PORGERA JOINT VENTURE

# ANNUAL ENVIRONMENT REPORT 2015

ISO 14001 Certified Environmental Management System

ERMCVS CERTIFIED ENVIRONMENTAL MANAGEMENT SYSTEM

UKAS MANAGEMENT SYSTEMS 067

ISO 14001 Certificate 489

Barrick Niugini Limited - Porgera Joint Venture

June 2016

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Cover Photo: Igege (SG5) Sunset August 2015

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Porgera Joint Venture

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Charlie Ross

Manager, Environment

Porgera Joint Venture

P.O Box 484, Mount Hagen WHP

Papua New Guinea

30 June 2016

Dear Charlie,

**Re: Porgera Joint Venture 2015 Annual Environmental Report**

Dr Graeme Batley and Dr Simon Apte have reviewed a draft of the 2015 Porgera Joint Venture Annual Environmental Report (AER) and provided detailed comments for consideration. Overall, the draft report was found to be technically sound and generally of extremely high quality. However, as might be expected with a report of this size, a number of minor 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. The revised report was assessed again by the review team and found to be satisfactory.

We commend your Department on their considerable efforts in producing this comprehensive 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 by Barrick Gold (47.5%), Zijin Mining (47.5%) and Mineral Resources Enga (5%), is known as the Porgera Joint Venture (PJV) and is managed by Barrick. 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 2027 with an annual production of 500 koz of gold. The site employs approximately 2700 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 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 five 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.

The scope and magnitude of environmental aspects in 2015 were consistent with recent years. There was no change to the area of land held by the mine and the quantity of ore and gold production were comparable with the previous five years. The volume of competent waste rock produced in 2015 was approximately half of that for recent years, with the majority being placed in the Kogai dump. The quantity of incompetent waste rock produced in 2015 was significantly greater than in 2014 due to development of Stage 5C of the open pit and the majority was disposed to Anjolek erodible dump. Anawe erodible dump continued to receive mud trucked from the floor of the open cut mine.

Tailings production also was consistent with previous years, and a significant proportion (9.7%) was diverted from riverine disposal and used for cemented backfill in the underground mine. The volume of tailings diverted in 2015 was the highest in the sites 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 internal pH target (93% compliance) occurred as a result of low pH events in September 2015 associated with interruptions to lime supply to the mine site, however the minimum recorded pH value was pH 6.2, and was only slightly below the target level. Total suspended sediment (TSS) concentrations were comparable to previous years. Concentrations of TSS, dissolved cadmium, copper, iron, 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 cadmium, iron, nickel and zinc exhibit an increasing trend over the past 5 years, and all other metals were either stable or decreasing.

Contact rainfall runoff from the site was typical of neutral mine drainage and exhibited elevated sulfate, alkalinity, TSS and concentrations of dissolved cadmium, copper, nickel and zinc.

## Background Environmental Conditions

Background environmental conditions in 2015 were influenced by a strong El Niño event which resulted in low rainfall and consequently low river flows throughout the upper rivers in the highlands, the lower rivers along the Strickland floodplain and at Lake Murray and off-river water bodies (ORWBs). Rainfall near the mine site was 14% below average, but was approximately 30% below average in the middle and lower reaches of the Strickland catchment. As a result the rate of dilution provided for mine-related inputs was reduced throughout the receiving environment.

Background conditions for environmental indicators of water quality, sediment quality, metals within the tissue of fish and prawns (tissue metals) and ecosystem health (abundance, richness, biomass and condition of fish and prawn communities), 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 are generally lower at the upper river reference sites than the baseline data from the upper river test sites, the reference sites do 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 display 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 97% of legal and other obligations throughout 2015, with non-compliance related to elevated TSS in discharge from three of the five sewage treatment plants on at least one occasion during the year. Corrective action continues to be applied, and resulted in 100% compliance throughout November and December 2015.

## 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 is 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 low river flows, decreased the dilution of mine inputs by natural runoff and sediments within the receiving environment during 2015.

Sediment inputs from the Anjolek and Anawe erodible dumps, tailings, 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 low river flow rates resulted in an increase of the proportion of mine derived TSS within the rivers downstream of the mine. The proportion of mine derived sediment at SG3, 164 km downstream of the mine, was 49% in 2015 compared with 34% in 2014 and a long-term median of 23%. However, 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 during 2015.

Inputs of metals dissolved in water and weak-acid-extractable (WAE) metals in particulates are considered bioavailable and are therefore used to assess risk.

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 lead and zinc concentrations in sediment discharged from Kogai and Anawe North competent waste rock dumps, 28 level and Yarik Portal.

### 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 elevated TSS in water posed a potential risk at SG1 in the upper river and at Avu, an oxbow on the Strickland floodplain. Although Avu is located some 600 km downstream from the mine, flood-flow from the Strickland River is the most likely source of elevated TSS.

**Silver**

Silver in the tailings solids contributed to the receiving environment. The concentrations of dissolved silver in receiving waters and WAE silver in benthic sediments were significantly less than the respective TVs throughout the upper and lower rivers, Lake Murray and ORWBs indicating low risk to the aquatic environment.

**Arsenic**

The concentrations of dissolved arsenic in tailings and all other discharges from the mine were low, but elevated concentrations of WAE arsenic were measured in the tailings solids. In the receiving environment, dissolved arsenic in water and WAE arsenic in sediment were not elevated at any of the test sites. However, arsenic concentrations in prawn abdomen at Bebelubi in the lower river, exceeded the TV, indicating the potential for environmental impact at this location.

There is an inconsistency between the low concentrations of dissolved arsenic in water and WAE arsenic in benthic sediment within the receiving environment and the bioaccumulation above that measured at the lower river reference site which suggests an alternative pathway of exposure to arsenic is possibly present.

**Cadmium**

Contributions of dissolved cadmium in water to the receiving environment are occurring from the tailings and the Kogai and Anawe North stable dumps. Within the receiving environment, median concentrations of dissolved cadmium in 2015 exceeded the TV in water only at SG1. WAE cadmium in benthic sediment was not elevated at any of the test sites. However, cadmium in prawn abdomen was significantly greater than the TV at Wasiba and was not significantly different than the respective TV at Wankipe, Bebelubi and Tiumsinawam test sites. The bioaccumulation above that measured at the reference sites indicates the potential for cadmium to cause environmental impact at these sites.

As with arsenic, there appears to be an inconsistency between the low concentrations of dissolved cadmium in water, WAE cadmium in sediment, and accumulation in the tissue of prawns, within the upper and lower river, suggesting an alternate exposure pathway may be present.

**Chromium**

None of the discharge points from the mine exhibited elevated chromium. Chromium in water and benthic sediments and in tissue metals of fish and prawns indicated low risk of impact throughout the receiving environment.

**Copper**

Elevated dissolved copper and WAE copper in tailings pose potential risk to the aquatic environment. In the receiving environment, dissolved copper indicated potential risk only at Bebelubi and at Tiumsinawam in the lower river. WAE copper in benthic sediments and copper in fish and prawn tissues were low throughout the river system indicating low risk.

### Mercury

Mercury concentrations were low in tailings and other discharges from the mine, as well as in receiving environment water and benthic sediment. Low concentrations of mercury in fish and prawn tissue at all test sites indicate low risk to the aquatic environment.

### Nickel

Dissolved nickel was elevated in tailings but was low at test sites throughout the river system. WAE nickel in tailings and in other discharges from the mine was less than the upper river TV indicating low risk. WAE nickel in benthic sediment was low in the upper rivers, but exceeded the respective TVs at SG5 on the lower river and at Lake Murray and at Avu ORWB. Nickel in prawn abdomen was not significantly different from the respective TVs at Wankipe and at Bebelubi and exceeded the TV at Tiumsinawam, which indicates the potential to contribute to environmental impact at these locations.

### Lead

Dissolved lead concentrations were low in tailings and all other discharges from the mine site, indicating low risk, which was reflected at all test sites in the receiving environment. WAE lead concentrations in tailings and mine drainage discharges were elevated compared to the TV for the upper rivers, indicating potential risk. Within the receiving environment, WAE lead concentrations in benthic sediment decreased with increasing distance downstream from the mine, and exceeded the TV at SG1, SG2, Wasiba and Wankipe. Lead concentrations in prawn abdomens were significantly greater than the TV at Wasiba and not significantly different from the TVs at Wankipe in the upper river and at Tiumsinawam in the lower river, indicating the potential to cause environmental impact at these sites. The data suggest that the dominant exposure pathway of lead to prawns is via benthic sediment.

### Selenium

The concentrations of selenium in discharges from the mine were not elevated in comparison to the upper river reference TVs and concentrations of dissolved selenium in water and WAE selenium in benthic sediment were consistently low throughout the river system. Selenium in prawn abdomen at Bebelubi was not significantly different from the TV. Overall, given the low concentration of dissolved selenium in water and WAE selenium in benthic sediments and throughout the receiving environment, and selenium in prawn abdomen at Wasiba and Bebelubi as the only indications of potential risk, 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 Kogai and Anawe North waste rock dumps. WAE zinc in tailings and sediment contact runoff discharges from the mine site exceeded the upper river TV indicating potential risk. Dissolved zinc in water at SG1 exceeded the TV but WAE zinc in benthic sediment was below the respective TV at all test sites throughout the receiving environment. Concentrations of dissolved zinc and WAE zinc in benthic sediments decreased with increasing distance downstream from the mine site. Zinc concentrations in prawn abdomen at Wasiba and at Bebelubi were not significantly different from the respective TVs, indicating potential risk to aquatic ecosystems at these sites.

Concentrations of metals in fish tissue were low throughout the upper and lower rivers indicating low risk. Concentrations of metals in prawn abdomen in the upper and lower rivers indicated risk in the upper river at Wasiba and Wankipe, and in the lower river at Bebelubi and Tiumsinawam. In most cases the metal concentrations in prawn tissue were not significantly different from the respective TV, so although potential risk was indicated by metal accumulation in prawn abdomen, overall the risk to aquatic ecosystem health is considered low.

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 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 do not pose a risk to drinking water sources for villages within the SML and LMPs. Risk is posed to people exposed through dermal contact with undiluted tailings as a result of low pH and elevated concentrations of dissolved cadmium, iron, nickel and zinc. However, low risk was posed through water-based activities downstream from the mine. All tissue metals in fish and prawns at Wasiba and Wankipe in the upper river, and Bebelubi and Tiumsinawam in the lower river were less than the relevant food standard, confirming they are 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 are posed by elevated concentrations of oxides of nitrogen from the Anawe Generator, and elevated particulate matter in discharge from the lime kilns.

Impact assessment was performed based on biological indicators of aquatic ecosystem health to confirm whether risks are resulting in actual impact to aquatic ecosystems. Potential impact is indicated where the trend of a biological indicator at a test site is declining relative to the trend at a reference site. Within the upper rivers, biological indicators show that potential impact is not occurring. In the lower rivers potential impact is indicated by a reduction in prawn condition at Bebelubi relative to the lower river reference sites, all other indicators show no potential impact. Biological monitoring in Lake Murray has not occurred since 2009 due to a lack of community support, data collected between 1993 and 2009 indicates no potential impact in Lake Murray.

Overall, the environmental performance of the operation in 2015 has been consistent with recent years. The site achieved a high level of compliance with legal obligations and the scope and magnitude of environmental aspects were consistent with recent years. The risk to the receiving environment was unchanged in 2015, despite consistent inputs from the mine coupled with reduced river flows and natural sediment inputs throughout the upper and lower rivers system associated with the strong El Niño event which occurred throughout the year. However, the condition of the receiving environment remains consistent with predictions made prior to operations commencing in 1990.

**Metals Bioavailability and Bioaccumulation Pathways**

The results of the environmental risk assessment indicate inconsistencies between low concentrations of dissolved metals in water and WAE metals in benthic sediment, and bioaccumulation of metals in the tissue of fish and prawns. A possible explanation is the adsorption of dissolved metals onto the fine (<63 um) fraction of sediment particles and the transport of these particles as suspended solids throughout the river system. Upon entering the receiving environment, concentrations of dissolved metals (such as cadmium, nickel and zinc) in water rapidly decrease as a result of a combination of dilution and conversion to particulate form through adsorption to particulate matter. These processes reduce the concentration of dissolved metals within the receiving environment to levels that pose low risk, but at the same time result in metals enrichment of suspended and benthic sediment within the receiving environment.

The segregation of fine and coarse sediment particles is likely to occur during transport along the river system, with the coarse fraction of sediment settling in the upper rivers and the fine fraction remaining suspended throughout the upper rivers and settling when the water flow velocities reduce on the

Strickland lowland. The behaviour of the concentrations of WAE lead in mine-derived sediment associated with both coarse and fine sediment particles appears to follow this pattern. The coarse sediment particles settle in the upper rivers where they comprised >60% by weight of benthic sediment and WAE lead in benthic sediment posed a risk at sites SG1, SG2, Wasiba and Wankipe, the latter which is 116km downstream of the mine. The fine sediment particles settle during lower flow velocities in the lower river where they comprised 57.5% of benthic sediment and WAE lead posed a risk only at Avu, which is approximately 600km downstream of the mine. The occurrence of metal-enriched fine sediment particles as suspended sediment throughout the river system as well as in benthic sediments in the lower river and subsequent ingestion by fish and prawns is proposed as an important exposure pathway. PJV continued to work with CSIRO in 2015 on investigation of bioaccumulation of metals, focusing on the analysis and interpretation of monitoring data.

## Recommendations for Improvement

Recommendations are proposed to improve the: certainty of the findings of future reports; 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 2014 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 lower river, Lake Murray and ORWB reference and test sites;
2. Continue to investigate potential bioaccumulation pathways for contaminants of concern within the receiving environment;
3. Continue to improve the methods for sampling fish and prawn populations to improve catch rates, reduce within-site variability, therefore improving consistency and increasing statistical power;
4. Continue to conduct an annual macroinvertebrate survey to establish a robust data set, with the aim of incorporating macroinvertebrates as an additional indicator of impact into future annual environment reports;
5. Continue to revise the QA/QC procedures associated with tissue metal sampling;

### Reduce Environmental Risk and Impact and Improve Performance

6. Continue to investigate options for reducing the bioavailability of metals within the receiving environment;
7. Continue to implement the Waste Rock Management Plan to minimise the release of metalliferous drainage from the competent waste rock dumps.

### Communication and Engagement

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

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**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: P**apua 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.

**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 definition).

**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 PJV Gold Mine is located in the Porgera Valley of Enga province in the Papua New Guinea highlands, approximately 630km NW of Port Moresby (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 2027 at an annual rate of approximately 500 koz of gold per annum. The site employs approximately 2700 local, national and expatriate staff and contractors.

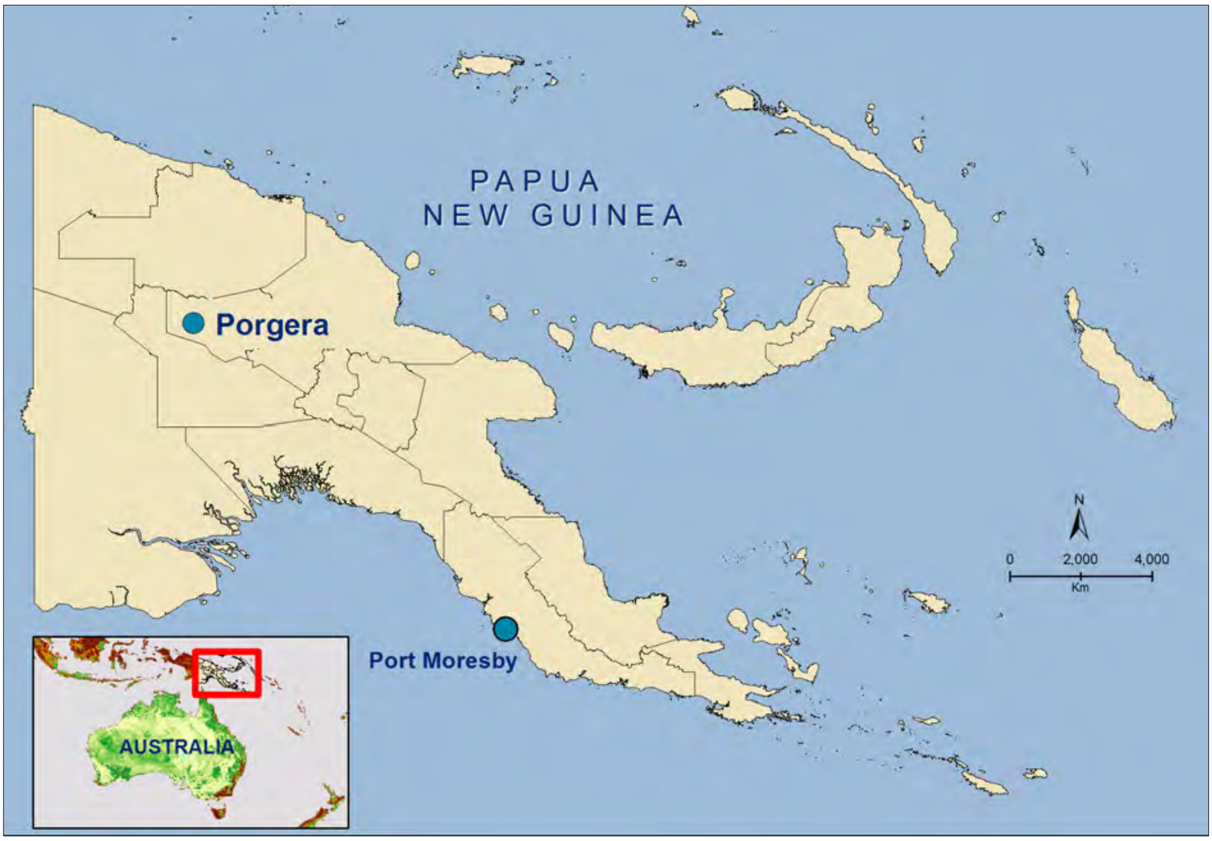


**Figure 1-1 Location of Porgera Operation**

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, mitigate potential environmental risks and continually improve environmental performance.

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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 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 potentially occurring (i.e. species diversity 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 sulphide 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 2500 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 4500 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 8500 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 2015 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.<br>First production Sept 1990.<br>CIP tails stored onsite for processing at a later stage.<br>Commenced discharge of flotation tailings to the river system. |
| 2 | Sept 1991 – Aug 1991 | 2,500 t/day | Increased underground mine production.<br>Installation of pressure oxidation circuit.<br>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.<br>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.<br>1997 – Increased open pit fleet capacity from 150 to 210 kt/day.<br>1999 – Further expansion of flotation circuit and additional oxygen plant.<br>2001 – Acacia reactor.<br>2003 – Secondary crusher.<br>2009 – Cyanide destruction plant, reduces WAD-CN in discharge to <0.2ppm<br>2011 – Paste plant, diverts approx 8% tailings volume to the underground mine for backfilling.<br>2015 – 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 and debris, 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 sulphides are oxidised in the autoclave process. Oxidation liberates gold bound to sulfides within the concentrate by oxidising sulfide to form sulphuric 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 sulphuric 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 – 100mg/L WAD-CN in the feed to <0.2mg/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.

Approximately 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 cycloned 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.

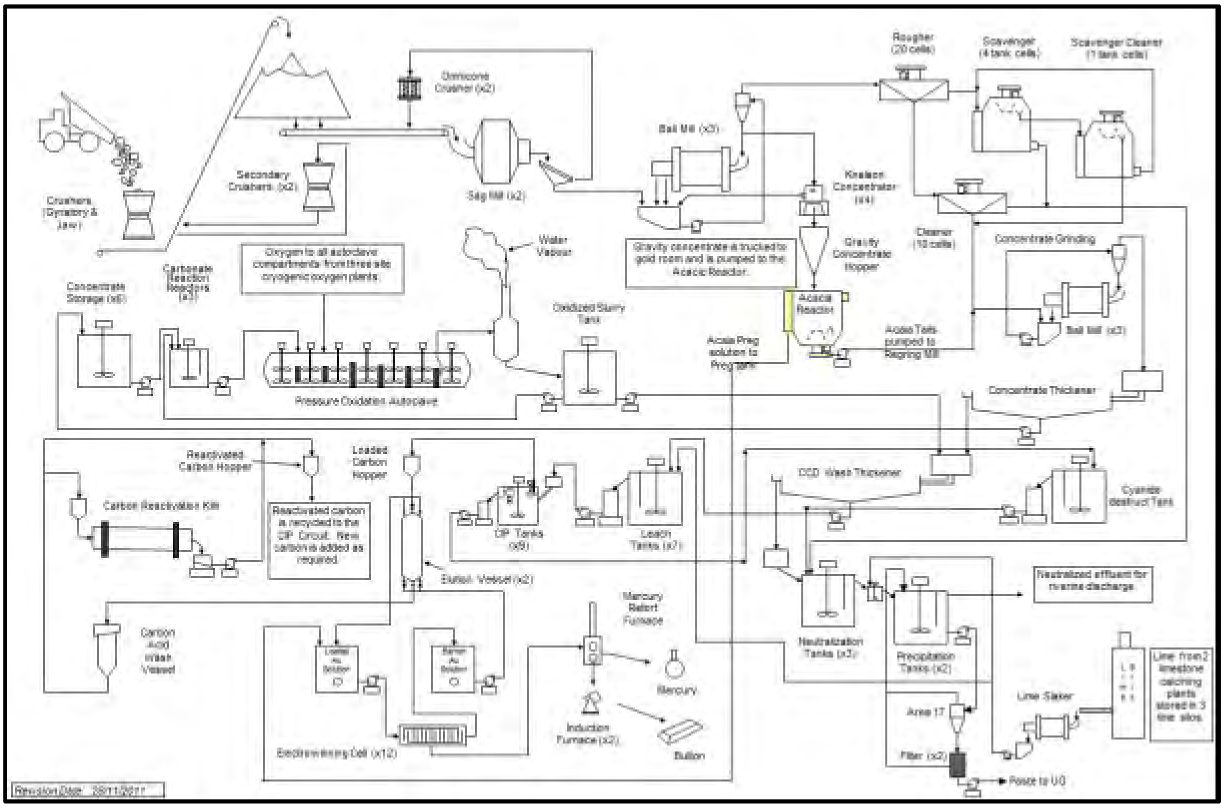



**Figure 1-2 Process flow chart**

# 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 trigger values 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 operations 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 trigger values (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. Exceedence 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.

