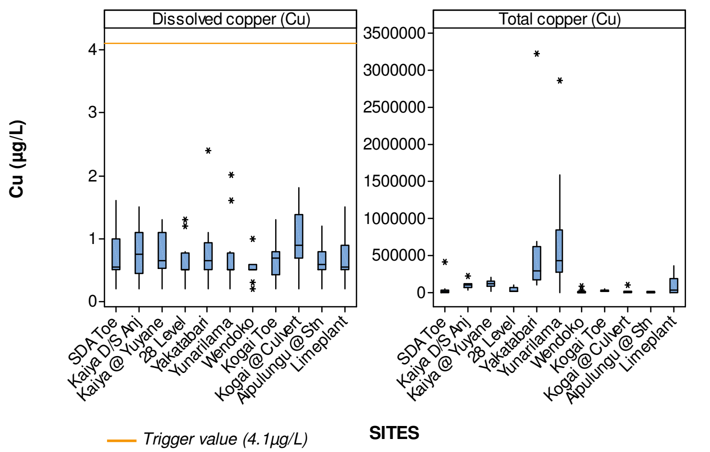

Figure C-17 Dissolved and total copper in contact runoff 2016

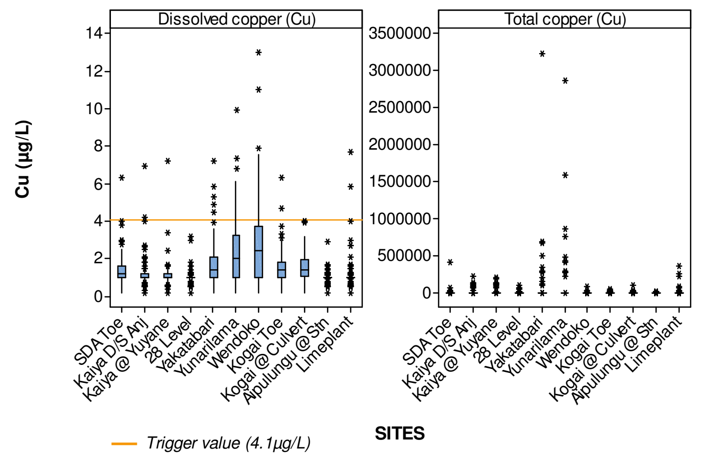

Figure C-18 Dissolved and total copper contact runoff 2007-2016

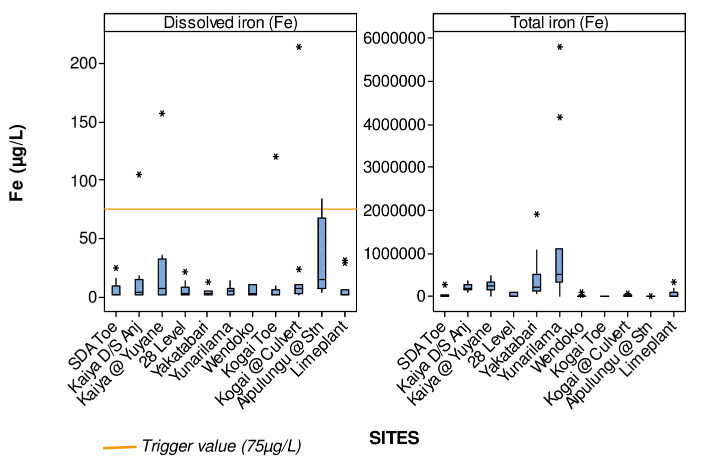

Figure C-19 Dissolved and total iron in contact runoff 2016

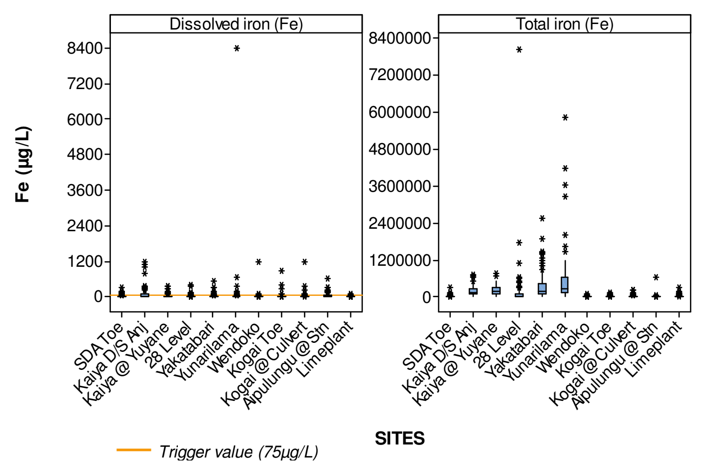

Figure C-20 Dissolved and total iron in contact runoff 2007-2016

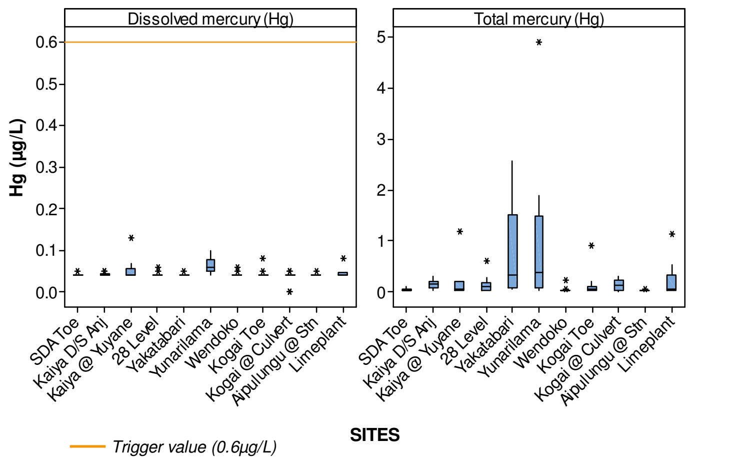

Figure C-21 Dissolved and total mercury in contact runoff 2016

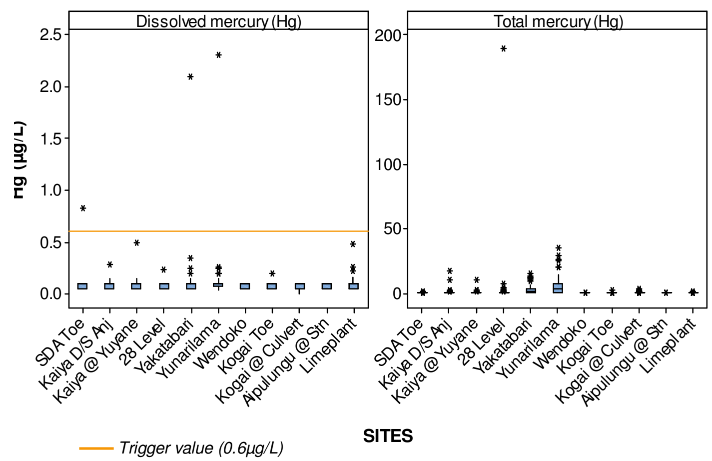

Figure C-22 Dissolved and total mercury in contact runoff 2007-2016

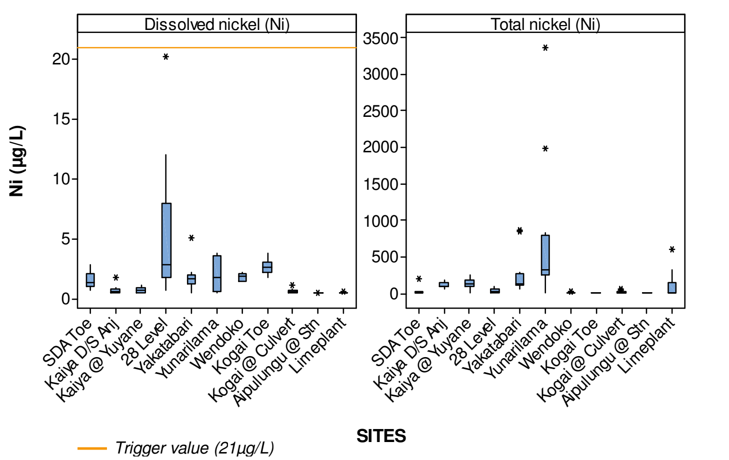

Figure C-23 Dissolved and total nickel in contact runoff 2016

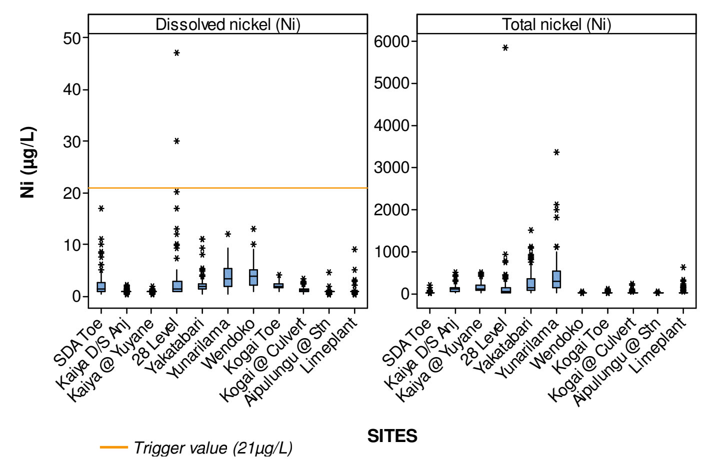

Figure C-23 Dissolved and total nickel in contact runoff 2007-2016

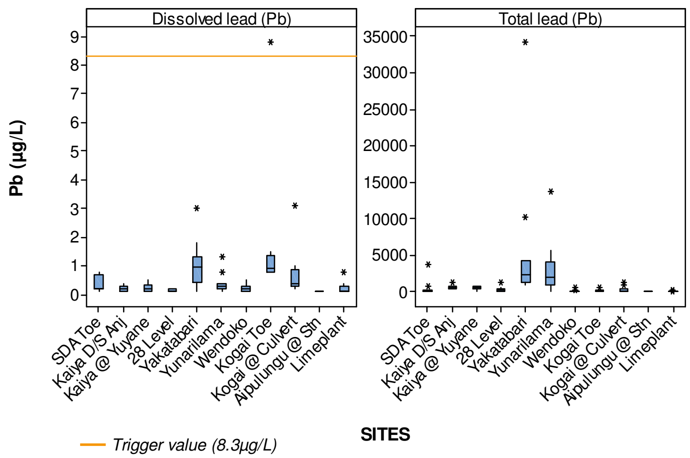

Figure C-24 Dissolved and total lead in contact runoff 2016

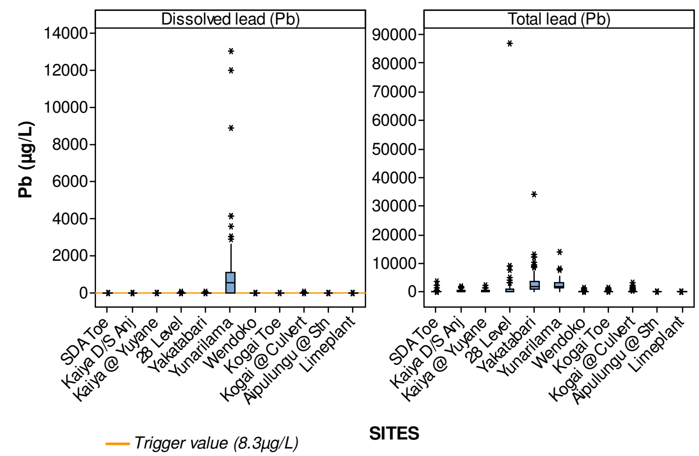

Figure C-25 Dissolved and total lead contact runoff 2007-2016

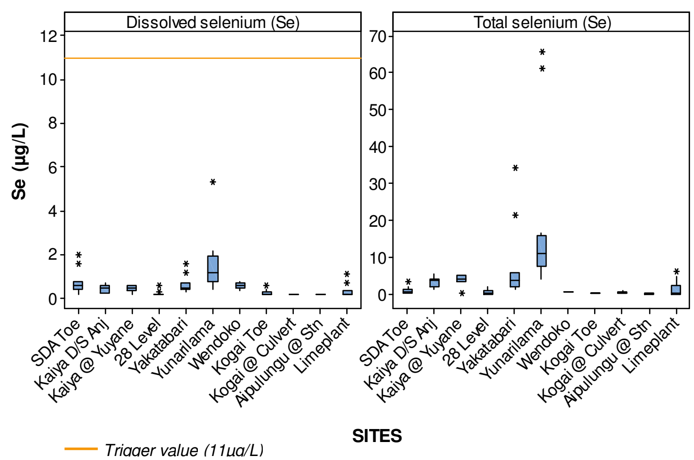

Figure C-25 Dissolved and total selenium in contact runoff 2016

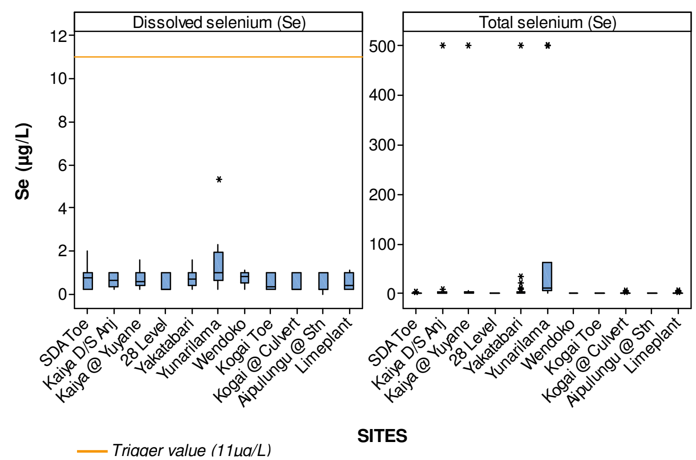

Figure C-26 Dissolved and total selenium in contact runoff 2007-2016

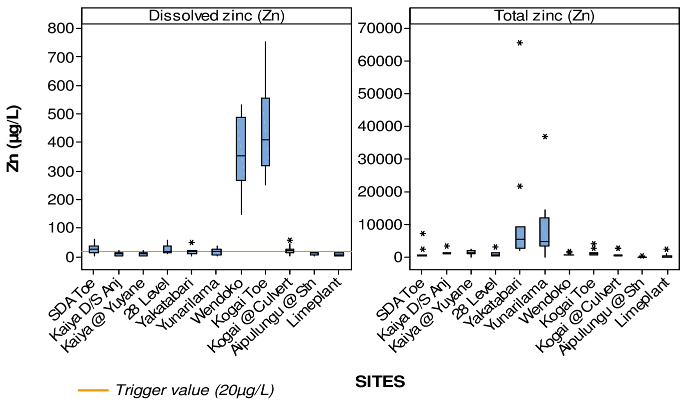

Figure C-27 Dissolved and total zinc in contact runoff 2016

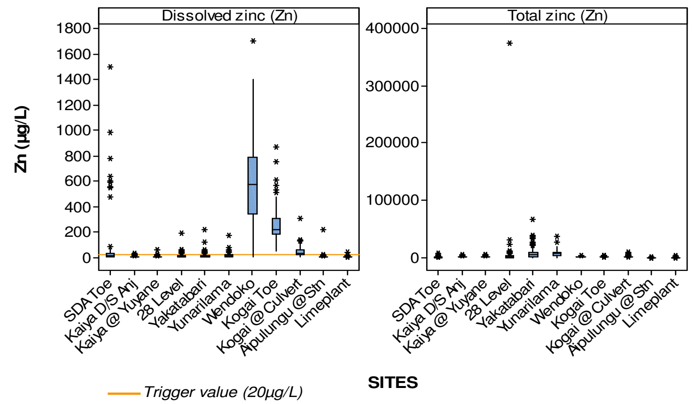

Figure C-28 Dissolved and total zinc in contact runoff 2007-2016

Table C-1 SDA Toe 2007 - 2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.240	0.011	Reduced
SO4-D	-0.487	<0.001	Reduced
Alk-T	-0.217	0.023	Reduced
TSS	0.277	0.003	Increased
Ag-D	-0.616	<0.001	Reduced
Ag-T	-0.050	0.609	No change
As-D	-0.398	<0.001	Reduced
As-T	0.135	0.161	No change
Cd-D	-0.525	<0.001	Reduced
Cd-T	-0.076	0.428	No change
Cr-D	-0.818	<0.001	Reduced
Cr-T	0.234	0.014	Increased
Cu-D	-0.587	<0.001	Reduced
Cu-T	0.208	0.029	Increased
Fe-D	0.062	0.520	No change
Fe-T	0.254	0.008	Increased
Hg-D	-0.760	<0.001	Reduced
Hg-T	-0.559	<0.001	Reduced
Ni-D	-0.559	<0.001	Reduced
Ni-T	0.002	0.984	No change
Pb-D	-0.095	0.326	No change
Pb-T	0.192	0.045	Increased
Se-D	-0.432	0.005	Reduced
Se-T	-0.219	0.169	No change
Zn-D	-0.161	0.095	No change
Zn-T	-0.090	0.348	No change

LOR = Analytical 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 C-2 Kaiya D/S Anjolek 2007 - 2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.490	<0.001	Reduced
SO4-D	0.022	0.825	No change
Alk-T	0.321	0.001	Increased
TSS	0.096	0.323	No change
Ag-D	-0.414	<0.001	Reduced
Ag-T	0.164	0.096	No change
As-D	-0.134	0.166	No change
As-T	0.238	0.013	Increased
Cd-D	-0.709	<0.001	Reduced
Cd-T	0.255	0.008	Increased
Cr-D	-0.712	<0.001	Reduced
Cr-T	0.284	0.003	Increased
Cu-D	-0.477	<0.001	Reduced
Cu-T	0.263	0.006	Increased
Fe-D	-0.370	<0.001	Reduced
Fe-T	0.258	0.007	Increased
Hg-D	-0.765	<0.001	Reduced
Hg-T	0.139	0.151	No change
Ni-D	-0.535	<0.001	Reduced
Ni-T	0.169	0.080	No change
Pb-D	-0.593	<0.001	Reduced
Pb-T	0.245	0.011	Increased
Se-D	-0.666	<0.001	Reduced
Se-T	0.428	0.006	Increased
Zn-D	0.016	0.867	No change
Zn-T	0.272	0.004	Increased

LOR = Analytical 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 C-3 Kaiya at Yuyan 2007-2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.570	<0.001	Reduced
SO4-D	-0.328	0.001	Reduced
Alk-T	0.078	0.422	No change
TSS	-0.109	0.266	No change
Ag-D	-0.446	<0.001	Reduced
Ag-T	0.279	0.004	Increased
As-D	-0.346	<0.001	Reduced
As-T	0.291	0.002	Increased
Cd-D	-0.712	<0.001	Reduced
Cd-T	0.345	<0.001	Increased
Cr-D	-0.787	<0.001	Reduced
Cr-T	0.125	0.201	No change
Cu-D	-0.374	<0.001	Reduced
Cu-T	0.270	0.005	Increased
Fe-D	-0.159	0.104	No change
Fe-T	0.193	0.049	Increased
Hg-D	-0.723	<0.001	Reduced
Hg-T	0.019	0.849	No change
Ni-D	-0.308	0.001	Reduced
Ni-T	0.099	0.315	No change
Pb-D	-0.335	<0.001	Reduced
Pb-T	0.212	0.029	Increased
Se-D	-0.650	<0.001	Reduced
Se-T	0.353	0.026	Increased
Zn-D	0.179	0.068	No change
Zn-T	0.234	0.016	Increased

LOR = Analytical 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 C-4 28 Level 20072016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.262	0.006	Reduced
SO4-D	-0.126	0.202	No change
Alk-T	-0.133	0.173	No change
TSS	-0.397	<0.001	Reduced
Ag-D	-0.690	<0.001	Reduced
Ag-T	-0.483	<0.001	Reduced
As-D	-0.724	<0.001	Reduced
As-T	-0.504	<0.001	Reduced
Cd-D	-0.425	<0.001	Reduced
Cd-T	-0.396	<0.001	Reduced
Cr-D	-0.778	<0.001	Reduced
Cr-T	-0.418	<0.001	Reduced
Cu-D	-0.585	<0.001	Reduced
Cu-T	-0.014	0.888	No change
Fe-D	-0.196	0.042	Reduced
Fe-T	-0.380	<0.001	Reduced
Hg-D	-0.813	<0.001	Reduced
Hg-T	-0.471	<0.001	Reduced
Ni-D	0.320	0.001	Increased
Ni-T	-0.348	<0.001	Reduced
Pb-D	-0.600	<0.001	Reduced
Pb-T	-0.431	<0.001	Reduced
Se-D	-0.797	<0.001	Reduced
Se-T	-0.391	0.008	Reduced
Zn-D	0.282	0.003	Increased
Zn-T	-0.366	<0.001	Reduced

LOR = Analytical 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 C-5 Yakatabari 2007-2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.392	<0.001	Reduced
SO4-D	-0.132	0.169	No change
Alk-T	-0.075	0.434	No change
TSS	-0.235	0.013	Reduced
Ag-D	-0.675	<0.001	Reduced
Ag-T	-0.069	0.474	No change
As-D	0.098	0.303	No change
As-T	-0.157	0.097	No change
Cd-D	-0.552	<0.001	Reduced
Cd-T	0.077	0.419	No change
Cr-D	-0.332	<0.001	Reduced
Cr-T	0.008	0.931	No change
Cu-D	-0.490	<0.001	Reduced
Cu-T	0.259	0.006	Increased
Fe-D	-0.016	0.867	No change
Fe-T	-0.105	0.269	No change
Hg-D	-0.770	<0.001	Reduced
Hg-T	-0.097	0.306	No change
Ni-D	-0.123	0.193	No change
Ni-T	-0.074	0.438	No change
Pb-D	0.241	0.010	Increased
Pb-T	0.011	0.909	No change
Se-D	-0.470	0.001	Reduced
Se-T	0.397	0.007	Increased
Zn-D	0.218	0.021	Increased
Zn-T	0.008	0.930	No change

LOR = Analytical 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 C-6 Yunarilama 2007-2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.522		Reduced
SO4-D	-0.358		Reduced
Alk-T	0.550		Increased
TSS	-0.014		No change
Ag-D	-0.625	<0.001	Reduced
Ag-T	0.368	<0.001	Increased
As-D	-0.625	<0.001	Reduced
As-T	0.075	0.485	No change
Cd-D	-0.372	<0.001	Reduced
Cd-T	0.268	0.011	Increased
Cr-D	-0.779	<0.001	Reduced
Cr-T	0.478	<0.001	Increased
Cu-D	-0.635	<0.001	Reduced
Cu-T	0.568	<0.001	Increased
Fe-D	-0.231	0.029	Reduced
Fe-T	0.448	<0.001	Increased
Hg-D	-0.593	<0.001	Reduced
Hg-T	0.008	0.940	No change
Ni-D	-0.012	0.907	No change
Ni-T	0.476	<0.001	Increased
Pb-D	-0.751	<0.001	Reduced
Pb-T	0.183	0.084	No change
Se-D	0.153	0.428	No change
Se-T	0.345	0.067	No change
Zn-D	0.140	0.192	No change
Zn-T	0.211	0.046	Increased

LOR = Analytical 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 C-7 Wendoko 2007-2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.306		Reduced
SO4-D	0.061		No change
Alk-T	-0.140		No change
TSS	0.040		No change
Ag-D	-0.663	<0.001	Reduced
Ag-T	-0.050	0.605	No change
As-D	-0.682	<0.001	Reduced
As-T	-0.043	0.656	No change
Cd-D	-0.503	<0.001	Reduced
Cd-T	-0.548	<0.001	Reduced
Cr-D	-0.777	<0.001	Reduced
Cr-T	-0.057	0.549	No change
Cu-D	-0.586	<0.001	Reduced
Cu-T	0.046	0.633	No change
Fe-D	-0.225	0.018	Reduced
Fe-T	0.107	0.265	No change
Hg-D	-0.813	<0.001	Reduced
Hg-T	-0.581	<0.001	Reduced
Ni-D	-0.465	<0.001	Reduced
Ni-T	-0.297	0.002	Reduced
Pb-D	-0.417	<0.001	Reduced
Pb-T	0.050	0.605	No change
Se-D	-0.660	<0.001	Reduced
Se-T	-0.549	<0.001	Reduced
Zn-D	-0.429	<0.001	Reduced
Zn-T	-0.428	<0.001	Reduced

LOR = Analytical 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 C-8 Kogai Toe 2007-2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	0.195	0.043	Increased
SO4-D	0.473	<0.001	Increased
Alk-T	0.447	<0.001	Increased
TSS	0.121	0.209	No change
Ag-D	-0.637	<0.001	Reduced
Ag-T	0.043	0.659	No change
As-D	-0.359	<0.001	Reduced
As-T	0.212	0.027	Increased
Cd-D	0.472	<0.001	Increased
Cd-T	0.459	<0.001	Increased
Cr-D	-0.794	<0.001	Reduced
Cr-T	0.202	0.036	Increased
Cu-D	-0.584	<0.001	Reduced
Cu-T	0.304	0.001	Increased
Fe-D	-0.278	0.003	Reduced
Fe-T	0.255	0.008	Increased
Hg-D	-0.809	<0.001	Reduced
Hg-T	-0.402	<0.001	Reduced
Ni-D	0.296	0.002	Increased
Ni-T	0.270	0.004	Increased
Pb-D	0.155	0.109	No change
Pb-T	0.213	0.026	Increased
Se-D	-0.742	<0.001	Reduced
Se-T	-0.693	<0.001	Reduced
Zn-D	0.552	<0.001	Increased
Zn-T	0.498	<0.001	Increased

LOR = Analytical 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 C-9 Kogai at Culvert 2007-2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.253	0.006	Reduced
SO4-D	-0.285	0.002	Reduced
Alk-T	-0.114	0.220	No change
TSS	0.173	0.064	No change
Ag-D	-0.668	<0.001	Reduced
Ag-T	0.137	0.146	No change
As-D	-0.389	<0.001	Reduced
As-T	-0.004	0.965	No change
Cd-D	-0.708	<0.001	Reduced
Cd-T	0.047	0.617	No change
Cr-D	-0.807	<0.001	Reduced
Cr-T	0.253	0.006	Increased
Cu-D	-0.402	<0.001	Reduced
Cu-T	0.443	<0.001	Increased
Fe-D	0.031	0.737	No change
Fe-T	0.352	<0.001	Increased
Hg-D	-0.819	<0.001	Reduced
Hg-T	0.161	0.083	No change
Ni-D	-0.601	<0.001	Reduced
Ni-T	0.211	0.023	Increased
Pb-D	-0.302	0.001	Reduced
Pb-T	0.116	0.212	No change
Se-D	-0.849	<0.001	Reduced
Se-T	-0.527	<0.001	Reduced
Zn-D	-0.652	<0.001	Reduced
Zn-T	0.109	0.244	No change

LOR = Analytical 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 C-10 Aipulungu at Station 2007-2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.386	<0.001	Reduced
SO4-D	-0.682	<0.001	Reduced
Alk-T	0.058	0.541	No change
TSS	0.021	0.825	No change
Ag-D	-0.679	<0.001	Reduced
Ag-T	-0.547	<0.001	Reduced
As-D	-0.693	<0.001	Reduced
As-T	0.016	0.864	No change
Cd-D	-0.681	<0.001	Reduced
Cd-T	-0.591	<0.001	Reduced
Cr-D	-0.798	<0.001	Reduced
Cr-T	0.015	0.876	No change
Cu-D	-0.477	<0.001	Reduced
Cu-T	0.161	0.084	No change
Fe-D	-0.196	0.035	Reduced
Fe-T	0.072	0.443	No change
Hg-D	-0.811	<0.001	Reduced
Hg-T	-0.766	<0.001	Reduced
Ni-D	-0.697	<0.001	Reduced
Ni-T	-0.026	0.781	No change
Pb-D	-0.601	<0.001	Reduced
Pb-T	0.003	0.972	No change
Se-D	-0.601	<0.001	Reduced
Se-T	-0.470	0.001	Reduced
Zn-D	0.112	0.232	No change
Zn-T	0.137	0.143	No change

LOR = Analytical 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 C-11 Lime plant 2007-2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.199	0.034	Reduced
SO4-D	-0.463	<0.001	Reduced
Alk-T	-0.072	0.445	No change
TSS	0.169	0.073	No change
Ag-D	-0.670	<0.001	Reduced
Ag-T	-0.117	0.221	No change
As-D	-0.703	<0.001	Reduced
As-T	0.180	0.054	No change
Cd-D	-0.709	<0.001	Reduced
Cd-T	0.088	0.351	No change
Cr-D	-0.062	0.507	No change
Cr-T	0.234	0.012	Increased
Cu-D	-0.518	<0.001	Reduced
Cu-T	0.380	<0.001	Increased
Fe-D	-0.412	<0.001	Reduced
Fe-T	0.282	0.002	Increased
Hg-D	-0.607	<0.001	Reduced
Hg-T	-0.356	<0.001	Reduced
Ni-D	-0.644	<0.001	Reduced
Ni-T	0.243	0.009	Increased
Pb-D	-0.392	<0.001	Reduced
Pb-T	0.342	<0.001	Increased
Se-D	-0.699	<0.001	Reduced
Se-T	-0.265	0.078	No change
Zn-D	-0.030	0.748	No change
Zn-T	0.369	<0.001	Increased