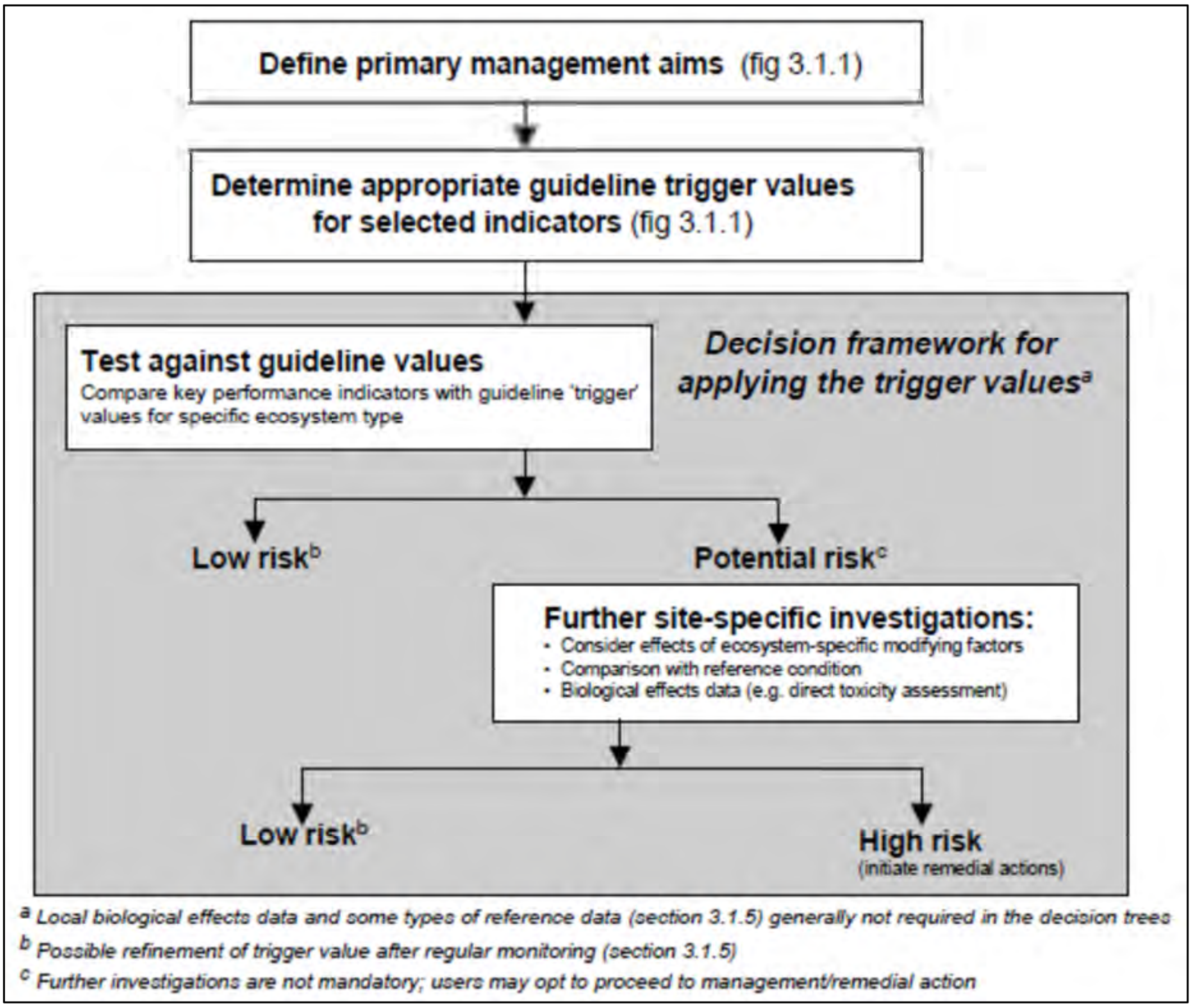



**Figure 2-1 ANZECC/ARMCANZ Risk Assessment Framework (ANZECC/ARMCANZ Fig 3.3.1)**

## 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 experimental 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 2.2.4. 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 mineralization 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 Wilcoxons test, a non-parametric rank test, to support the comparison of the TV with the TSM 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 (2015) – 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)<br>*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)<br>Cd, Hg, Pb – European Food Safety Authority (EC 2006)<br>Cr – Hong Kong Food Adulteration (Metallic Contamination) Regulations (HK 1997)<br>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)<br>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 TVs for parameters other than pH

Water quality TVs for all parameters 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 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 trigger values 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 are 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 comparison 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  and Table 2-3.

**Table 2-2 Water quality TVs**

| Indicator Parameter | Trigger Value (TV) Derivation |
|---|---|
| Water Quality:<br>Physical and chemical stressors (except pH) and toxicants | Adopt whichever is higher:<br>- Baseline 80%ile (full data set)<br>- Regional reference site 80%ile (most recent 24-month data set), or<br>- ANZECC/ARMCANZ default guideline for 95% species protection (hardness modified where appropriate) |

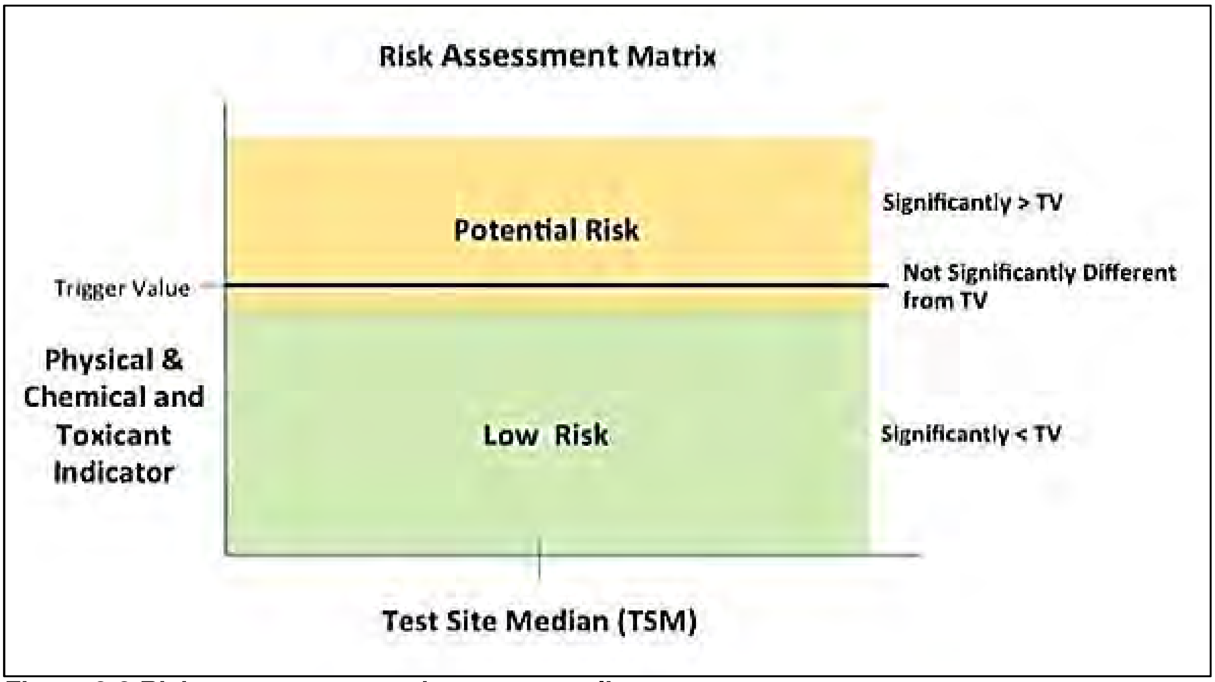


**Figure 2-2 Risk assessment matrix – water quality**

**Table 2-3 Risk assessment matrix – water quality**

| 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<br><br>And TV, TSM and TSM data set not all ≤ LOR. | | |
| TSM not significantly different from TV<br><br>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 TVs for 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 pH TVs**

| Indicator Parameter | Trigger Value (TV) Derivation |
|---|---|
| Water:<br>pH – upper | Adopt whichever is higher:<br>- Baseline 80%ile (full data set)<br>- Regional reference 80%ile (most recent 24months data set), or<br>- ANZECC/ARMCANZ upper limit for upland rivers in tropical Australia |
| Water:<br>pH – lower | Adopt whichever is lower:<br>- Baseline 20%ile (full data set)<br>- Regional reference 20%ile (most recent 24months data set), or<br>- ANZECC/ARMCANZ lower limit for upland rivers in tropical Australia |

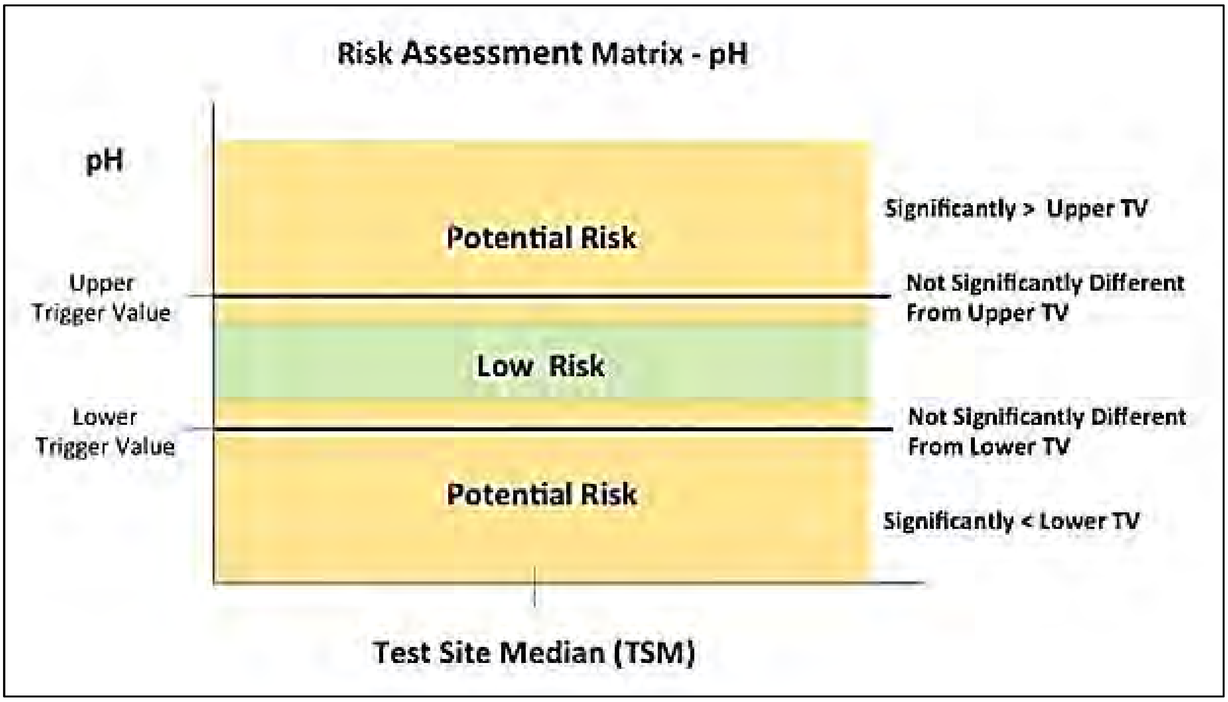



**Figure 2-3 Risk assessment matrix – pH**

**Table 2-5 Risk assessment matrix – pH**

| 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 2008). 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 derived 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 mineralization 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), Wilcoxons 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:<br>- Reference site 80%ile WAE in whole sediment (most recent 24months data set), or<br>- ANZECC/ARMCANZ (2000) ISQG-low |

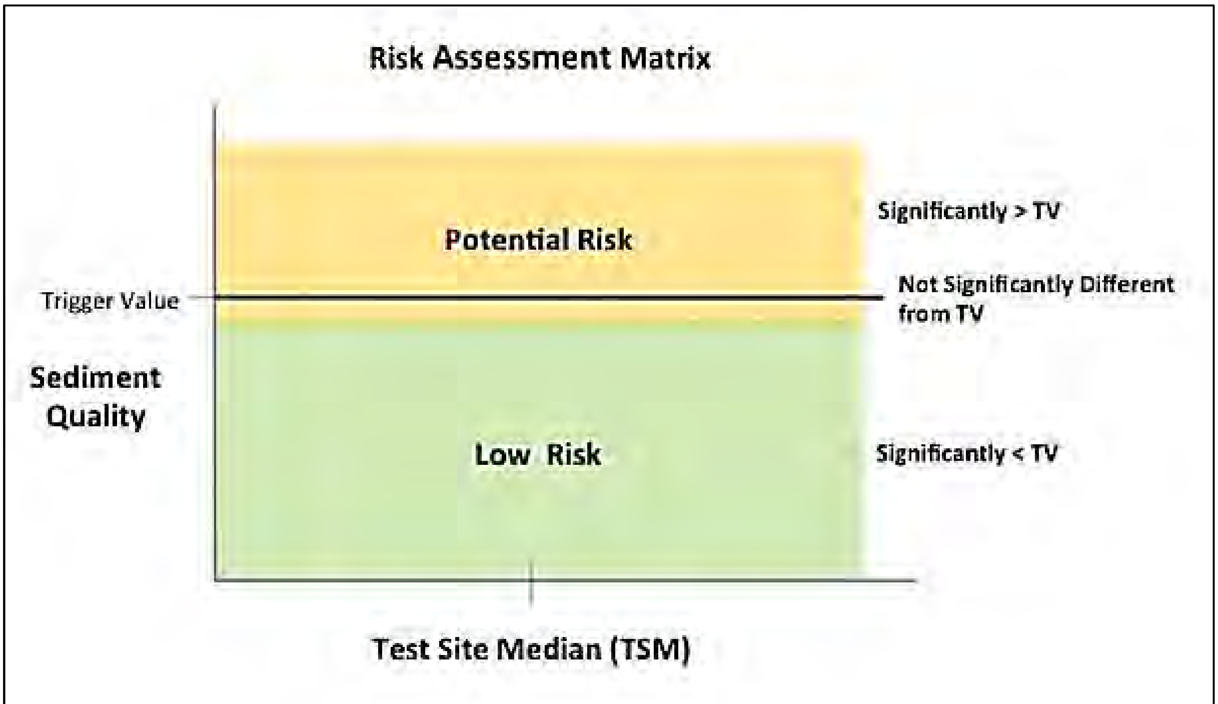



**Figure 2-4 Risk assessment matrix – sediment quality**

**Table 2-7 Risk assessment matrix – sediment quality**

| 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<br><br>And TV, TSM and TSM data set not all ≤ LOR. | | |
| TSM not significantly different from TV<br><br>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

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 mineralization 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 trigger value 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 2015). 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:<br>- Baseline 80%ile (full data set)<br>- Reference site 80%ile (most recent 24 months), or<br>- USEPA criterion (available for Selenium (Se) only) |

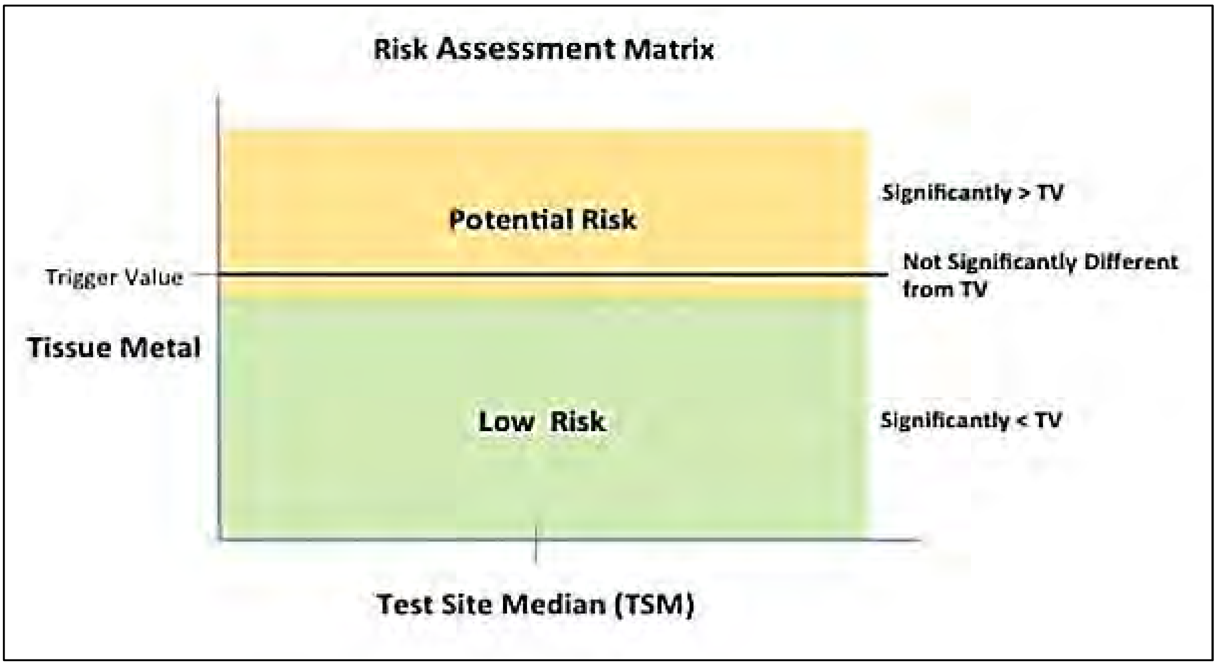



**Figure 2-5 Risk assessment matrix – tissue metal concentrations**

**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<br>And TV, TSM and TSM data set not all ≤ LOR. | | |
| TSM not significantly different from TV<br>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 7.4.

Water-based activities involve contact with water, in PJVs context this includes gold panning, swimming, washing 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 100mL of water is ingested during the recreational activity. The results of the risk assessment are presented in Section 7.5.

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 7.6.

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 7.7.

**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:<br>Water quality – village water supplies | *PNG Public Health (Drinking Water) Regulation 1984* – Schedule 1 Standards for Raw Water (PNG 1984) |
| Water-based activities:<br>Water quality – receiving environment 2015 TSM | ANZECC/ARMCANZ (2000) Guidelines for recreational water quality and aesthetics (Chapter 5)<br>*PNG Public Health (Drinking Water) Regulation 1984* – Schedule 1 Standards for Raw Water (PNG 1984) |
| Fish and prawn consumption:<br>Tissue metals – fish and prawns 2015 TSM | As – Australia New Zealand Food Standards Code – Standard 1.4.1 – Contaminants and natural toxicants (ANZFS 2016)<br>Cd, Hg, Pb – European Food Safety Authority (EC 2006)<br>Cr – Hong Kong Food Adulteration (Metallic Contamination) Regulations (HK 1997)<br>Cu, Se, Zn – Food Standards Australia New Zealand GEL for Metal Contaminants 90%ile (ANZFA 2001) |
| Air quality:<br>Emissions at point source | NSW Protection of the Environment Operations (Clean Air) Regulation 2010 (NSW 2010)<br>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

ANZECC/ARMCANZ (2000) recommends deriving impact assessment criteria in the form of TVs from the most recent 24 months observations of aquatic fauna at the reference site(s). This method is consistent with the approach used for risk assessment based on physical and chemical parameters indicators. However, the regional reference site data set(s) upon which this approach is based must achieve minimum quality requirements in order for the TVs to be valid.

In 2013, initial analysis of the ability of the Porgera data set to support this approach identified issues related to small sample size, high variability, low replication and poor catch rate. Small sample size resulted in low statistical power and poor catch rates resulted in narrow data range within the results, which ultimately produced TVs with very low values, with sometimes zero catch recorded at reference sites. These issues appeared to relate to a combination of sampling methods used, limitations of habitat availability, sampling difficulties, and naturally low diversity and abundance of fish and prawns. Therefore, it was concluded that the data being used to develop biological TVs using the 24month method were not suitable for supporting robust and accurate impact assessment.

This issue was first identified in the 2013 AER and in response PJV has developed an alternative method for impact assessment using fish and prawn catch data, and in 2014 began a pilot study to investigate the validity of benthic macroinvertebrates as an additional biological indicator.

The alternative approach for impact assessment based on fish and prawn catch data uses the Spearman Rank Test, which was selected as a statistically conservative method of comparing temporal trends in fish and prawn catch data between test and reference sites. The approach involves applying the Spearman Rank Test (the test) to the test site data and then to the reference site data using data from the most recent 5 years. The test is capable of determining whether the given indicator is increasing, decreasing or remaining constant over the monitoring period to a pre-determined level of statistical significance, and thereby allows a comparison of the trend at the test sites against that of the reference sites.

It should be noted however, that given the limitations to the data outlined above, the 5-year trend must similarly be treated with caution. Therefore, the results of the Spearman Rank tests are considered suitable for use only as an indicator of potential impact.

The Spearman Rank Test is run using Minitab software and produces a correlation coefficient (Spearman's rho), and a statistical probability (P) for each data set. The results of the Spearman Rank Test are interpreted in accordance with Table 2-12 and the impact assessment is conducted in accordance with the decision matrix presented in Table 2-13.

**Table 2-12 Interpretation of Spearman Rank Test results**

| Indicator Parameter | Spearman's rho sign | Probability (P) | Conclusion about indicator behaviour |
|---|---|---|---|
| Trend of annual median of fish and prawn<br>- Abundance<br>- Richness<br>- Biomass<br>- Condition | Positive sign (+) | $P < 0.05$ | Significant increase over time |
| | Negative sign (-) | $P < 0.05$ | Significant decrease over time |
| | Either positive or negative | $P \geq 0.05$ | No significant change over time<br>(i.e. no statistically significant increase or decrease over time) |

**Table 2-13 Impact assessment matrix – Fish and Prawns**

| Indicator Parameter | Reference site | Test Site | Impact Rating |
|---|---|---|---|
| Trend of annual median from 2011 - 2015 using Spearman rank sign and significance for fish and prawn:<br>- Abundance<br>- Richness<br>- Biomass<br>- Condition | No significant change over time | No significant change over time | No potential adverse impact indicated.<br>Trend of annual median at test sites stable or increasing over time relative to reference sites. |
| | No significant change over time | Significant increasing trend over time | |
| | Significant decreasing trend over time | No significant change over time | |
| | Significant decreasing trend over time | Significant increasing trend over time | |
| | Significant decreasing trend over time | Significant decreasing trend over time [1] | |
| | Significant increasing trend over time | Significant increasing trend over time [1] | |
| | No significant change over time | Significant decreasing over time | Potential adverse impact indicated.<br>Trend of annual median at test sites reducing over time relative reference sites. |
| | Significant increasing trend over time | No significant change over time | |
| | Significant increasing trend over time | Significant decreasing trend over time | |

1 – Indicates "system-wide" change and not mine-related, i.e. occurring at the reference sites and test sites

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

### 2.6.2 Benthic Macroinvertebrates

Given that the challenges associated with the fish and prawn monitoring program reduce the ability of the impact assessment process to detect change, 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 will be performed again in 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.

Compared to fish and prawns, benthic macroinvertebrate assemblages are more easily sampled, function at a lower spatial scale, are less mobile, and support species with a range in sensitivities to a range of stressors, providing greater ability to detect mine impacts. 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 on the Strickland River. The sites were chosen to allow direct, pairwise comparison of data between the test and the reference sites.

## 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 data set 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 test used for determining statistical significance of trends over time to support the impact assessment using fish and prawn data is the Spearman Rank Test, 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).

Both 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 impacts assessments for water quality, sediment quality and tissue metals are shown as expanded assessment matrices in Appendix D, E and F respectively.

For macroinvertebrates, a range of univariate and multivariate statistical tests were 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, but also indices dependent on number of taxa known to be sensitive to a range of pollutants, 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, 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. 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 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 Parameters | Biological Parameters |
|---|---|---|---|
| Riverine tailings disposal | Volume discharged, TSS concentration, pH, conductivity | Metal concentrations<br>WAD CN | NA – applied only in receiving environment |
| Waste rock disposal to water | Volume discharged | Metal concentrations | NA – applied only in receiving environment |
| Waste rock disposal to land | Area disturbed<br>Volume of waste disposed to land (solid waste and competent waste rock) | Metal concentrations | NA – applied only in receiving environment |
| Water extraction | Volume extracted | NA | NA – applied only in receiving environment |
| Discharge to air | Emission rate, particulate concentration | Metal concentrations<br>Greenhouse gas volume | NA – applied only in receiving environment |
| Land disturbance | Area disturbed<br>% rehabilitated | NA | NA |

| Environmental Aspect | Physical Parameters | Chemical Parameters | Biological Parameters |
|---|---|---|---|
| Resource consumption | Volume consumed<br>Consumption efficiency | NA | NA |
| Waste generation | Volume generated<br>% to landfill<br>%incinerated<br>% recycled | Waste type | NA |

## 3.2 Environmental Conditions

To determine the scope and magnitude of the interactions between the operations 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 allow 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 parameters**

| Environmental Aspect | Indicator Parameters Physical | Medium and toxicant | Biological |
|---|---|---|---|
| Riverine tailings disposal | River profiling – cross-sections<br>Water quality – TSS concentration, pH, conductivity | Water Quality – Metal concentrations, WAD-CN<br>Stream Sediment Quality – Metal concentration<br>Metal concentrations in fish and prawn tissue | Diversity, richness, biomass and condition of fish and prawns.<br>Macroinvertebrate assemblages. |
| Waste rock disposal to water | River profiling – cross-sections<br>Water quality – TSS concentration, pH, conductivity | Water Quality – Metal concentrations<br>Stream Sediment Quality – Metal concentration<br>Metal concentrations in fish and prawn tissue | Diversity, richness, biomass and condition of fish and prawns.<br>Macroinvertebrate assemblages. |
| Waste rock disposal to land | Area of disturbance<br>Volume waste disposed to land (solid waste and competent waste rock) | Geotechnical characteristics – Competency<br>Geochemical characteristics - Metal concentrations, sulfur concentrations | Terrestrial flora and fauna communities. |
| Water extraction | Flow downstream of water extraction points | NA | Macroinvertebrate communities. |
| Discharge to air | Particulate concentration | Air Quality - Metal concentration | NA |
| Land disturbance | Area of disturbance | NA | Terrestrial flora and fauna communities. |
| Resource consumption | NA | 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 Table 3-1 and Figure 3-2 shows monitoring locations within Lake Murray.

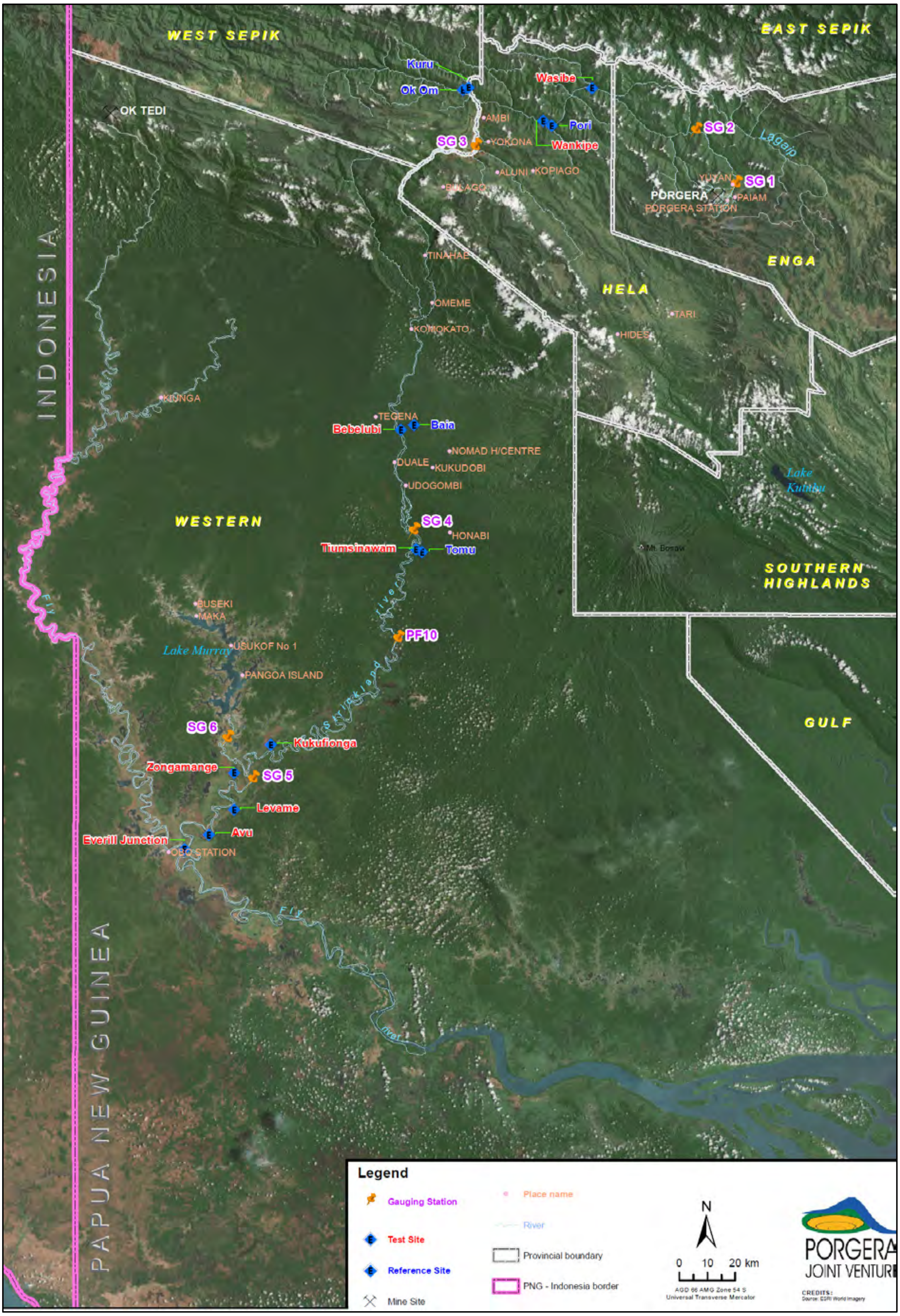



**Figure 3-1 Receiving environment monitoring sites**

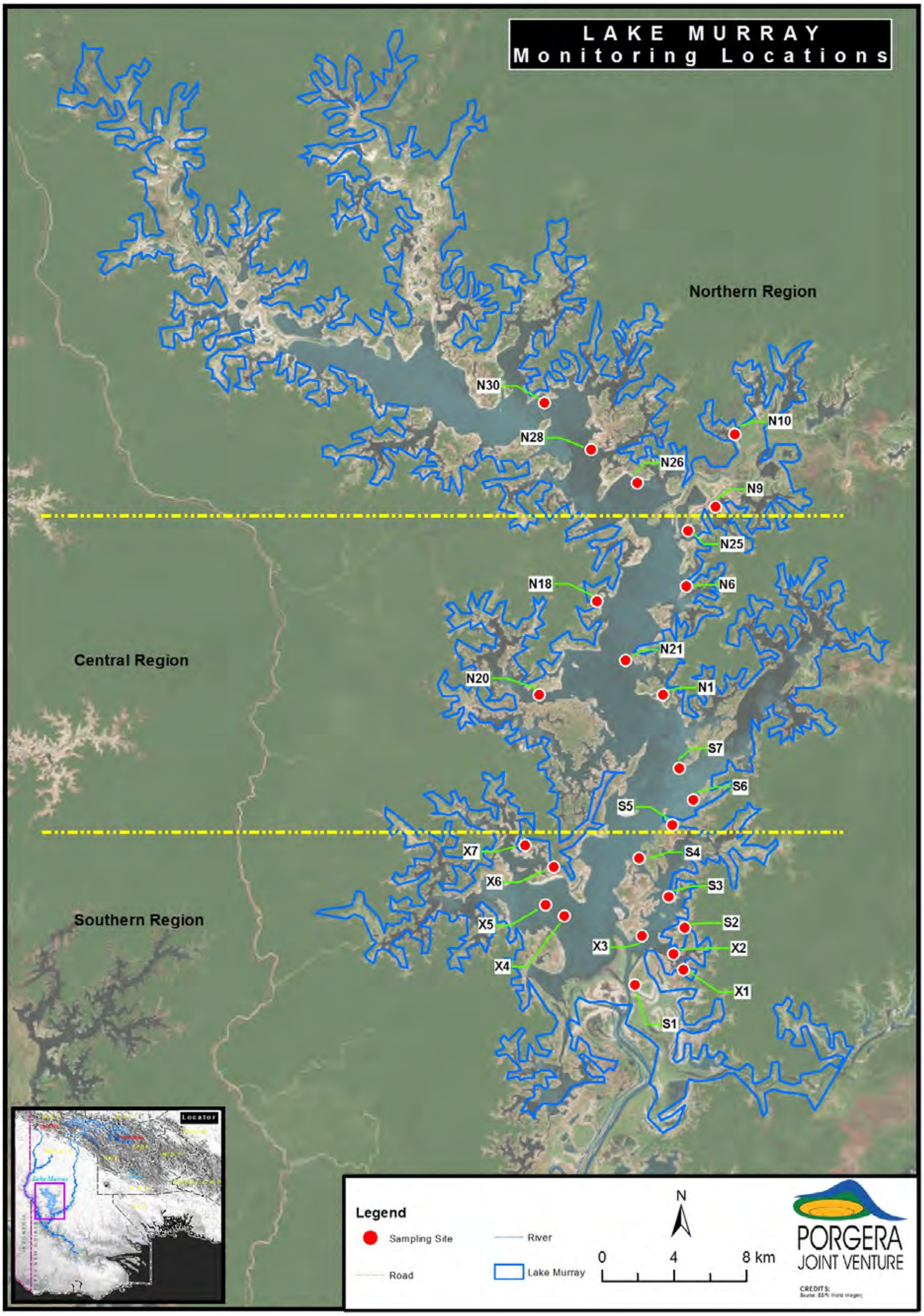



**Figure 3-2 Lake Murray monitoring locations**

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

| Test Site | | Reference Sites and Parameters | | | | |
|---|---|---|---|---|---|---|
| | | **Profile** | **Water and Sediment** | **Tissue Metal** | **Diversity, Richness and Biomass** | **Condition** |
| Upper River | SG1 | NAR[1] | Ok Om<br>Kuru<br>Pori | NA[2] | NA[2] | NA[2] |
| | SG2 | Ok Om | Ok Om<br>Kuru<br>Pori | NA[2] | NA[2] | NA[2] |
| | Wasiba | Ok Om | Ok Om<br>Kuru<br>Pori | Ok Om<br>Kuru<br>Pori | Ok Om | Ok Om<br>Kuru<br>Pori |
| | Wankipe | Ok Om | Ok Om<br>Kuru<br>Pori | Ok Om<br>Kuru<br>Pori | Ok Om | Ok Om<br>Kuru<br>Pori |
| | SG3 | Ok Om | Ok Om<br>Kuru<br>Pori | NA[2] | NA[2] | NA[2] |
| Lower Strickland River | Bebelubi | NA[2] | Baia<br>Tomu | Baia<br>Tomu | Baia<br>Tomu | Baia<br>Tomu |
| | Tiumsinawam/SG4 | NA[2] | Baia<br>Tomu | Baia<br>Tomu | Baia<br>Tomu | Baia<br>Tomu |
| | PF10 | NAR | NA[2] | NA[2] | NA[2] | NA[2] |
| | SG5 | NAR | Baia<br>Tomu | Baia<br>Tomu | Baia<br>Tomu | Baia<br>Tomu |
| | Upstream of Everil Junction | NA[2] | Baia<br>Tomu | Baia<br>Tomu | Baia<br>Tomu | Baia<br>Tomu |
| Lakes and Off-River Water Bodies | South Lake Murray<br>Central Lake Murray<br>SG6 | NA[2] | North Lake Murray | North Lake Murray | North Lake Murray | North Lake Murray |
| | Kukufionga | | | | | |
| | Zongamange | | | | | |
| | Avu | | | | | |
| | Levame | | | | | |
| Drinking Water | Villages surrounding Porgera Mine | NA[2] | NA[3] | NA[2] | NA[2] | NA[2] |
| Air Quality | Hides Power Station boundary<br>Villages surrounding Porgera Mine | NA[2] | NA[3] | NA[2] | NA[2] | NA[2] |

[1] NAR – No appropriate reference

[2] NA – Indicator not applied at monitoring site

[3] NA – 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 Group | Regional Ref Sites | Test Sites | Suitability Assessment | | | Comments |
|---|---|---|---|---|---|---|
| | | | Phys | Chem and Toxicant | Bio | |
| Upper River | Upper Lagaip | SG1<br>SG2<br>Wasiba<br>Wankipe<br>SG3 | Good | Poor | Poor | Lower mineralization<br>Naturally depauperate fish and prawn populations<br>Fish and prawns potentially exposed to elevated metals if migrating between test and reference sites. |
| | Pori | | Poor | Poor | Poor | Small tributary<br>Lower mineralization<br>Lower flows<br>Lower suspended sediment<br>Different habitat types<br>Reference site biology potentially indirectly impacted (i.e. fish and prawn migration)<br>Fish and prawns potentially exposed to elevated metals if migrating between test and reference sites. |
| | Kuru | | Fair | Poor | Poor | Small tributary<br>Lower mineralization<br>Lower flows<br>Lower suspended sediment<br>Different habitat types<br>Reference site biology potentially indirectly impacted<br>Fish and prawns potentially exposed to elevated metals if migrating between test and reference sites. |
| | Ok Om | | Good | Poor | Fair | Lower mineralization<br>Fish and prawns potentially exposed to elevated metals if migrating between test and ref sites. |

| Reference Site Group | Regional Ref Sites | Test Sites | Suitability Assessment | | | Comments |
|---|---|---|---|---|---|---|
| | | | Phys | Chem and Toxicant | Bio | |
| Lower River | Baia | Bebelubi<br>Tiumsinawam<br>PF10<br>SG5<br>Upstream Everil Junction | Fair | Fair | Poor | Medium size tributary<br>Lower mineralization<br>Different habitat types<br>Ref site biology potentially indirectly impacted<br>Fish and prawns potentially exposed to elevated metals if migrating between test and ref sites. |
| | Tomu | | Fair | Fair | Poor | Medium size tributary<br>Lower mineralization<br>Different habitat types<br>Ref site biology potentially indirectly impacted<br>Fish and prawns potentially exposed to elevated metals if migrating between test and ref sites. |
| Lake Murray | North Lake Murray | Central LM<br>South LM | Good | Good | Good | Nth Lake is potentially impacted. |
| ORWBs | North Lake Murray | Kukufionga<br>Zongemange<br>Avu<br>Levame | Poor | Poor | Poor | Nth Lake is potentially impacted by mine aspects.<br>Different habitats in Lake and ORWBs.<br>Different biological and biochemical and hydrological processing occurring in ORWBs than in Nth Lake. |

### 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 and data recovery in 2015**

| 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 defendable.

The QA/QC program consists of training and competency assessment, equipment calibration, method validation, field blanks, field duplicates, certified reference material, proficiency testing and inter-laboratory analysis. Analysis of metals in water, benthic sediment and prawn and fish tissue is performed 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, based on positive field blank, field duplicate and proficiency testing 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 B.

# 4 OPERATIONS AND ENVIRONMENTAL ASPECTS

This section provides a summary of key operational parameters and environmental aspects for 2015 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 2015**

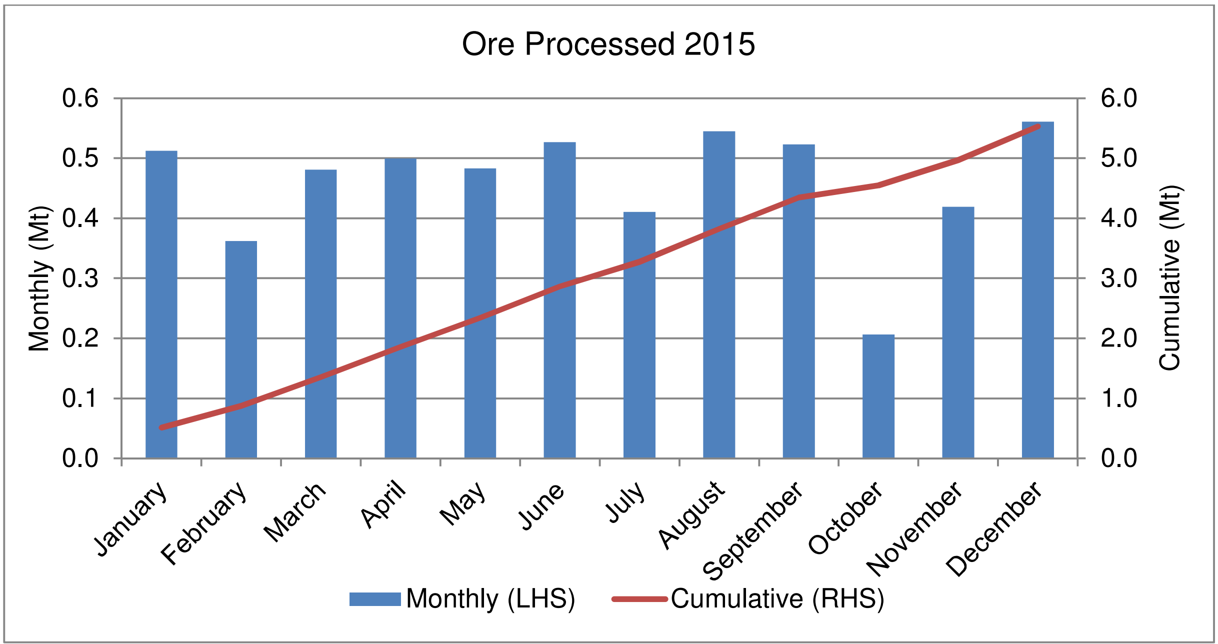
| Operational and Environmental Aspects | 2015 | Life of Mine Total | Comments |
|---|---|---|---|
| Ore processed (Mt) | 5.53 | 119.37 | Consistent with recent years. |
| Gold production (oz) | 554,094 | 18,664,435 | Met 2015 guidance. |
| Competent waste rock produced (Mt) | 4.26 | 419.07 | Lower than previous years. |
| Incompetent waste rock produced – Anawe (Mt) | 3.56 | 224.05 | Consistent with previous years. |
| Incompetent waste rock produced – Anjolek (Mt) | 9.67 | 221.95 | Significantly higher than recent years due Stage 5C mining. |
| Tailings to underground paste (% total tailings volume) | 9.7 | NA | Record volume diverted in 2015. |
| Tailings discharged (Mt) | 5.02 | 116.64 | Consistent with recent years. |
| Total sediment discharged to river (Mt) (from tailings and erodible dumps) | 14.0 | NA | Lower than recent years due to lower rainfall, reducing transport. |
| Sewage discharge ($m^3$) | 259,008 | NA | Consistent with recent years. |
| Mine contact rainfall runoff ($Mm^3$) | 65,589 | NA | Lower than recent years due to lower rainfall. |
| Greenhouse gas and energy efficiency (kg CO2-e / t processed ore) | 79 | NA | 2.6% reduced efficiency compared to 2014, negative trend maintained. |
| Water use and efficiency (L / t processed ore) | 5,166 | NA | 9.6% increased efficiency compared to 2014. |
| Area land disturbed | 2330 | 41% of total leased area is undisturbed. | |
| Area of disturbed land under rehab | 239 ha (10%) | Consistent with recent years. | |