LOR = Analytical 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 C-12 Aipulungu U/S Lime plant 2007 2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.185	0.048	Reduced
SO4-D	-0.557	<0.001	Reduced
Alk-T	0.267	0.004	Increased
TSS	-0.159	0.091	No change
Ag-D	-0.655	<0.001	Reduced
Ag-T	-0.540	<0.001	Reduced
As-D	-0.697	<0.001	Reduced
As-T	-0.654	<0.001	Reduced
Cd-D	-0.706	<0.001	Reduced
Cd-T	-0.574	<0.001	Reduced
Cr-D	-0.743	<0.001	Reduced
Cr-T	-0.435	<0.001	Reduced
Cu-D	-0.676	<0.001	Reduced
Cu-T	-0.364	<0.001	Reduced
Fe-D	-0.227	0.014	Reduced
Fe-T	-0.379	<0.001	Reduced
Hg-D	-0.751	<0.001	Reduced
Hg-T	-0.727	<0.001	Reduced
Ni-D	-0.708	<0.001	Reduced
Ni-T	-0.373	<0.001	Reduced
Pb-D	-0.616	<0.001	Reduced
Pb-T	-0.375	<0.001	Reduced
Se-D	-0.861	<0.001	Reduced
Se-T	-0.801	<0.001	Reduced
Zn-D	0.143	0.125	No change
Zn-T	-0.315	0.001	Reduced

LOR = Analytical 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 C-13 Waile Creek 2007-2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.326	<0.001	Reduced
SO4-D	-0.473	<0.001	Reduced
Alk-T	-0.069	0.471	No change
TSS	0.100	0.288	No change
Ag-D	-0.658	<0.001	Reduced
Ag-T	-0.596	<0.001	Reduced
As-D	-0.716	<0.001	Reduced
As-T	-0.685	<0.001	Reduced
Cd-D	-0.672	<0.001	Reduced
Cd-T	-0.581	<0.001	Reduced
Cr-D	-0.776	<0.001	Reduced
Cr-T	-0.631	<0.001	Reduced
Cu-D	-0.541	<0.001	Reduced
Cu-T	-0.355	<0.001	Reduced
Fe-D	0.114	0.229	No change
Fe-T	-0.346	<0.001	Reduced
Hg-D	-0.774	<0.001	Reduced
Hg-T	-0.750	<0.001	Reduced
Ni-D	-0.699	<0.001	Reduced
Ni-T	-0.396	<0.001	Reduced
Pb-D	-0.648	<0.001	Reduced
Pb-T	-0.452	<0.001	Reduced
Se-D	-0.859	<0.001	Reduced
Se-T	-0.807	<0.001	Reduced
Zn-D	0.424	<0.001	Increased
Zn-T	-0.225	0.017	Reduced

LOR = Analytical 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 C-14 Kaiya U/S Anjolek 2007-2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.570	<0.001	Reduced
SO4-D	-0.471	<0.001	Reduced
Alk-T	0.066	0.498	No change
TSS	-0.227	0.018	Reduced
Ag-D	-0.564	<0.001	Reduced
Ag-T	-0.392	<0.001	Reduced
As-D	-0.561	<0.001	Reduced
As-T	-0.290	0.002	Reduced
Cd-D	-0.691	<0.001	Reduced
Cd-T	-0.496	<0.001	Reduced
Cr-D	-0.808	<0.001	Reduced
Cr-T	-0.163	0.091	No change
Cu-D	-0.571	<0.001	Reduced
Cu-T	-0.148	0.123	No change
Fe-D	-0.283	0.003	Reduced
Fe-T	-0.165	0.089	No change
Hg-D	-0.772	<0.001	Reduced
Hg-T	-0.548	<0.001	Reduced
Ni-D	-0.693	<0.001	Reduced
Ni-T	-0.153	0.113	No change
Pb-D	-0.633	<0.001	Reduced
Pb-T	-0.230	0.016	Reduced
Se-D	-0.829	<0.001	Reduced
Se-T	-0.672	<0.001	Reduced
Zn-D	0.165	0.089	No change
Zn-T	-0.063	0.518	No change

LOR = Analytical 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 C-15 Pongema 2007-2016 (trend of all data)

Parameter	Spearman's rho	p-Value (p=0.05)	Trend
pH	-0.381	<0.001	Reduced
SO4-D	-0.550	<0.001	Reduced
Alk-T	0.049	0.601	No change
TSS	0.028	0.764	No change
Ag-D	-0.636	<0.001	Reduced
Ag-T	-0.398	<0.001	Reduced
As-D	-0.694	<0.001	Reduced
As-T	-0.492	<0.001	Reduced
Cd-D	-0.664	<0.001	Reduced
Cd-T	-0.526	<0.001	Reduced
Cr-D	-0.796	<0.001	Reduced
Cr-T	-0.183	0.047	Reduced
Cu-D	-0.569	<0.001	Reduced
Cu-T	-0.182	0.048	Reduced
Fe-D	-0.158	0.086	No change
Fe-T	-0.117	0.206	No change
Hg-D	-0.797	<0.001	Reduced
Hg-T	-0.640	<0.001	Reduced
Ni-D	-0.690	<0.001	Reduced
Ni-T	-0.236	0.010	Reduced
Pb-D	-0.629	<0.001	Reduced
Pb-T	-0.172	0.062	No change
Se-D	-0.861	<0.001	Reduced
Se-T	-0.709	<0.001	Reduced
Zn-D	0.057	0.540	No change
Zn-T	-0.210	0.022	Reduced

LOR = Analytical 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 C-16 28 Level 2016 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	7.6	LowerTV<TSM<UpTV	Step 1/2	6.0-8.1	0.001	LOW
TSS	12	12	496	TSM < TV	Step 1	2,837	0.019	LOW
Ag-D	9	8	0.01	TSM < TV	Step 1	0.05	0.007	LOW
As-D	12	12	1.3	TSM < TV	Step 1	24	0.001	LOW
Cd-D	12	12	0.08	TSM < TV	Step 1	0.4	0.003	LOW
Cr-D	12	12	0.20	TSM < TV	Step 1	1.0	0.002	LOW
Cu-D	12	12	0.50	TSM < TV	Step 1	4.1	0.001	LOW
Fe-D	12	12	3.0	TSM < TV	Step 1	75	0.001	LOW
Hg-D	12	12	0.04	TSM < TV	Step 1	0.6	0.001	LOW
Ni-D	12	12	2.9	TSM < TV	Step 1	21	0.001	LOW
Pb-D	12	12	0.10	TSM < TV	Step 1	8.4	0.001	LOW
Se-D	12	12	0.20	TSM < TV	Step 1	11	0.001	LOW
Zn-D	12	11	19	TSM < TV	Step 1	20	0.775	POTENTIAL

Table C-17 Anjolek SDA 2016 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	11	11	7.6	LowerTV<TSM<UpTV	Step 1/2	6.0-8.1	0.002/0.034	LOW
TSS	11	11	229	TSM < TV	Step 1	2,837	0.028	LOW
Ag-D	11	11	0.02	TSM < TV	Step 1	0.05	0.03	LOW
As-D	11	11	0.93	TSM < TV	Step 1	24	0.002	LOW
Cd-D	11	11	0.06	TSM < TV	Step 1	0.4	0.002	LOW
Cr-D	11	11	0.20	TSM < TV	Step 1	1.0	0.002	LOW
Cu-D	11	11	1.0	TSM < TV	Step 1	4.1	0.002	LOW
Fe-D	11	11	2.0	TSM < TV	Step 1	75	0.002	LOW
Hg-D	11	11	0.04	TSM < TV	Step 1	0.6	0.002	LOW
Ni-D	11	11	1.4	TSM < TV	Step 1	21	0.002	LOW
Pb-D	11	11	0.20	TSM < TV	Step 1	8.4	0.002	LOW
Se-D	11	11	0.60	TSM < TV	Step 1	11	0.002	LOW
Zn-D	11	11	26	TSM > TV	Step 2	20	0.153	POTENTIAL

Table C-18 Kaiya at Yuyan Bridge 2016 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	11	11	7.6	LowerTV <TSM<UpTV	Step 1	6.0-8.1	0.002/0.002	LOW
TSS	11	11	5,635	TSM ≥ TV	Step 2	2,837	0.018	POTENTIAL
Ag-D	7	4	0.05	TSM < TV	Step 1	0.05	Direct Comparison	*LOW
As-D	10	10	1.3	TSM < TV	Step 1	24	0.003	LOW
Cd-D	10	10	0.05	TSM < TV	Step 1	0.4	0.003	LOW
Cr-D	10	10	0.20	TSM < TV	Step 1	1.0	0.003	LOW
Cu-D	10	10	0.65	TSM < TV	Step 1	4.1	0.003	LOW
Fe-D	10	10	7.5	TSM < TV	Step 1	75	0.042	LOW
Hg-D	10	10	0.04	TSM < TV	Step 1	0.6	0.003	LOW
Ni-D	10	10	0.80	TSM < TV	Step 1	21	0.003	LOW
Pb-D	10	10	0.20	TSM < TV	Step 1	8.4	0.003	LOW
Se-D	10	10	0.50	TSM < TV	Step 1	11	0.003	LOW
Zn-D	10	10	12	TSM < TV	Step 1	20	0.006	LOW

*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-19 Kaiya River d/s Anjolek Erodible Dump 2016 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	11	11	7.6	LowerTV <TSM<UpTV	Step 1	6.0-8.1	0.002	LOW
TSS	11	11	3,823	TSM ≥ TV	Step 2	2,837	0.115	POTENTIAL
Ag-D	7	7	0.05	TSM < TV	Step 1	0.05	Direct Comparison	*LOW
As-D	10	10	1.1	TSM < TV	Step 1	24	0.003	LOW
Cd-D	10	10	0.05	TSM < TV	Step 1	0.4	0.003	LOW
Cr-D	10	10	0.20	TSM < TV	Step 1	1.0	0.003	LOW
Cu-D	10	10	0.75	TSM < TV	Step 1	4.1	0.003	LOW
Fe-D	10	10	4.5	TSM < TV	Step 1	75	0.004	LOW
Hg-D	10	10	0.04	TSM < TV	Step 1	0.6	0.003	LOW
Ni-D	10	10	0.65	TSM < TV	Step 1	21	0.003	LOW
Pb-D	10	10	0.20	TSM < TV	Step 1	8.4	0.003	LOW
Se-D	10	10	0.50	TSM < TV	Step 1	11	0.003	LOW
Zn-D	10	10	10.5	TSM < TV	Step 1	20	0.004	LOW

*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-20 Kogai Culvert 2016 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	7.8	LowerTV <TSM<UpTV	Step 1	6.0-8.1	0.001	LOW
TSS	12	12	440	TSM < TV	Step 1	2,837	0.019	LOW
Ag-D	9	8	0.01	TSM < TV	Step 1	0.05	0.007	LOW
As-D	12	12	1.1	TSM < TV	Step 1	24	0.001	LOW
Cd-D	12	12	0.12	TSM < TV	Step 1	0.4	0.001	LOW
Cr-D	12	12	0.20	TSM < TV	Step 1	1.0	0.001	LOW
Cu-D	12	12	0.90	TSM < TV	Step 1	4.1	0.001	LOW
Fe-D	12	12	7.5	TSM < TV	Step 1	75	0.019	LOW
Hg-D	12	12	0.04	TSM < TV	Step 1	0.6	0.001	LOW
Ni-D	12	12	0.69	TSM < TV	Step 1	21	0.001	LOW
Pb-D	12	12	0.40	TSM < TV	Step 1	8.4	0.001	LOW
Se-D	12	12	0.20	TSM < TV	Step 1	11	0.001	LOW
Zn-D	12	12	20.5	TSM ≥ TV	Step 2	20	0.305	POTENTIAL

Table C-21 Kogai Stable Dump Toe Area 2016 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<UpTV	Step 1	6.0-8.1	0.001	LOW
TSS	12	12	130	TSM < TV	Step 1	2,837	0.019	LOW
Ag-D	9	9	0.01	TSM < TV	Step 1	0.05	Direct Comparison	LOW
As-D	12	12	0.85	TSM < TV	Step 1	24	0.001	LOW
Cd-D	12	12	2.2	TSM ≥ TV	Step 2	0.4	0.001	POTENTIAL
Cr-D	12	12	0.20	TSM < TV	Step 1	1.0	0.002	LOW
Cu-D	12	12	0.80	TSM < TV	Step 1	4.1	0.001	LOW
Fe-D	12	12	2.85	TSM < TV	Step 1	75	0.002	LOW
Hg-D	12	12	0.04	TSM < TV	Step 1	0.6	0.001	LOW
Ni-D	12	12	2.7	TSM < TV	Step 1	21	0.001	LOW
Pb-D	12	12	0.90	TSM < TV	Step 1	8.4	0.002	LOW
Se-D	12	12	0.20	TSM < TV	Step 1	11	0.001	LOW
Zn-D	12	12	411	TSM ≥ TV	Step 2	20	0.001	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-22 Lime Plant Discharge 2016 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	12	12	11.4	TSM ≥ TV	Step 2	6.0-8.1	0.001	POTENTIAL
TSS	12	12	561	TSM < TV	Step 1	2,837	0.033	LOW
Ag-D	12	12	0.01	TSM < TV	Step 1	0.05	0.007	LOW
As-D	12	12	0.20	TSM < TV	Step 1	24	0.001	LOW
Cd-D	12	12	0.05	TSM < TV	Step 1	0.4	0.001	LOW
Cr-D	12	11	4.6	TSM ≥ TV	Step 2	1.0	0.006	POTENTIAL
Cu-D	12	12	0.56	TSM < TV	Step 1	4.1	0.001	LOW
Fe-D	12	12	2.5	TSM < TV	Step 1	75	0.001	LOW
Hg-D	12	12	0.04	TSM < TV	Step 1	0.6	0.001	LOW
Ni-D	12	12	0.50	TSM < TV	Step 1	21	0.001	LOW
Pb-D	12	12	0.10	TSM < TV	Step 1	8.4	0.001	LOW
Se-D	12	12	0.20	TSM < TV	Step 1	11	0.001	LOW
Zn-D	12	12	1.1	TSM < TV	Step 1	20	0.001	LOW

Table C-23 Wendoko Creek d/s Anawe Nth 2016 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	11	11	7.7	LowerTV < TSM < UpTV	Step 1	6.0-8.1	0.002	LOW
TSS	11	11	45	TSM < TV	Step 1	2,837	0.028	LOW
Ag-D	11	11	0.01	TSM < TV	Step 1	0.05	0.011	LOW
As-D	11	11	1.1	TSM < TV	Step 1	24	0.002	LOW
Cd-D	11	11	0.78	TSM ≥ TV	Step 2	0.4	0.003	POTENTIAL
Cr-D	11	11	0.20	TSM < TV	Step 1	1.0	0.002	LOW
Cu-D	11	11	0.50	TSM < TV	Step 1	4.1	0.002	LOW
Fe-D	11	11	3.0	TSM < TV	Step 1	75	0.002	LOW
Hg-D	11	11	0.04	TSM < TV	Step 1	0.6	0.002	LOW
Ni-D	11	11	1.9	TSM < TV	Step 1	21	0.002	LOW
Pb-D	11	11	0.20	TSM < TV	Step 1	8.4	0.002	LOW
Se-D	11	11	0.60	TSM < TV	Step 1	11	0.002	LOW
Zn-D	11	11	355	TSM ≥ TV	Step 2	20	0.002	POTENTIAL

Table C-24 Yakatabari Creek d/s 28 level 2016 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
Yakatab	N	N(Test)	Median	Result	Go to			
pH	12	12	7.5	LowerTV <TSM<UpTV	Step 1	6.0-8.1	0.001	LOW
TSS	12	12	4,528	TSM ≥ TV	Step 2	2,837	0.033	POTENTIAL
Ag-D	9	8	0.01	TSM < TV	Step 1	0.05	0.007	LOW
As-D	12	12	6.7	TSM < TV	Step 1	24	0.001	LOW
Cd-D	12	12	0.07	TSM < TV	Step 1	0.4	0.019	LOW
Cr-D	12	12	0.20	TSM < TV	Step 1	1.0	0.001	LOW
Cu-D	12	12	0.65	TSM < TV	Step 1	4.1	0.001	LOW
Fe-D	12	12	3.3	TSM < TV	Step 1	75	0.001	LOW
Hg-D	12	12	0.04	TSM < TV	Step 1	0.6	0.001	LOW
Ni-D	12	12	1.8	TSM < TV	Step 1	21	0.001	LOW
Pb-D	12	12	0.95	TSM < TV	Step 1	8.4	0.001	LOW
Se-D	12	12	0.50	TSM < TV	Step 1	11	0.001	LOW
Zn-D	12	12	19.5	TSM < TV	Step 1	20	0.216	POTENTIAL

Table C-25 Yunarilama at Portal 2016 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
Yunar	N	N(Test)	Median	Result	Go to			
pH	12	12	7.5	LowerTV <TSM<UpTV	Step 1	6.0-8.1	0.001	LOW
TSS	12	12	7,368	TSM ≥ TV	Step 2	2,837	0.007	POTENTIAL
Ag-D	9	9	0.02	TSM < TV	Step 1	0.05	0.203	LOW
As-D	12	12	1.7	TSM < TV	Step 1	24	0.001	LOW
Cd-D	12	12	0.12	TSM < TV	Step 1	0.4	0.001	LOW
Cr-D	12	12	0.20	TSM < TV	Step 1	1.0	0.001	LOW
Cu-D	12	12	0.50	TSM < TV	Step 1	4.1	0.001	LOW
Fe-D	12	12	5.5	TSM < TV	Step 1	75	0.001	LOW
Hg-D	12	12	0.06	TSM < TV	Step 1	0.6	0.001	LOW
Ni-D	12	12	1.8	TSM < TV	Step 1	21	0.001	LOW
Pb-D	12	12	0.30	TSM < TV	Step 1	8.4	0.001	LOW
Se-D	12	12	1.2	TSM < TV	Step 1	11	0.001	LOW
Zn-D	12	11	17.5	TSM < TV	Step 1	20	0.212	POTENTIAL

Table C-26 Tailings Slurry 2016 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	6.4	Lower TV < TSM < Higher TV	Step 1 / 2	6.0-8.1	<0.001	LOW
TSS	48	48	171,150	TSM > TV	Step 2	2,837	<0.001	POTENTIAL
Ag-D	40	40	0.05	TSM < TV	Step 1	0.05	0.664	POTENTIAL
As-D	48	48	0.85	TSM < TV	Step 1	24	<0.001	LOW
Cd-D	48	48	124	TSM > TV	Step 2	0.4	<0.001	POTENTIAL
Cr-D	48	46	0.20	TSM < TV	Step 1	1.0	<0.001	LOW
Cu-D	48	48	44	TSM > TV	Step 2	4.1	<0.001	POTENTIAL
Fe-D	48	48	21	TSM < TV	Step 1	75	0.020	LOW
Hg-D	48	48	0.14	TSM < TV	Step 1	0.6	<0.001	LOW
Ni-D	48	48	1625	TSM > TV	Step 2	21	<0.001	POTENTIAL
Pb-D	48	48	0.10	TSM < TV	Step 1	8.4	<0.001	LOW
Se-D	48	48	1.7	TSM < TV	Step 1	11	<0.001	LOW
Zn-D	48	48	41600	TSM > TV	Step 2	20	<0.001	POTENTIAL

Table C-28 Tailings Solids 2016 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	36	36	0.33	TSM < TV	Step 1	1.0	<0.001	LOW
As- WAE	36	36	47	TSM > TV	Step 2	20	<0.001	POTENTIAL
Cd- WAE	36	36	9.0	TSM > TV	Step 2	1.5	<0.001	POTENTIAL
Cr- WAE	36	36	21	TSM < TV	Step 1	80	<0.001	LOW
Cu- WAE	36	36	90	TSM > TV	Step 2	65	<0.001	POTENTIAL
Hg- WAE	36	36	0.30	TSM > TV	Step 2	0.15	<0.001	POTENTIAL
Ni- WAE	36	36	22	TSM < TV	Step 1	26	<0.001	LOW
Pb- WAE	36	36	178	TSM > TV	Step 2	50	<0.001	POTENTIAL
Se- WAE	36	36	0.10	TSM < TV	Step 1	0.50	<0.001	LOW
Zn- WAE	36	36	1500	TSM > TV	Step 2	200	<0.001	POTENTIAL

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

Table D-1 Expanded risk matrix – water quality – metals and TSS

Initial Assessment Result	Go To
TSM < TV	Step 1
TSM ≥ TV and TV, TSM and full TSM data set are ≰ LOR	Step 2
TSM = TV and TV, TSM and full TSM data set ≤ LOR	Step 3

Step	Alt Hypothesis	Null Hypothesis	Sig Test Result		Risk Assessment
1	TSM < TV	TSM = TV	p < 0.05	Accept Alt	LOW
			p > 0.05	Accept Null	POTENTIAL
			Error	Accept Neither	ND
2	TSM ≥ TV and TV, TSM and full TSM data set are ≰ LOR				POTENTIAL
3	TSM = TV and TV, TSM and full TSM data set are ≤ LOR				LOW

TSM = Test Site Median

ND = No determination

Table D-2 Expanded risk matrix – water quality – pH

Initial Assessment Result	Go To
Lower TV < TSM < Upper TV	Step 1
TSM ≤ Lower TV	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 - SG1 2016 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
SG1	N	N(Test)	Median	Result	Go to			
pH			Not Sampled					
TSS*			Not Sampled					
Ag-D*			Not Sampled					
As-D*			Not Sampled					
Cd-D*			Not Sampled					
Cr-D*			Not Sampled					
Cu-D*			Not Sampled					
Fe-D*			Not Sampled					
Hg-D*			Not Sampled					
Ni-D*			Not Sampled					
Pb-D*			Not Sampled					
Se-D*			Not Sampled					
Zn-D *			Not Sampled					

Table D-4 Water quality upper river test sites - SG2 2016 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	6	6	7.5	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.1	0.018 / 0.018	LOW
TSS	5	5	1880	TSM < TV	Step 1	2837	0.053	*LOW
Ag-D	6	6	0.01	TSM < TV	Step 1	0.05	0.201	*LOW
As-D	6	6	1.1	TSM < TV	Step 1	24	0.018	LOW
Cd-D	6	6	0.24	TSM > TV	Step 2	0.40	0.799	*LOW
Cr-D	6	6	0.20	TSM < TV	Step 1	1.0	0.018	LOW
Cu-D	6	6	2.2	TSM < TV	Step 1	4.1	0.018	LOW
Fe-D	6	6	3.0	TSM < TV	Step 1	75	0.018	LOW
Hg-D	6	6	0.04	TSM < TV	Step 1	0.6	0.018	LOW
Ni-D	6	6	0.90	TSM < TV	Step 1	21	0.018	LOW
Pb-D	6	6	0.10	TSM < TV	Step 1	8.4	0.018	LOW
Se-D	6	6	0.20	TSM < TV	Step 1	11	0.018	LOW
Zn-D	6	5	19.5	TSM < TV	Step 1	20	0.657	*LOW

*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 D-5 Water quality upper river test sites - Wasiba 2016 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	20	20	7.7	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.1	<0.001 / <0.001	LOW
TSS	20	20	1385	TSM < TV	Step 1	2837	0.032	LOW
Ag-D	16	16	0.01	TSM < TV	Step 1	0.05	<0.001	LOW
As-D	22	22	1.2	TSM < TV	Step 1	24	<0.001	LOW
Cd-D	22	20	0.15	TSM < TV	Step 1	0.4	<0.001	LOW
Cr-D	22	22	0.20	TSM < TV	Step 1	1.0	<0.001	LOW
Cu-D	22	22	1.0	TSM < TV	Step 1	4.1	<0.001	LOW
Fe-D	22	22	4.0	TSM < TV	Step 1	75	<0.001	LOW
Hg-D	22	22	0.04	TSM < TV	Step 1	0.6	<0.001	LOW
Ni-D	22	22	0.65	TSM < TV	Step 1	21	<0.001	LOW
Pb-D	22	22	0.10	TSM < TV	Step 1	8.4	<0.001	LOW
Se-D	22	22	0.20	TSM < TV	Step 1	11	<0.001	LOW
Zn-D	22	19	15	TSM < TV	Step 1	20	0.001	LOW

Table D-6 Water quality upper river test sites - Wankipe 2016 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	21	21	7.6	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.1	<0.001 / <0.001	LOW
TSS	21	21	920	TSM < TV	Step 1	2837	0.002	LOW
Ag-D	15	15	0.01	TSM < TV	Step 1	0.05	0.011	LOW
As-D	21	21	1.1	TSM < TV	Step 1	24	<0.001	LOW
Cd-D	21	21	0.08	TSM < TV	Step 1	0.4	<0.001	LOW
Cr-D	21	21	0.20	TSM < TV	Step 1	1.0	<0.001	LOW
Cu-D	21	21	1.4	TSM < TV	Step 1	4.1	<0.001	LOW
Fe-D	21	21	4.0	TSM < TV	Step 1	75	<0.001	LOW
Hg-D	21	21	0.04	TSM < TV	Step 1	0.6	<0.001	LOW
Ni-D	21	21	0.50	TSM < TV	Step 1	21	<0.001	LOW
Pb-D	21	21	0.10	TSM < TV	Step 1	8.4	<0.001	LOW
Se-D	21	21	0.20	TSM < TV	Step 1	11	<0.001	LOW
Zn-D	21	21	14	TSM < TV	Step 1	20	<0.001	LOW

Table D-7 Water quality upper river test sites - SG3 2016 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	192	191	7.7	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.1	<0.001 / <0.001	LOW
TSS	192	192	1775	TSM < TV	Step 1	2837	<0.001	LOW
Ag-D	128	126	0.01	TSM < TV	Step 1	0.05	<0.001	LOW
As-D	192	192	1.1	TSM < TV	Step 1	24	<0.001	LOW
Cd-D	192	192	0.05	TSM < TV	Step 1	0.4	<0.001	LOW
Cr-D	192	191	0.20	TSM < TV	Step 1	1.0	<0.001	LOW
Cu-D	192	192	1.1	TSM < TV	Step 1	4.1	<0.001	LOW
Fe-D	192	192	6.0	TSM < TV	Step 1	75	<0.001	LOW
Hg-D	192	192	0.04	TSM < TV	Step 1	0.6	<0.001	LOW
Ni-D	192	192	0.50	TSM < TV	Step 1	21	<0.001	LOW
Pb-D	192	192	0.10	TSM < TV	Step 1	8.3	<0.001	LOW
Se-D	192	192	0.20	TSM < TV	Step 1	11	<0.001	LOW
Zn-D	192	189	11.6	TSM < TV	Step 1	20	<0.001	LOW

Table D-8 Water quality lower river test sites - Bebelubi 2016 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*	5	5	7.4	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.2	0.03	LOW
TSS	5	5	528	TSM < TV	Step 1	983	0.05	*LOW
Ag-D	5	5	0.02	TSM < TV	Step 1	0.05	0.03	LOW
As-D	5	5	1.0	TSM < TV	Step 1	24	0.03	LOW
Cd-D	5	5	0.05	TSM < TV	Step 1	0.2	0.03	LOW
Cr-D	5	5	0.20	TSM < TV	Step 1	1	0.03	LOW
Cu-D	5	5	1.1	TSM < TV	Step 1	1.4	0.09	*LOW
Fe-D	5	5	9.0	TSM < TV	Step 1	75	0.05	LOW
Hg-D	5	5	0.04	TSM < TV	Step 1	0.6	0.03	LOW
Ni-D	5	5	0.50	TSM < TV	Step 1	15	0.03	LOW
Pb-D	5	5	0.10	TSM < TV	Step 1	3.4	0.03	LOW
Se-D	5	5	0.20	TSM < TV	Step 1	11	0.03	LOW
Zn-D	5	5	13	TSM > TV	Step 2	10	0.09	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 D-9 Water quality lower river test sites - SG4 2016 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	5	5	7.6	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.2	0.03	LOW
TSS	5	5	364	TSM < TV	Step 1	983	0.05	LOW
Ag-D	5	5	0.01	TSM < TV	Step 1	0.05	0.03	LOW
As-D	5	5	0.80	TSM < TV	Step 1	24	0.03	LOW
Cd-D	5	5	0.05	TSM < TV	Step 1	0.2	0.03	LOW
Cr-D	5	5	0.20	TSM < TV	Step 1	1	0.03	LOW
Cu-D	5	5	1.0	TSM <TV	Step 2	1.4	0.10	*LOW
Fe-D	5	5	15	TSM < TV	Step 1	75	0.03	LOW
Hg-D	5	5	0.04	TSM < TV	Step 1	0.6	0.03	LOW
Ni-D	5	5	0.50	TSM < TV	Step 1	15	0.03	LOW
Pb-D	5	5	0.10	TSM < TV	Step 1	3.4	0.03	LOW
Se-D	5	5	0.20	TSM < TV	Step 1	11	0.03	LOW
Zn-D	5	5	13	TSM >TV	Step 2	10	0.14	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 D-10 Water quality lower river test sites - SG5 2016 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	3	3	7.5			6.0-8.2	NA	*LOW
TSS	3	3	486			983	NA	*LOW
Ag-D	3	3	0.01			0.05	NA	*LOW
As-D	3	3	1.0			24	NA	*LOW
Cd-D	3	3	0.05			0.2	NA	*LOW
Cr-D	3	3	0.20			1.0	NA	*LOW
Cu-D	3	3	1.0			1.4	NA	*LOW
Fe-D	3	3	30			75	NA	*LOW
Hg-D	3	3	0.04			0.6	NA	*LOW
Ni-D	3	3	0.50			15	NA	*LOW
Pb-D	3	3	0.20			3.4	NA	*LOW
Se-D	3	3	0.20			11	NA	*LOW
Zn-D	3	3	7.0			10	NA	*LOW

*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.