## 4.1 Production

### 4.1.1 Mining and Processing Operations

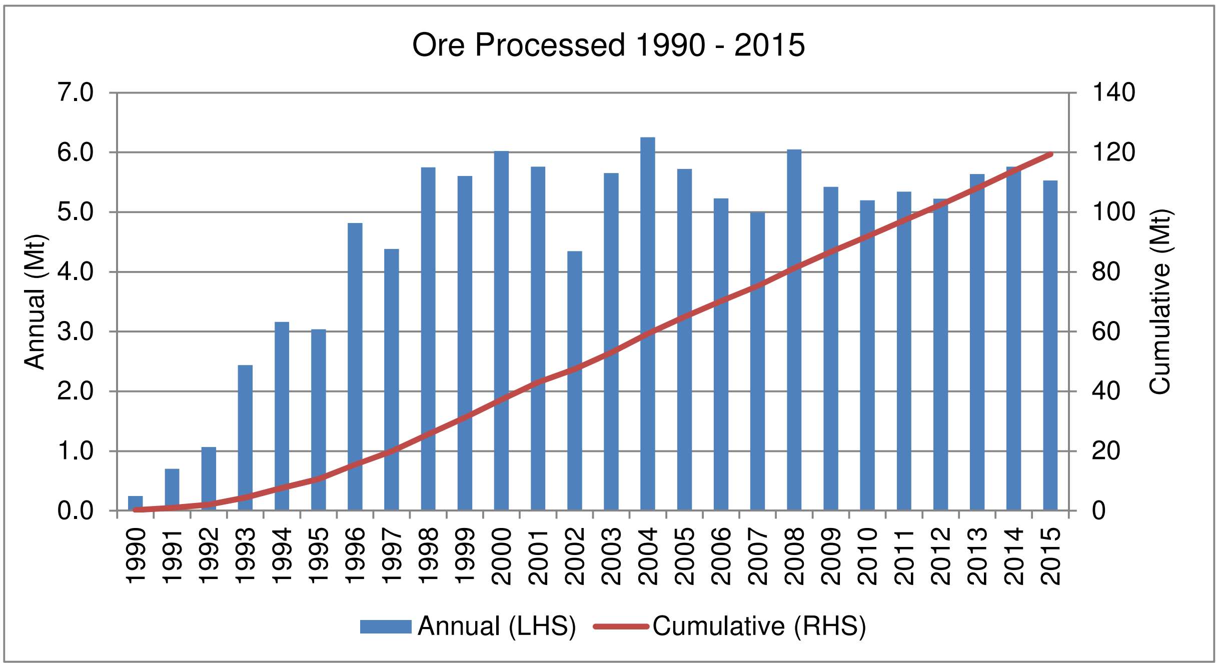
### 4.1.2 Total Ore Processed

The total quantity of ore processed in 2015 was 5.53 million tonnes (Mt). Figure 4-1 shows the monthly and cumulative quantities of ore processed in 2015. The cumulative quantity of ore processed from 1990 to 2015 was 119.4 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 2015**

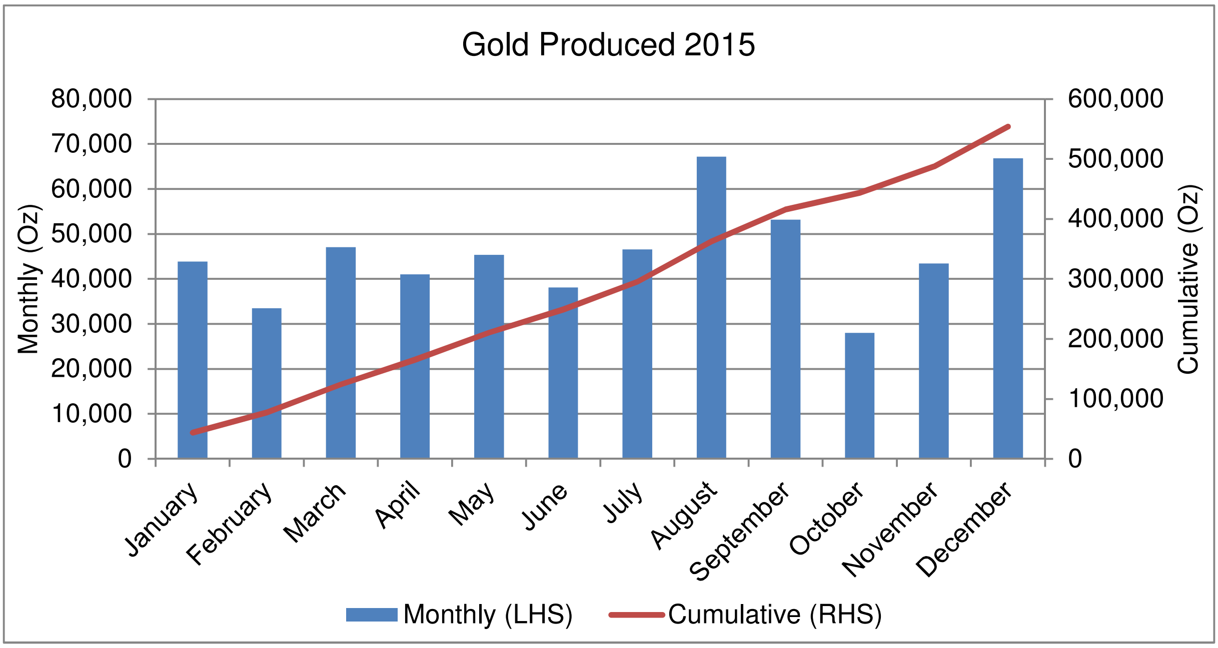



LHS = Left hand side y-axis, RHS = Right hand side y-axis

**Figure 4-2 Yearly and cumulative ore processed 1990 - 2015**

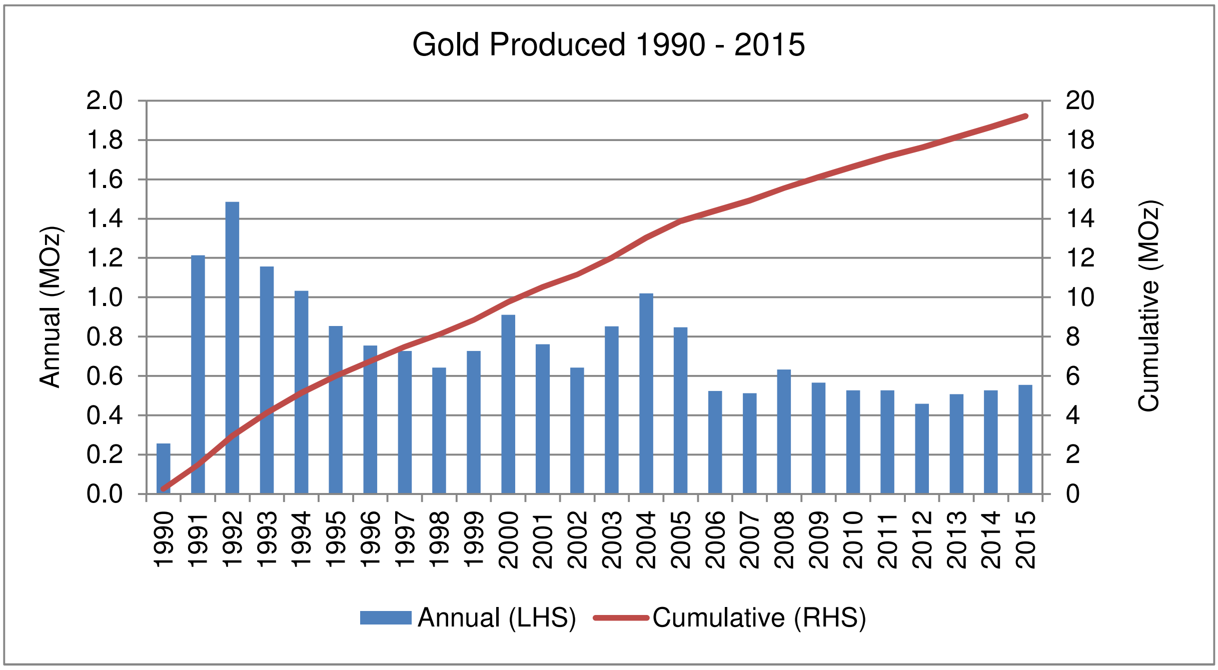
### 4.1.3 Gold Production

Total gold production in 2015 was 554koz. Figure 4-3 shows monthly and cumulative gold production during 2015. Total gold production from 1990 to 2015 was 19.2 million ounces. Figure 4-4 shows annual and cumulative gold production since operations began in 1990.




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

**Figure 4-3 Monthly and cumulative gold production in 2015**




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

**Figure 4-4 Yearly and cumulative gold production 1990 - 2015**

## 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.

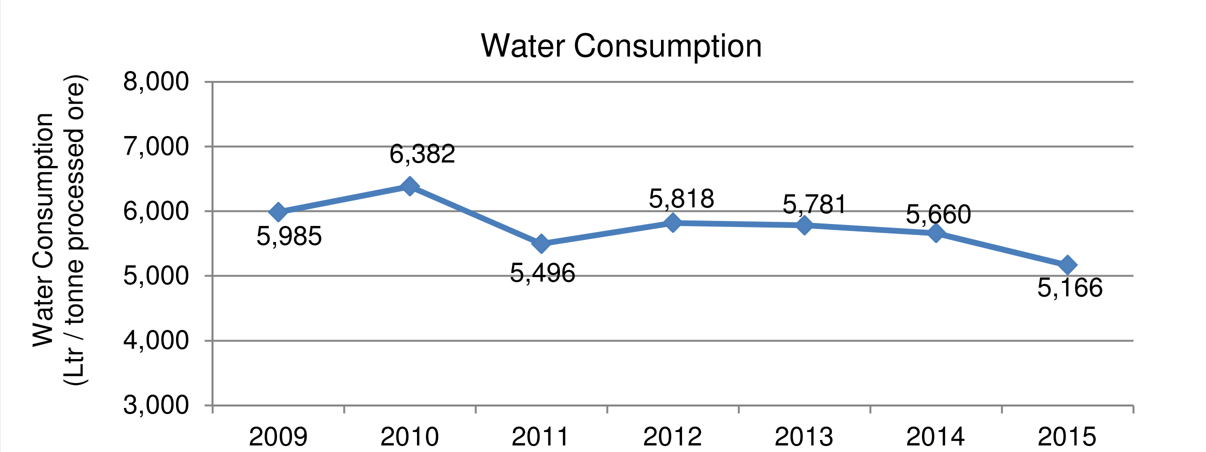



**Figure 4-5 Water use efficiency 2009 - 2015**

## 4.3 Land Disturbance

### 4.3.1 Land Disturbance

Porgera mine holds eight leases with a total area of 3,926.79 ha, the leases are listed in Table 4-2 and are 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 ongoing 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 in 2015 was 2,330 ha, equating to approximately 59% of the total leased areas. The total area of disturbance increased by 11.9 ha during 2015, 2.6 ha was due to expansion of the erodible dumps, 0.7 ha due to expansion of the Kogai diversion drain, 0.5 ha was due to expansion at Anawe competent dump, 6.3 ha was due to mining expansion at Open pit and 1.8 ha due to expansion of the Pangalita limestone quarry.

**Table 4-2 Areas of cumulative land disturbance and reclamation to December 2015**

| Lease | Total Lease Area (ha) | Disturbed (ha) | Undisturbed (ha) | Under Progressive Reclamation (ha) |
|---|---|---|---|---|
| SML | 2107 | 1352 | 755 | 239 |
| Kogai LMP | 424 | 193 | 251 | 0 |
| Kaiya LMP | 602 | 342 | 260 | 0 |
| Anawe North LMP 72 | 220 | 113 | 106 | 0 |
| Anawe South LMP 77 | 204 | 130 | 74 | 0 |
| Anawe LMP3 | 81 | 81 | 0.00 | 0 |
| Suyan LMP | 69 | 45 | 25 | 0 |
| Pangalita LMP | 135 | 59 | 76 | 0 |
| Waile LMP | 85 | 16 | 69 | 0 |
| **TOTAL** | **3927** | **2330** | **1616** | **239** (10.3% of disturbed) |

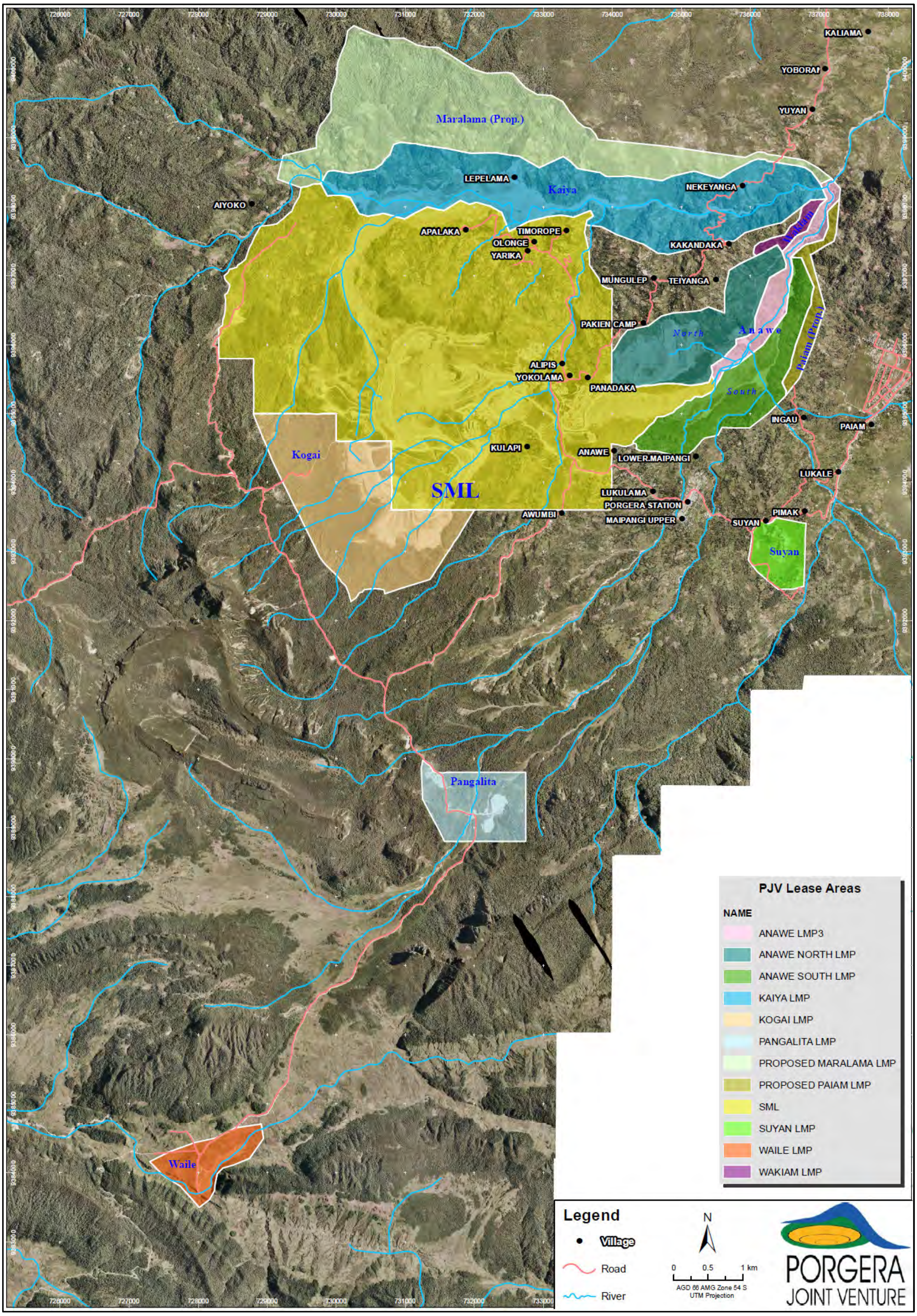



**Figure 4-6 Special mining lease and leases for mining purposes boundaries**

## 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.

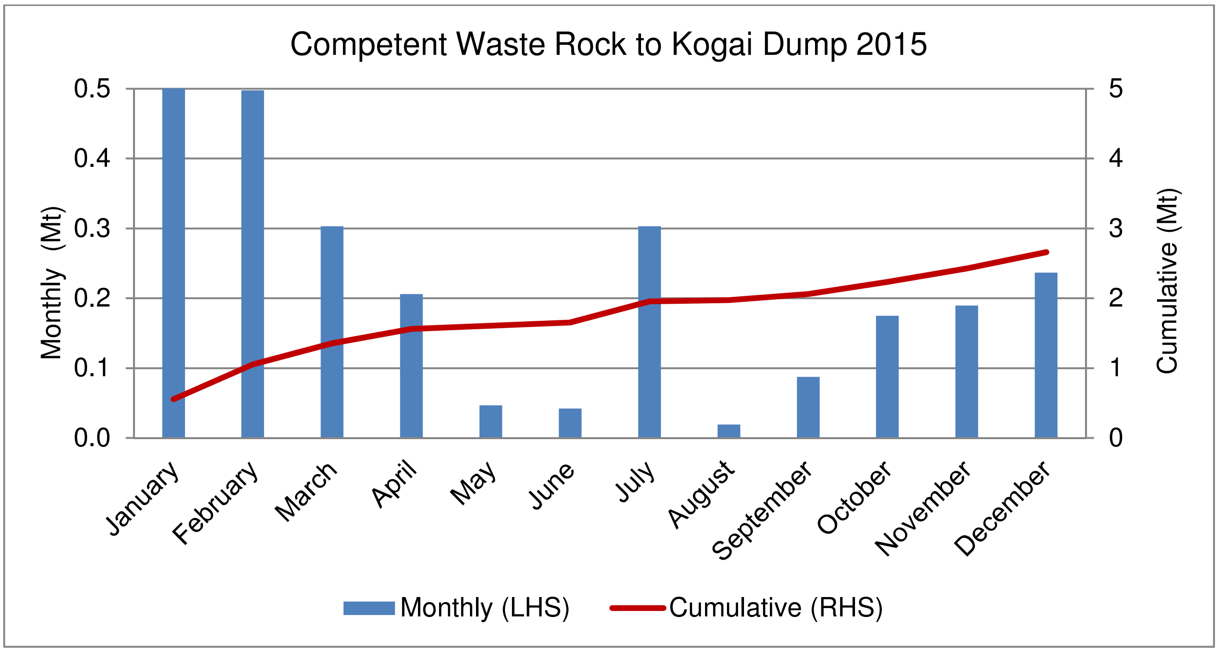
The mass of competent and incompetent waste rock produced and its disposal location between 1989 and 2015 is presented in Table 4-3. The data show that to date, the quantity of competent waste rock placed at Kogai dump is approx twice the total amount placed at Anawe North competent dump since dumping 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 - 2015**

| Waste dump | Total Volume (Mt) |
|---|---|
| Anawe North Competent | 134.23 |
| Kogai Competent | 284.84 |
| ***Competent Sub-Total*** | ***419.07*** |
| Anawe Erodible | 224.05 |
| Anjolek Erodible | 222.95 |
| ***Erodible Sub-Total*** | ***446.00*** |
| **TOTAL** | **865.07** |

### 4.4.1 Kogai Competent Dump

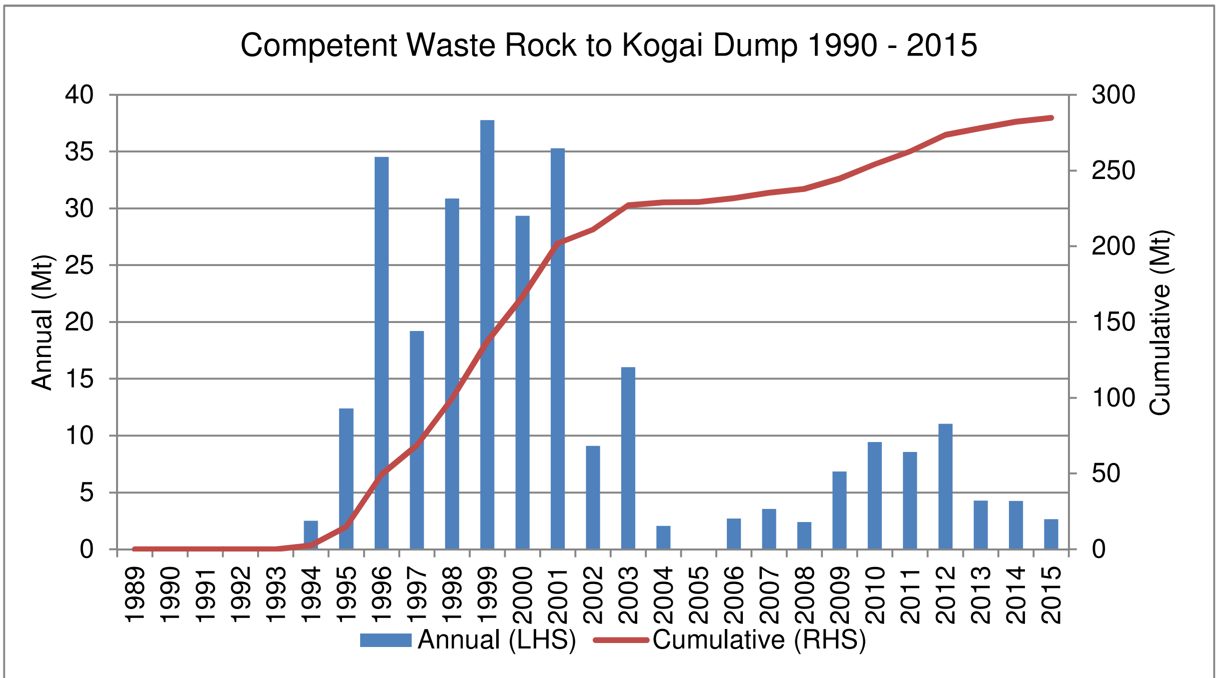
The total quantity of competent waste rock placed at the Kogai dump in 2015 was 2.66 million tonnes, Figure 4-7 shows the monthly and cumulative quantities sent to Kogai during 2015. The dump received the competent waste rock mined from Stages 5B and 5C of the Open Pit during the year.




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 2015**

The total quantity of competent waste rock placed at Kogai since 1989 was 284 million tonnes, Figure 4-8 shows the annual and cumulative quantities placed at Kogai since construction of the dump began in 1989. As can be seen from the graph, most of the waste was placed between 1989 and 2001 when mining was being carried out at the upper zones of the open pit.