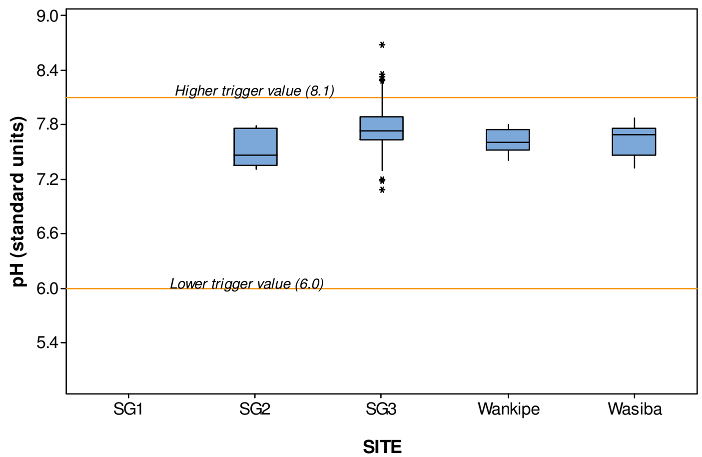

Figure D-1 pH in water upper river test sites 2016

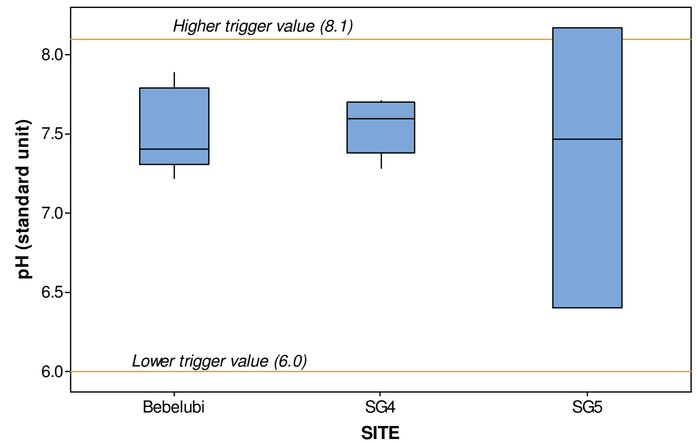

Figure D-2 pH in water at lower river test sites 2016

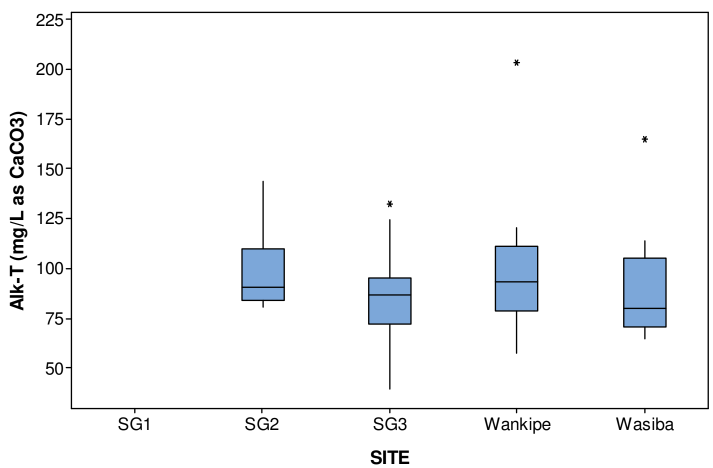

Figure D-3 Alkalinity in water upper river test sites 2016

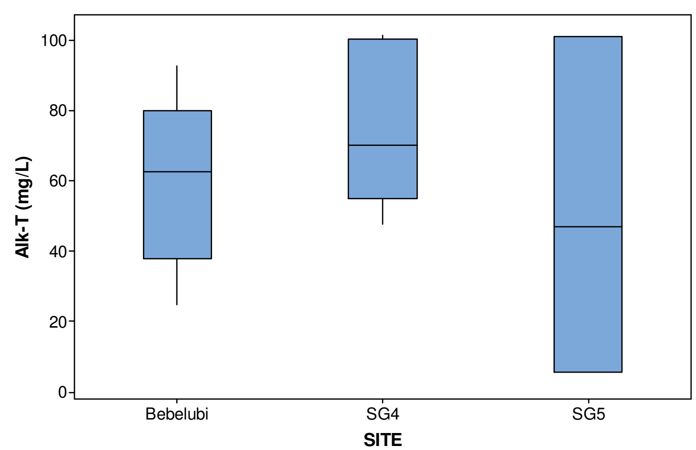

Figure D-4 Alkalinity in water lower river test sites 2016

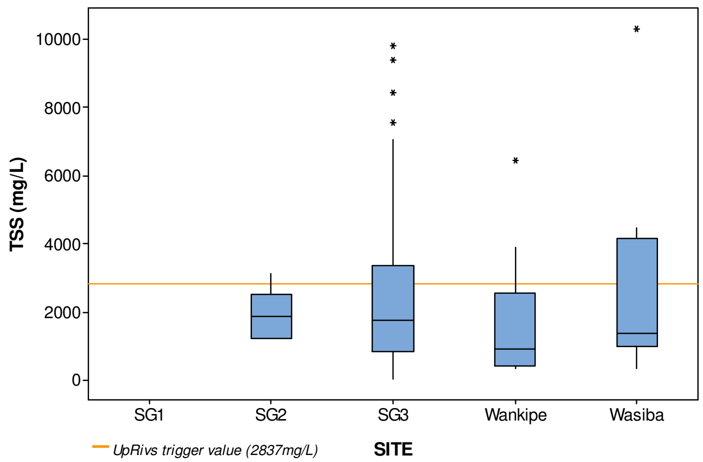

Figure D-5 TSS in water upper river test sites 2016

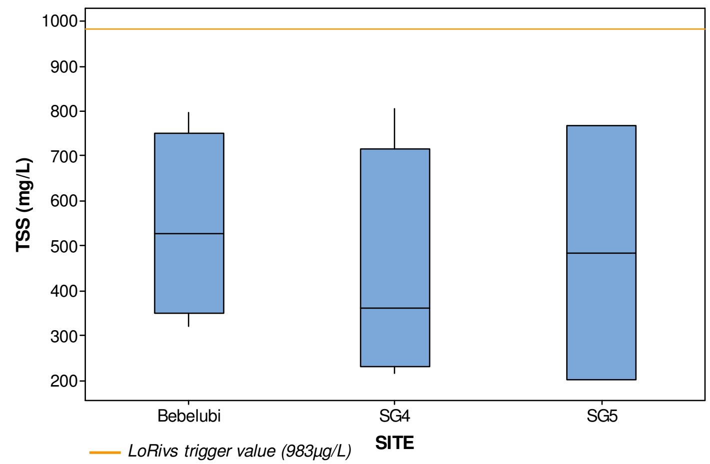

Figure D-6 TSS in water lower river test sites 2016

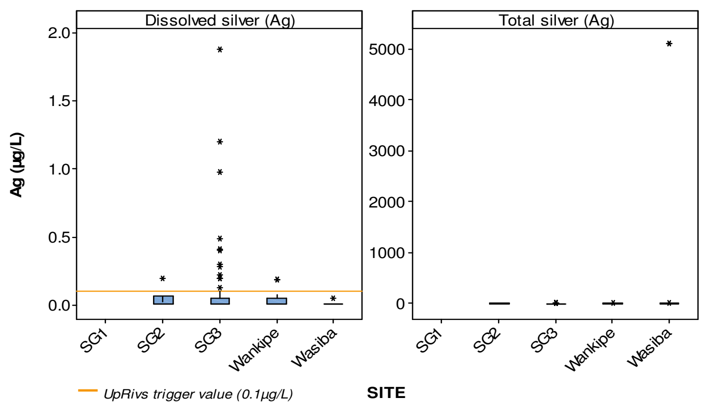

Figure D-7 Silver in water upper river test sites 2016

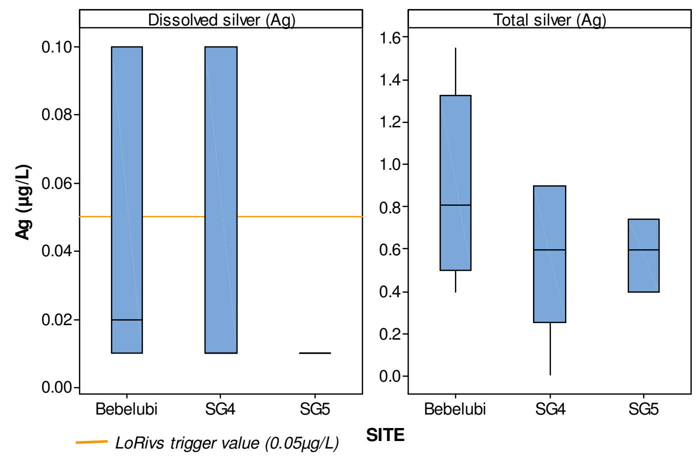

Figure D-8 Silver in water lower river test sites 2016

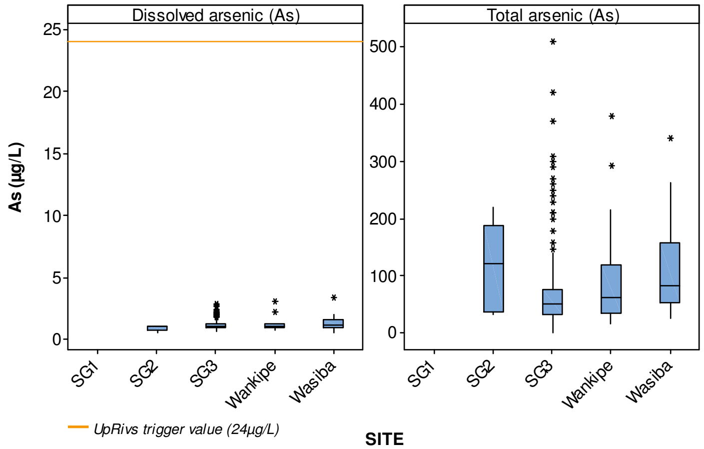

Figure D-9 Arsenic in water upper river test sites 2016

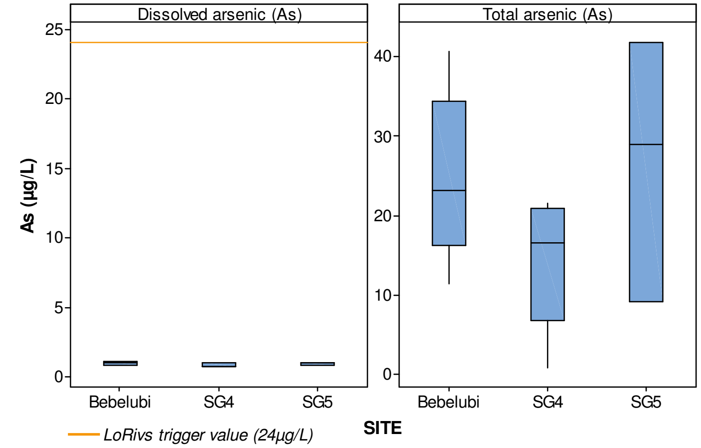

Figure D-10 Arsenic in water lower river test sites 2016

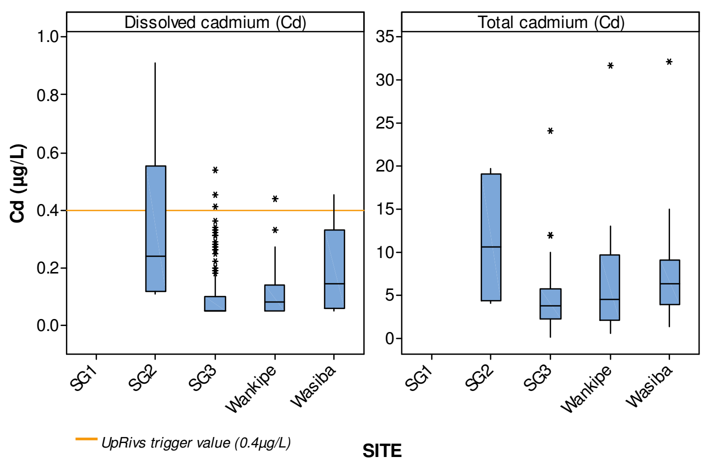

Figure D-11 Cadmium in water upper river test sites 2016

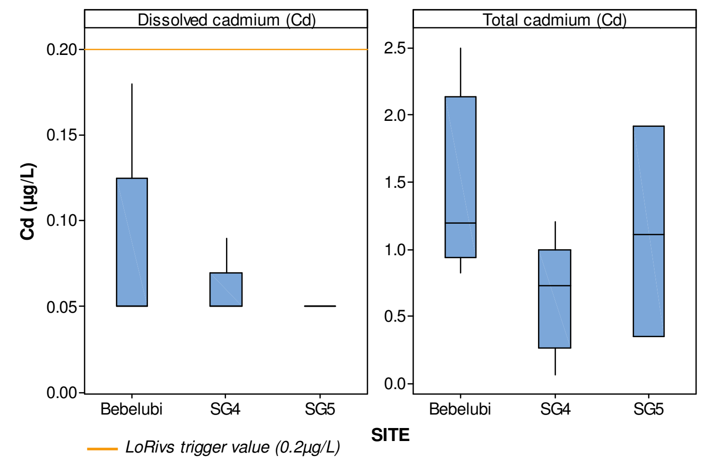

Figure D-12 Cadmium in water lower river test sites 2016

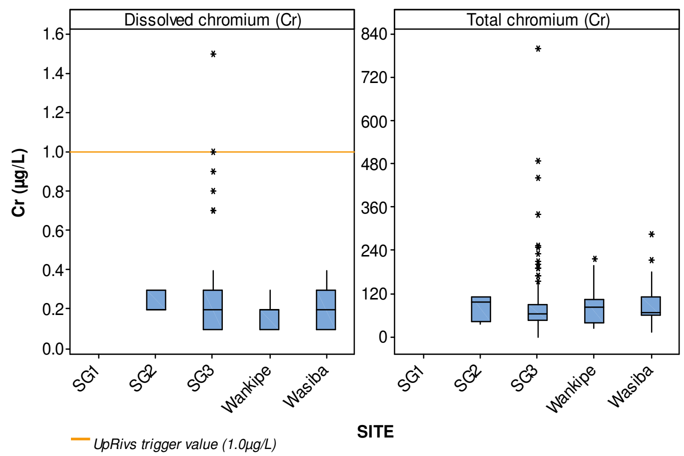

Figure D-13 Chromium in water upper river test sites 2016

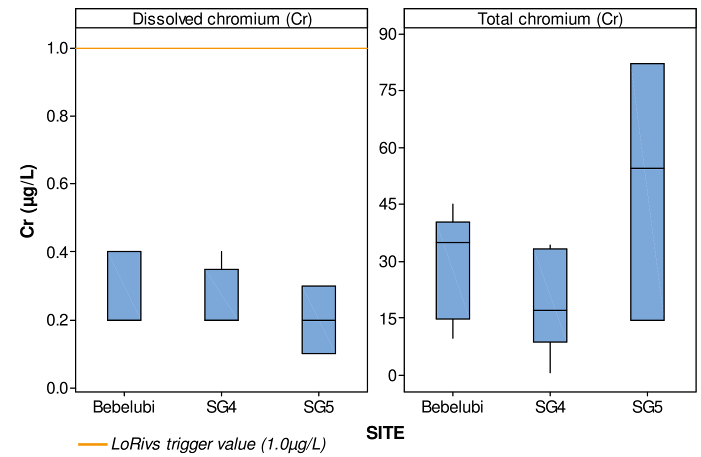

Figure D-14 Chromium in water lower river test sites 2016

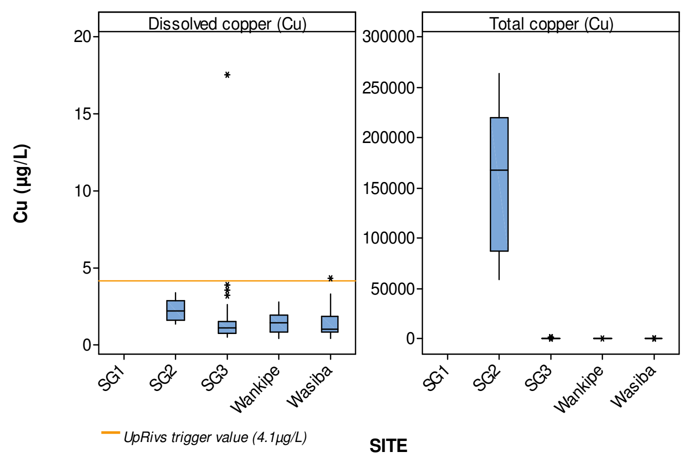

Figure D-15 Copper in water upper river test sites 2016

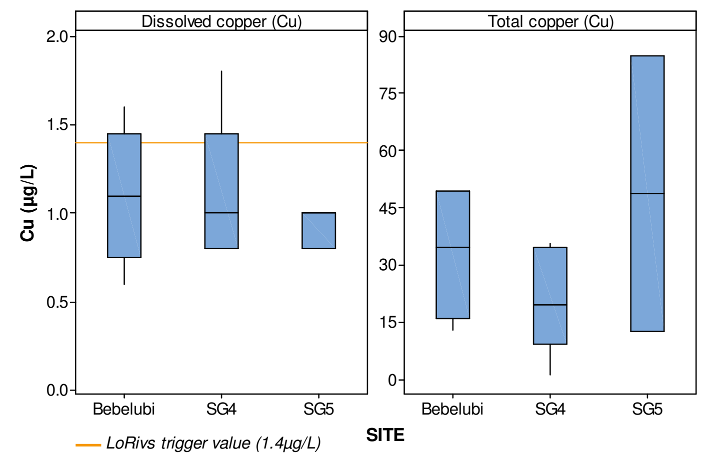

Figure D-16 Copper in water lower river test sites 2016

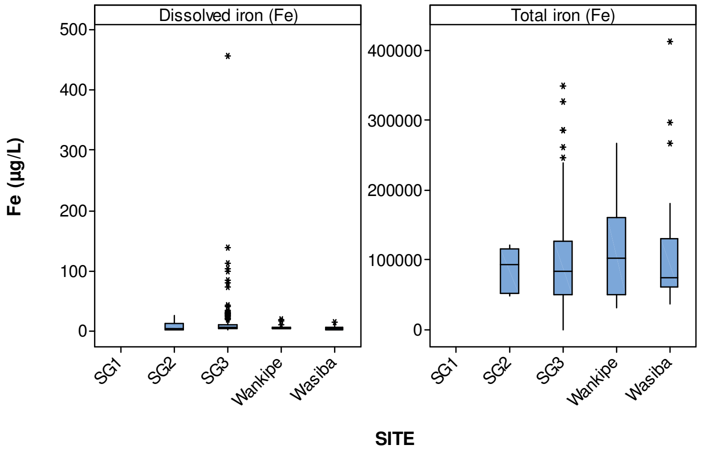

Figure D-17 Iron in water upper river test sites 2016

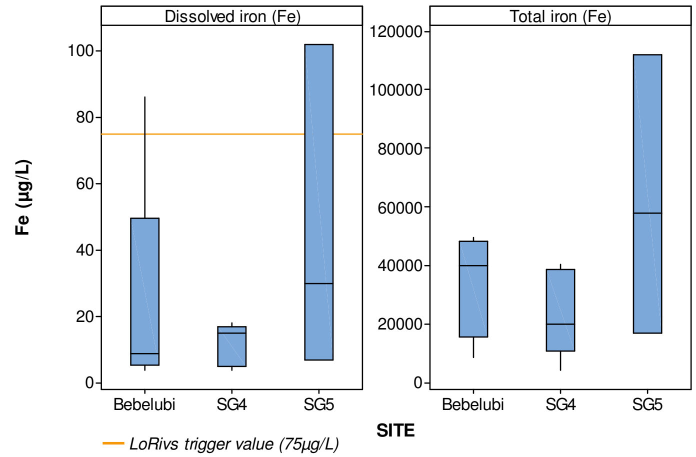

Figure D-18 Iron in water lower river test sites 2016

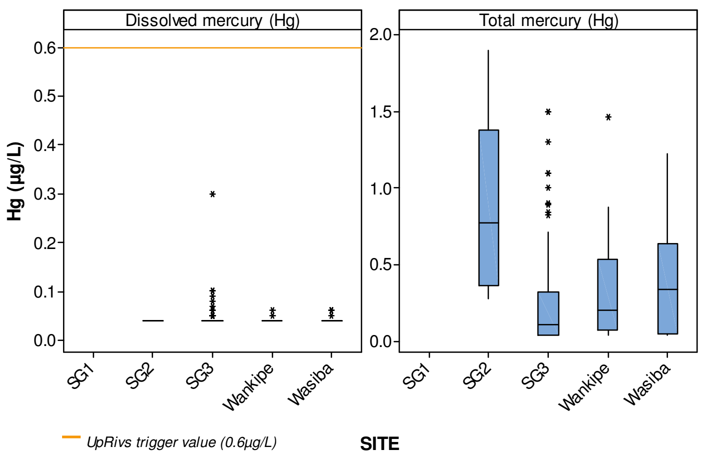

Figure D-19 Mercury in water upper river test sites 2016

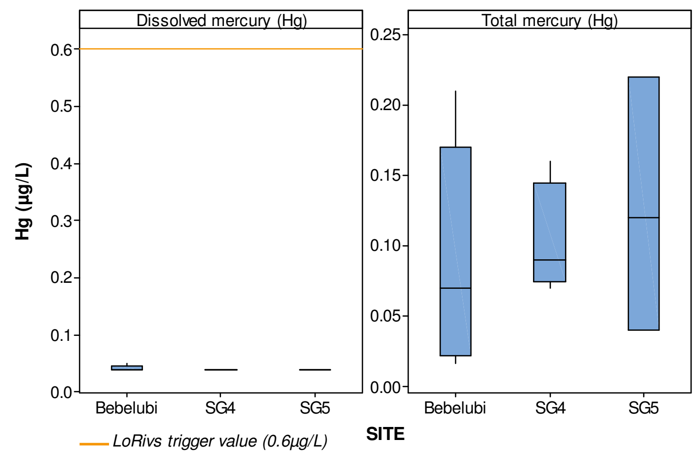

Figure D-20 Mercury in water lower river test sites 2016

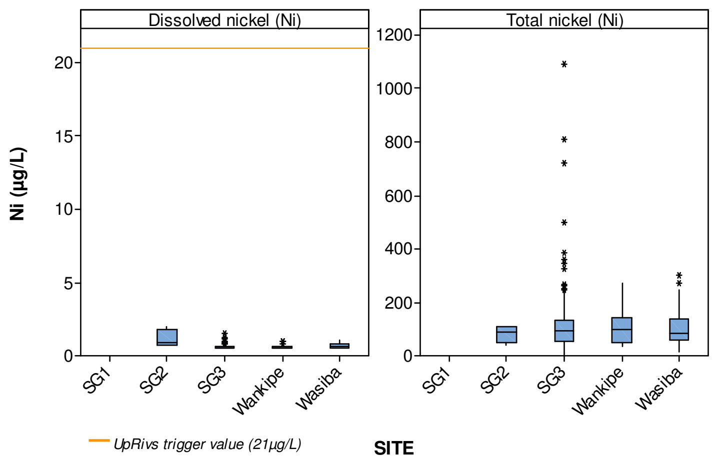

Figure D-21 Nickel in water upper river test sites 2016

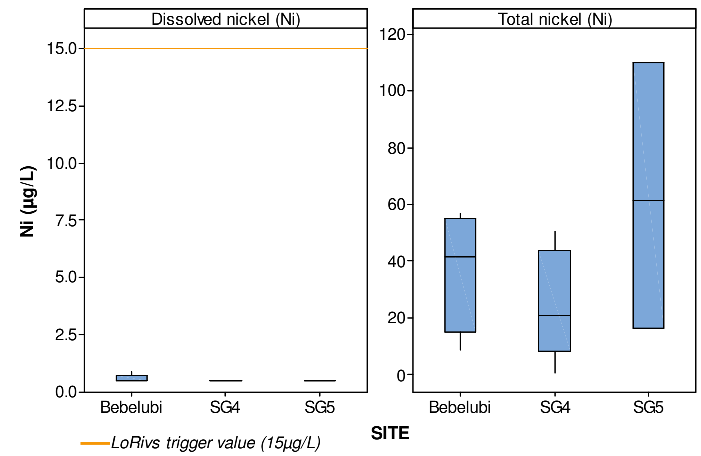

Figure D-22 Nickel in water lower river test sites 2016

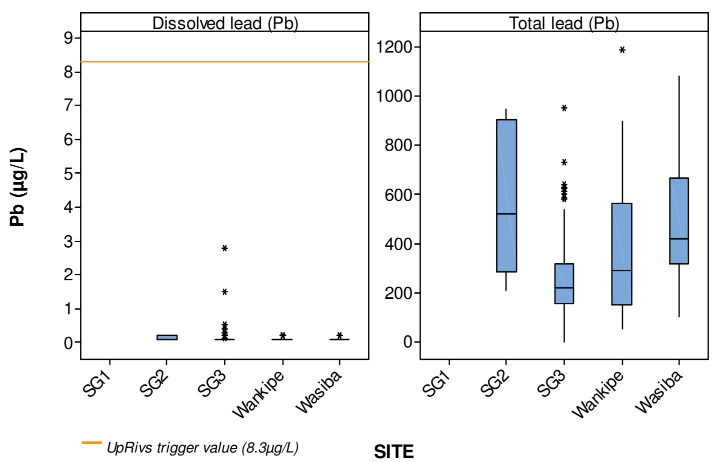

Figure D-23 Lead in water upper river test sites 2016

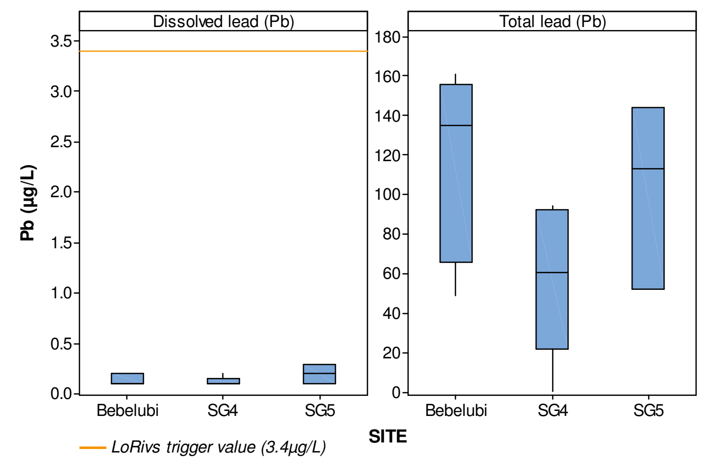

Figure D-24 Lead in water lower river test sites 2016

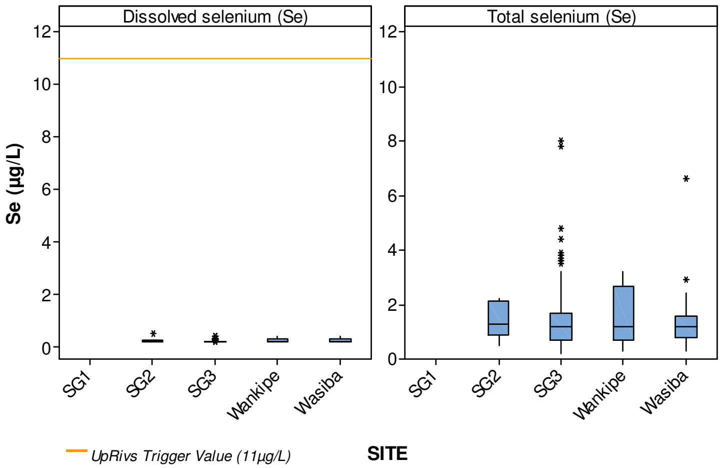

Figure D-25 Selenium in water upper river test sites 2016

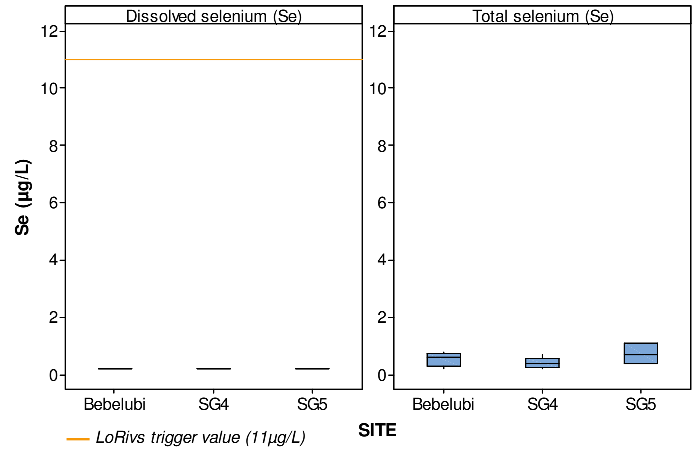

Figure D-26 Selenium in water lower river test sites 2016

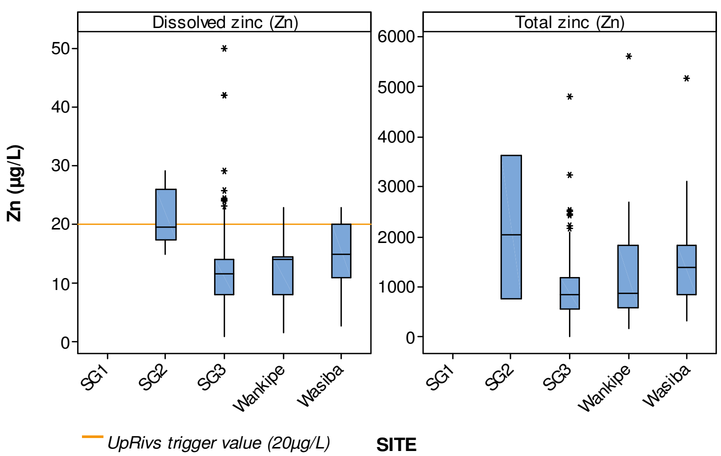

Figure D-27 Zinc in water upper river test sites 2016

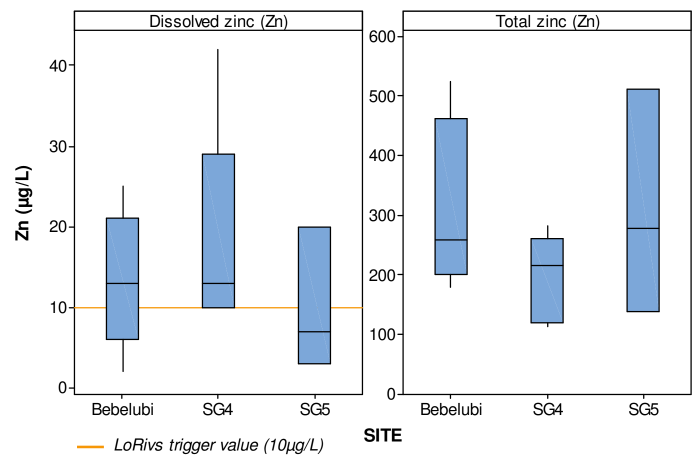

Figure D-28 Zinc in water lower river test sites 2016

Table D-11 Performance assessment – Based on the trend of water quality indicators (all data) at upper river test sites between 2007 and 2015 using Spearman Rank Test.

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2007 - 2016
SG1 (Trend of all data 2007 - 2015) Monitoring not conducted in 2016	pH	-0.219	0.043	Reduced over time
	TSS	-0.228	0.036	Reduced over time
	Ag-D	-0.331	0.002	Reduced over time
	As-D	-0.514	<0.001	Reduced over time
	Cd-D	0.076	0.489	No change over time
	Cr-D	-0.696	<0.001	Reduced over time
	Cu-D	-0.369	<0.001	Reduced over time
	Fe-D	-0.114	0.295	No change over time
	Hg-D	-0.471	<0.001	Reduced over time
	Ni-D	-0.164	0.13	No change over time
	Pb-D	-0.286	0.008	Reduced over time
	Se-D	-0.663	0.001	Reduced over time
	Zn-D	0.032	0.769	No change over time
SG2 (Trend of all data 2007 - 2016)	pH	-0.294	0.001	Reduced over time
	TSS	-0.057	0.539	No change over time
	Ag-D	-0.56	<0.001	Reduced over time
	As-D	-0.34	<0.001	Reduced over time
	Cd-D	-0.06	0.519	No change over time
	Cr-D	-0.704	<0.001	Reduced over time
	Cu-D	-0.398	<0.001	Reduced over time
	Fe-D	-0.289	0.002	Reduced over time
	Hg-D	-0.731	<0.001	Reduced over time
	Ni-D	0.064	0.488	No change over time
	Pb-D	-0.543	<0.001	Reduced over time
	Se-D	-0.832	<0.001	Reduced over time
	Zn-D	0.066	0.483	No change over time
Wasiba (Trend of all data 2007 - 2016)	pH	0.477	0.001	Increased over time
	TSS	0.225	0.137	No change over time
	Ag-D	-0.923	<0.001	Reduced over time
	As-D	-0.239	0.101	No change over time
	Cd-D	-0.112	0.448	No change over time
	Cr-D	-0.461	0.001	Reduced over time
	Cu-D	-0.202	0.168	No change over time
	Fe-D	-0.196	0.181	No change over time
	Hg-D	-0.506	<0.001	Reduced over time
	Ni-D	-0.474	0.001	Reduced over time
	Pb-D	-0.683	<0.001	Reduced over time
	Se-D	-0.41	0.004	Reduced over time
	Zn-D	0.559	<0.001	Increased over time

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2007 - 2016
Wankipe (Trend of all data 2007 - 2016)	pH	-0.462	<0.001	Reduced over time
	TSS	-0.24	0.009	Reduced over time
	Ag-D	-0.772	<0.001	Reduced over time
	As-D	-0.391	<0.001	Reduced over time
	Cd-D	-0.467	<0.001	Reduced over time
	Cr-D	-0.847	<0.001	Reduced over time
	Cu-D	-0.084	0.365	No change over time
	Fe-D	-0.358	<0.001	Reduced over time
	Hg-D	-0.865	<0.001	Reduced over time
	Ni-D	-0.59	<0.001	Reduced over time
	Pb-D	-0.752	<0.001	Reduced over time
	Se-D	-0.738	<0.001	Reduced over time
	Zn-D	0.293	0.001	Increased over time
SG3 (Trend of all data 2007 - 2016)	pH	-0.406	<0.001	Reduced over time
	TSS	0.08	0.001	Increased over time
	Ag-D	-0.606	<0.001	Reduced over time
	As-D	-0.191	<0.001	Reduced over time
	Cd-D	-0.519	<0.001	Reduced over time
	Cr-D	-0.794	<0.001	Reduced over time
	Cu-D	-0.04	0.088	No change over time
	Fe-D	-0.277	<0.001	Reduced over time
	Hg-D	-0.8	<0.001	Reduced over time
	Ni-D	-0.663	<0.001	Reduced over time
	Pb-D	-0.616	<0.001	Reduced over time
	Se-D	-0.816	<0.001	Reduced over time
	Zn-D	0.215	<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-12 Performance assessment – Based on the trend of water quality indicators (all data) at lower river test sites between 2007 and 2015 using Spearman Rank Test.

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2007 - 2016
Bebelubi (Trend of all data 2007 - 2016)	pH	-0.221	0.074	No change over time
	TSS	-0.340	0.005	Reduced over time
	Ag-D	-0.659	<0.001	Reduced over time
	As-D	0.009	0.941	No change over time
	Cd-D	-0.645	<0.001	Reduced over time
	Cr-D	-0.757	<0.001	Reduced over time
	Cu-D	0.007	0.953	No change over time
	Fe-D	-0.231	0.047	Reduced over time
	Hg-D	-0.721	<0.001	Reduced over time
	Ni-D	-0.603	<0.001	Reduced over time
	Pb-D	-0.629	<0.001	Reduced over time
	Se-D	-0.864	<0.001	Reduced over time
	Zn-D	0.411	<0.001	Increased over time
SG4 (Trend of all data 2007 - 2016)	pH	-0.151	0.127	No change over time
	TSS	0.053	0.593	No change over time
	Ag-D	-0.561	<0.001	Reduced over time
	As-D	-0.226	0.018	Reduced over time
	Cd-D	-0.560	<0.001	Reduced over time
	Cr-D	-0.685	<0.001	Reduced over time
	Cu-D	-0.083	0.388	No change over time
	Fe-D	-0.358	<0.001	Reduced over time
	Hg-D	-0.685	<0.001	Reduced over time
	Ni-D	-0.550	<0.001	Reduced over time
	Pb-D	-0.528	<0.001	Reduced over time
	Se-D	-0.864	<0.001	Reduced over time
	Zn-D	0.317	0.001	Increased over time
SG5 (Trend of all data 2007 - 2016)	pH	-0.410	0.011	Reduced over time
	TSS	-0.086	0.617	No change over time
	Ag-D	-0.889	<0.001	Reduced over time
	As-D	-0.344	0.032	Reduced over time
	Cd-D	-0.869	<0.001	Reduced over time
	Cr-D	-0.741	<0.001	Reduced over time
	Cu-D	-0.199	0.224	No change over time
	Fe-D	-0.504	0.001	Reduced over time
	Hg-D	-0.629	<0.001	Reduced over time
	Ni-D	-0.869	<0.001	Reduced over time
	Pb-D	-0.730	<0.001	Reduced over time
	Se-D	≤LOR	≤LOR	No change over time
	Zn-D	-0.204	0.214	No change over time

LOR = Analytical 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 D-13 Water quality Lake Murray and ORWBs test sites - Central Lake Murray 2016 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	11	11	6.6	Lower TV < TSM < Upper TV	Step 1 / 2	5.3-8.0	0.002 / 0.002	LOW
TSS	11	11	5.0	TSM < TV	Step 1	24	0.002	LOW
Ag-D	11	11	0.01	TSM < TV	Step 1	0.05	0.002	LOW
As-D	11	11	0.20	TSM < TV	Step 1	24	0.002	LOW
Cd-D	11	11	0.05	TSM < TV	Step 1	0.72	0.002	LOW
Cr-D	11	11	0.30	TSM < TV	Step 1	1.0	0.002	LOW
Cu-D	11	11	0.50	TSM < TV	Step 1	1.4	0.002	LOW
Fe-D	11	11	137	TSM < TV	Step 1	340	0.002	LOW
Hg-D	11	11	0.04	TSM < TV	Step 1	0.60	<0.001	LOW
Ni-D	11	11	0.50	TSM < TV	Step 1	11	0.002	LOW
Pb-D	11	11	0.10	TSM < TV	Step 1	3.4	0.002	LOW
Se-D	11	11	0.20	TSM < TV	Step 1	11	0.002	LOW
Zn-D	11	11	6.0	TSM < TV	Step 1	9.4	0.133	POTENTIAL

Table D-14 Water quality Lake Murray and ORWBs test sites - South Lake Murray 2016 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	6.9	Lower TV < TSM < Upper TV	Step 1 / 2	5.3-8.0	0.003 / 0.003	LOW
TSS	10	10	5.0	TSM < Upper TV	Step 1	24	0.003	LOW
Ag-D	10	10	0.01	TSM < Upper TV	Step 1	0.05	0.003	LOW
As-D	10	10	0.20	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	0.50	TSM < Upper TV	Step 1	1.4	0.003	LOW
Fe-D	10	10	101	TSM < Upper TV	Step 1	340	0.003	LOW
Hg-D	10	10	0.04	TSM < Upper TV	Step 1	0.60	<0.001	LOW
Ni-D	10	10	0.50	TSM < Upper TV	Step 1	11	0.003	LOW
Pb-D	10	10	0.10	TSM < Upper TV	Step 1	3.4	0.003	LOW
Se-D	10	10	0.20	TSM < Upper TV	Step 1	11	0.003	LOW
Zn-D	10	10	6.0	TSM < Upper TV	Step 1	9.4	0.238	POTENTIAL

Table D-15 Water quality Lake Murray and ORWBs test sites - SG6 2016 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	2	2	6.9			5.3-8.0	NA	*LOW
TSS	2	2	86			24	NA	*LOW^
Ag-D	2	2	0.01			0.05	NA	*LOW
As-D	2	2	0.55			24	NA	*LOW
Cd-D	2	2	0.05			0.72	NA	*LOW
Cr-D	2	2	0.20			1	NA	*LOW
Cu-D	2	2	0.55			1.4	NA	*LOW
Fe-D	2	2	140			340	NA	*LOW
Hg-D	2	2	0.06			0.60	NA	*LOW
Ni-D	2	2	0.55			11	NA	*LOW
Pb-D	2	2	0.15			3.4	NA	*LOW
Se-D	2	2	0.20			11	NA	*LOW
Zn-D*	2	2	2.5			9.4	NA	*LOW

*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.

^ Shown as low risk even though the TV is exceeded as the TV in this case is not considered applicable to SG6 and off river water bodies.

Table D-16 Water quality Lake Murray and ORWBs test sites - Kukufionga 2016 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Kukufiong	N	N (Test)	Median	Result	Go to			
pH	1		7.5			5.3-8.0	NA	*LOW
TSS	1		5.0			23	NA	*LOW
Ag-D	1		0.01			0.05	NA	*LOW
As-D	1		2.6			24	NA	*LOW
Cd-D	1		0.05			0.72	NA	*LOW
Cr-D	1		0.2			1	NA	*LOW
Cu-D	1		0.5			2.5	NA	*LOW
Fe-D	1		2			340	NA	*LOW
Hg-D	1		0.04			0.60	NA	*LOW
Ni-D	1		0.5			11	NA	*LOW
Pb-D	1		0.1			3.4	NA	*LOW
Se-D	1		0.2			11	NA	*LOW
Zn-D	1		3			9.4	NA	*LOW

Table D-17 Water quality Lake Murray and ORWBs test sites - Zongamange 2016 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Zongamange	N	N (Test)	Median	Result	Go to			
pH	1		7.4			5.3-8.0	NA	*LOW
TSS	1		28			24	NA	*LOW^
Ag-D	1		0.01			0.05	NA	*LOW
As-D	1		1.0			24	NA	*LOW
Cd-D	1		0.05			0.72	NA	*LOW
Cr-D	1		0.2			1	NA	*LOW
Cu-D	1		0.7			2.5	NA	*LOW
Fe-D	1		22			340	NA	*LOW
Hg-D	1		0.04			0.60	NA	*LOW
Ni-D	1		0.7			11	NA	*LOW
Pb-D	1		0.1			3.4	NA	*LOW
Se-D	1		0.20			11	NA	*LOW
Zn-D	1		3.0			9.4	NA	*LOW

*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 D-18 Water quality Lake Murray and ORWBs test sites - Avu 2016 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Avu	N	N (Test)	Median	Result	Go to			
pH	1		6.5			5.3-8.0	NA	*LOW
TSS	1		5.0			23	NA	*LOW
Ag-D	1		0.01			0.05	NA	*LOW
As-D	1		0.4			24	NA	*LOW
Cd-D	1		0.05			0.72	NA	*LOW
Cr-D	1		0.4			1	NA	*LOW
Cu-D	1		0.5			1.4	NA	*LOW
Fe-D	1		183			340	NA	*LOW
Hg-D	1		0.10			0.60	NA	*LOW
Ni-D	1		0.60			11	NA	*LOW
Pb-D	1		0.10			3.4	NA	*LOW
Se-D	1		0.20			11	NA	*LOW
Zn-D	1		10			9.4	NA	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 D-19 Water quality Lake Murray and ORWBs test sites - Avu 2016 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Levame	N	N (Test)	Median	Result	Go to			
pH	1		7.8			5.3-8.0	NA	*LOW
TSS	1		30			23	NA	*LOW^
Ag-D	1		0.01			0.05	NA	*LOW
As-D	1		2.9			24	NA	*LOW
Cd-D	1		0.05			0.72	NA	*LOW
Cr-D	1		0.2			1	NA	*LOW
Cu-D	1		0.5			1.4	NA	*LOW
Fe-D	1		55			340	NA	*LOW
Hg-D	1		0.04			0.60	NA	*LOW
Ni-D	1		0.5			11	NA	*LOW
Pb-D	1		0.10			3.4	NA	*LOW
Se-D	1		0.20			11	NA	*LOW
Zn-D	1		5.0			9.4	NA	*LOW

*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.

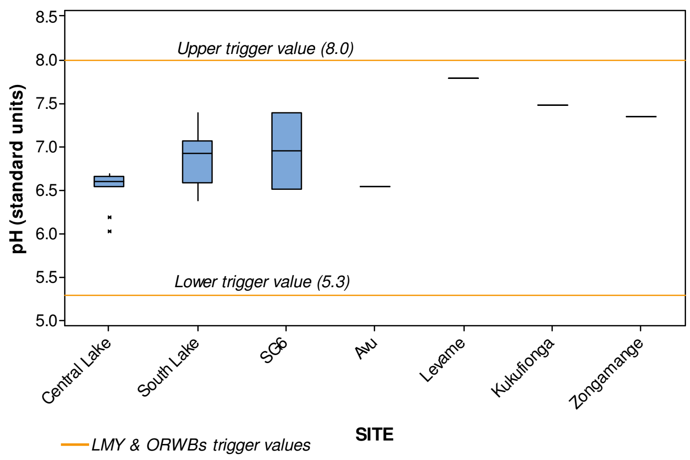

Figure D-29 pH in water Lake Murray and ORWBs test sites 2016

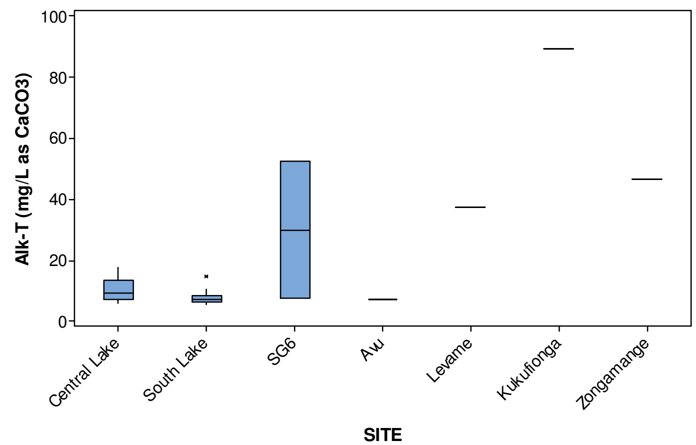

Figure D-30 Alkalinity in water Lake Murray and ORWBs test sites 2016

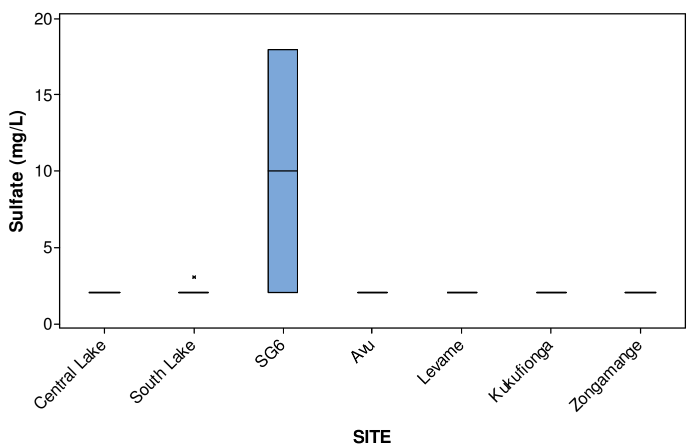

Figure D-31 Sulfate in water Lake Murray and ORWBs test sites 2016

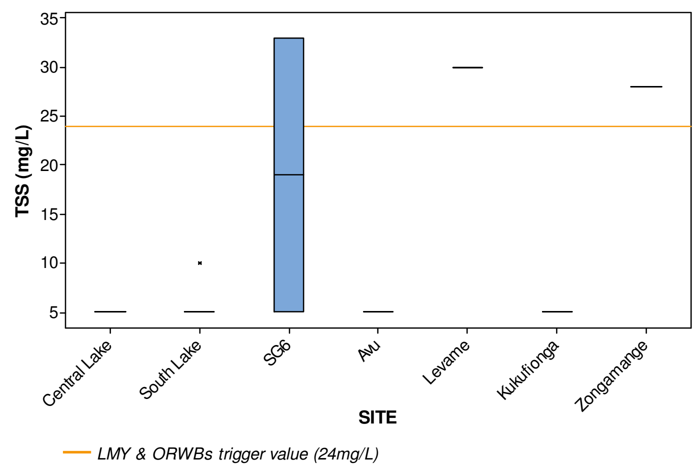

Figure D-32 TSS in water Lake Murray and ORWBs test sites 2016

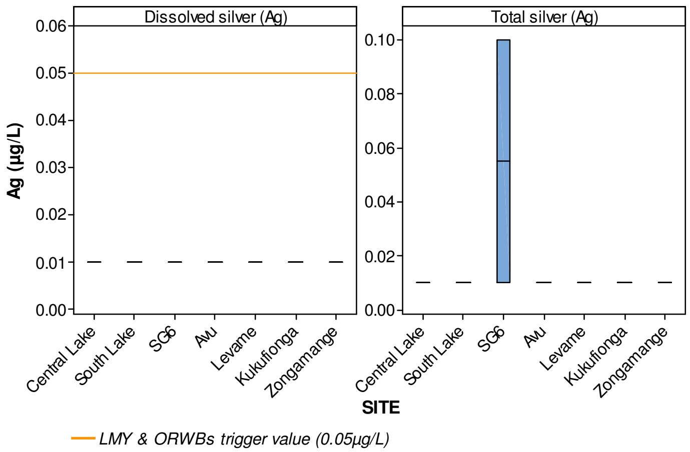

Figure D-33 Silver in water Lake Murray and ORWBs test sites 2016

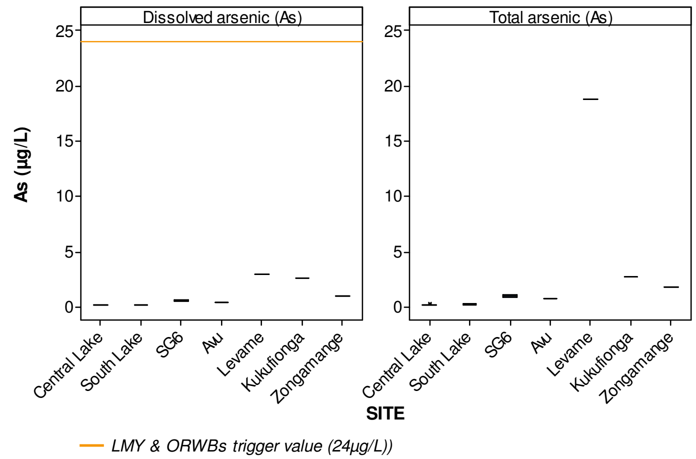

Figure D-34 As in water Lake Murray and ORWBs test sites 2016

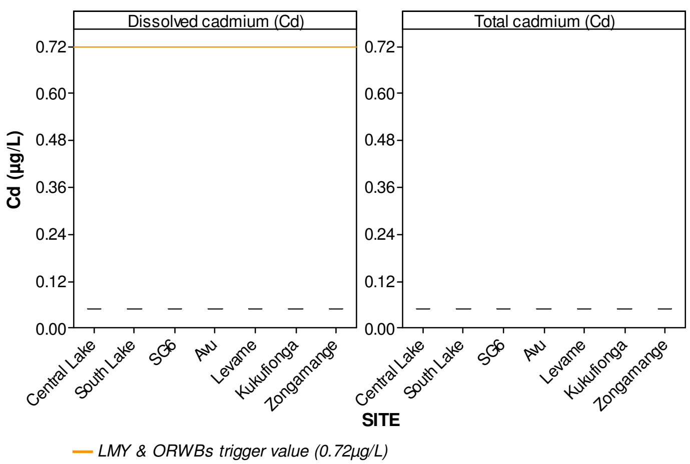

Figure D-35 Cadmium in water Lake Murray and ORWBs test sites 2016

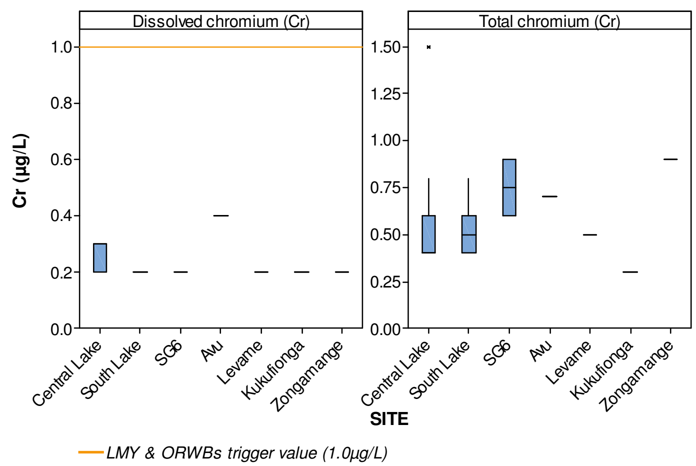

Figure D-36 Cr in water Lake Murray and ORWBs test sites 2016

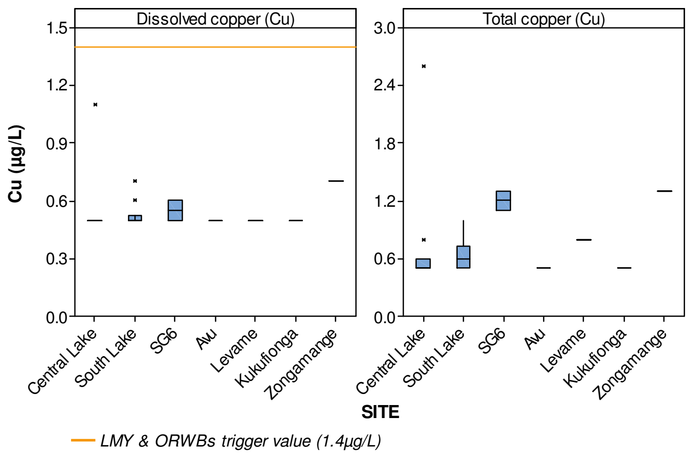

Figure D-37 Copper in water Lake Murray and ORWBs test sites 2016

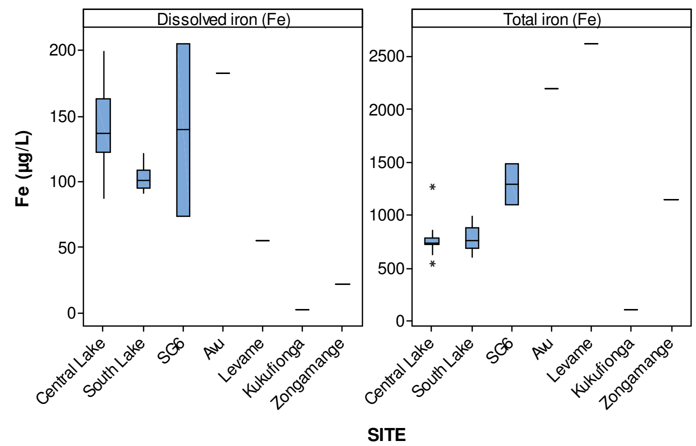

Figure D-38 Iron in water Lake Murray and ORWBs test sites 2016

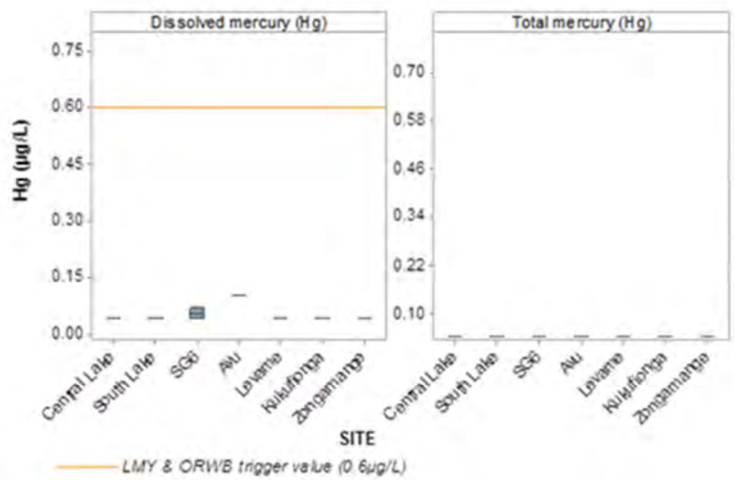

Figure D-39 Mercury in water Lake Murray and ORWBs test sites 2016

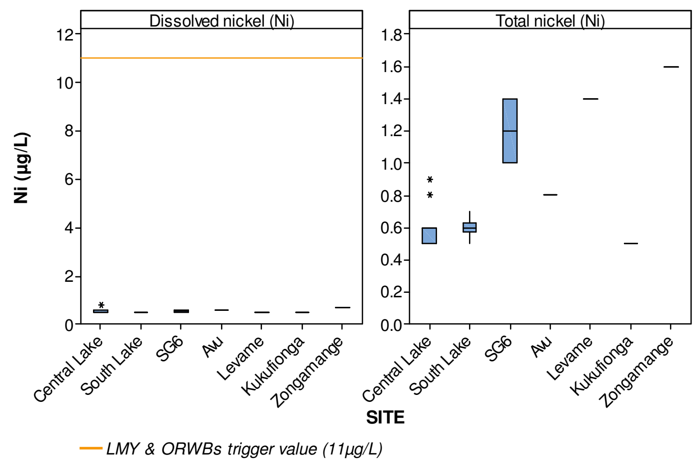

Figure D-40 Nickel in water Lake Murray and ORWBs test sites 2016

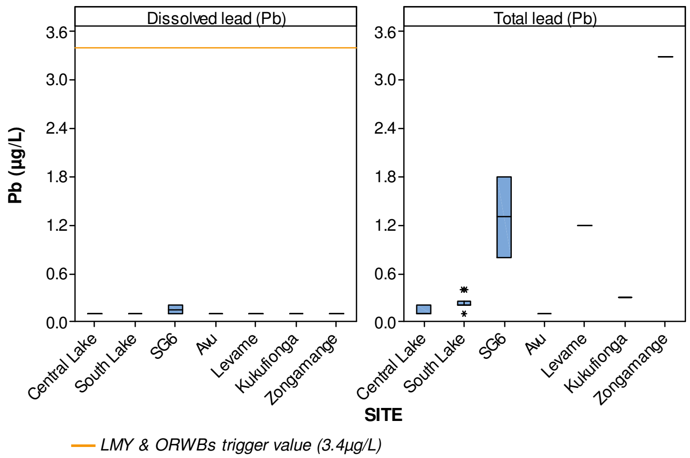

Figure D-41 Lead in water Lake Murray and ORWBs test sites 2016

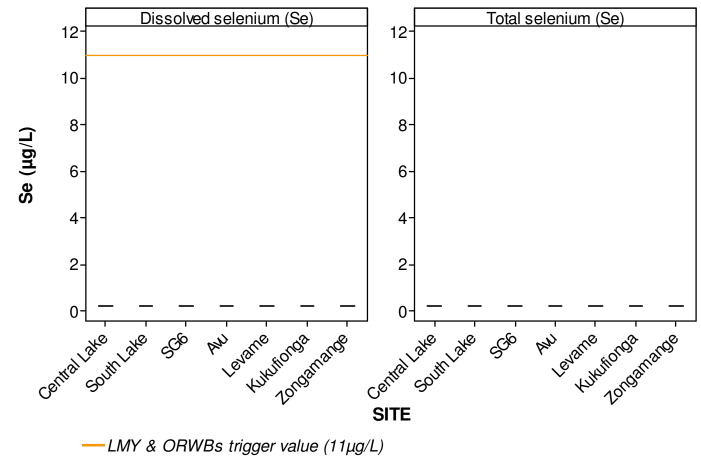

Figure D-42 Selenium in water Lake Murray and ORWBs test sites 2016

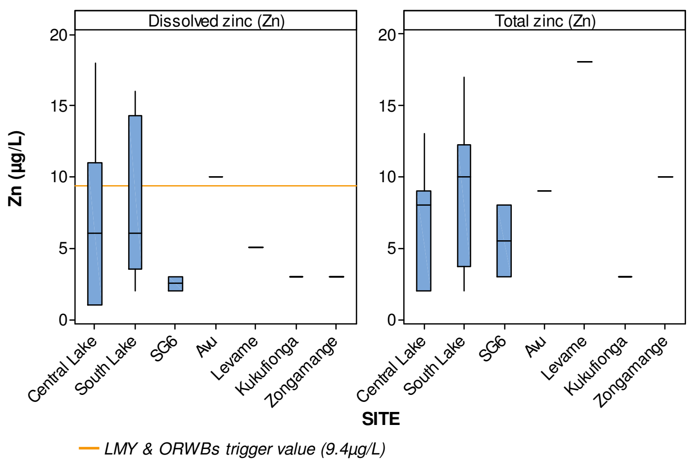

Figure D-43 Zinc in water Lake Murray and ORWBs test sites 2016

Table D-20 Performance assessment – Based on the trend of water quality indicators (all data) at Lake Murray and ORWB test sites between 2007 and 2015 using Spearman Rank Test.