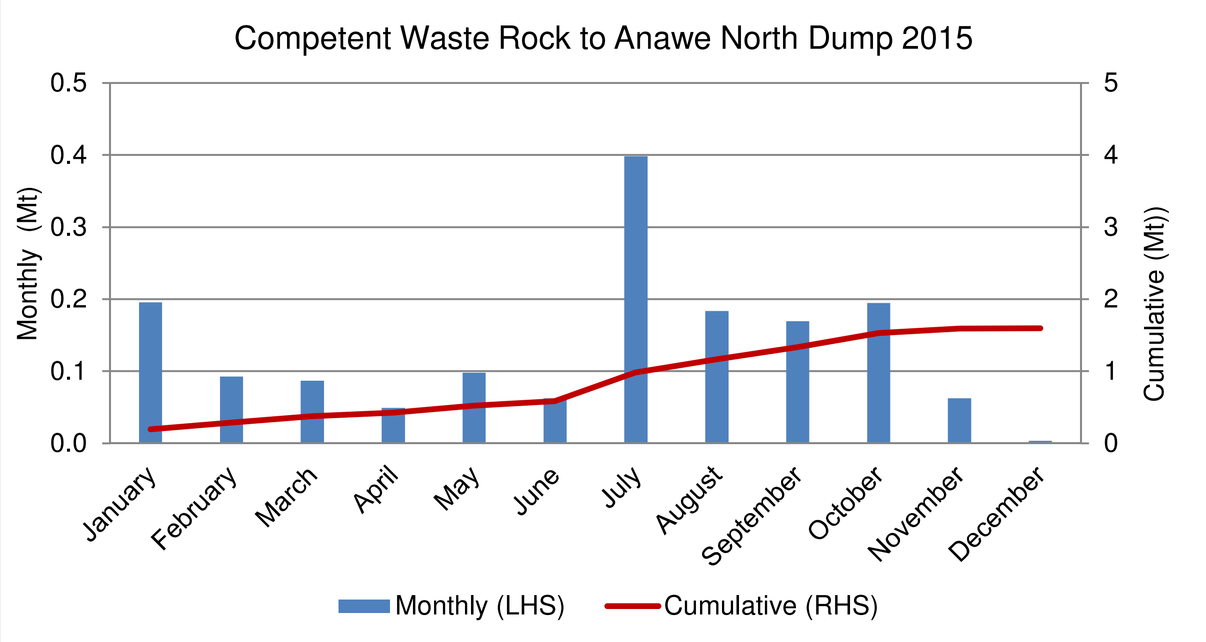



LHS = Left hand side y-axis, RHS = Right hand side y-axis

**Figure 4-8 Yearly tonnages of competent waste rock placed at Kogai Dump 1989 - 2015**

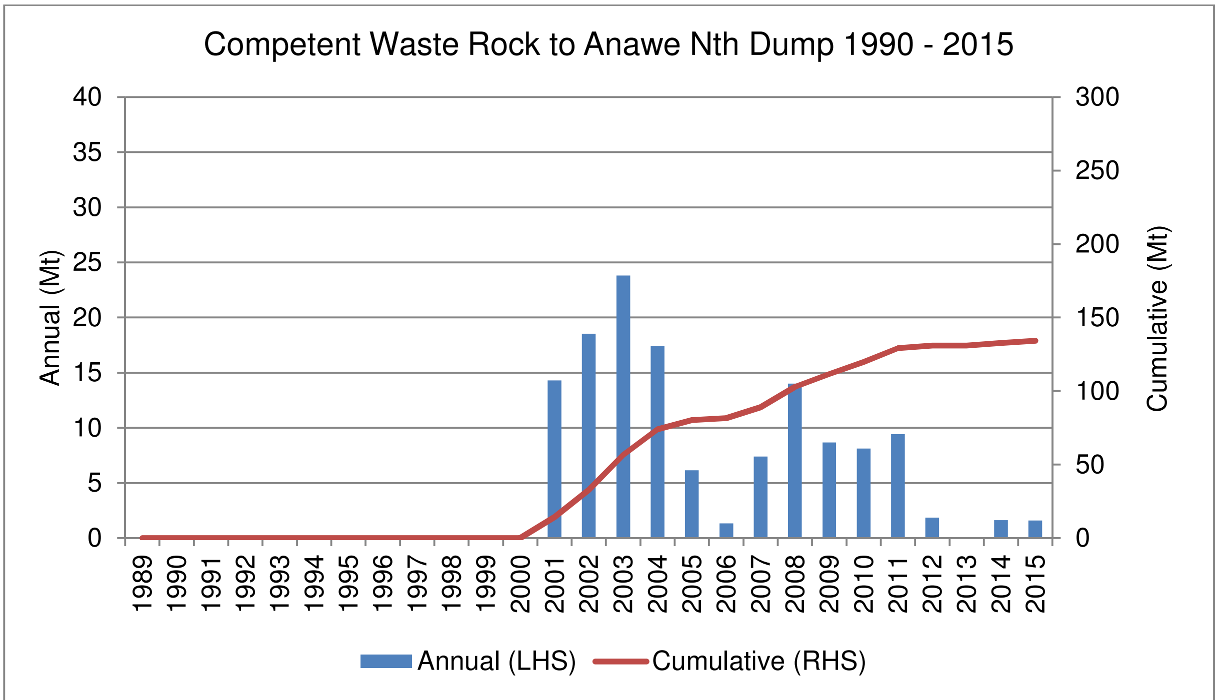
### 4.4.2 Anawe North Competent Dump

Anawe North received 1.6 Mt of competent waste rock in 2015. Figure 4-9 shows the monthly and cumulative quantities of competent rock placed at Anawe North during 2015. The total quantity of competent waste rock placed at Anawe North dump since construction began in 2001 was 134.2 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 2015**




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

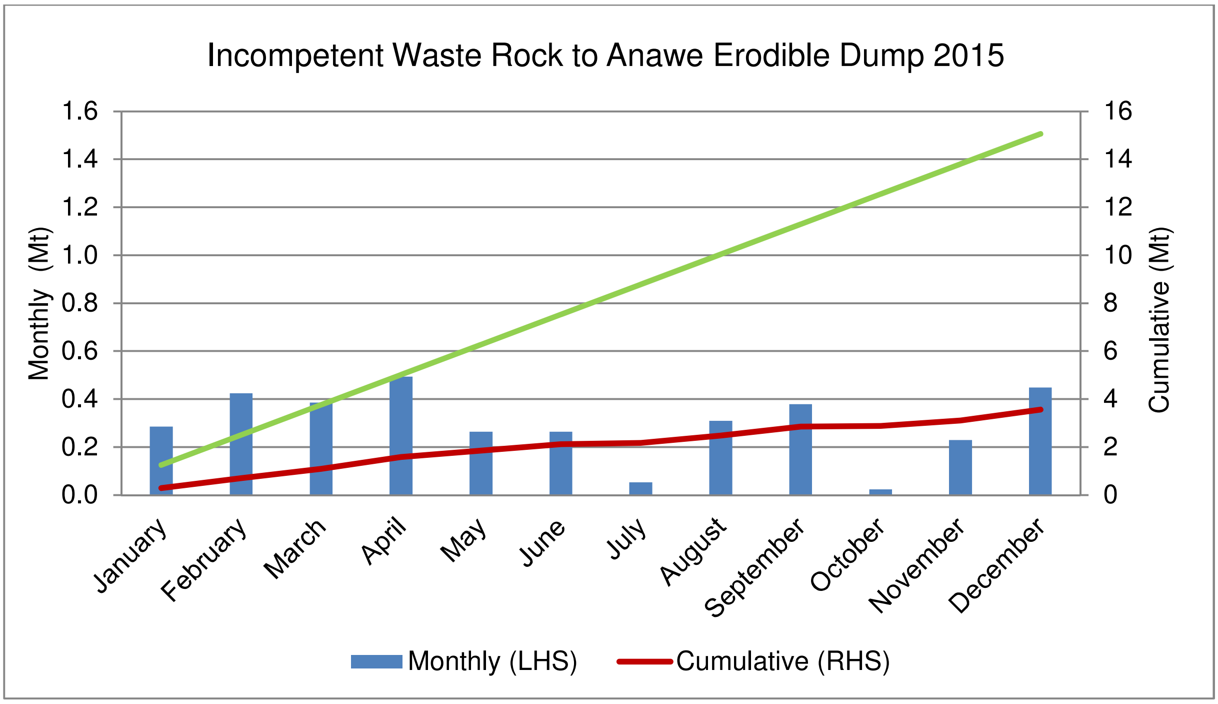
**Figure 4-10 Yearly tonnages of competent waste rock placed at Anawe North Dump 2001 - 2015**

## 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 2015 were slightly less than previous years due to decreased mining of incompetent material from the bottom of the open pit.

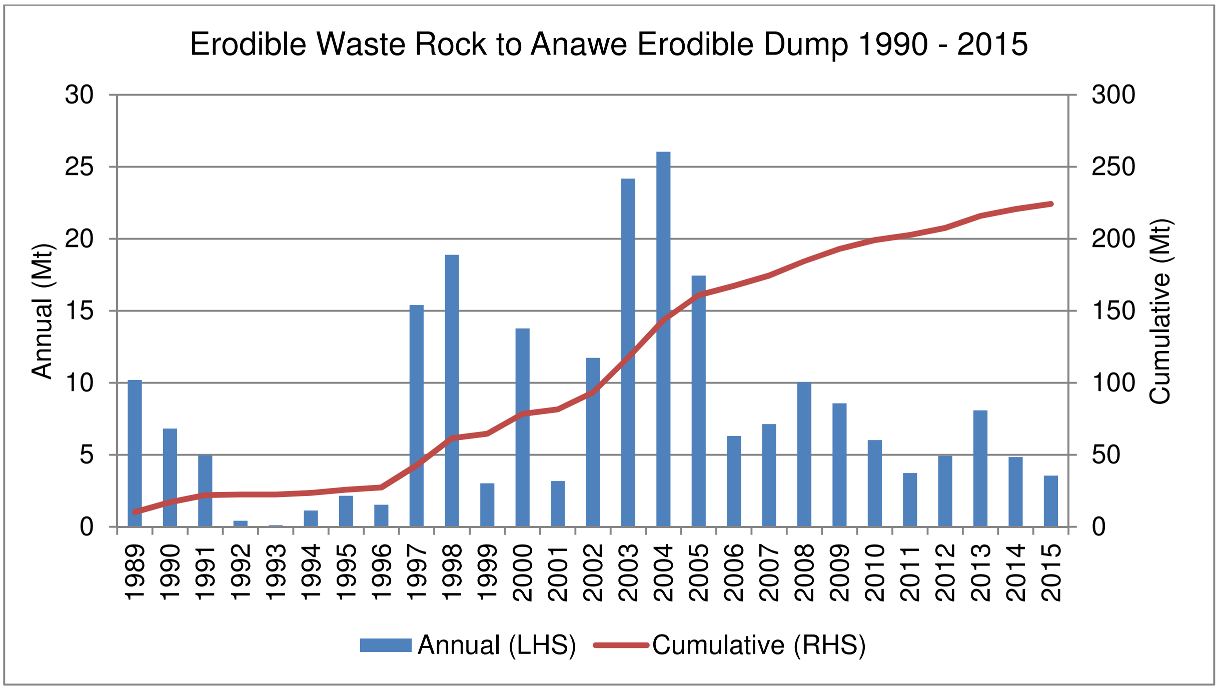
#### *4.5.1.1 Anawe Erodible Dump*

Monthly volumes to Anawe erodible dump in 2015 are shown in Figure 4-11. A total of 3.56 Mt of incompetent waste was placed in Anawe during 2015, the majority of which was mudstone material excavated from the bottom of the open pit. The volume placed was 24% of the annual permit limit of 15.07 Mt. Figure 4-12 shows the annual volumes of spoil 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 spoil placed at Anawe Erodible Dump in 2015**




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

**Figure 4-12 Yearly tonnages of spoil placed at Anawe Erodible Dump July 1989 - 2015**

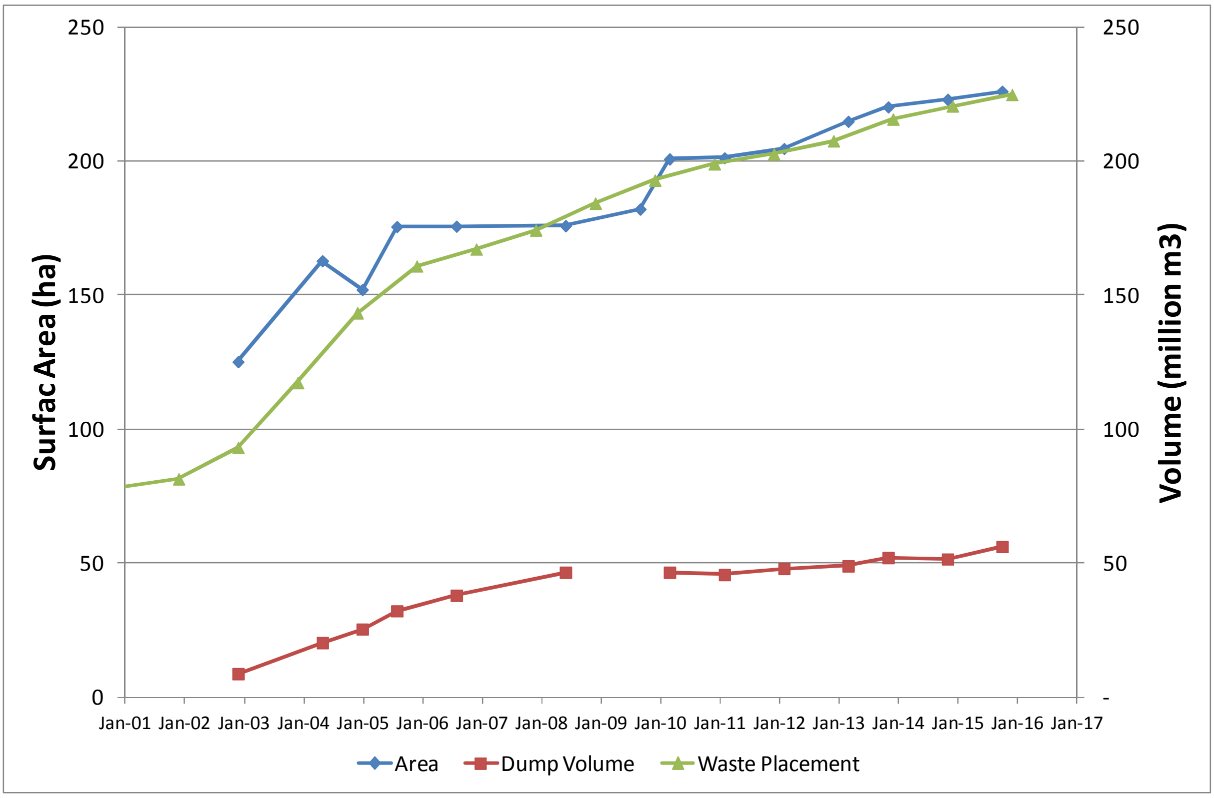
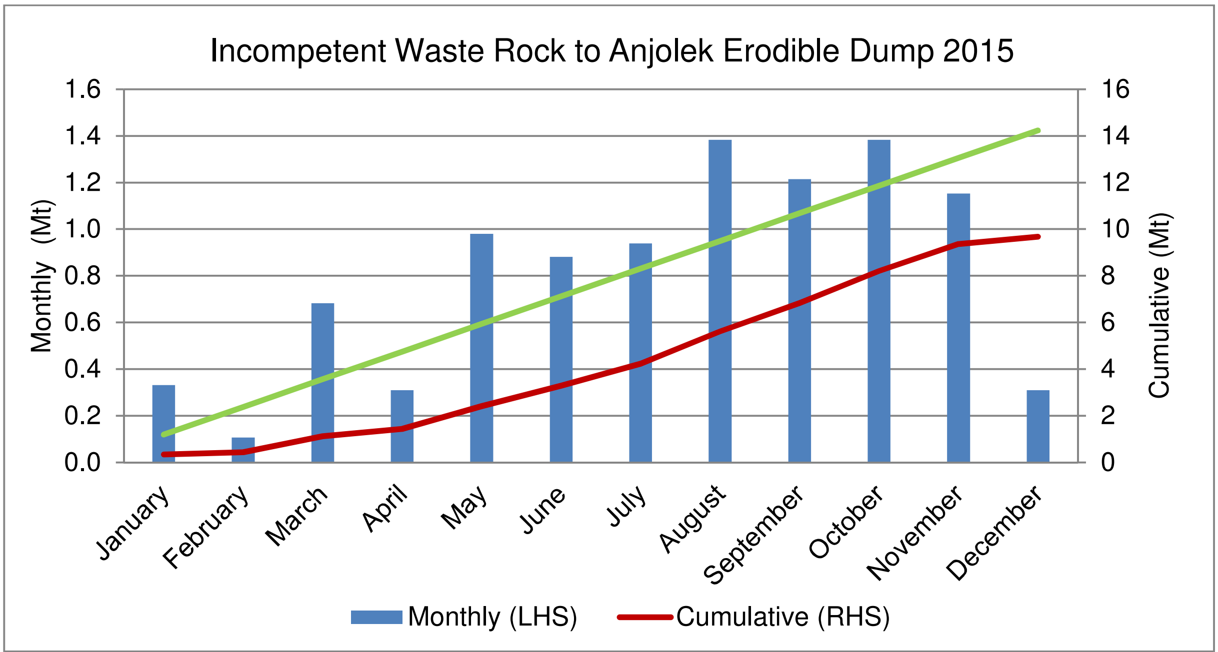



**Figure 4-13 Area and volume of Anawe Erodible Dump based on LiDAR survey 2001 - 2015**

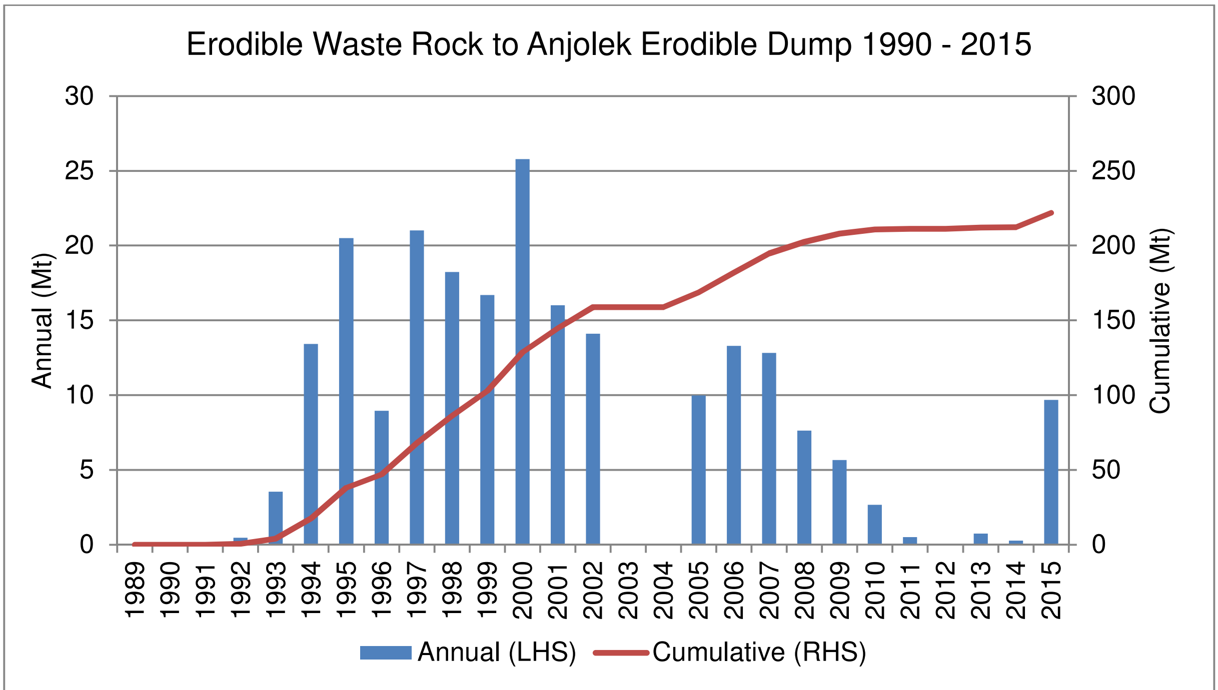
#### *4.5.1.2 Anjolek Erodible Dump*

Figure 4-14 shows monthly volumes to Anjolek dump during 2015. A total of 9.7 Mt was placed during 2015, the majority of which was mudstone from a cut-back of the west wall of the open pit. This was equivalent to 68% of the annual permit limit of 14.23 Mt. The volume dumped in 2015 was significantly higher than previous years due to an increase in mining of the west wall cut-back during 2015. Figure 4-15 shows the volume of spoil 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 spoil placed at Anjolek Erodible Dump in 2015**




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

**Figure 4-15 Yearly tonnages of spoil placed at Anjolek Erodible Dump 1992 - 2015**

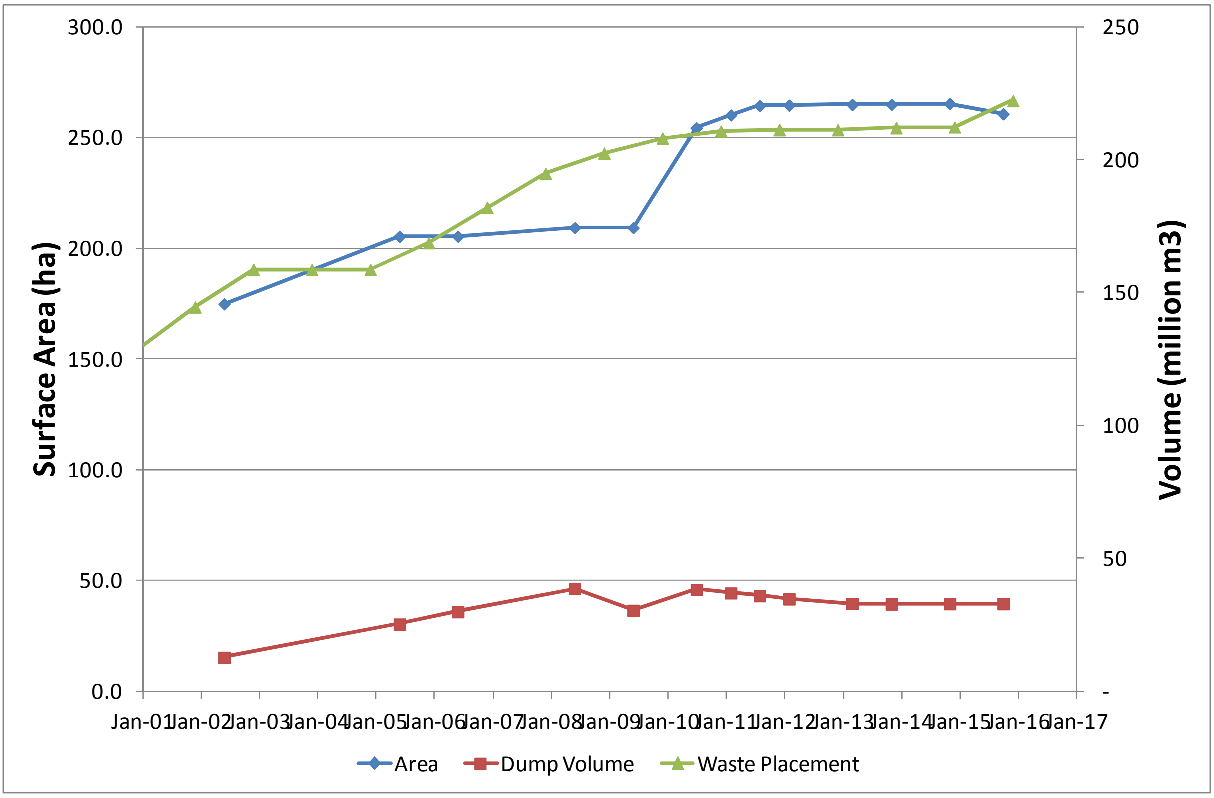



**Figure 4-16 Area and volume of Anjolek Erodible Dump based on LiDAR survey 2001 - 2015**

## 4.6 Status of the Erodible Dumps in 2015

### 4.6.1 Anawe Erodible Dump

An aerial inspection of Anawe Dump conducted in April 2016 showed that there had been no significant changes to the morphology of the dump in comparison with recent year's surveys. The upper part of the dump tract above Pongema River confluence appeared to have degraded/incised and was generally a concave cross section shape. This caused surface drainage (including tailings) to be directed towards the centreline rather than the flanks, see Figure 4-17. Further downstream, adjacent to the Pongema River confluence, the dump depth increased and the surface profile became convex, thus directing/shedding surface flows towards the flanks. There was little noticeable change to the morphology of the Maiapam slide toe as it intersects the southern edge of the dump downslope from Porgera Township, although general lowering of the dump surface in that area had exposed a greater depth of the toe area and this may warrant closer geotechnical inspection. On the north bank opposite the Pongema River confluence, there appeared to be increased sediment runout from Anawe North stable dump, see Figure 4-18. Although sediment runout from the dump had been noted in previous years, a failure of a bench of the dump had recently increased this sediment input. Between Anawe North and the toe, ongoing but minor fluvial erosion of the lower slopes of the northern hillslopes was noted due to the effect of tailings and water flows being confined between these slopes and the north flank of the dump. Similarly at the southern boundary of the dump below the Pongema River confluence, ongoing fluvial erosion of the toes of the natural (Paiam) hillslopes was noted. There appeared to be no significant change to the morphology of the toe area, although a minor landslip near the toe on the southern hillslope was noted.