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2007 - 2016
Central (Trend of all data 2007 - 2016)	pH	0.051	0.668	No change over time
	TSS	-0.077	0.524	No change over time
	Ag-D	-0.893	<0.001	Reduced over time
	As-D	-0.786	<0.001	Reduced over time
	Cd-D	-0.861	<0.001	Reduced over time
	Cr-D	-0.795	<0.001	Reduced over time
	Cu-D	-0.757	<0.001	Reduced over time
	Fe-D	-0.47	<0.001	Reduced over time
	Hg-D	-0.579	<0.001	Reduced over time
	Ni-D	-0.802	<0.001	Reduced over time
	Pb-D	-0.853	<0.001	Reduced over time
	Se-D	-0.499	0.002	Reduced over time
	Zn-D	0.434	<0.001	Increased over time
Southern (Trend of all data 2007 - 2016)	pH	-0.089	0.346	No change over time
	TSS	-0.284	0.003	Reduced over time
	Ag-D	-0.769	<0.001	Reduced over time
	As-D	-0.529	<0.001	Reduced over time
	Cd-D	-0.761	<0.001	Reduced over time
	Cr-D	-0.736	<0.001	Reduced over time
	Cu-D	-0.666	<0.001	Reduced over time
	Fe-D	-0.295	0.001	Reduced over time
	Hg-D	-0.769	<0.001	Reduced over time
	Ni-D	-0.758	<0.001	Reduced over time
	Pb-D	-0.761	<0.001	Reduced over time
	Se-D	0.785	<0.001	Increased over time
	Zn-D	0.437	<0.001	Increased over time
SG6 (Trend of all data 2007 - 2016)	pH	-0.111	0.624	No change over time
	TSS	-0.002	0.993	No change over time
	Ag-D	-0.912	<0.001	Reduced over time
	As-D	-0.339	0.097	No change over time
	Cd-D	-0.86	<0.001	Reduced over time
	Cr-D	-0.635	0.001	Reduced over time
	Cu-D	-0.477	0.016	Reduced over time
	Fe-D	-0.39	0.054	No change over time
	Hg-D	-0.617	0.001	Reduced over time
	Ni-D	-0.724	<0.001	Reduced over time
	Pb-D	-0.777	<0.001	Reduced over time
	Se-D	-0.457	0.065	No change over time
	Zn-D	-0.017	0.936	No change over time

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2007 - 2016
Kukufionga (Trend of all data 2007 - 2016)	pH	-0.693	<0.001	Reduced over time
	TSS	0.217	0.298	No change over time
	Ag-D	-0.869	<0.001	Reduced over time
	As-D	0.457	0.013	Increased over time
	Cd-D	-0.861	<0.001	Reduced over time
	Cr-D	-0.828	<0.001	Reduced over time
	Cu-D	-0.789	<0.001	Reduced over time
	Fe-D	-0.135	0.485	No change over time
	Hg-D	-0.346	0.066	No change over time
	Ni-D	-0.861	<0.001	Reduced over time
	Pb-D	-0.861	<0.001	Reduced over time
	Se-D	-0.739	0.006	Reduced over time
	Zn-D	0.04	0.836	No change over time
Zongamange (Trend of all data 2007 - 2016)	pH	-0.127	0.727	No change over time
	TSS	0.642	0.062	No change over time
	Ag-D	-0.967	<0.001	Reduced over time
	As-D	0.59	0.034	Increased over time
	Cd-D	-0.919	<0.001	Reduced over time
	Cr-D	-0.762	0.002	Reduced over time
	Cu-D	-0.779	0.002	Reduced over time
	Fe-D	-0.682	0.01	Reduced over time
	Hg-D	-0.334	0.264	No change over time
	Ni-D	-0.779	0.002	Reduced over time
	Pb-D	-0.919	<0.001	Reduced over time
	Se-D	-0.75	0.02	Reduced over time
	Zn-D	-0.413	0.16	No change over time
Avu (Trend of all data 2007 - 2016)	pH	0.245	0.378	No change over time
	TSS	0.256	0.376	No change over time
	Ag-D	-0.908	<0.001	Reduced over time
	As-D	-0.31	0.21	No change over time
	Cd-D	-0.853	<0.001	Reduced over time
	Cr-D	-0.506	0.032	Reduced over time
	Cu-D	-0.389	0.11	No change over time
	Fe-D	-0.39	0.11	No change over time
	Hg-D	-0.015	0.953	No change over time
	Ni-D	-0.312	0.207	No change over time
	Pb-D	-0.462	0.053	No change over time
	Se-D	-0.56	0.037	Reduced over time
	Zn-D	0.057	0.823	No change over time

LOR = Analytical Limit of Reporting

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

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 - SG1 2016 median (WAE whole sediment mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
SG1	N	N (Test)	Median	Result	Go to			
Ag-WAE							Not sampled	
As-WAE							Not sampled	
Cd-WAE							Not sampled	
Cr-WAE							Not sampled	
Cu-WAE							Not sampled	
Hg-WAE							Not sampled	
Ni-WAE							Not sampled	
Pb-WAE							Not sampled	
Se-WAE							Not sampled	
Zn-WAE							Not sampled	

Table E-3 Sediment quality upper river test sites - SG2 2016 median (WAE whole sediment mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
SG2	N	N (Test)	Median	Result	Go to			
Ag-WAE	8	8	0.075	TSM < Upper TV	Step 1	1.0	0.007	LOW
As-WAE	8	8	6.3	TSM < Upper TV	Step 1	20	0.007	LOW
Cd-WAE	8	8	1.1	TSM < Upper TV	Step 1	1.5	0.181	*LOW
Cr-WAE	8	8	5.0	TSM < Upper TV	Step 1	80	0.007	LOW
Cu-WAE	8	8	10.5	TSM < Upper TV	Step 1	65	0.007	LOW
Hg-WAE	8	8	0.025	TSM < Upper TV	Step 1	0.15	0.007	LOW
Ni-WAE	8	8	6.6	TSM < Upper TV	Step 1	26	0.007	LOW
Pb-WAE	8	8	152	TSM > Upper TV	Step 2	50	NA	POTENTIAL
Se-WAE	8	7	0.15	TSM < Upper TV	Step 1	0.50	0.011	LOW
Zn-WAE	8	8	152	TSM < Upper TV	Step 1	200	0.221	*LOW

*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 E-4 Sediment quality upper river test sites - Wasiba 2016 median (WAE whole sediment mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Wasiba	N	N (Test)	Median	Result	Go to			
Ag-WAE	12	11	0.05	TSM < Upper TV	Step 1	1.0	0.002	LOW
As-WAE	12	12	4.3	TSM < Upper TV	Step 1	20	0.001	LOW
Cd-WAE	12	12	0.52	TSM < Upper TV	Step 1	1.5	0.001	LOW
Cr-WAE	12	12	3.5	TSM < Upper TV	Step 1	80	0.001	LOW
Cu-WAE	12	12	9.3	TSM < Upper TV	Step 1	65	0.001	LOW
Hg-WAE	12	10	0.015	TSM < Upper TV	Step 1	0.15	0.003	LOW
Ni-WAE	12	12	9.8	TSM < Upper TV	Step 1	26	0.073	POTENTIAL
Pb-WAE	12	12	35	TSM < Upper TV	Step 1	50	0.054	POTENTIAL
Se-WAE	12	12	0.10	TSM < Upper TV	Step 1	0.50	0.001	LOW
Zn-WAE	12	12	71	TSM < Upper TV	Step 1	200	0.001	LOW

Table E-5 Sediment quality upper river test sites - Wankipe 2016 median (WAE whole sediment mg/kg)

Test Site				Initial Assessment			Statistical Test Result (p=0.05)	Risk Assessment
Wankipe	N	N (Test)	Median	Result	Go to	TV		
Ag-WAE	11	10	0.05	TSM < Upper TV	Step 1	1.0	0.003	LOW
As-WAE	11	11	3.6	TSM < Upper TV	Step 1	20	0.003	LOW
Cd-WAE	11	11	0.40	TSM < Upper TV	Step 1	1.5	0.002	LOW
Cr-WAE	11	11	3.3	TSM < Upper TV	Step 1	80	0.002	LOW
Cu-WAE	11	11	7.6	TSM < Upper TV	Step 1	65	0.002	LOW
Hg-WAE	11	10	0.015	TSM < Upper TV	Step 1	0.15	0.003	LOW
Ni-WAE	11	11	9.8	TSM < Upper TV	Step 1	26	0.002	LOW
Pb-WAE	11	11	29	TSM < Upper TV	Step 1	50	0.0071	LOW
Se-WAE	11	11	0.10	TSM < Upper TV	Step 1	0.50	0.002	LOW
Zn-WAE	11	11	53	TSM < Upper TV	Step 1	200	0.002	LOW

Table E-6 Sediment quality upper river test sites - SG3 2016 median (WAE whole sediment mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
SG3	N	N (Test)	Median	Result	Go to			
Ag-WAE	26	21	0.05	TSM < Upper TV	Step 1	1.0	<0.001	LOW
As-WAE	26	26	4.0	TSM < Upper TV	Step 1	20	<0.001	LOW
Cd-WAE	26	26	0.45	TSM < Upper TV	Step 1	1.5	<0.001	LOW
Cr-WAE	26	26	3.3	TSM < Upper TV	Step 1	80	<0.001	LOW
Cu-WAE	26	26	7.6	TSM < Upper TV	Step 1	65	<0.001	LOW
Hg-WAE	26	25	0.10	TSM < Upper TV	Step 1	0.15	<0.001	LOW
Ni-WAE	26	26	9.5	TSM < Upper TV	Step 1	26	<0.001	LOW
Pb-WAE	26	25	31	TSM < Upper TV	Step 1	50	<0.001	LOW
Se-WAE	26	21	0.10	TSM < Upper TV	Step 1	0.50	<0.001	LOW
Zn-WAE	26	26	59	TSM < Upper TV	Step 1	200	<0.001	LOW

Table E-7 Sediment quality lower river test sites - Bebelubi 2016 median (WAE whole sediment mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Bebelubi	N	N (Test)	Median	Result	Go to			
Ag-WAE	3	3	0.05			1.0	NA	*LOW
As-WAE	3	3	4.0			20	NA	*LOW
Cd-WAE	3	3	0.36			1.5	NA	*LOW
Cr-WAE	3	3	4.1			80	NA	*LOW
Cu-WAE	3	3	6.8			65	NA	*LOW
Hg-WAE	3	3	0.01			0.15	NA	*LOW
Ni-WAE	3	3	16			21	NA	*LOW
Pb-WAE	3	3	21			50	NA	*LOW
Se-WAE	3	3	0.10			0.50	NA	*LOW
Zn-WAE	3	3	44			200	NA	*LOW

*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 E-8 Sediment quality lower river test sites - SG4/SG4 2016 median (WAE whole sediment mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Tium/SG4	N	N (Test)	Median	Result	Go to			
Ag-WAE	3	3	0.50			1.0	NA	*LOW
As-WAE	3	3	3.6			20	NA	*LOW
Cd-WAE	3	3	0.35			1.5	NA	*LOW
Cr-WAE	3	3	4.4			80	NA	*LOW
Cu-WAE	3	3	6.6			65	NA	*LOW
Hg-WAE	3	3	0.01			0.15	NA	*LOW
Ni-WAE	3	3	15			21	NA	*LOW
Pb-WAE	3	3	17			50	NA	*LOW
Se-WAE	3	3	0.20			0.50	NA	*LOW
Zn-WAE	3	3	49			200	NA	*LOW

*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 E-9 Sediment quality lower river test sites - SG5 2016 median (WAE whole sediment mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
SG5	N	N (Test)	Median	Result	Go to			
Ag-WAE	3	3	0.50			1.0	NA	*LOW
As-WAE	3	3	3.2			20	NA	*LOW
Cd-WAE	3	3	0.22			1.5	NA	*LOW
Cr-WAE	3	3	2.8			80	NA	*LOW
Cu-WAE	3	3	6.3			65	NA	*LOW
Hg-WAE	3	3	0.01			0.2	NA	*LOW
Ni-WAE	3	3	8.1			21	NA	*LOW
Pb-WAE	3	3	16			50	NA	*LOW
Se-WAE	3	3	0.10			0.5	NA	*LOW
Zn-WAE	3	3	38			200	NA	*LOW

*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.

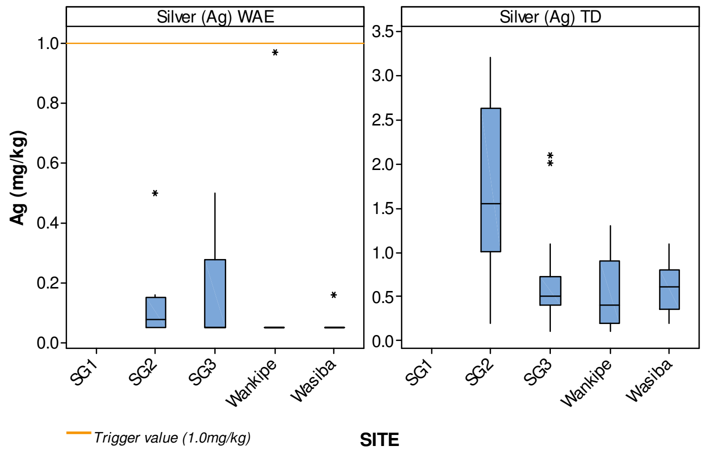

Figure E-1 Silver in sediment upper river test sites 2016

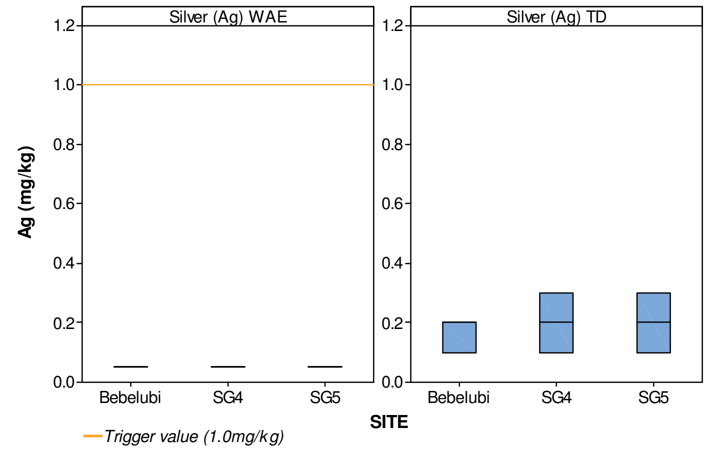

Figure E-2 Silver in sediment lower river test sites 2016

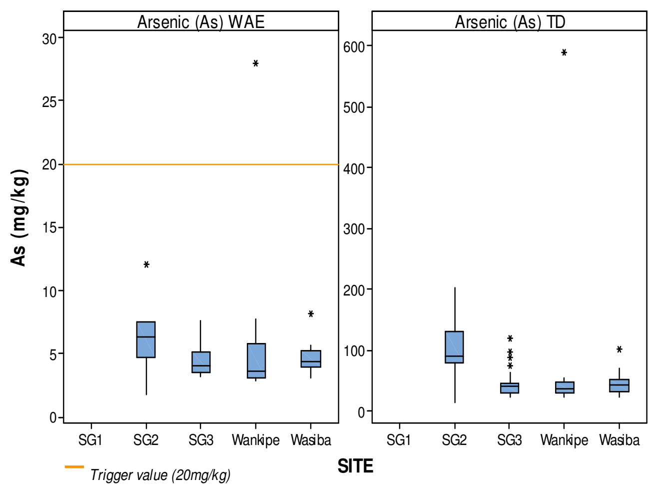

Figure E-3 Arsenic in sediment upper river test sites 2016

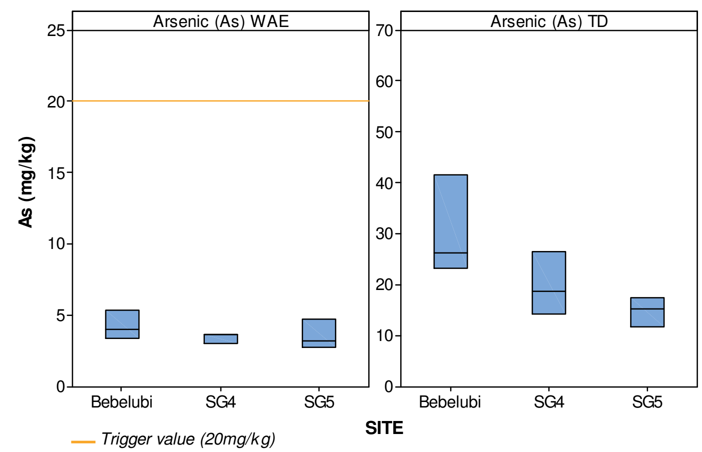

Figure E-4 Arsenic in sediment lower river test sites 2016

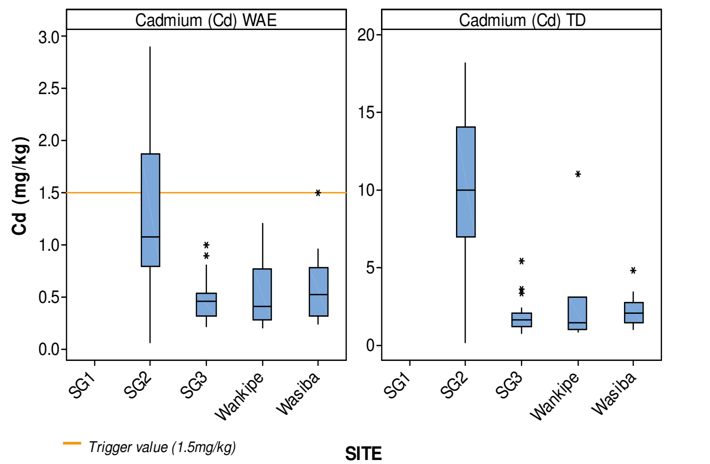

Figure E-5 Cadmium in sediment upper river test sites 2016

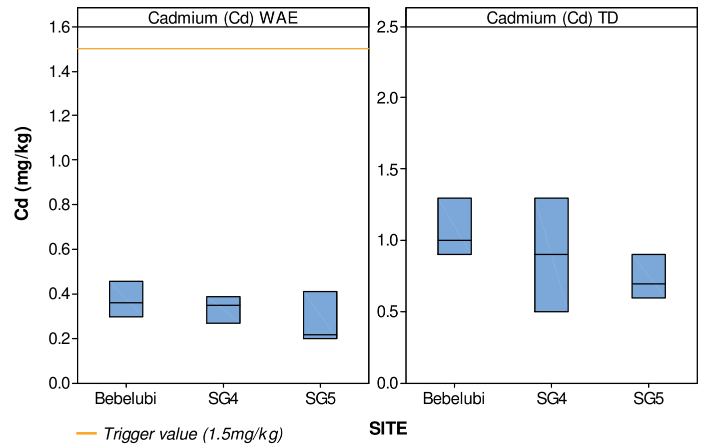

Figure E-6 Cadmium in sediment lower river test sites 2016

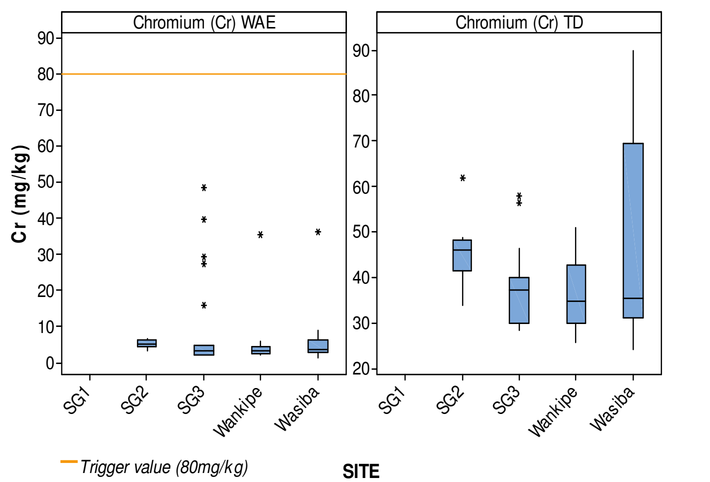

Figure E-7 Chromium in sediment upper river test sites 2016

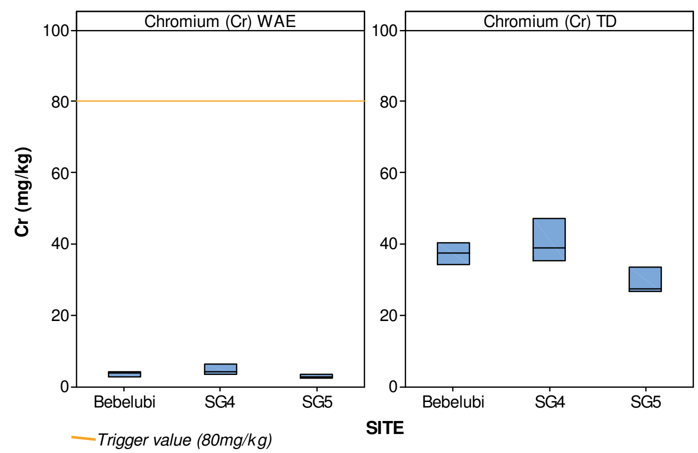

Figure E-8 Chromium in sediment lower river test sites 2016

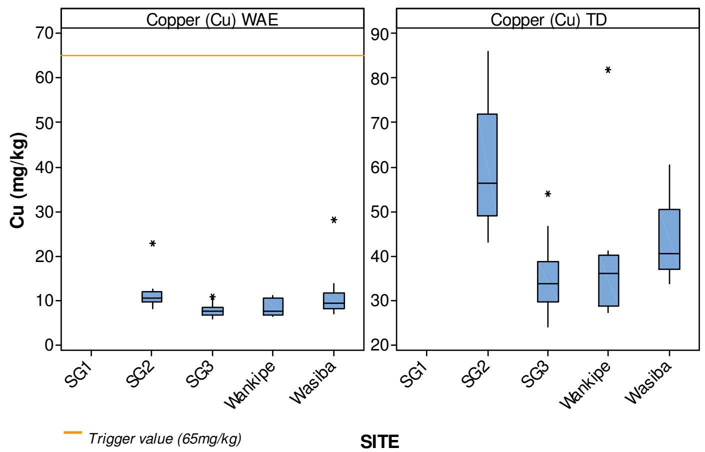

Figure E-9 Copper in sediment upper river test sites 2016

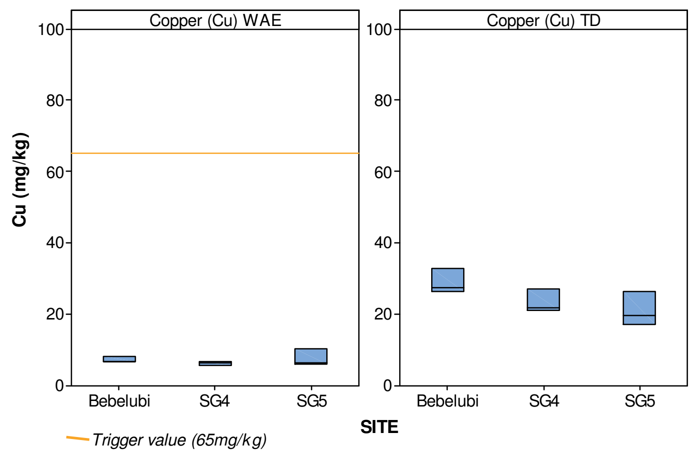

Figure E-10 Copper in sediment lower river test sites 2016

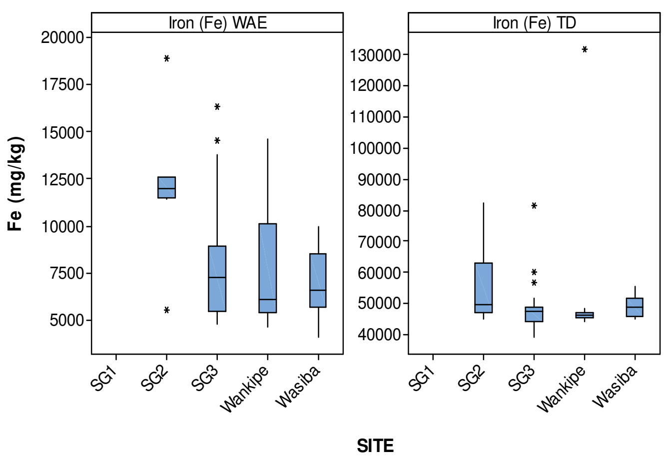

Figure E-11 Iron in sediment upper river test sites 2016

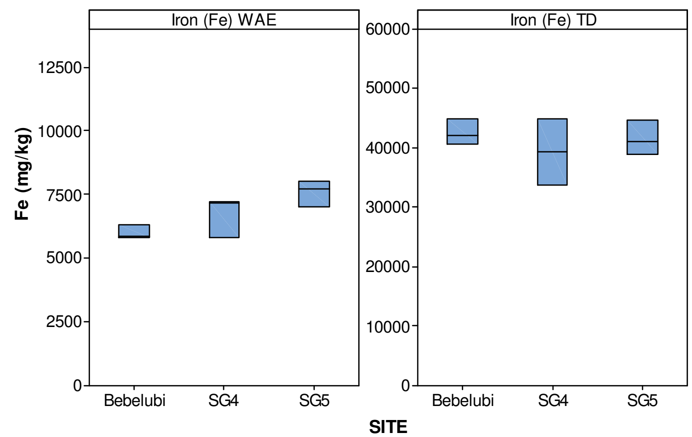

Figure E-12 Iron in sediment lower river test sites 2016

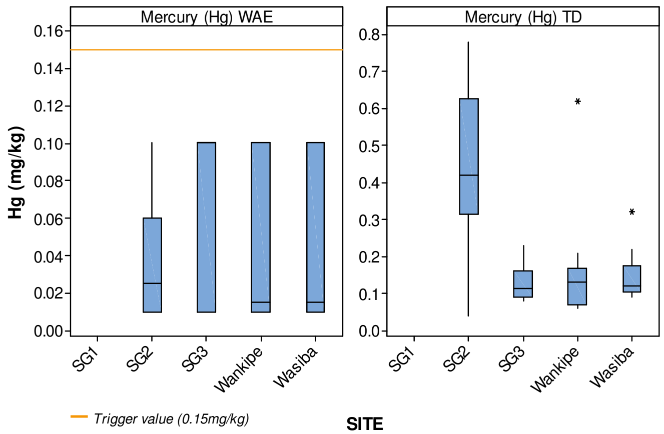

Figure E-13 Mercury in sediment upper river test sites 2016

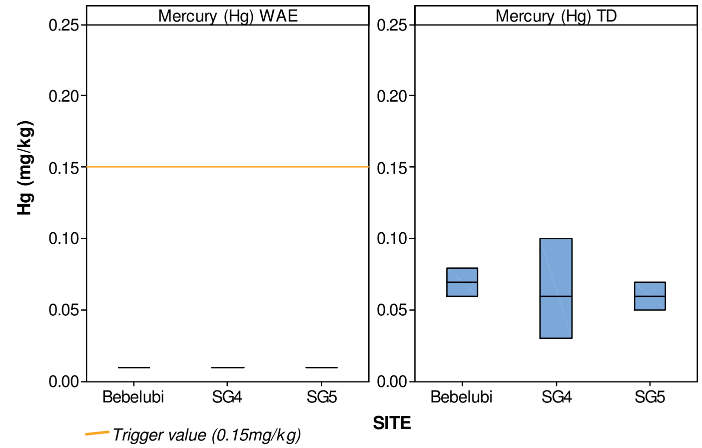

Figure E-14 Mercury in sediment lower river test sites 2016

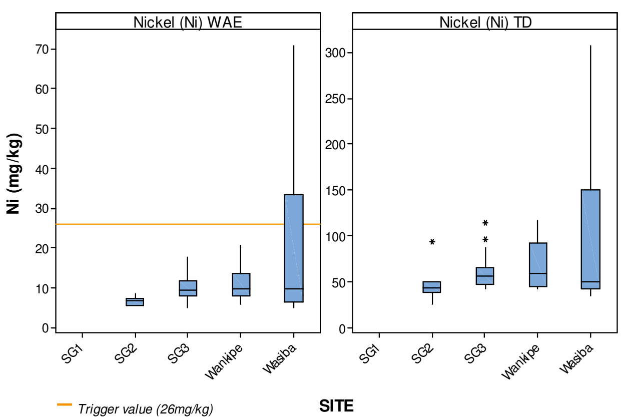

Figure E-15 Nickel in sediment upper river test sites 2016

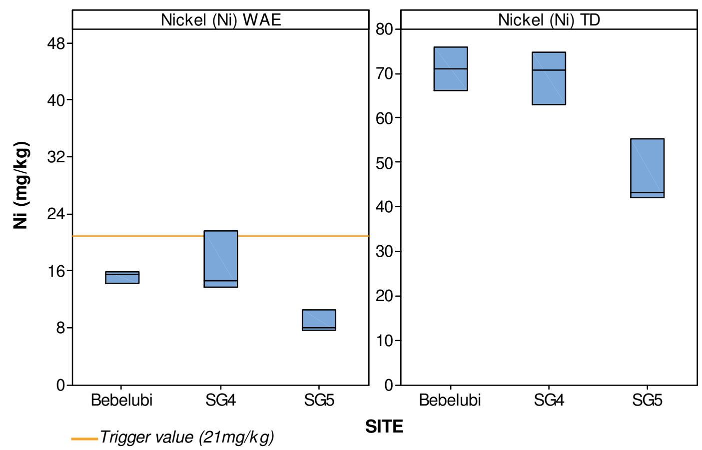

Figure E-16 Nickel in sediment lower river test sites 2016

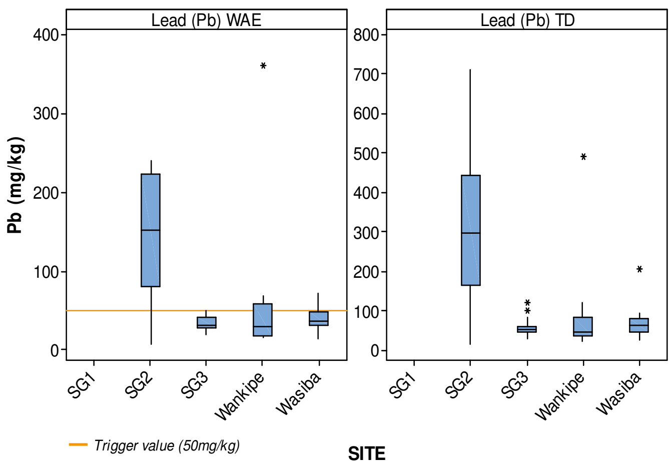

Figure E-17 Lead in sediment upper river test sites 2016

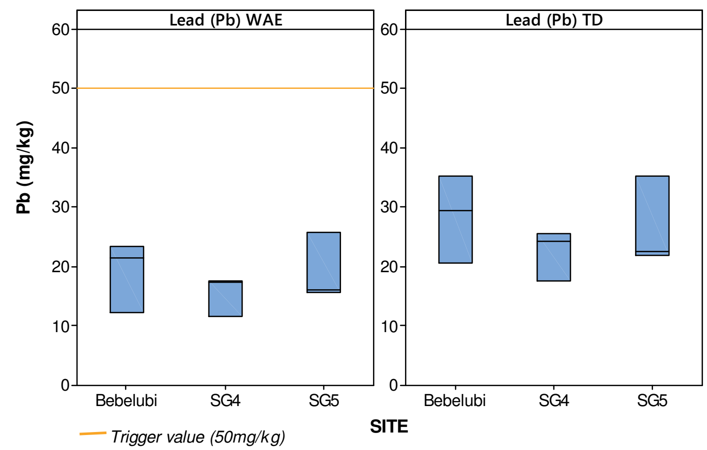

Figure E-18 Lead in sediment lower river test sites 2016

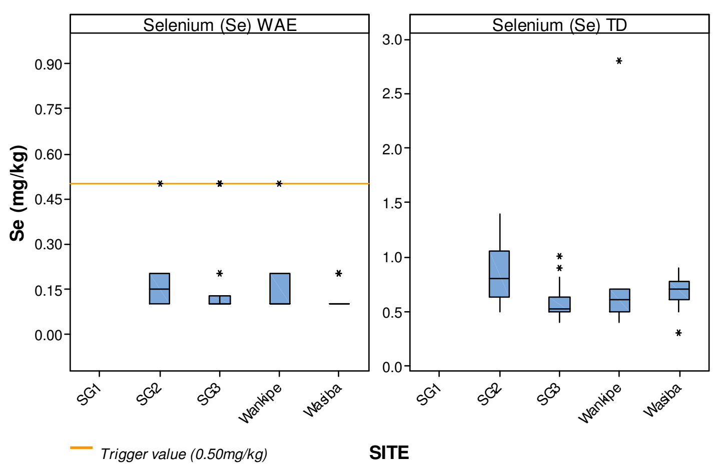

Figure E-19 Selenium in sediment upper river test sites 2016

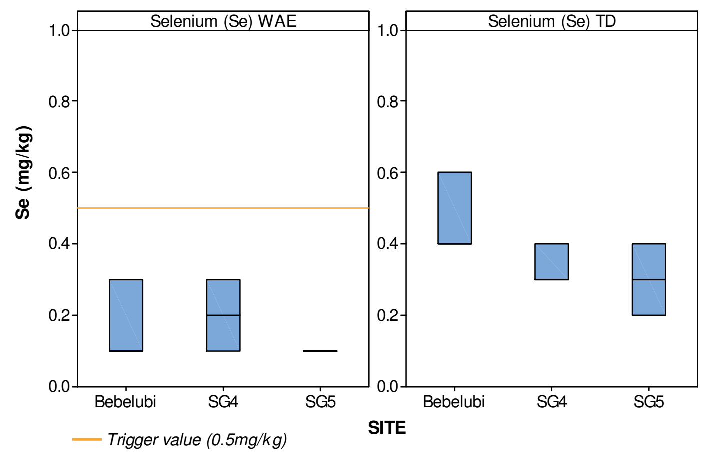

Figure E-20 Selenium in sediment lower river test sites 2016

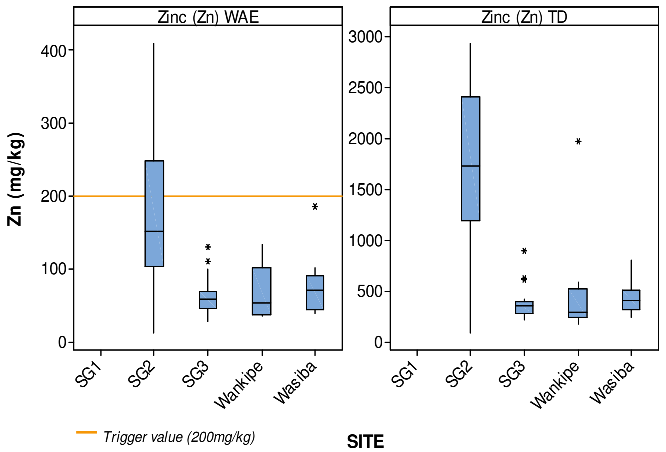

Figure E-21 Zinc in sediment upper river test sites 2016

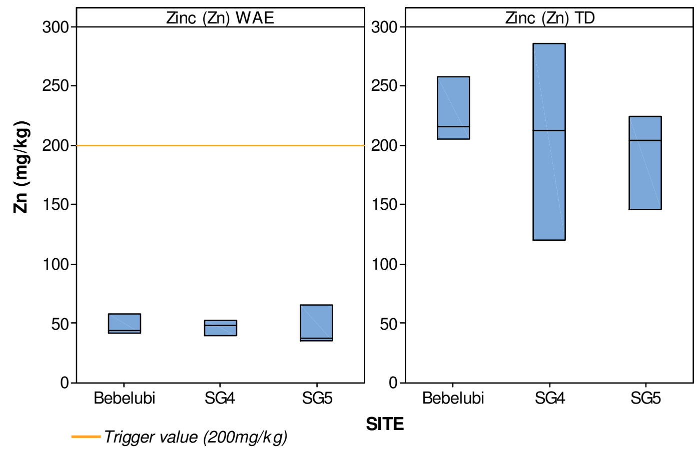

Figure E-22 Zinc in sediment lower river test sites 2016

Table E-10 Performance assessment – Based on the trend of sediment quality indicators (all data) at upper river test sites between 2007 and 2015 using Spearman Rank Test.

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 - 2016)	Ag-WAE	-0.681	<0.001	Reduced over time
	As-WAE	0.363	0.03	Increased over time
	Cd-WAE	0.279	0.099	No change over time
	Cr-WAE	0.579	<0.001	Increased over time
	Cu-WAE	0.079	0.646	No change over time
	Fe-WAE	0.562	<0.001	Increased over time
	Pb-WAE	0.331	0.049	Increased over time
	Hg-WAE	-0.045	0.794	No change over time
	Ni-WAE	0.393	0.018	Increased over time
	Se-WAE	-0.686	<0.001	Reduced over time
	Zn-WAE	0.339	0.043	Increased over time
Wasiba (Trend of all data 2013 - 2016)	Ag-WAE	-0.795	<0.001	Reduced over time
	As-WAE	0.031	0.857	No change over time
	Cd-WAE	-0.04	0.814	No change over time
	Cr-WAE	0.114	0.501	No change over time
	Cu-WAE	0.117	0.491	No change over time
	Fe-WAE	-0.001	0.995	No change over time
	Pb-WAE	-0.225	0.18	No change over time
	Hg-WAE	0.309	0.071	No change over time
	Ni-WAE	0.099	0.559	No change over time
	Se-WAE	-0.784	<0.001	Reduced over time
	Zn-WAE	-0.192	0.255	No change over time
Wankipe (Trend of all data 2013 - 2016)	Ag-WAE	-0.619	<0.001	Reduced over time
	As-WAE	0.255	0.095	No change over time
	Cd-WAE	0.006	0.97	No change over time
	Cr-WAE	0.414	0.005	Increased over time
	Cu-WAE	0.338	0.025	Increased over time
	Fe-WAE	0.236	0.123	No change over time
	Pb-WAE	0.087	0.575	No change over time
	Hg-WAE	-0.08	0.612	No change over time
	Ni-WAE	0.307	0.042	Increased over time
	Se-WAE	-0.722	<0.001	Reduced over time
	Zn-WAE	0.221	0.149	No change over time

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend
SG3 (Trend of all data 2013 - 2016)	Ag-WAE	-0.503	<0.001	Reduced over time
	As-WAE	0.712	<0.001	Increased over time
	Cd-WAE	0.128	0.089	No change over time
	Cr-WAE	0.648	<0.001	Increased over time
	Cu-WAE	0.656	<0.001	Increased over time
	Fe-WAE	0.647	<0.001	Increased over time
	Pb-WAE	0.606	<0.001	Increased over time
	Hg-WAE	0.04	0.601	No change over time
	Ni-WAE	0.15	0.046	Increased over time
	Se-WAE	-0.56	<0.001	Reduced over time
	Zn-WAE	0.586	<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 E-11 Performance assessment – Based on the trend of sediment quality indicators (all data) at lower river test sites between 2007 and 2015 using Spearman Rank Test.

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend
Bebelubi (Trend of all data 2013 - 2016)	Ag-WAE	-0.695	0.004	Reduced over time
	As-WAE	0.327	0.234	No change over time
	Cd-WAE	-0.587	0.021	Reduced over time
	Cr-WAE	0.689	0.005	Increased over time
	Cu-WAE	0.503	0.056	No change over time
	Fe-WAE	0.238	0.393	No change over time
	Hg-WAE	-0.371	0.173	No change over time
	Ni-WAE	0.573	0.025	Increased over time
	Pb-WAE	-0.047	0.869	No change over time
	Se-WAE	-0.691	0.004	Reduced over time
	Zn-WAE	0.399	0.141	No change over time
SG4 (Trend of all data 2013 - 2016)	Ag-WAE	-0.662	0.004	Reduced over time
	As-WAE	0.286	0.265	No change over time
	Cd-WAE	-0.662	0.004	Reduced over time
	Cr-WAE	0.73	0.001	Increased over time
	Cu-WAE	0.481	0.05	Increased over time
	Fe-WAE	0.509	0.037	Increased over time
	Hg-WAE	-0.381	0.131	No change over time
	Ni-WAE	0.461	0.062	No change over time
	Pb-WAE	0.284	0.269	No change over time
	Se-WAE	-0.662	0.004	Reduced over time
	Zn-WAE	0.611	0.009	Increased over time
SG5 (Trend of all data 2013 - 2016)	Ag-WAE	-0.633	0.004	Reduced over time
	As-WAE	0.150	0.540	No change over time
	Cd-WAE	-0.216	0.375	No change over time
	Cr-WAE	0.065	0.792	No change over time
	Cu-WAE	0.171	0.483	No change over time
	Fe-WAE	0.116	0.637	No change over time
	Hg-WAE	-0.113	0.645	No change over time
	Ni-WAE	0.105	0.667	No change over time
	Pb-WAE	0.407	0.084	No change over time
	Se-WAE	-0.633	0.004	Reduced over time
	Zn-WAE	0.159	0.516	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-12 Sediment quality Lake Murray and ORWBs test sites Central Lake 2016 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Central	N	N (Test)	Median	Result	Go to			
Ag-WAE	15	15	0.12	TSM < TV	Step 1	1.0	<0.001	LOW
As-WAE	15	15	2.6	TSM < TV	Step 1	20	<0.001	LOW
Cd-WAE	15	15	0.13	TSM < TV	Step 1	1.5	<0.001	LOW
Cr-WAE	15	15	6.4	TSM < TV	Step 1	80	<0.001	LOW
Cu-WAE	15	15	13	TSM < TV	Step 1	65	<0.001	LOW
Hg-WAE	15	15	0.02	TSM < TV	Step 1	0.15	<0.001	LOW
Ni-WAE	15	15	11	TSM < TV	Step 1	21	<0.001	LOW
Pb-WAE	15	15	22	TSM < TV	Step 1	50	<0.001	LOW
Se-WAE*	15	15	0.10	TSM < TV	Step 1	0.32	<0.001	LOW
Zn-WAE	15	15	54	TSM < TV	Step 1	200	<0.001	LOW

Table E-13 Sediment quality Lake Murray and ORWBs test sites South Lake 2016 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Southern	N	N (Test)	Median	Result	Go to			
Ag-WAE	9	9	0.06	TSM < TV	Step 1	1.0	0.005	LOW
As-WAE	9	9	4.9	TSM < TV	Step 1	20	0.005	LOW
Cd-WAE	9	9	0.26	TSM < TV	Step 1	1.5	0.005	LOW
Cr-WAE	9	9	3.9	TSM < TV	Step 1	80	0.005	LOW
Cu-WAE	9	9	14	TSM < TV	Step 1	65	0.005	LOW
Hg-WAE	9	9	0.01	TSM < TV	Step 1	0.15	0.005	LOW
Ni-WAE	9	9	8.6	TSM < TV	Step 1	21	0.005	LOW
Pb-WAE	9	9	42	TSM < TV	Step 1	50	0.318	POTENTIAL
Se-WAE	9	9	0.10	TSM < TV	Step 1	0.32	0.005	LOW
Zn-WAE	9	9	65	TSM < TV	Step 1	200	0.005	LOW

*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 E-14 Sediment quality Lake Murray and ORWBs test sites SG6 2016 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
SG6	N	N (Test)	Median	Result	Go to			
Ag-WAE	2	2	0.05			1.0	Direct Comparison	LOW
As-WAE	2	2	4.1			20	Direct Comparison	LOW
Cd-WAE	2	2	0.19			1.5	Direct Comparison	LOW
Cr-WAE	2	2	4.7			80	Direct Comparison	LOW
Cu-WAE	2	2	12			65	Direct Comparison	LOW
Hg-WAE	2	2	0.02			0.15	Direct Comparison	LOW
Ni-WAE	2	2	6.8			21	Direct Comparison	LOW
Pb-WAE	2	2	29			50	Direct Comparison	LOW
Se-WAE	2	2	0.10			0.32	Direct Comparison	LOW
Zn-WAE	2	2	44			200	Direct Comparison	LOW

*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 E-15 Sediment quality Lake Murray and ORWBs test sites Kukufionga 2016 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Kukufionga	N	N (Test)	Median	Result	Go to			
Ag-WAE	1		0.05			1.0	Direct Comparison	LOW
As-WAE	1		8.2			20	Direct Comparison	LOW
Cd-WAE	1		0.38			1.5	Direct Comparison	LOW
Cr-WAE	1		4.5			80	Direct Comparison	LOW
Cu-WAE	1		18			65	Direct Comparison	LOW
Hg-WAE	1		0.01			0.15	Direct Comparison	LOW
Ni-WAE	1		9.2			21	Direct Comparison	LOW
Pb-WAE	1		61			50	Direct Comparison	POTENTIAL
Se-WAE	1		0.10			0.32	Direct Comparison	LOW
Zn-WAE	1		98			200	Direct Comparison	LOW

*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 E-16 Sediment quality Lake Murray and ORWBs test sites Zongamange 2016 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Zongamange	N	N (Test)	Median	Result	Go to			
Ag-WAE	1		0.05			1.0	Direct Comparison	LOW
As-WAE	1		3.7			20	Direct Comparison	LOW
Cd-WAE	1		0.45			1.5	Direct Comparison	LOW
Cr-WAE	1		3.4			80	Direct Comparison	LOW
Cu-WAE	1		15			65	Direct Comparison	LOW
Hg-WAE	1		0.01			0.15	Direct Comparison	LOW
Ni-WAE	1		11			21	Direct Comparison	LOW
Pb-WAE	1		30			50	Direct Comparison	LOW
Se-WAE	1		0.10			0.32	Direct Comparison	LOW
Zn-WAE	1		73			200	Direct Comparison	LOW

*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 E-17 Sediment quality Lake Murray and ORWBs test sites Avu 2016 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Avu	N	N (Test)	Median	Result	Go to			
Ag-WAE	1		0.11			1.0	Direct Comparison	LOW
As-WAE	1		1.8			20	Direct Comparison	LOW
Cd-WAE	1		0.24			1.5	Direct Comparison	LOW
Cr-WAE	1		3.1			80	Direct Comparison	LOW
Cu-WAE	1		24			65	Direct Comparison	LOW
Hg-WAE	1		0.01			0.15	Direct Comparison	LOW
Ni-WAE	1		11			21	Direct Comparison	LOW
Pb-WAE	1		25			50	Direct Comparison	LOW
Se-WAE*	1		0.2			0.32	Direct Comparison	LOW
Zn-WAE	1		86			200	Direct Comparison	LOW

*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 E-18 Sediment quality Lake Murray and ORWBs test sites Levame 2016 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Levame	N	N (Test)	Median	Result	Go to			
Ag-WAE			0.05			1.0	Direct Comparison	LOW
As-WAE			3.2			20	Direct Comparison	LOW
Cd-WAE			0.37			1.5	Direct Comparison	LOW
Cr-WAE			2.9			80	Direct Comparison	LOW
Cu-WAE			9			65	Direct Comparison	LOW
Hg-WAE			0.01			0.15	Direct Comparison	LOW
Ni-WAE			8.1			21	Direct Comparison	LOW
Pb-WAE			20			50	Direct Comparison	LOW
Se-WAE*			0.10			0.32	Direct Comparison	LOW
Zn-WAE			59			200	Direct Comparison	LOW

*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.

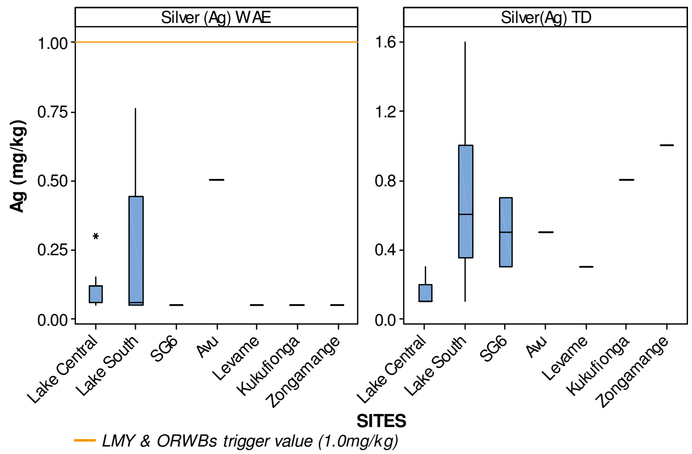

Figure E-23 Silver in sediment LMY and ORWB test sites 2016

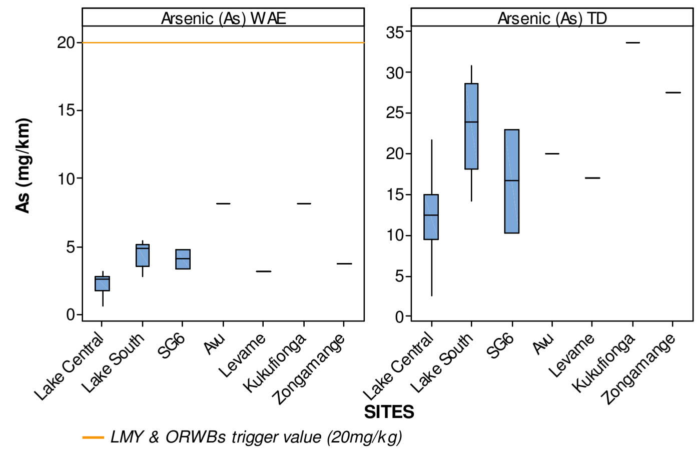

Figure E-24 Arsenic in sediment LMY and ORWB test sites 2016

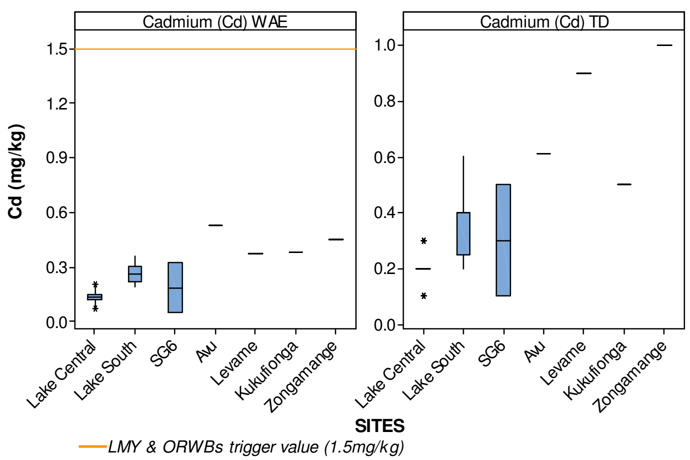

Figure E-25 Cadmium in sediment LMY and ORWB test sites 2016

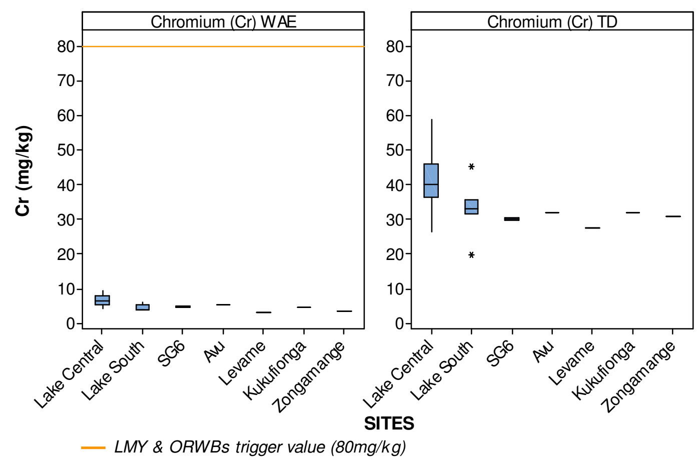

Figure E-26 Chromium in sediment LMY and ORWB test sites 2016

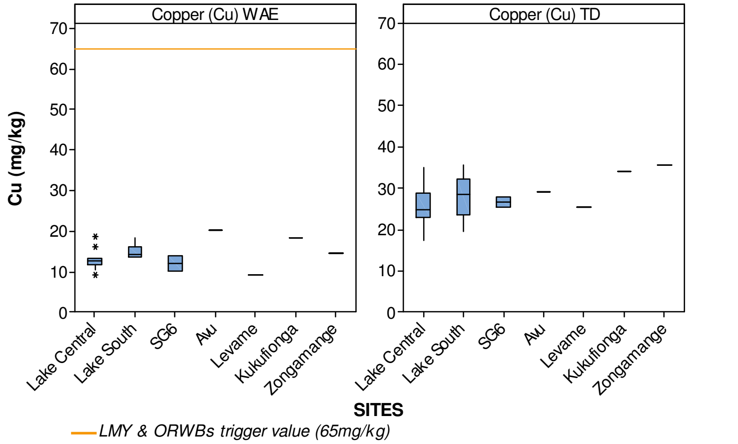

Figure E-27 Copper in sediment LMY and ORWB test sites 2016

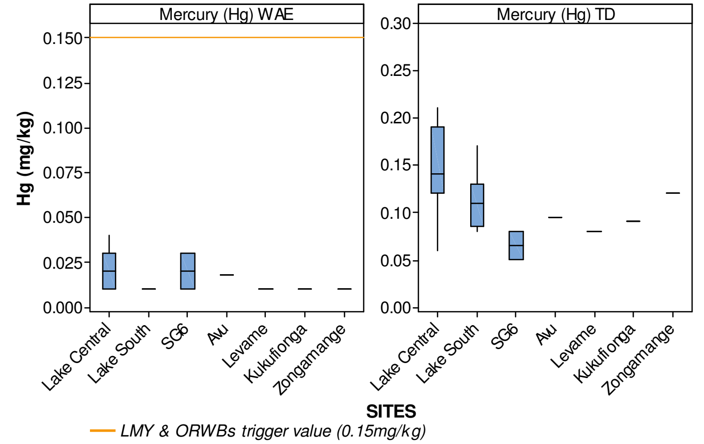

Figure E-28 Mercury in sediment LMY and ORWB test sites 2016

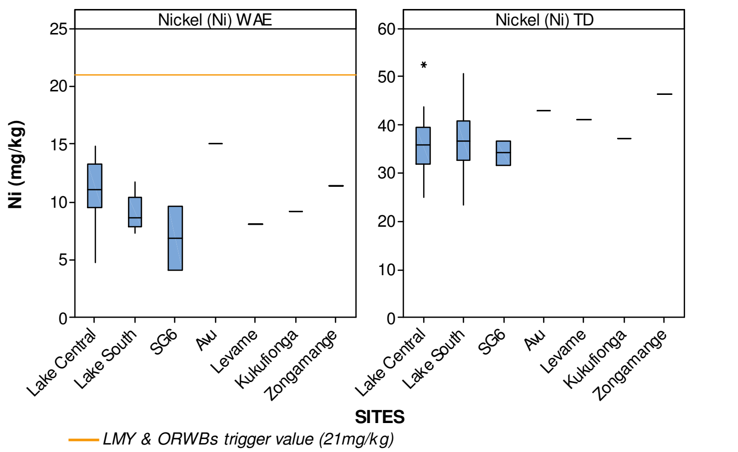

Figure E-29 Nickel in sediment LMY and ORWB test sites 2016

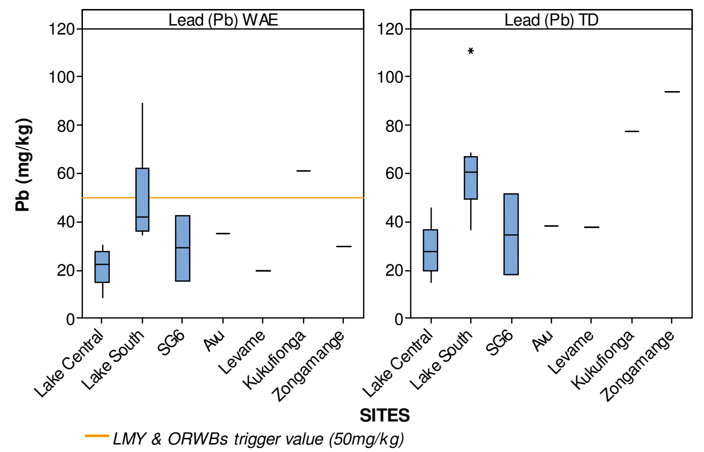

Figure E-30 Lead in sediment LMY and ORWB test sites 2016

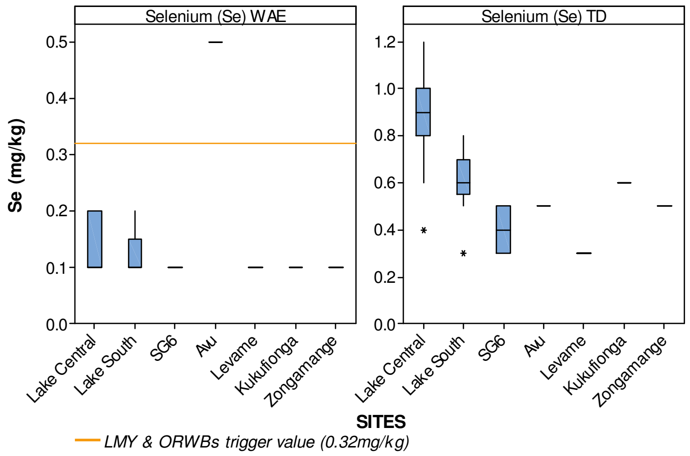

Figure E-31 Selenium in sediment LMY and ORWB test sites 2016

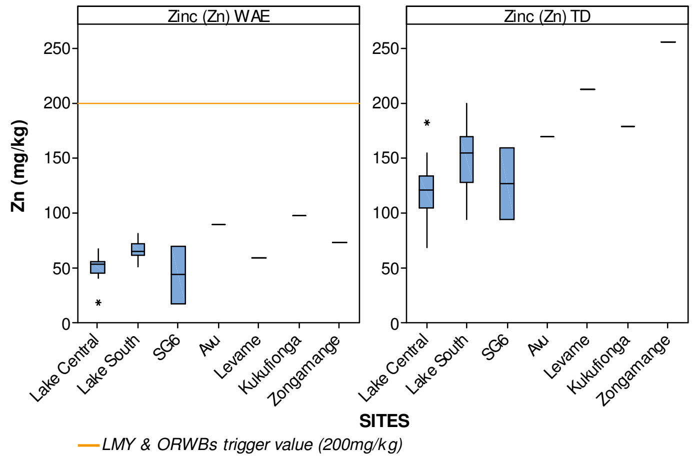

Figure E-32 Zinc in sediment LMY and ORWB test sites 2016

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. (Total Digest whole sediment)