LiDAR survey data from October 2015 showed that there had been about a 9% increase in dump volume and about a 1% increase in surface area over the last year. While the increase in surface area is consistent with previous year's data, the increase in volume was larger than expected given the amount of waste material dumped. Inputs from Anawe North dump may have contributed to this volume change as the LiDAR cross section/long section profiles show that generally the 2015 dump surface, and therefore dump volume, increased notably in the lower dump tract below Anawe North. Cross sections also showed that the lateral extent of the dump surface increased most in the lower tract, supporting observations that the dump was 'spreading out' and forcing the northern and southern (Pongema) channels towards the respective hillslopes.

Although not obvious from visual inspections, the survey data showed that the toe area had also thickened compared to previous surveys. The survey data confirms that, overall, the dump outline has increased, mostly below the Pongema River confluence/Anawe North intersection, and that the toe had advanced.

**Figure 4-17 Anawe looking downstream showing eroded and concave surface profile**

**Figure 4-18 Anawe looking upstream showing runout from Anawe North Stable Dump**

### 4.6.2 Anjolek Erodible Dump

In the last year, Anjolek recorded a very minor (<1%) increase in net volume and an equally minor (<1%) decrease in net surface area. Recent addition of material from waste dumping appeared to have been balance by erosion of waste from the lower tract.

The helicopter inspection of April 2016, supported by LiDAR data, showed that the most notable change to Anjolek morphology was in the upper dump tract between the tip heads and the Kaiya River Confluence. While some erosion was noted in areas immediately below the tip heads, the gullies and erosion features noted in 2015 in the remainder of the reach had largely been 'filled in' by recent dumping. While the overall dump surface in this area was well below historically high surface levels, thickening had occurred throughout this reach compared to recent surveys, most notably between the Aiyoko ridge and the Kaiya River Confluence, see Figure 4-19. Below the confluence, after the dump heads east, the surface was predominantly erosional, with the 2015 surface generally below previous surveyed surfaces. Boundary plans showed that, while the toe had continued to retreat, there was little other notable change to the footprint of the dump. With regard to surface drainage, it was noted that the Kaiya River continued to maintain its path along the centreline of the dump, although a small amount of flow remained in the former course of the river adjacent to the northern slopes. The dump cross section profile was generally convex in the middle and lower tract, thus shedding surface drainage preferentially to the northern and southern flanks. This notwithstanding, the Kaiya River remained deeply incised along a roughly centreline path. There was no notable change to the morphology of the Kaiya River Fan where the river intersects the dump. While the upper dump tract was relatively 'fresh' and devoid of vegetation due to recent dumping activity, surface vegetation cover generally increased downstream below the Kaiya River confluence.

**Figure 4-19 Upper tract of Anjolek where aggradation has occurred**

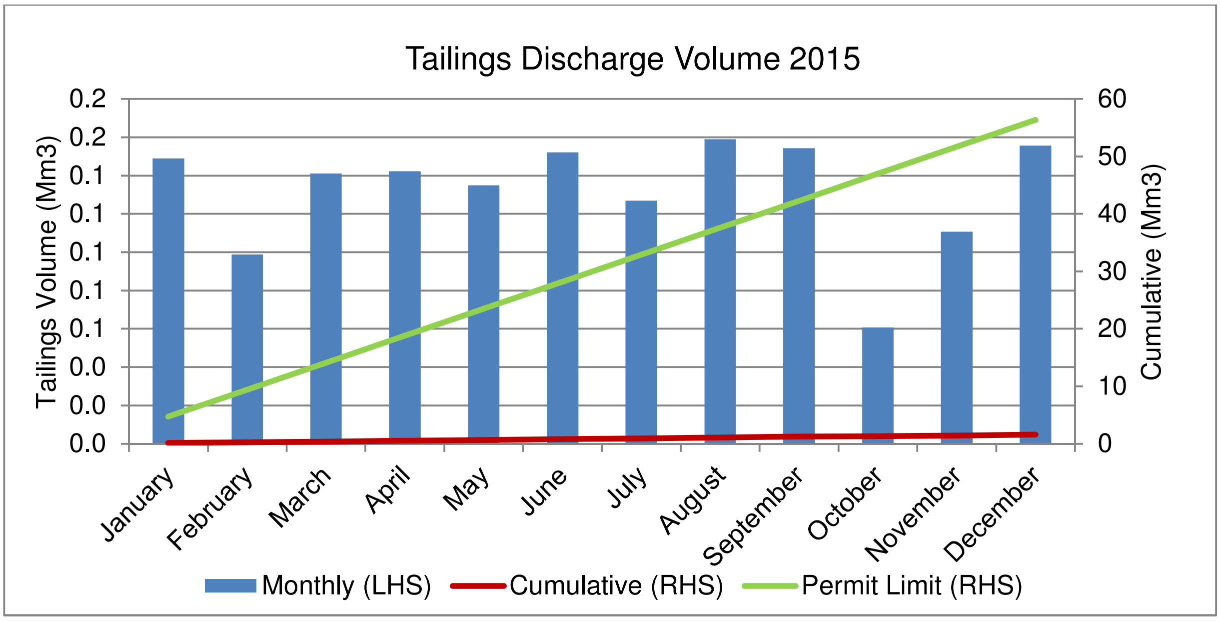
**Figure 4-20 Central tract of Anjolek showing surface drainage**

## 4.7 Tailings Disposal

### 4.7.1 Riverine Tailings Disposal

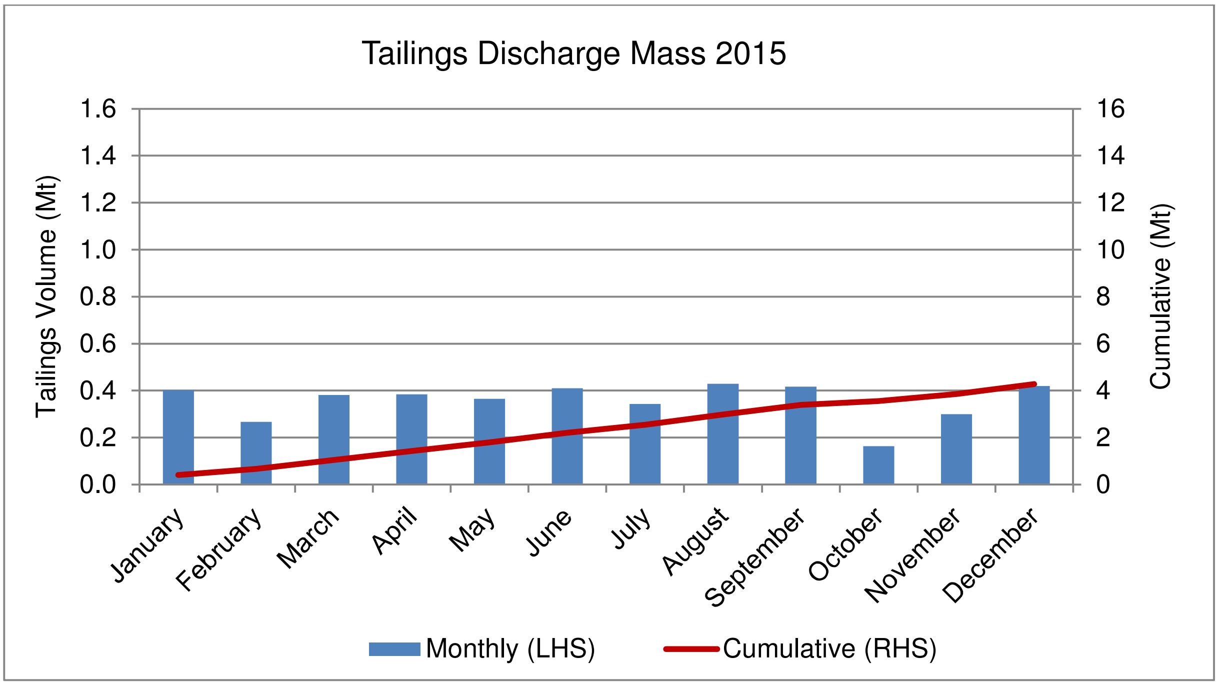
Monthly and cumulative volumes ($m^3$) of tailings solids discharged in 2015 are shown in Figure 4-21 and are reported in $m^3$ for comparison with the permit limits which are applied in $m^3$. The total volume of tailings solids discharged in 2015 was 1.59 $Mm^3$ and is compliant with the environmental 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 2015 was consistent with historical volumes. Discharge mass (t) is reported to allow comparison with erodible waste rock discharge mass.



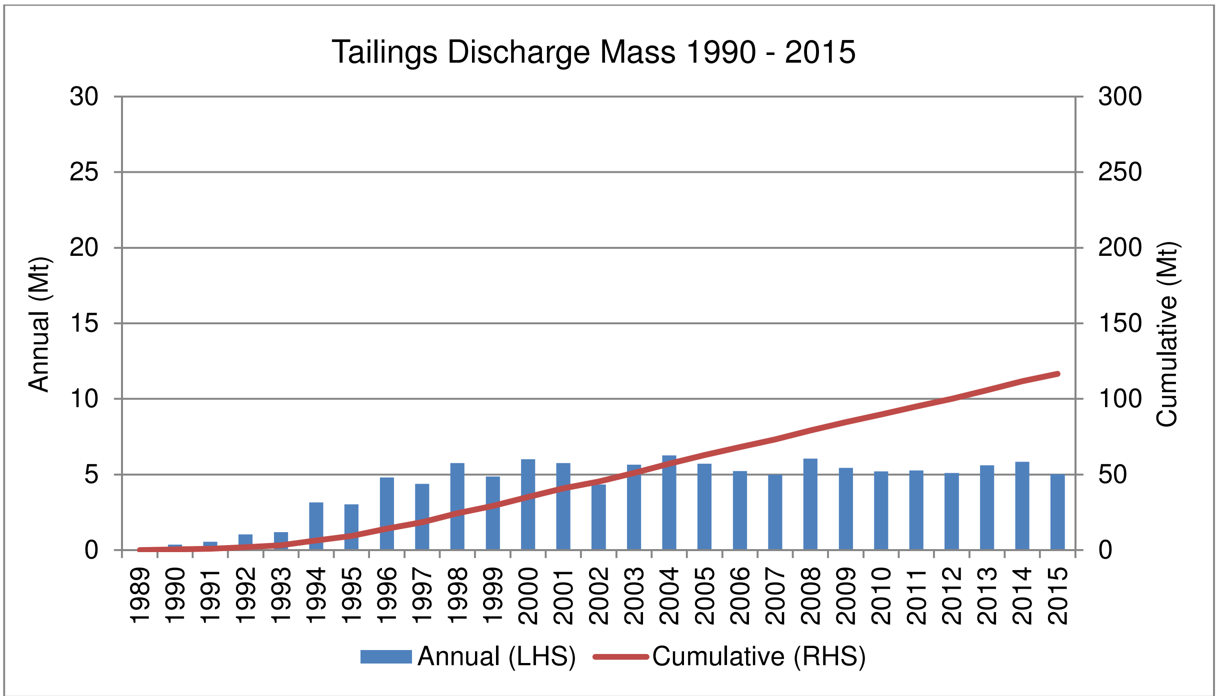

LHS = Left hand side y-axis, RHS = Right hand side y-axis

**Figure 4-21 2015 Monthly and cumulative tailings discharge volumes ($Mm^3$)**




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

**Figure 4-22 2015 Monthly and cumulative tailings discharge mass (Mt)**

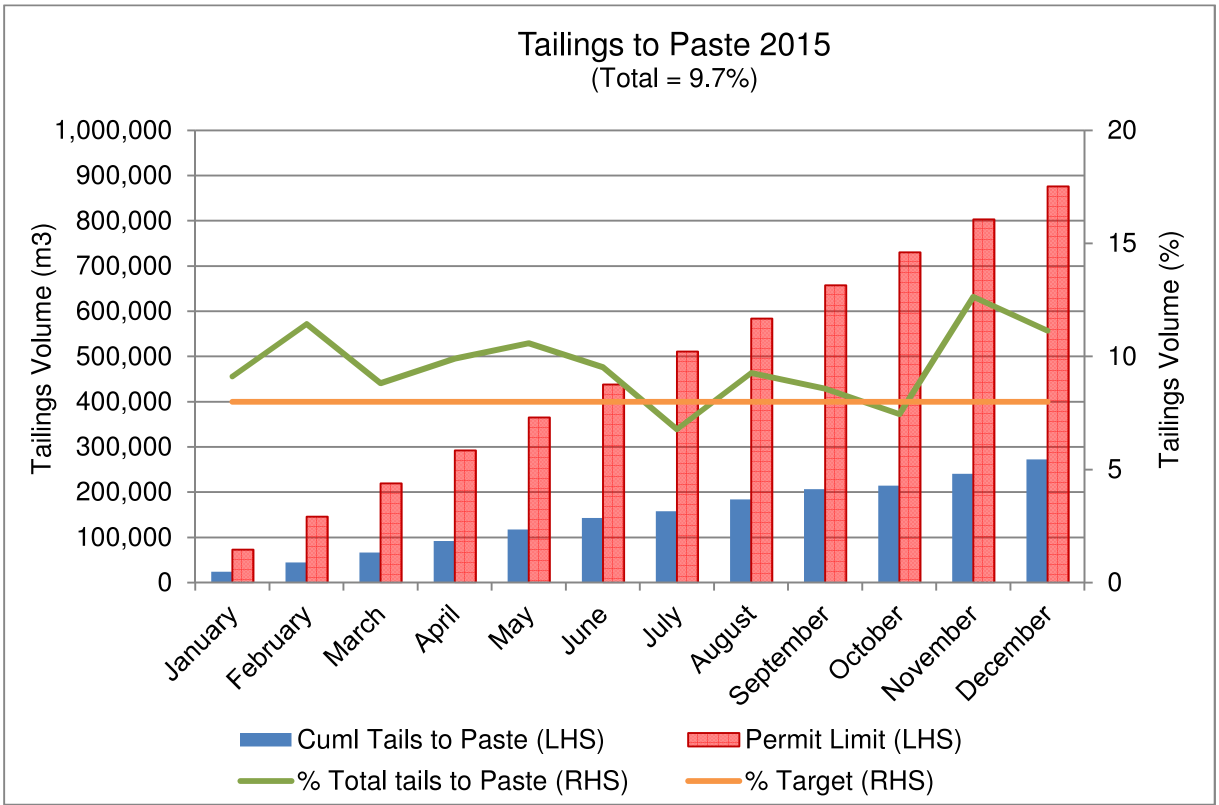



LHS = Left hand side y-axis, RHS = Right hand side y-axis

**Figure 4-23 Annual and cumulative tailings discharge mass (Mt) (dry solids) (1989 - 2015)**

### 4.7.2 Tailings used as Underground Mine Backfill

The paste plant operated consistently throughout 2015. The monthly and cumulative volumes diverted to the underground mine are shown in Figure 4-24. A total of 272,234 $m^3$ of the coarse fraction of tailings were diverted to paste in 2015, which is approximately 9.7% of the total tailings produced. The volume of tailings diverted in 2015 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 monthly to underground backfill in 2015**

## 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 rate of tailings production, geochemistry of the ore, the gold extraction process and the operational effectiveness of the tailings treatment circuit. A summary of 2015 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 rate of discharge and the slurry density, which influence TSS concentration of the tailings, have remained relatively consistent throughout the history of the operation. Discharge volumes and TSS concentration in 2015 were consistent with historical levels and are shown in Figure 4-25 and Figure 4-26.

The pH of the tailings discharge is dictated by the geochemistry of the ore, the gold extraction process and by the addition of lime during the tailings treatment stage. Controlling pH is critical for limiting the concentration of dissolved/bioavailable metals in the discharge. A range of metals within the discharge have the potential to impact the downstream environment if the treatment process is not managed appropriately to reduce their bioavailability. The metals are found naturally within the ore body and pass through the process plant with the tailings, they are dissolved into soluble form during the oxidation process, which reaches as low as pH1. 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 2015 achieved 93% compliance with the internal site-developed end-of-pipe criteria for pH, results for 2015 are shown in Figure 4-27. Variation from the target occurred as a result of low pH events in September caused by interruptions to lime supply, however the minimum recorded pH value was pH 6.2, only slightly below the target level. Results from 2011 – 2015 are shown in Figure 4-28, the high level of compliance with the targets is attributable to the implementation 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 that pH strays from the target range.

Cyanide concentrations within the tailings discharge are dictated by the volume 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. Cyanide concentrations in the tailings discharge during 2015 were low and in compliance with the site-developed end of pipe criteria, results for 2015 are shown in Figure 4-30. The performance achieved during 2015 has continued the trend of low 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 tailings slurry (water/solids mixture) during 2015 are shown in Table 4-4. Monthly concentrations for 2015 and annual concentrations between 2011 and 2015 are shown in Figure 4-33 to Figure 4-54 for all metals.

In 2015 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.

Concentrations of dissolved cadmium, copper, iron, nickel and zinc in tailings slurry were elevated in 2015. A moderate proportion of cadmium (6.1%), nickel (24%) and zinc (9.4%) were present in dissolved form throughout 2015 as shown in Table 4-5.

Metals concentrations in tailings solids are presented in Table 4-7 and show that concentrations of WAE arsenic, WAE cadmium, WAE copper, WAE mercury, WAE lead and WAE zinc are higher than the upper river trigger values and therefore pose a potential risk to the receiving environment.

Long-term trends throughout the history of the operation are shown in Table 4-7. The details of the statistical analysis are shown in Appendix C.