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend
Central (Trend of all data 2013 - 2016)	Ag-WAE	-0.863	<0.001	Reduced over time
	As-WAE	0.651	<0.001	Increased over time
	Cd-WAE	-0.860	<0.001	Reduced over time
	Cr-WAE	0.075	0.698	No change over time
	Cu-WAE	0.529	0.003	Increased over time
	Fe-WAE	0.231	0.228	No change over time
	Pb-WAE	0.780	<0.001	Increased over time
	Hg-WAE	-0.692	<0.001	Reduced over time
	Ni-WAE	0.057	0.771	No change over time
	Se-WAE	-0.875	<0.001	Reduced over time
	Zn-WAE	0.359	0.056	No change over time
South (Trend of all data 2013 - 2016)	Ag-WAE	-0.435	0.014	Reduced over time
	As-WAE	0.652	<0.001	Increased over time
	Cd-WAE	-0.783	<0.001	Reduced over time
	Cr-WAE	0.412	0.021	Increased over time
	Cu-WAE	0.507	0.004	Increased over time
	Fe-WAE	0.477	0.007	Increased over time
	Pb-WAE	0.664	<0.001	Increased over time
	Hg-WAE	-0.872	<0.001	Reduced over time
	Ni-WAE	0.397	0.027	Increased over time
	Se-WAE	-0.790	<0.001	Reduced over time
	Zn-WAE	0.432	0.015	Increased over time
SG6 (Trend of all data 2013 - 2016)	Ag-WAE	-0.559	0.02	Reduced over time
	As-WAE	0.233	0.368	No change over time
	Cd-WAE	-0.278	0.28	No change over time
	Cr-WAE	0.194	0.456	No change over time
	Cu-WAE	-0.009	0.974	No change over time
	Fe-WAE	0.175	0.501	No change over time
	Pb-WAE	0.386	0.126	No change over time
	Hg-WAE	0.259	0.316	No change over time
	Ni-WAE	0.124	0.635	No change over time
	Se-WAE	-0.559	0.02	Reduced over time
	Zn-WAE	0.272	0.29	No change over time
Kukufionga (Trend of all data 2013 - 2016)	Ag-WAE	-0.362	0.098	No change over time
	As-WAE	-0.082	0.716	No change over time
	Cd-WAE	-0.362	0.098	No change over time
	Cr-WAE	-0.183	0.414	No change over time
	Cu-WAE	-0.010	0.965	No change over time
	Fe-WAE	-0.167	0.458	No change over time
	Pb-WAE	0.137	0.544	No change over time
	Hg-WAE	-0.362	0.098	No change over time
	Ni-WAE	-0.308	0.163	No change over time
	Se-WAE	-0.362	0.098	No change over time
	Zn-WAE	0.040	0.861	No change over time

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend
Zongamange (Trend of all data 2013 - 2016)	Ag-WAE	-0.422	0.103	No change over time
	As-WAE	0.284	0.287	No change over time
	Cd-WAE	-0.422	0.103	No change over time
	Cr-WAE	0.474	0.064	No change over time
	Cu-WAE	0.307	0.248	No change over time
	Fe-WAE	0.498	0.05	Increased over time
	Pb-WAE	-0.228	0.395	No change over time
	Hg-WAE	-0.541	0.031	Reduced over time
	Ni-WAE	0.413	0.112	No change over time
	Se-WAE	-0.422	0.103	No change over time
	Zn-WAE	-0.038	0.889	No change over time
Avu (Trend of all data 2013 - 2016)	Ag-WAE	-0.410	0.102	No change over time
	As-WAE	0.432	0.084	No change over time
	Cd-WAE	-0.045	0.863	No change over time
	Cr-WAE	0.620	0.008	Increased over time
	Cu-WAE	0.731	0.001	Increased over time
	Fe-WAE	0.773	<0.001	Increased over time
	Pb-WAE	0.469	0.057	No change over time
	Hg-WAE	-0.293	0.253	No change over time
	Ni-WAE	0.620	0.008	Increased over time
	Se-WAE	-0.410	0.102	No change over time
	Zn-WAE	0.615	0.009	Increased over time

LOR = Analytical 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.

APPENDIX F. TISSUE METAL – RISK AND PERFORMANCE ASSESSMENT – DETAILS OF STATISTICAL ANALYSIS & BOX PLOTS

Table F-1 Expanded risk matrix – tissue metal

Initial Assessment Result	Go To
$TSM < TV$	Step 1
$TSM \geq TV$ and TV, TSM and full TSM data set are $\nleq$ LOR	Step 2
$TSM = TV$ and TV, TSM and full TSM data set $\leq$ 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	$TSM \geq TV$ and TV, TSM and full TSM data set are $\nleq$ LOR				POTENTIAL
3	$TSM = TV$ and TV, TSM and full TSM data set are $\leq$ LOR				LOW

TSM = Test Site Median

ND = No determination

Table F-2 Tissue metal fish flesh upper river test sites 2016 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	0.02	<	Step 1	0.20	0.001	LOW
Cd	12	12	0.003	<	Step 1	0.02	0.001	LOW
Cr	12	11	0.01	<	Step 1	0.02	0.002	LOW
Cu	12	12	0.18	<	Step 1	0.48	0.001	LOW
Hg	12	11	0.07	<	Step 1	0.09	0.028	LOW
Ni	12	12	0.01	<	Step 1	0.10	0.001	LOW
Pb	12	12	0.01	<	Step 1	0.17	0.001	LOW
Se	12	12	0.32	<	Step 1	2.26	0.001	LOW
Zn	12	12	5.6	<	Step 1	10.4	0.001	LOW
Test Site				**Initial Assessment**		**TV**	**Statistical Test Result (p=0.05)**	**Risk Assessment**
Wankipe	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	12	12	0.02	<	Step 1	0.20	0.001	LOW
Cd	12	12	0.004	<	Step 1	0.02	0.001	LOW
Cr	12	11	0.01	<	Step 1	0.02	0.002	LOW
Cu	12	12	0.19	<	Step 1	0.48	0.001	LOW
Hg	12	11	0.06	<	Step 1	0.09	0.003	LOW
Ni	12	12	0.01	<	Step 1	0.10	0.001	LOW
Pb	12	12	0.01	<	Step 1	0.17	0.001	LOW
Se	12	12	0.26	<	Step 1	2.26	0.001	LOW
Zn	12	12	4.9	<	Step 1	10.4	0.001	LOW

Table F-3 Tissue metal prawn abdomen upper river test sites 2016 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	11	0.03	<	Step 1	0.06	0.002	LOW
Cd	12	12	0.012	>	Step 3	0.01	0.133	POTENTIAL
Cr	12	12	0.02	<	Step 1	0.11	0.001	LOW
Cu	12	12	4.85	<	Step 1	9.8	0.002	LOW
Hg*	12	0	0.01	=	Step 3	0.01	-	LOW
Ni	12	12	0.01	<	Step 1	0.02	0.001	LOW
Pb	12	10	0.04	>	Step 2	0.01	0.238	POTENTIAL
Se	12	12	0.56	>	Step 2	0.43	0.006	POTENTIAL
Zn	12	9	15	<	Step 1	16	0.157	POTENTIAL
Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Wankipe	N	N (Test)	Median	Result	Go to			
As	12	12	0.04	<	Step 1	0.06	0.001	LOW
Cd	12	10	0.007	<	Step 2	0.01	0.093	POTENTIAL
Cr	12	12	0.03	<	Step 1	0.11	0.001	LOW
Cu	12	12	5.95	<	Step 1	9.8	0.001	LOW
Hg*	12	0	0.01	=	Step 3	0.01	-	LOW
Ni	12	12	0.01	<	Step 1	0.02	0.001	LOW
Pb	12	1	0.01	=	Step 3	0.01	-	LOW
Se	12	12	0.42	<	Step 1	0.43	0.484	POTENTIAL
Zn	12	11	14	<	Step 1	16	0.006	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 2016 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	1	1	0.01	<	NA	0.07	Direct comparison	LOW
Cd	1	1	0.003	<	NA	0.003	Direct comparison	LOW
Cr	1	1	0.01	<	NA	0.03	Direct comparison	LOW
Cu	1	1	0.14	<	NA	0.17	Direct comparison	LOW
Hg	1	1	0.10	<	NA	0.12	Direct comparison	LOW
Ni	1	1	0.01	<	NA	0.03	Direct comparison	LOW
Pb	1	1	0.01	<	NA	0.17	Direct comparison	LOW
Se	1	1	0.12	<	NA	2.26	Direct comparison	LOW
Zn	1	1	3.9	<	NA	4.8	Direct comparison	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	<	Step1	0.003	0.001	LOW
Cr	12	12	0.01	<	Step1	0.03	0.001	LOW
Cu	12	12	0.09	<	Step1	0.17	0.042	LOW
Hg	12	11	0.09	<	Step1	0.12	0.115	POTENTIAL
Ni	12	12	0.01	<	Step1	0.03	0.002	LOW
Pb	12	12	0.01	<	Step1	0.17	0.001	LOW
Se	12	12	0.16	<	Step1	2.26	0.001	LOW
Zn	12	12	3.45	<	Step1	4.8	0.002	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.

NA – Not applicable

Table F-5 Bioaccumulation prawn abdomen lower river test sites 2016 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	12	12	0.08	>	Step 2	0.01	0.001	POTENTIAL
Cd	12	12	0.005	<	Step 1	0.01	0.023	LOW
Cr	12	12	0.02	<	Step 1	0.06	0.001	LOW
Cu	12	12	5.75	<	Step 1	11.6	0.002	LOW
Hg*	12	0	0.01	=	Step 3	0.01	-	LOW
Ni	12	0	0.01	=	Step 3	0.01	-	LOW
Pb	12	0	0.01	=	Step 3	0.01	-	LOW
Se	12	11	0.29	<	Step 1	0.31	0.065	POTENTIAL
Zn	12	10	13.5	<	Step 1	16	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	0.06	>	Step 2	0.01	0.001	POTENTIAL
Cd	12	12	0.007	<	Step 1	0.01	0.128	POTENTIAL
Cr	12	12	0.02	<	Step 1	0.06	0.001	LOW
Cu	12	12	9.15	<	Step 1	11.6	0.002	LOW
Hg^	12	1	0.01	=	Step 3	0.01	1.000	LOW
Ni^	12	1	0.01	=	Step 3	0.01	1.000	LOW
Pb	12	0	0.01	=	Step 3	0.01	-	LOW
Se	12	12	0.34	>	Step 2	0.31	0.183	POTENTIAL
Zn	12	11	13.5	<	Step 1	16	0.012	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.

^ Result indicates that 1 result within the data set (n = 12) is greater than the TV, the remaining results are equal to the TV, which is also equal to the LOR. The result in this case has been modified from potential risk to low risk.