**Table 4-4 Tailings slurry discharge quality 2015 (µg/L except where shown)**

| Parameter | 20%ile | Median | 80%ile |
|---|---|---|---|
| pH^ | 6.3 | 6.4 | 6.5 |
| WAD-CN* | 0.2 | 0.2 | 0.2 |
| Sulfate* | 2,200 | 2,861 | 3,800 |
| ALK-T* | 132 | 193 | 244 |
| TSS* | 126,180 | 161,000 | 225,080 |
| Hardness* | 2,849 | 3,345 | 3,869 |
| Ag-D | 0.05 | 0.05 | 0.05 |
| Ag-T | 824 | 1,500 | 2,180 |
| As-D | 0.19 | 0.29 | 1.1 |
| As-T | 26,000 | 37,000 | 43,800 |
| Cd-D | 51 | 73 | 128 |
| Cd-T | 522 | 810 | 1,360 |
| Cr-D | 0.10 | 0.10 | 0.27 |
| Cr-T | 6,320 | 9,300 | 11,800 |
| Cu-D | 11 | 30 | 73 |
| Cu-T | 8,900 | 12,000 | 16,000 |
| Fe-D | 4.7 | 5,400 | 40,800 |
| Fe-T | 3,794,000 | 5,330,000 | 6,876,000 |
| Hg-D | 0.05 | 0.10 | 0.20 |
| Hg-T | 56 | 82 | 128 |
| Ni-D | 1,202 | 1,600 | 2,000 |
| Ni-T | 3,420 | 5,100 | 6,380 |
| Pb-D | 0.10 | 0.10 | 0.11 |
| Pb-T | 44,400 | 67,000 | 99,200 |
| Se-D | 1.6 | 2.4 | 4.2 |
| Se-T | 500 | 500 | 500 |
| Zn-D | 14,000 | 19,000 | 30,800 |
| Zn-T | 93,800 | 150,000 | 248,000 |
| | > 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 (µg/L)**

| | % Total in Dissolved Form 2015 | | |
|---|---|---|---|
| **Parameter** | **20%ile** | **Median** | **80%ile** |
| Ag-D | 0.10 | 0.02 | 0.02 |
| As-D | 0.00 | 0.00 | 0.01 |
| Cd-D | 4.9 | 6.1 | 9.2 |
| Cr-D | 0.01 | 0.02 | 0.03 |
| Cu-D | 0.24 | 0.32 | 0.61 |
| Fe-D | 0.00 | 0.00 | 0.11 |
| Hg-D | 0.07 | 0.11 | 0.23 |
| Ni-D | 21 | 24 | 36 |
| Pb-D | 0.00 | 0.00 | 0.00 |
| Se-D | 0.43 | 0.57 | 0.68 |
| Zn-D | 7.2 | 9.4 | 16 |

D – Dissolved fraction

**Table 4-6 Tailings solids discharge quality 2015 (mg/kg whole sediment)**

| Parameter | 20%ile | Median | 80%ile |
|---|---|---|---|
| Ag-TD | 8.8 | 11 | 16 |
| Ag-WAE | 0.50 | 0.50 | 0.61 |
| As-TD | 192 | 240 | 322 |
| As-WAE | 55 | 74 | 126 |
| Cd-TD | 4.2 | 6.0 | 9.0 |
| Cd-WAE | 3.1 | 4.0 | 7.2 |
| Cr-TD | 62 | 71 | 90 |
| Cr-WAE | 18 | 22 | 25 |
| Cu-TD | 82 | 110 | 130 |
| Cu-WAE | 66 | 84 | 110 |
| Fe-TD | 40,880 | 48,200 | 52,140 |
| Fe-WAE | 12,160 | 15,400 | 16,480 |
| Hg-TD | 0.33 | 0.51 | 0.84 |
| Hg-WAE | 0.10 | 0.16 | 0.27 |
| Ni-TD | 35 | 41 | 49 |
| Ni-WAE | 20 | 22 | 25 |
| Pb-TD | 328 | 450 | 786 |
| Pb-WAE | 41 | 74 | 116 |
| Se-TD | 0.51 | 0.73 | 1.0 |
| Se-WAE | 0.50 | 0.50 | 0.50 |
| Zn-TD | 742 | 1,030 | 1,528 |
| Zn-WAE | 476 | 680 | 1,186 |
| | > UpRiv TV = Potential Risk | | |

WAE - Weak acid extractable, TD - Total digest

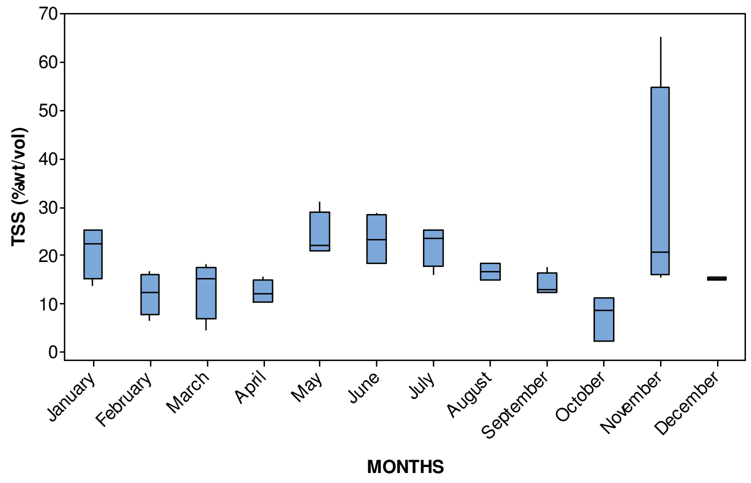



**Figure 4-25 Monthly TSS in tailings discharge in 2015 (mg/L)**

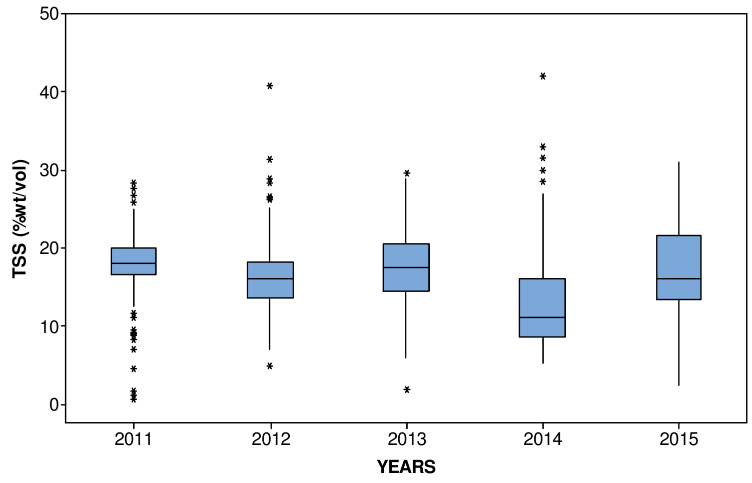



**Figure 4-26 Annual TSS in tailings discharge 2011 - 2015 (mg/L)**

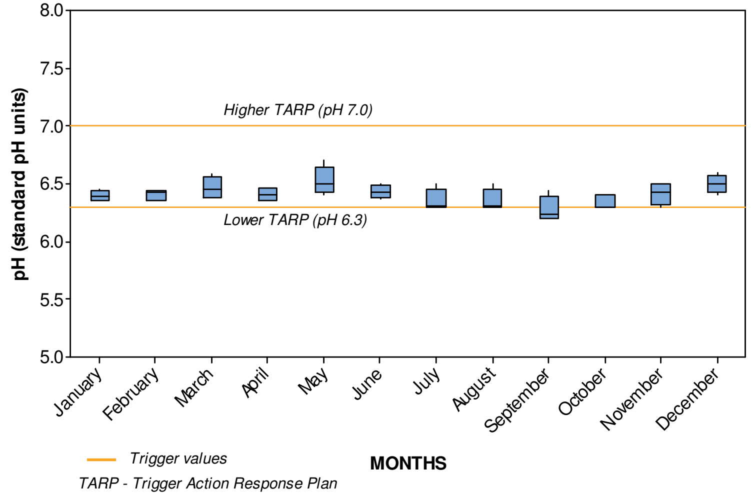



**Figure 4-27 Monthly pH in tailings discharge in 2015**

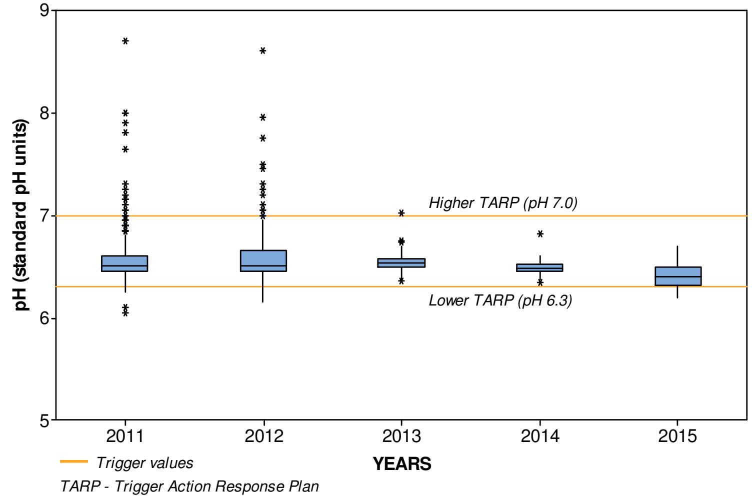



**Figure 4-28 Annual pH in tailings discharge 2011 - 2015**

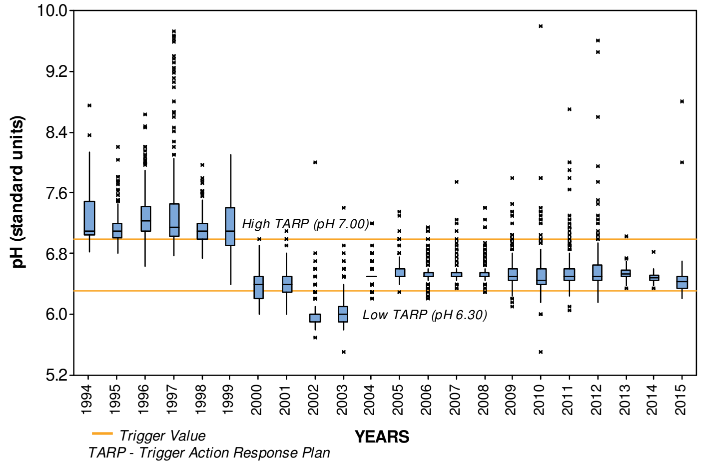



**Figure 4-29 pH in tailings discharge 1994 - 2015**

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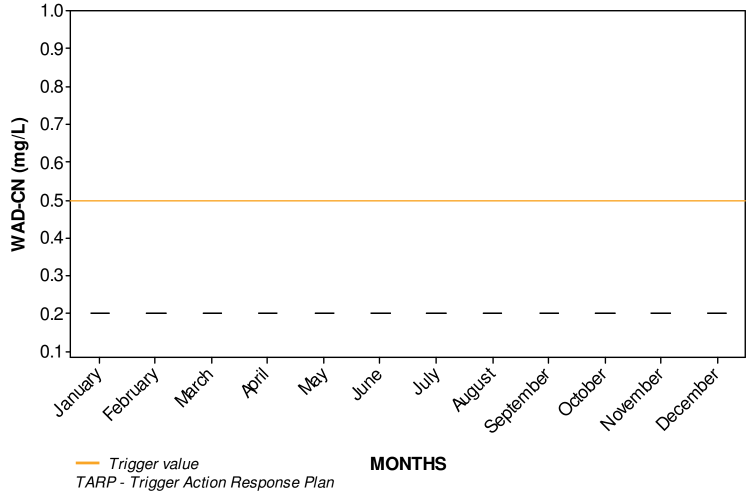


**Figure 4-30 Monthly WAD-CN concentration in tailings discharge in 2015 (mg/L)**

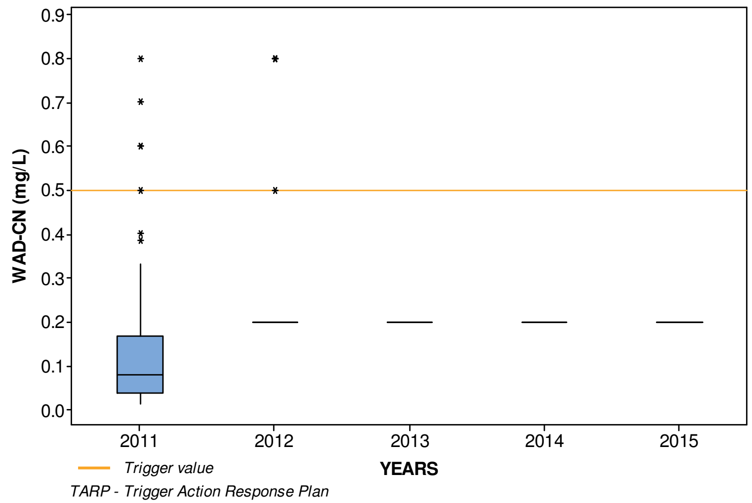


**Figure 4-31 Annual WAD CN concentration in tailings discharge 2011 - 2015 (mg/L)**

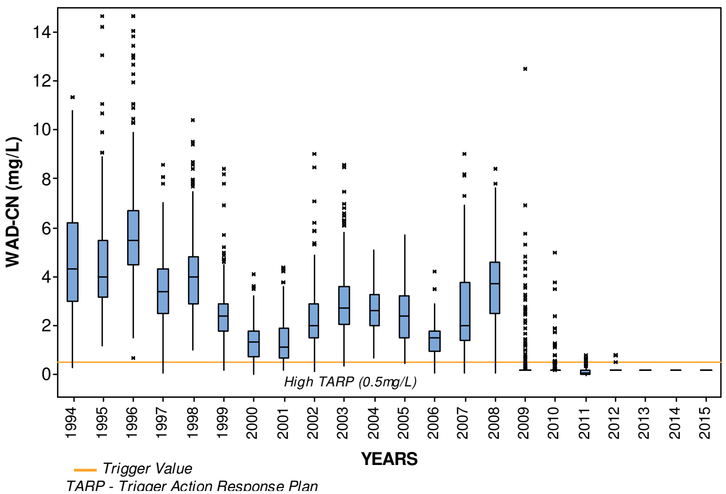


**Figure 4-32 WAD CN in tailings discharge 1994 - 2015**

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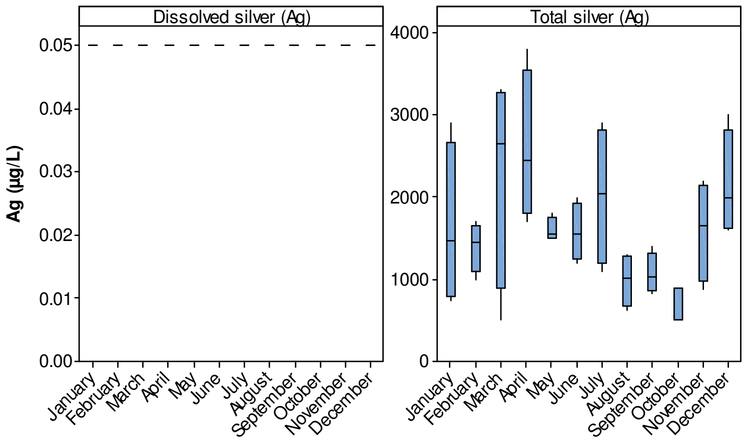



**Figure 4-33 Monthly dissolved and total silver concentrations in tailings 2015 (µg/L)**

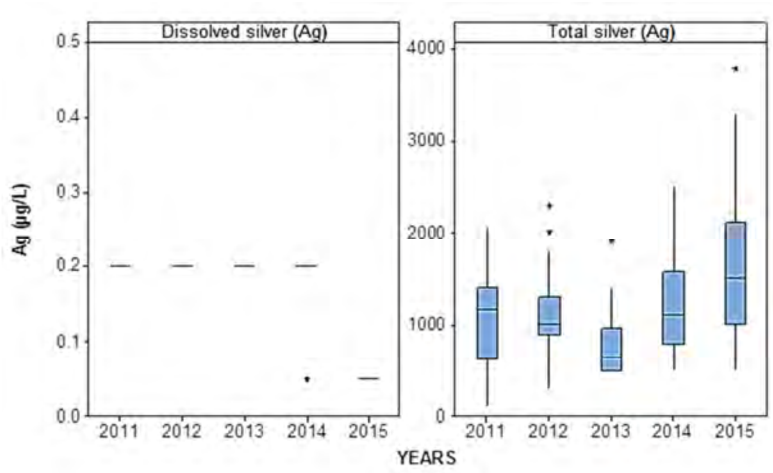



**Figure 4-34 Annual dissolved and total silver concentrations in tailings 1994 - 2015 (µg/L)**

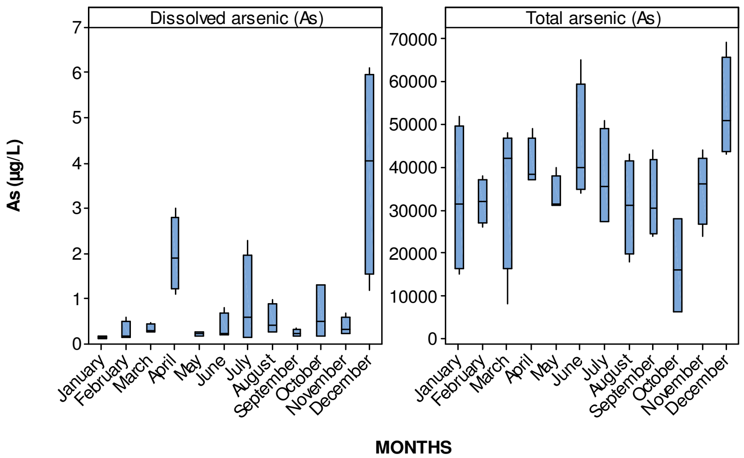



**Figure 4-35 Monthly dissolved and total arsenic concentrations in tailings 2015 (µg/L)**

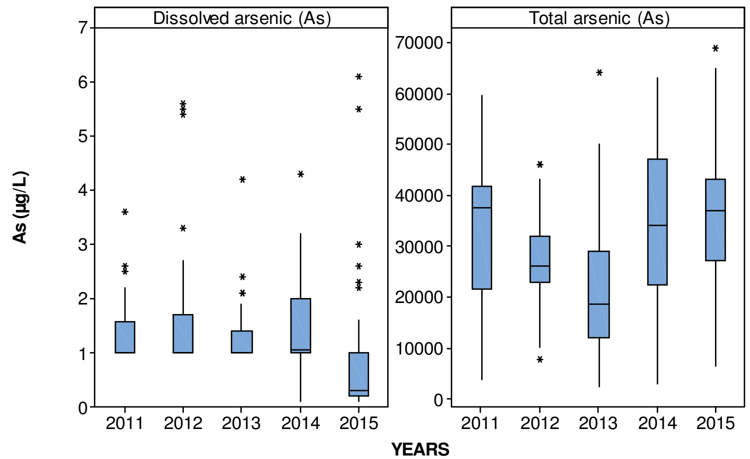



**Figure 4-36 Annual dissolved and total arsenic concentrations in tailings 2011 - 2015 (µg/L)**

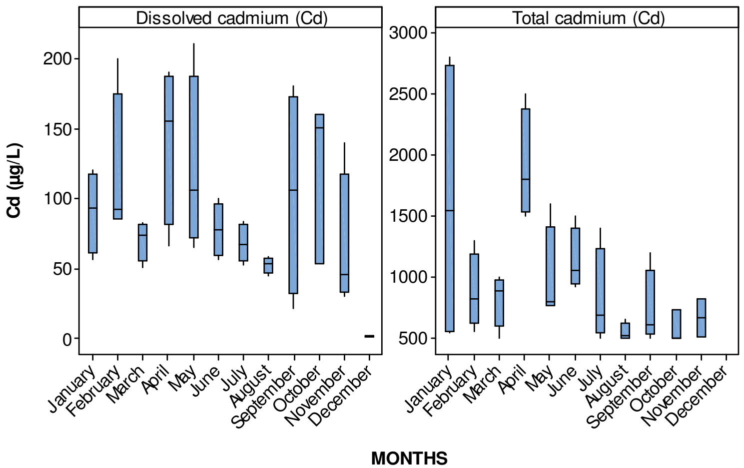



**Figure 4-37 Monthly dissolved and total cadmium concentrations in tailings 2015 (µg/L)**

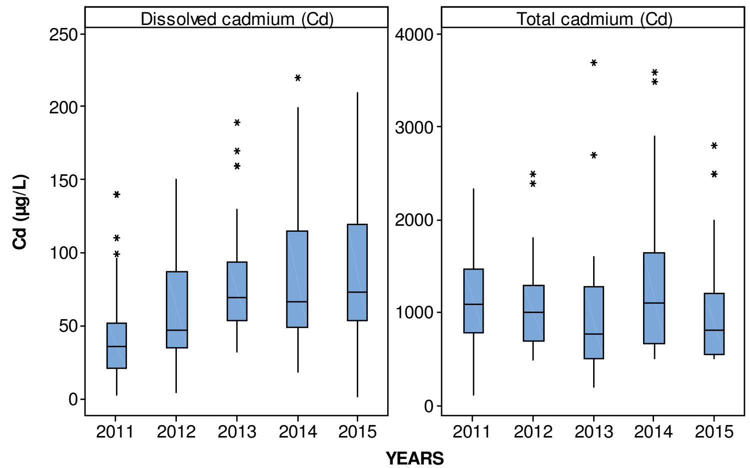



**Figure 4-38 Annual dissolved and total cadmium concentrations in tailings 2011 - 2015 (µg/L)**

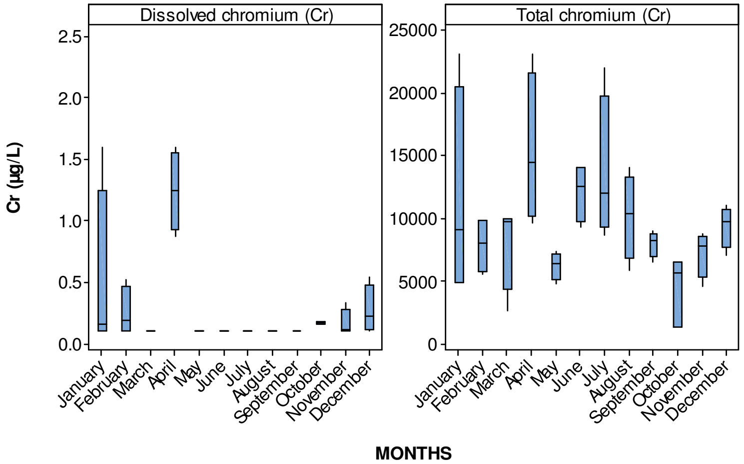



Figure 4-39 Monthly dissolved and total chromium concentrations in tailings 2015 (µg/L)

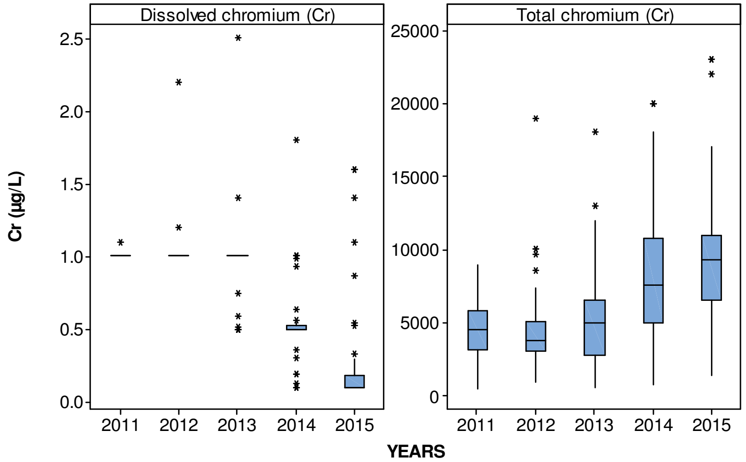



Figure 4-40 Annual dissolved and total chromium concentrations in tailings 2011 - 2015 (µg/L)

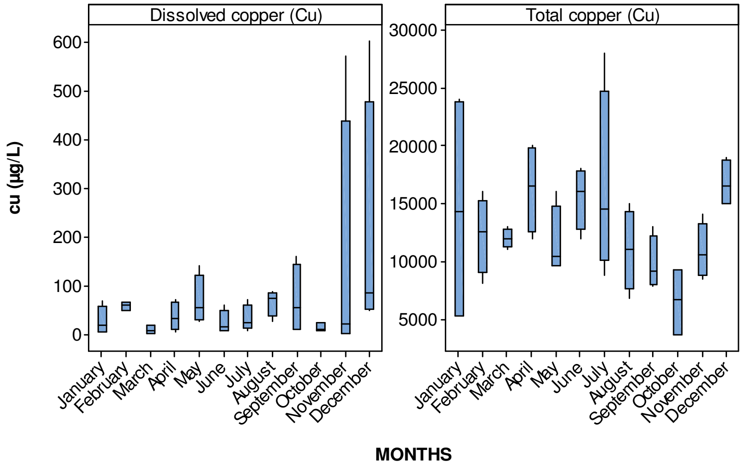



Figure 4-41 Monthly dissolved and total copper concentrations in tailings 2015 (µg/L)