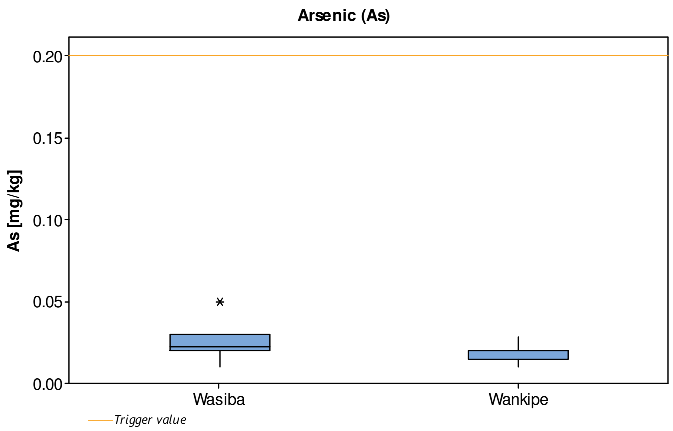

Figure F-1 Arsenic in fish flesh upper river test sites 2016

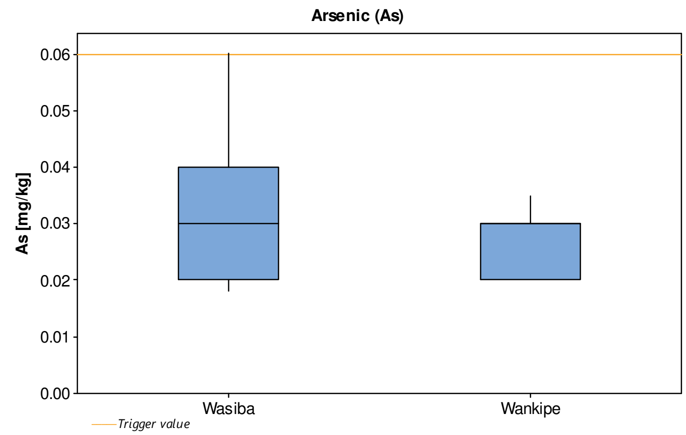

Figure F-2 Arsenic in prawn abdomen upper river test sites 2016

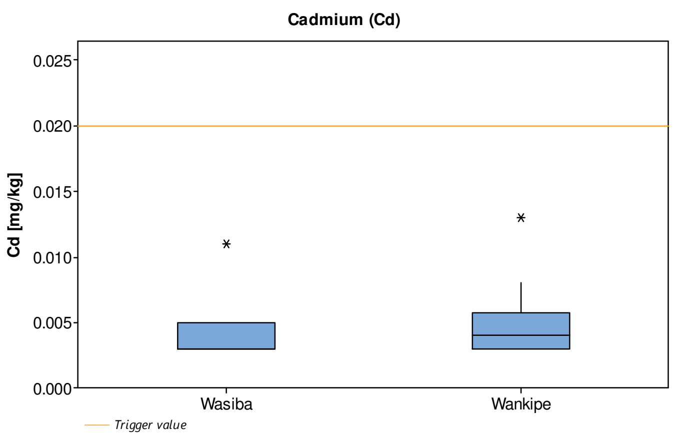

Figure F-3 Cadmium in fish flesh upper river test sites 2016

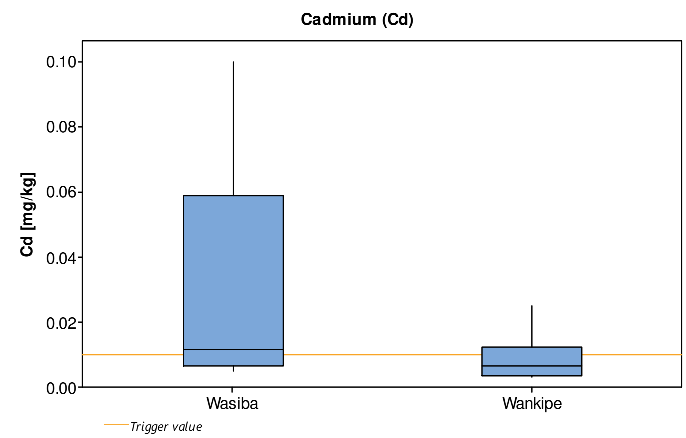

Figure F-4 Cadmium in prawn abdomen upper river test sites 2016

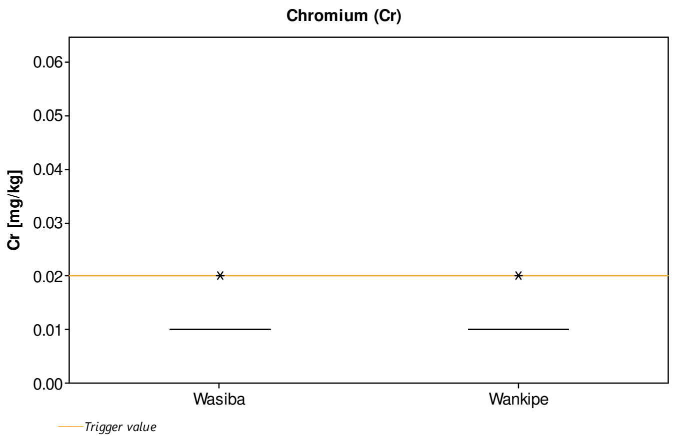

Figure F-5 Chromium in fish flesh upper river test sites 2016

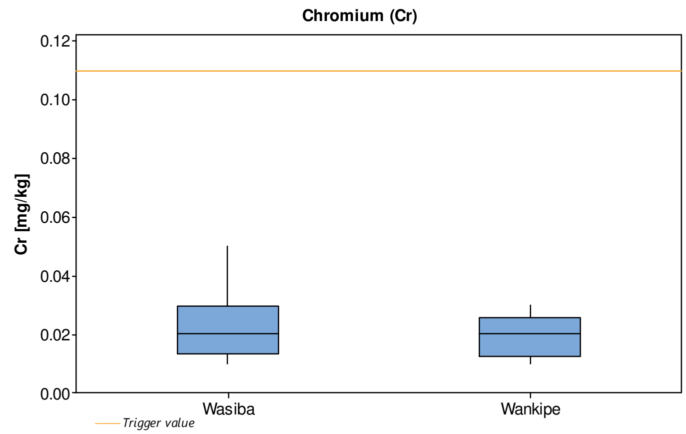

Figure F-6 Chromium in prawn abdomen Upper River test sites 2016

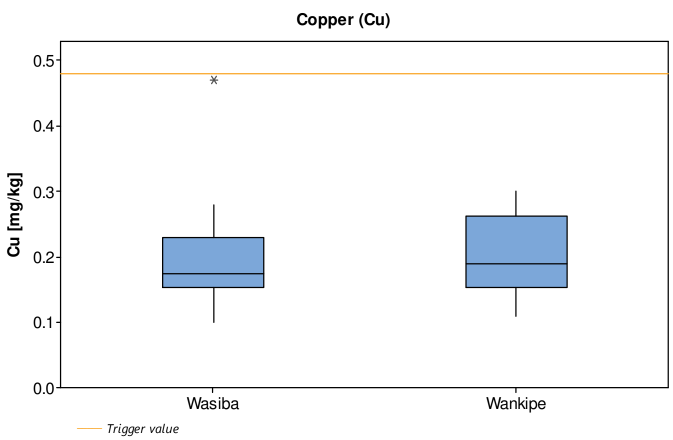

Figure F-7 Copper in fish flesh upper river test sites 2016

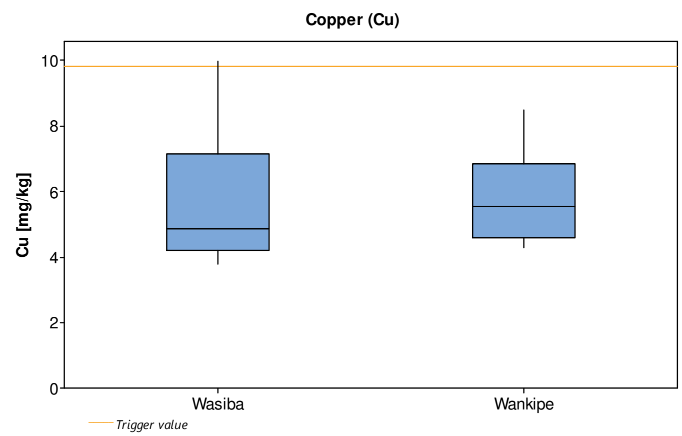

Figure F-8 Copper in prawn abdomen upper river test sites 2016

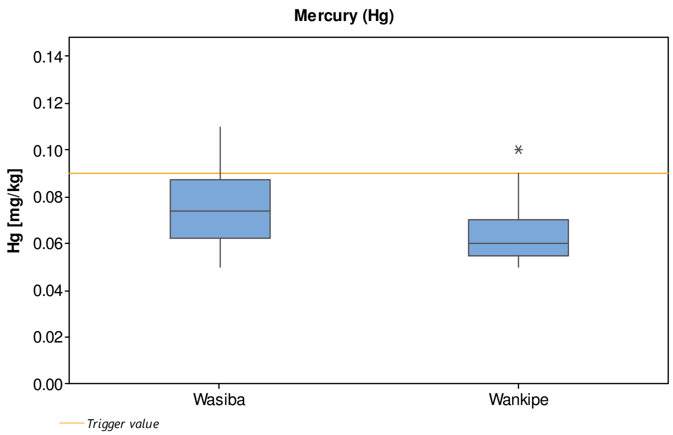

Figure F-9 Mercury in fish flesh upper river test sites 2016

Figure F-10 Mercury in prawn abdomen upper river test sites 2016

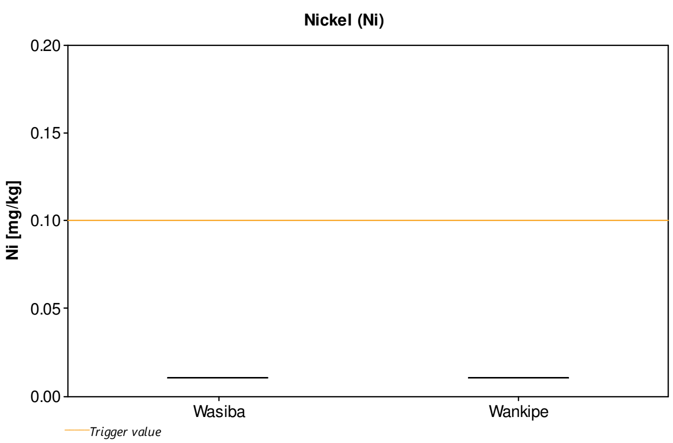

Figure F-11 Nickel in fish flesh upper river test sites 2016

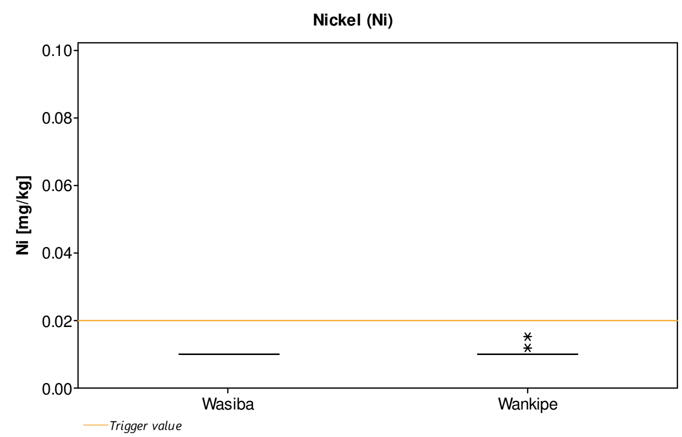

Figure F-12 Nickel in prawn abdomen upper river test sites 2016

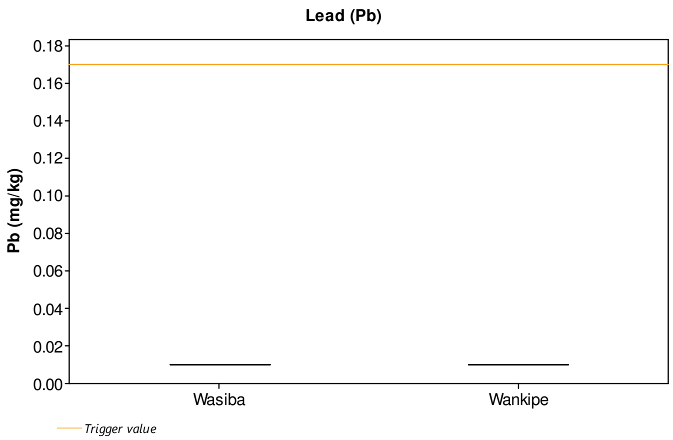

Figure F-13 Lead in fish flesh upper river test sites 2016

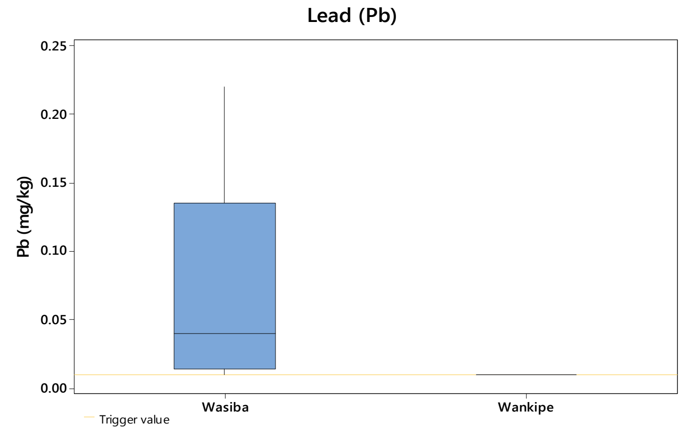

Figure F-14 Lead in prawn abdomen upper river test sites 2016

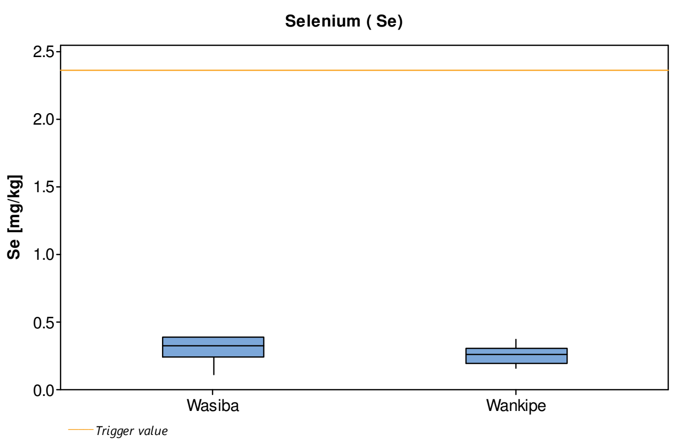

Figure F-15 Selenium in fish flesh upper river test sites 2016

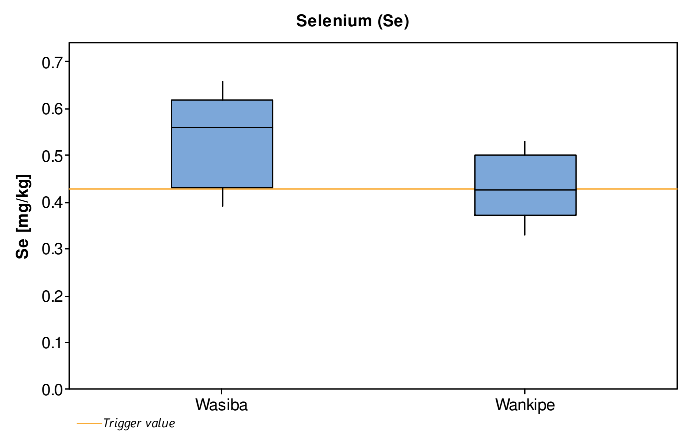

Figure F-16 Selenium in prawn abdomen upper river test sites 2016

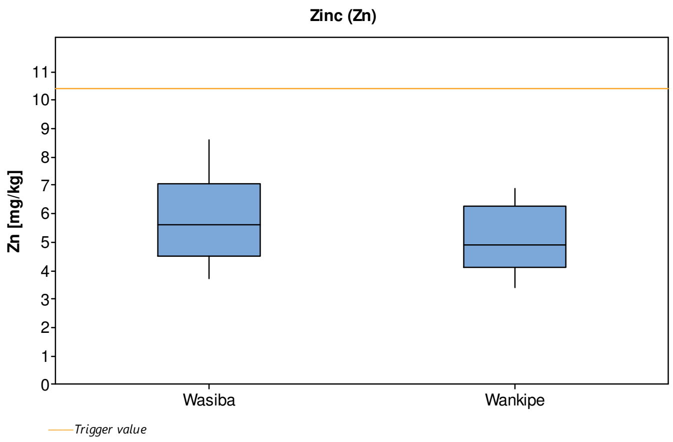

Figure F-17 Zinc in fish flesh upper river test sites 2016

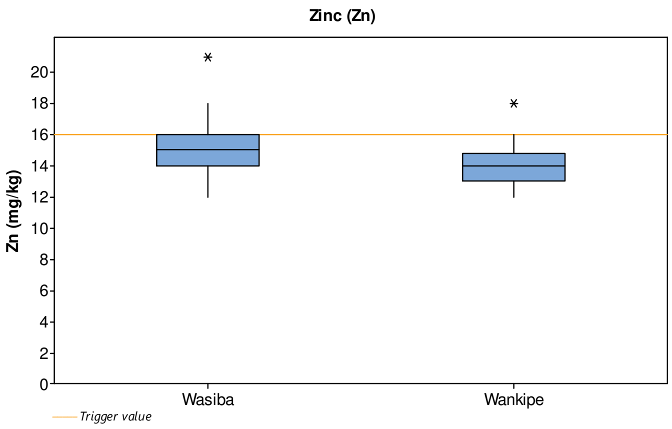

Figure F-18 Zinc in prawn abdomen upper river test sites 2016

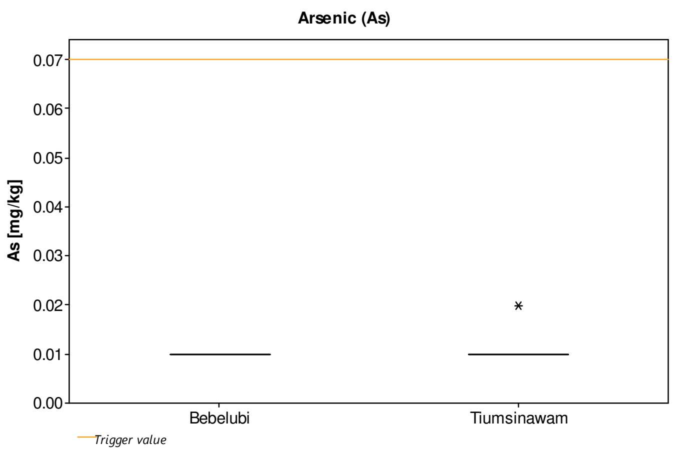

Figure F-19 Arsenics in fish flesh lower river test sites 2016

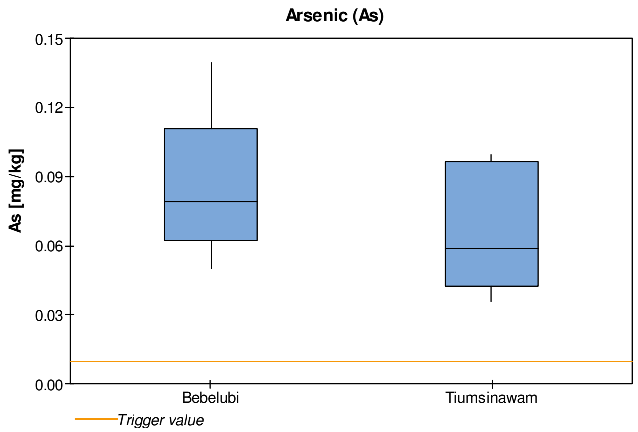

Figure F-20 Arsenic in prawn abdomen lower river test sites 2016

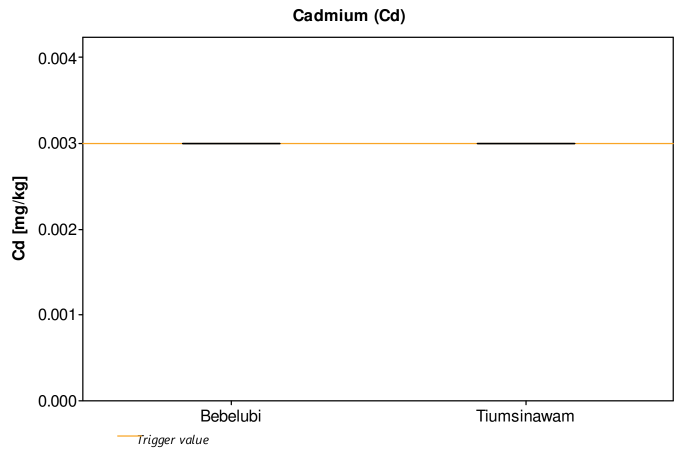

Figure F-21 Cadmium in fish flesh lower river test sites 2016

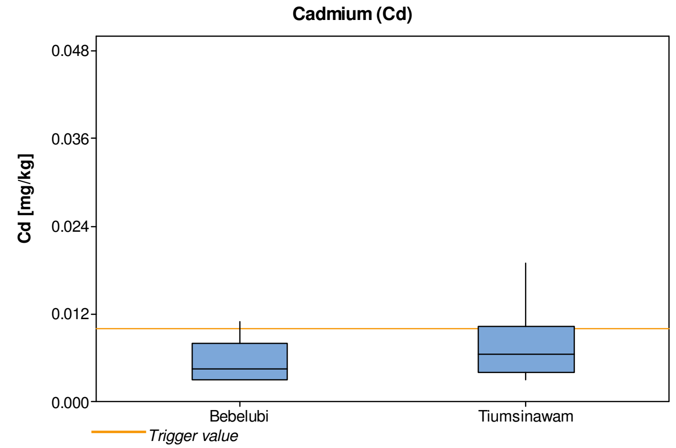

Figure F-22 Cadmium in prawn abdomen lower river test sites 2016

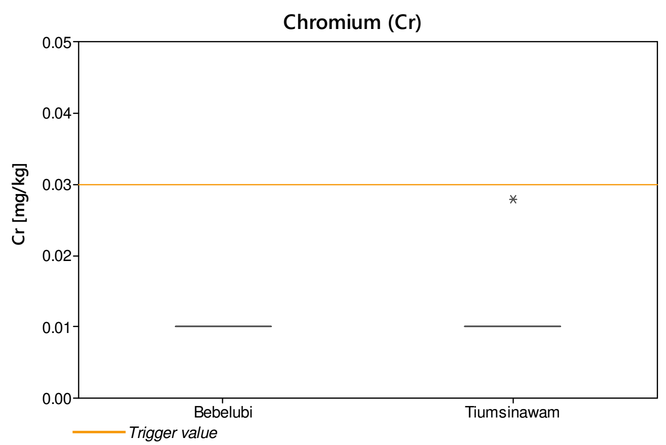

Figure F-23 Chromium in fish flesh lower river test sites 2016

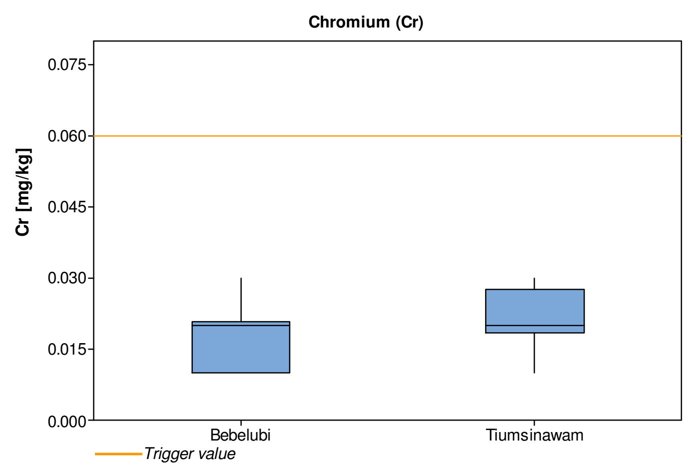

Figure F-24 Chromium in prawn abdomen lower river test sites 2016

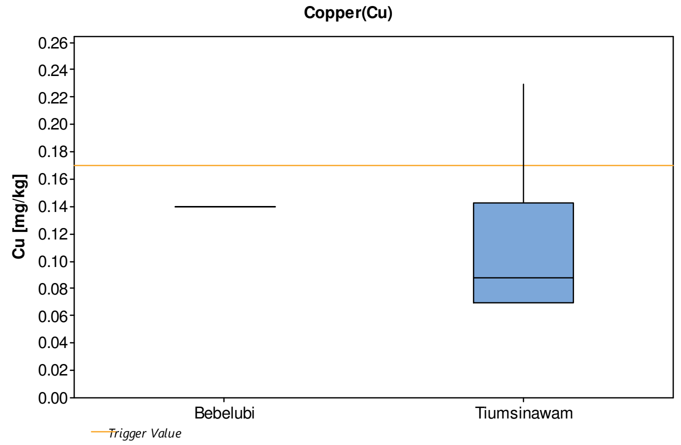

Figure F-25 Copper in fish flesh lower river test sites 2016

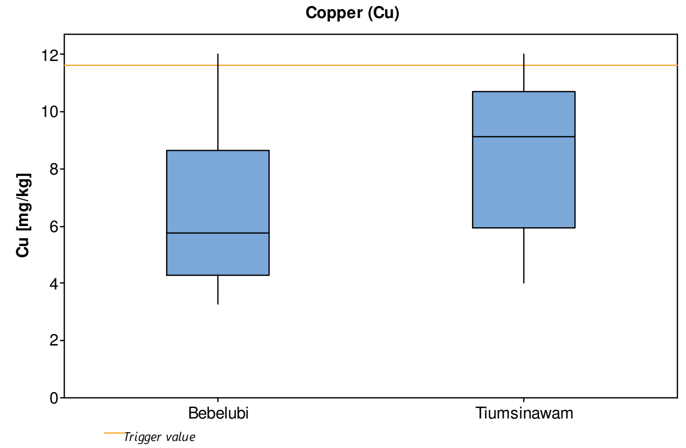

Figure F-26 Copper in prawn abdomen lower river test sites 2016

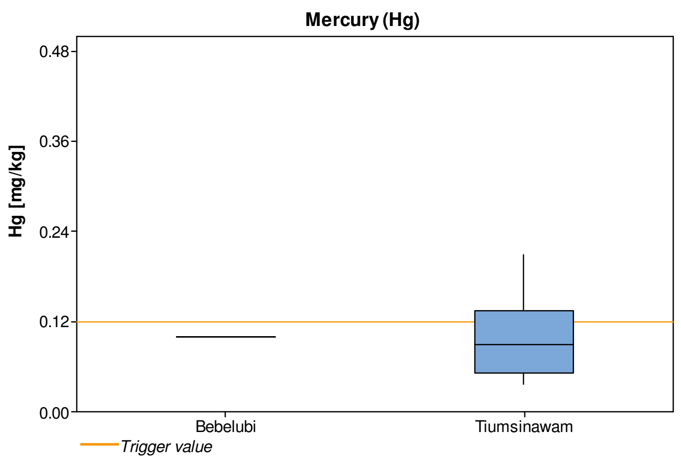

Figure F-27 Mercury in fish flesh lower river test sites 2016

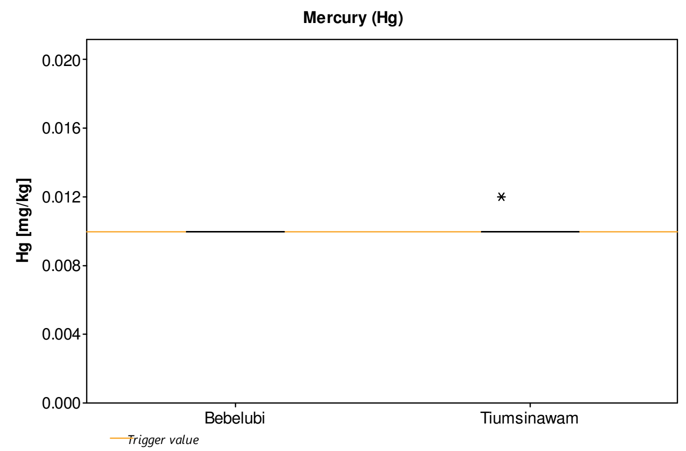

Figure F-28 Mercury in prawn abdomen lower river test sites 2016

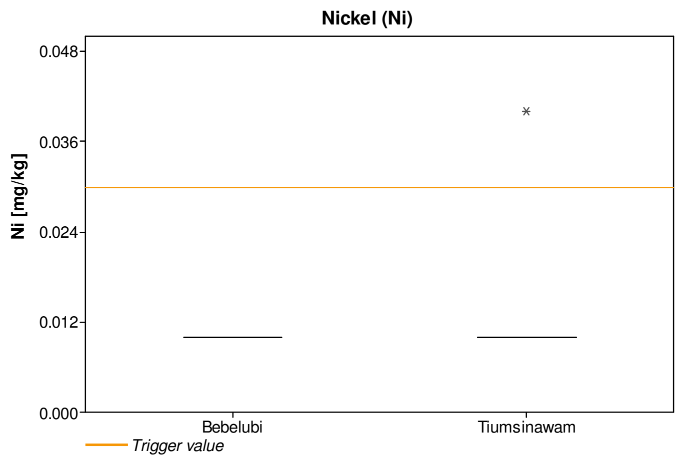

Figure F-29 Nickel in fish flesh lower river test sites 2016

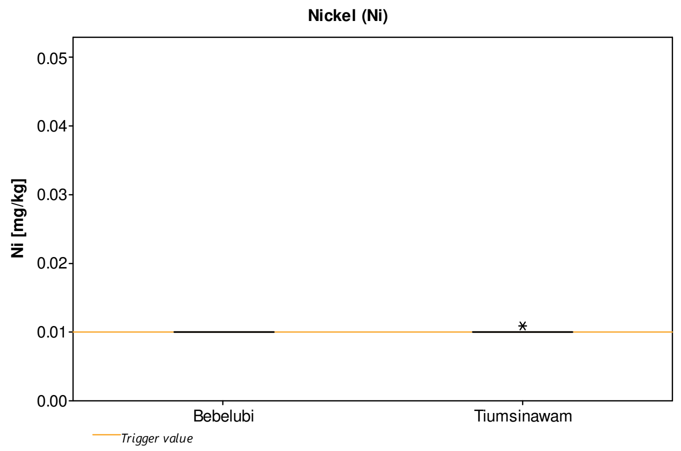

Figure F-30 Nickel in prawn abdomen lower river test sites 2016

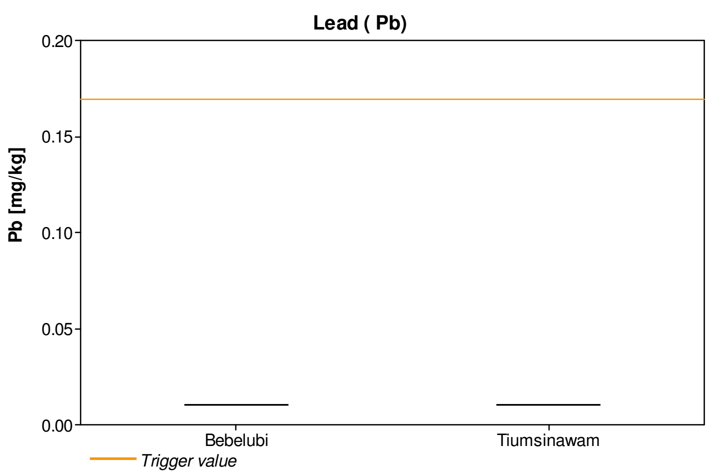

Figure F-31 Lead in fish flesh lower river test sites 2016

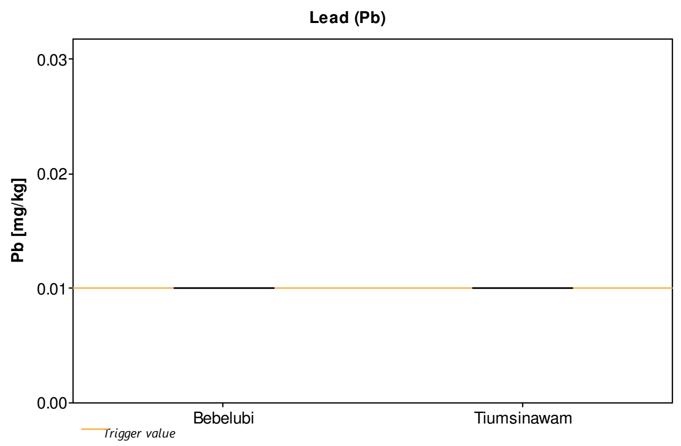

Figure F-32 Lead in prawn abdomen lower river test site 2016

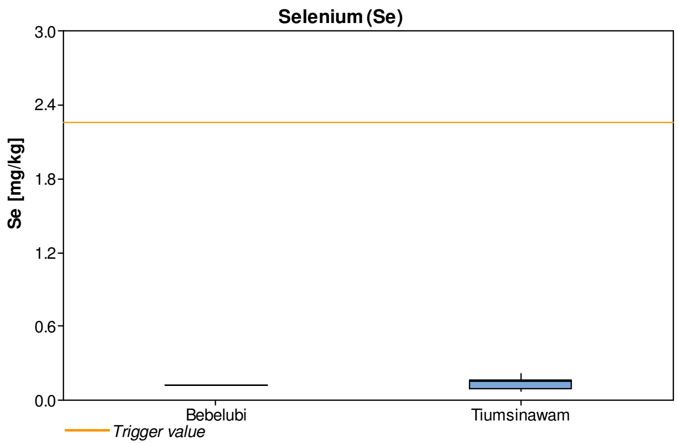

Figure F-33 Selenium in fish flesh lower river test sites 2016

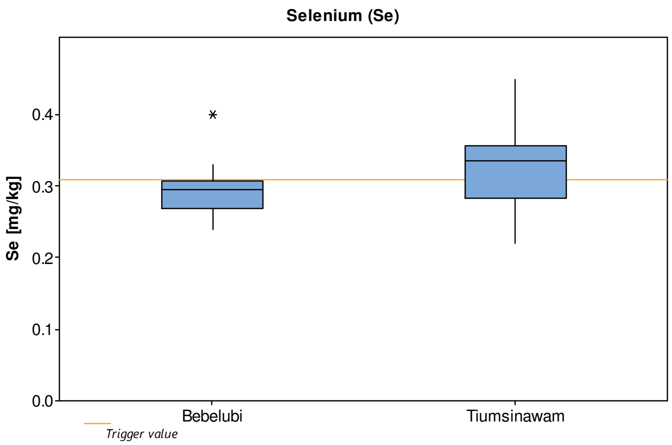

Figure F-34 Selenium in prawn abdomen lower river test sites 2016

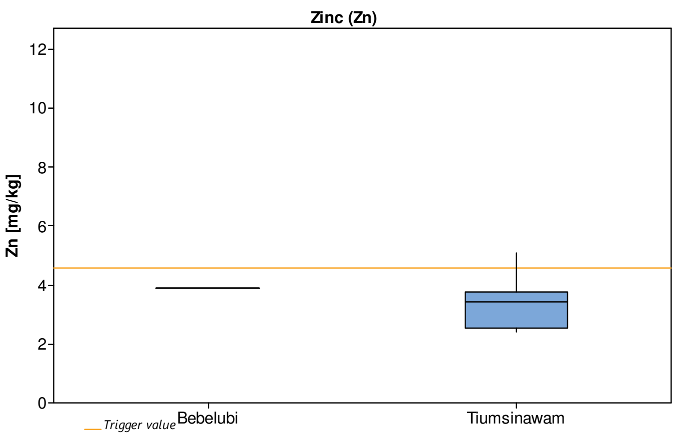

Figure F-35 Zinc in fish flesh lower river test sites 2016

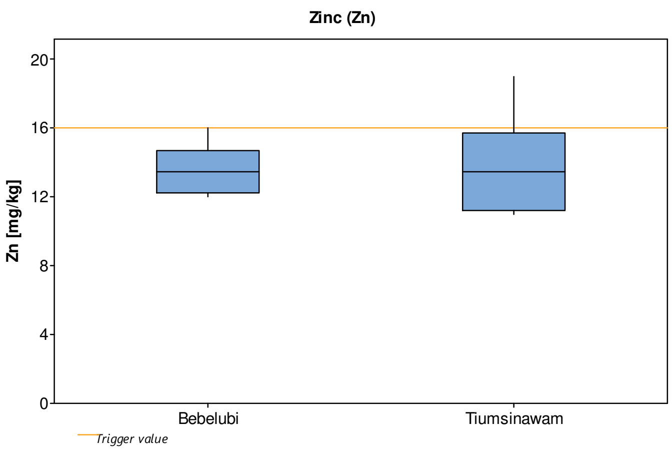

Figure F-36 Zinc in prawn abdomen lower river test sites 2016

Table F-6 Performance assessment – Based on the trend of tissue metals in fish flesh at upper river test sites from 2007-2016 using Spearman Rank Test.

Fish Flesh Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2007 - 2016
Wasiba (Trend of Annual Median 2007 - 2016)	As	-0.220	0.001	Reduced over time
	Cd	-0.578	<0.001	Reduced over time
	Cr	0.125	0.051	No change over time
	Cu	-0.144	0.024	Reduced over time
	Hg	-0.020	0.751	No change over time
	Ni	-0.057	0.376	No change over time
	Pb	-0.041	0.522	No change over time
	Se	-0.444	<0.001	Reduced over time
	Zn	-0.074	0.248	No change over time
Wankipe (Trend of Annual Median 2007 - 2016)	As	-0.261	<0.001	Reduced over time
	Cd	-0.498	<0.001	Reduced over time
	Cr	-0.114	0.062	No change over time
	Cu	-0.073	0.235	No change over time
	Hg	-0.068	0.271	No change over time
	Ni	-0.122	0.047	Reduced over time
	Pb	-0.045	0.466	No change over time
	Se	-0.357	<0.001	Reduced over time
	Zn	-0.141	0.022	Reduced over time

Table F-7 Performance assessment – Based on the trend of tissue metals in prawn abdomen at upper river test sites from 2007-2016 using Spearman Rank Test.

Prawn Abdomen Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2007 - 2016
Wasiba (Trend of Annual Median 2007 - 2016)	As	-0.352	<0.001	Reduced over time
	Cd	-0.434	<0.001	Reduced over time
	Cr	0.016	0.797	No change over time
	Cu	-0.138	0.024	Reduced over time
	Hg	0.071	0.247	No change over time
	Ni	0.002	0.968	No change over time
	Pb	0.197	0.001	Increased over time
	Se	0.265	<0.001	Increased over time
	Zn	0.109	0.074	No change over time
Wankipe (Trend of Annual Median 2007 - 2016)	As	-0.148	0.008	Reduced over time
	Cd	-0.287	<0.001	Reduced over time
	Cr	-0.044	0.440	No change over time
	Cu	-0.111	0.048	Reduced over time
	Hg	-0.009	0.870	No change over time
	Ni	0.292	<0.001	Increased over time
	Pb	0.120	0.033	Increased over time
	Se	-0.108	0.055	No change over time
	Zn	-0.199	<0.001	Reduced over time

Table F-8 Performance assessment – Based on the trend of tissue metals in fish flesh at lower river test sites from 2007-2016 using Spearman Rank Test.

Fish flesh Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2007 - 2016
Bebelubi (Trend of Annual Median 2007 - 2016)	As	-0.384	0.005	Reduced over time
	Cd	-0.376	0.006	Reduced over time
	Cr	0.045	0.748	No change over time
	Cu	-0.270	0.050	Reduced over time
	Hg	0.088	0.531	No change over time
	Ni	0.099	0.479	No change over time
	Pb	<LOR	<LOR	No change over time
	Se	-0.104	0.459	No change over time
	Zn	-0.184	0.187	No change over time
SG4 (Trend of Annual Median 2007 - 2016)	As	-0.431	<0.001	Reduced over time
	Cd	-0.596	<0.001	Reduced over time
	Cr	0.098	0.102	No change over time
	Cu	-0.184	0.002	Reduced over time
	Hg	0.005	0.927	No change over time
	Ni	-0.153	0.011	Reduced over time
	Pb	0.036	0.554	No change over time
	Se	-0.152	0.011	Reduced over time
	Zn	-0.051	0.399	No change over time

Table F-9 Performance assessment – Based on the trend of tissue metals in prawn abdomen at lower river test sites from 2007-2016 using Spearman Rank Test.

Prawn Abdomen Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2007 - 2016
Bebelubi (Trend of Annual Median 2007 - 2016)	As	0.022	0.739	No change over time
	Cd	-0.371	<0.001	Reduced over time
	Cr	-0.037	0.567	No change over time
	Cu	0.262	<0.001	Increased over time
	Hg	0.000	-	No change over time
	Ni	0.100	0.122	No change over time
	Pb	0.082	0.206	No change over time
	Se	0.332	<0.001	Increased over time
	Zn	0.233	<0.001	Increased over time
SG4 (Trend of Annual Median 2007 - 2016)	As	-0.178	0.001	Reduced over time
	Cd	-0.233	<0.001	Reduced over time
	Cr	0.080	0.139	No change over time
	Cu	0.209	<0.001	Increased over time
	Hg	-0.035	0.523	No change over time
	Ni	0.306	<0.001	Increased over time
	Pb	-0.017	0.759	No change over time
	Se	-0.044	0.417	No change over time
	Zn	-0.066	0.225	No change over time

APPENDIX G. FISH AND PRAWN ABUNDANCE – IMPACT ASSESSMENT – DETAILS OF STATISTICAL ANALYSIS AND BOX PLOTS

Table G-1 Expanded impact matrix – Fish and prawn abundance

Initial Assessment Result					Go To
TSM ≥ TV					Step 1
TSM < TV					Step 2
Step	**Alt Hypothesis**	**Null Hypothesis**	**Sig Test Result**		**Impact Assessment**
1	TSM ≥ TV				LOW
2	TSM < TV	TSM = TV	$p < 0.05$	Accept Alt	POTENTIAL IMPACT
			$p > 0.05$	Accept Null	LOW
			Error	Accept Neither	ND

Table G-2 Fish abundance upper river test sites 2016 median

Test Site				TV (2016 Mean)	Two-sample T-Test	
Site	Species	N	Mean (2016)		p (p=0.05)	Impact Assessment
Wasiba	*Neosilurus equinus*	8	7.6	14.9	0.061	No impact
Wankipe	*Neosilurus equinus*	8	10.6	14.9	0.379	No impact

Table G-3 Prawn abundance upper river test sites 2016 median

Test Site				TV (2016 Mean)	Two-Sample T-Test	
Site	Species	N	Mean (2016)		p (p=0.05)	Impact Assessment
Wasiba	*Macrobrachium handschini*	8	11.1	9.6	0.745	No impact
	Macrobrachium lorentzi	8	43.6	41.3	0.901	No impact
Wankipe	*Macrobrachium handschini*	8	1.5	9.6	0.073	No impact
	Macrobrachium lorentzi	8	12.6	41.3	0.082	No impact

Table G-4 Fish abundance lower river test sites 2016 median

Test Site				TV (2016 Mean)	Two-Sample T-Test	
Site	Species	N	Mean (2016)		p (p=0.05)	Impact Assessment
Bebelubi	*Potamosilurus latirostris*	8	0.75	3.4	0.161	No impact
	Potamosilurus macrorhynchus	8	0.25	0.25	1.000	No impact
SG4	*Potamosilurus latirostris*	8	1.5	10.4	0.086	No impact
	Potamosilurus macrorhynchus	8	5.9	4.8	0.718	No impact

Table G-5 Prawn abundance lower river test sites 2016 median

Test Site				TV (2016 Mean)	Two-Sample T-Test	
Site	Species	N	Mean (2016)		p (p=0.05)	Impact Assessment
Bebelubi	*Macrobrachium rosenbergii*	8	6.6	8.5	0.793	No impact
SG4	*Macrobrachium rosenbergii*	8	5.3	7.4	0.724	No impact