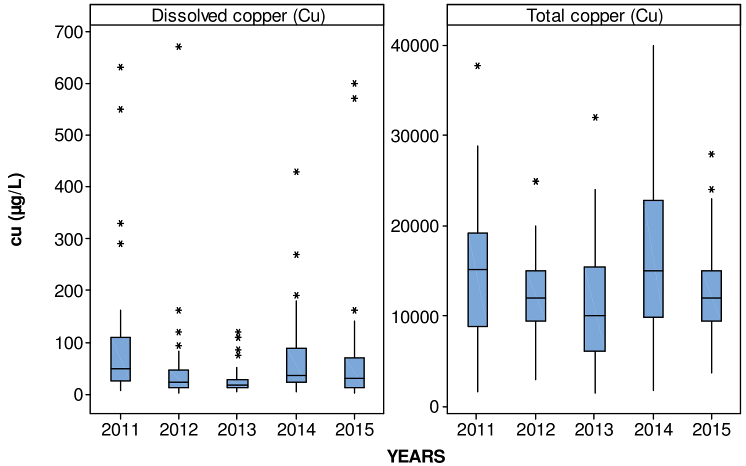



Figure 4-42 Annual dissolved and total copper concentrations in tailings 2011 - 2015 (µg/L)

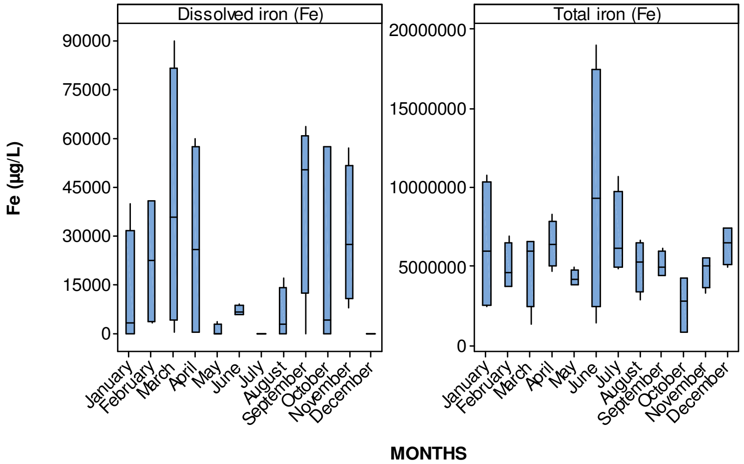



**Figure 4-43 Monthly dissolved and total iron concentrations in tailings 2015 (µg/L)**

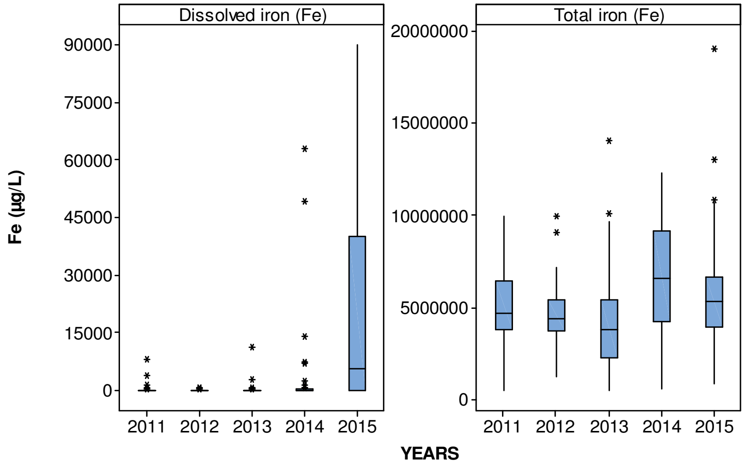



**Figure 4-44 Annual dissolved and total iron concentrations in tailings 2011 - 2015 (µg/L)**

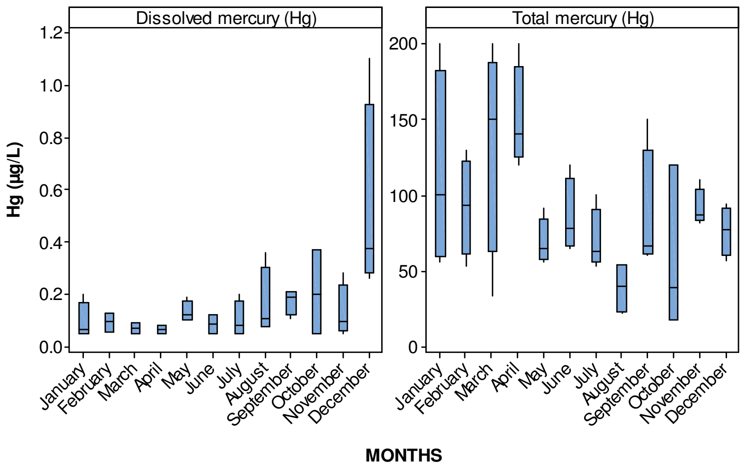



**Figure 4-45 Monthly dissolved and total mercury concentrations in tailings 2015 (µg/L)**

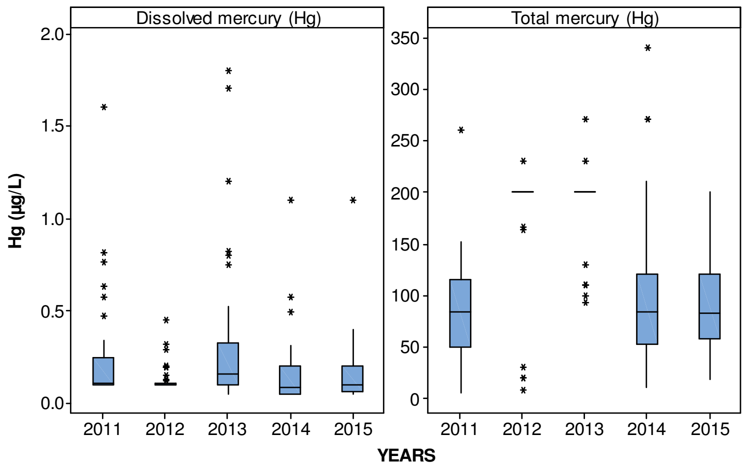



**Figure 4-46 Annual dissolved and total mercury concentrations in tailings 2011 - 2015 (µg/L)**

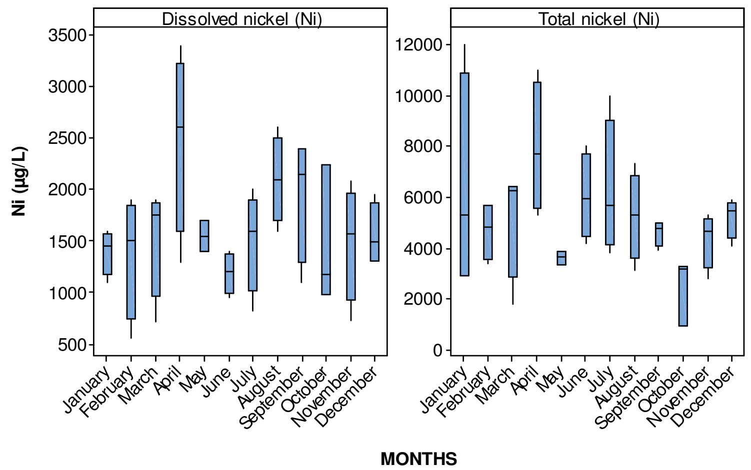



**Figure 4-47 Monthly dissolved and total nickel concentrations in tailings 2015 (µg/L)**

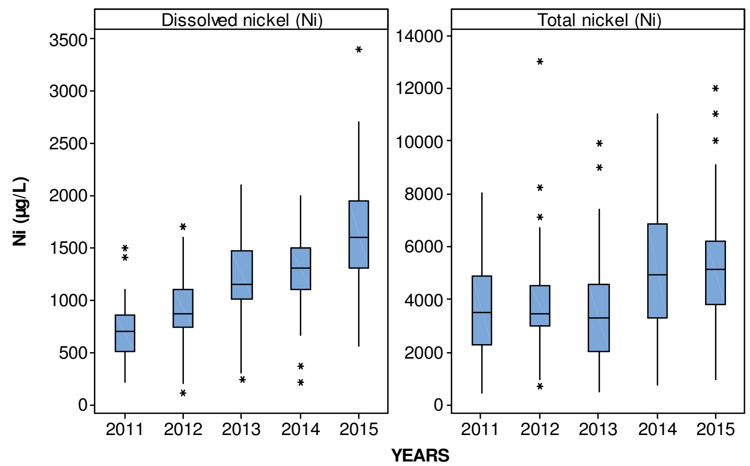



**Figure 4-48 Annual dissolved and total nickel concentrations in tailings 2011 - 2015 (µg/L)**

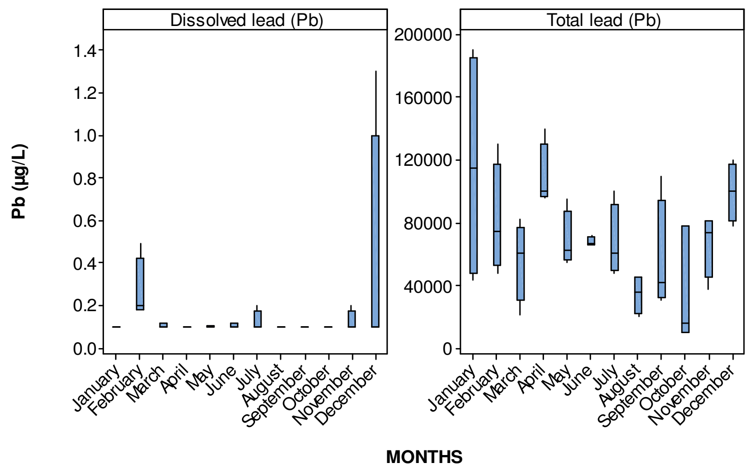



**Figure 4-49 Monthly dissolved and total lead concentrations in tailings 2015 (µg/L)**

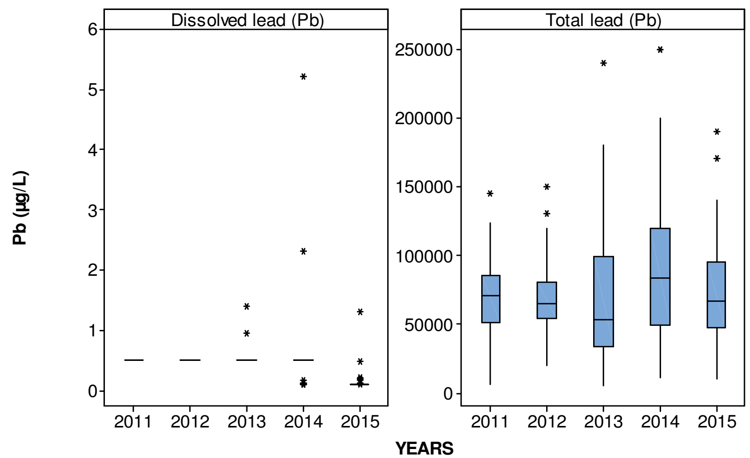



**Figure 4-50 Annual dissolved and total lead concentrations in tailings 2011 - 2015 (µg/L)**

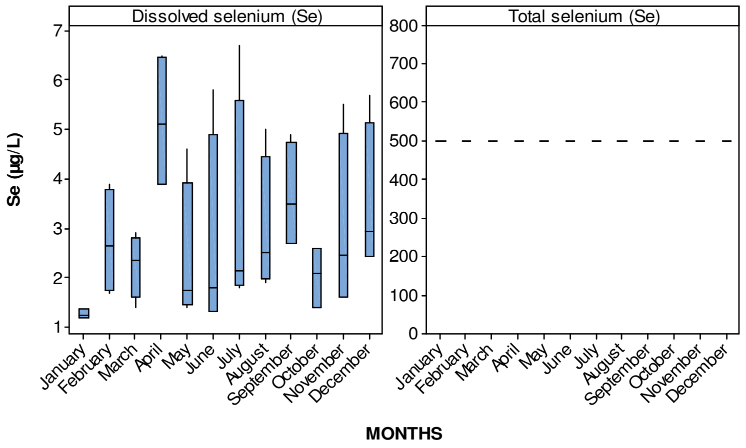



Figure 4-51 Monthly dissolved and total selenium concentration in tailings 2015 (µg/L)

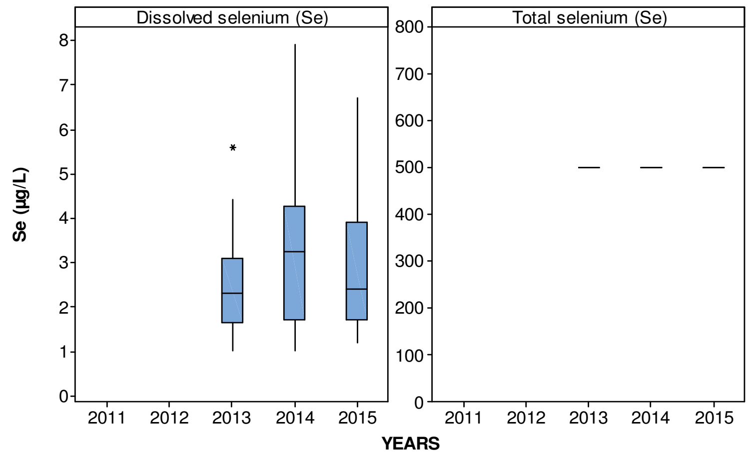



Figure 4-52 Annual dissolved and total selenium concentrations in tailings discharge 2011 - 2015 (µg/L)

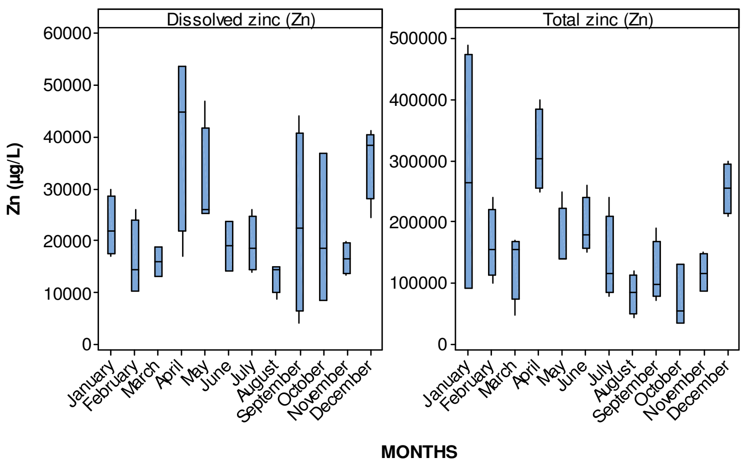



Figure 4-53 Monthly dissolved and total zinc concentrations in tailings 2015 (µg/L)

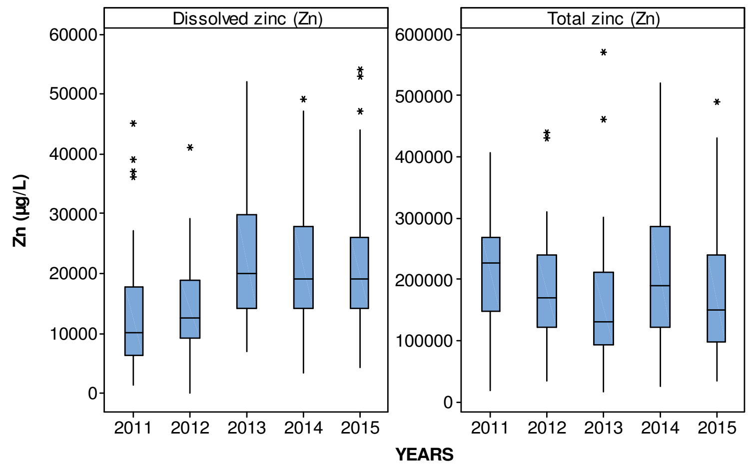



Figure 4-54 Annual dissolved and total zinc concentrations in tailings 2011 - 2015 (µg/L)

**Table 4-7 Trends of tailings quality 2011 - 2015**

| Indicator | Spearman's rho | P-Value (P=0.05) | Trend (2011 – 2015) |
|---|---|---|---|
| pH | -0.075 | 0.027 | Decreased over time |
| WAD-CN | ≤LOR | ≤LOR | No change over time |
| Sulfate | -0.299 | <0.001 | Decreased over time |
| ALK-T | 0.303 | 0.001 | Increased over time |
| TSS | -0.277 | <0.001 | Decreased over time |
| Hardness | -0.185 | 0.030 | Decreased over time |
| Ag-D* | -0.728 | <0.001 | No change over time |
| Ag-T | 0.234 | <0.001 | Increased over time |
| As-D* | -0.316 | <0.001 | No change over time |
| As-T | 0.126 | 0.052 | No change over time |
| Cd-D | 0.376 | <0.001 | Increased over time |
| Cd-T | -0.087 | 0.184 | No change over time |
| Cr-D* | -0.725 | <0.001 | No change over time |
| Cr-T | 0.492 | <0.001 | Increased over time |
| Cu-D | -0.049 | 0.448 | No change over time |
| Cu-T | 0.008 | 0.902 | No change over time |
| Fe-D | 0.343 | <0.001 | Increased over time |
| Fe-T | 0.164 | 0.011 | Increased over time |
| Hg-D | -0.212 | 0.001 | Decreased over time |
| Hg-T | -0.156 | 0.016 | Decreased over time |
| Ni-D | 0.646 | <0.001 | Increased over time |
| Ni-T | 0.290 | <0.001 | Increased over time |
| Pb-D* | -0.623 | <0.001 | No change over time |
| Pb-T | 0.059 | 0.365 | No change over time |
| Se-D | 0.111 | 0.193 | No change over time |
| Se-T | ≤LOR | ≤LOR | No change over time |
| Zn-D | 0.360 | <0.001 | Increased over time |
| Zn-T | -0.103 | 0.112 | 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.

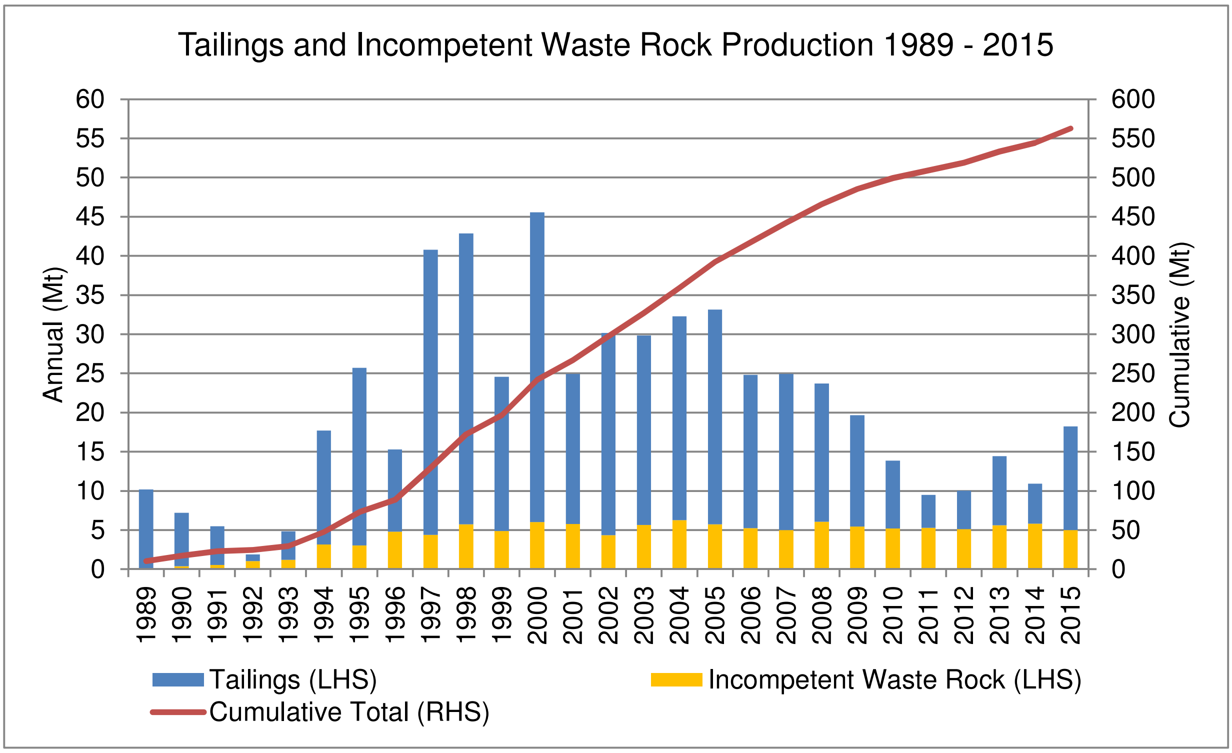
D – Dissolved fraction, T – Total, LOR - Limit of Reporting

## 4.10 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 2015 and 1989 - 2015**

| Discharge Location | Total for 2015 (Mt) | Total 1989 – 2015 (Mt) |
|---|---|---|
| Anawe Erodible Dump | 4.31 | 224.8 |
| Anjolek Erodible Dump | 9.9 | 222.2 |
| Tailings Discharge (dry solids) | 5.0 | 116.6 |
| **TOTAL** | **19.2** | **563.6** |




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

**Figure 4-55 Production of incompetent rock and tailings 1989 - 2015**

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 is discharged across the Anawe erodible dump and as result a small fraction of the tailings solids settles along the body of 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 factor for each of these mechanisms is 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 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 to 2015) 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 (these figures do not account for valley wall erosion). 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 65% for Anawe and 170% for Anjolek. This partly reflects the lower rates of dumping in recent years, particularly to Anjolek dump, whilst 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.

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 9.2 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 | 61 | 4.3 | 4.5 (170%) |
| Anawe | 46 | 4.6 | 4.7 (65%) |
| **Total** | **NA** | **8.9** | **9.2** |

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 2015**

| Source | Total Sediment Discharged from Dumps (Mt/y) | Suspended Sediment Component (Mt/y) | Comments |
|---|---|---|---|
| Erodible Dumps | 9.2 | 5.4 | Assumes 59% (silt fraction) travels as suspended load |
| Tailings | 4.8<br>(5.02 x 0.95) | 4.6<br>(4.8 x 0.95) | Assumes 95% of tailings is transported to the river system and 5% remains stored in Anawe dump |
| **TOTAL 2015** | **14** | **10** | |

## 4.11 Other Discharges to Water

### 4.11.1 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.

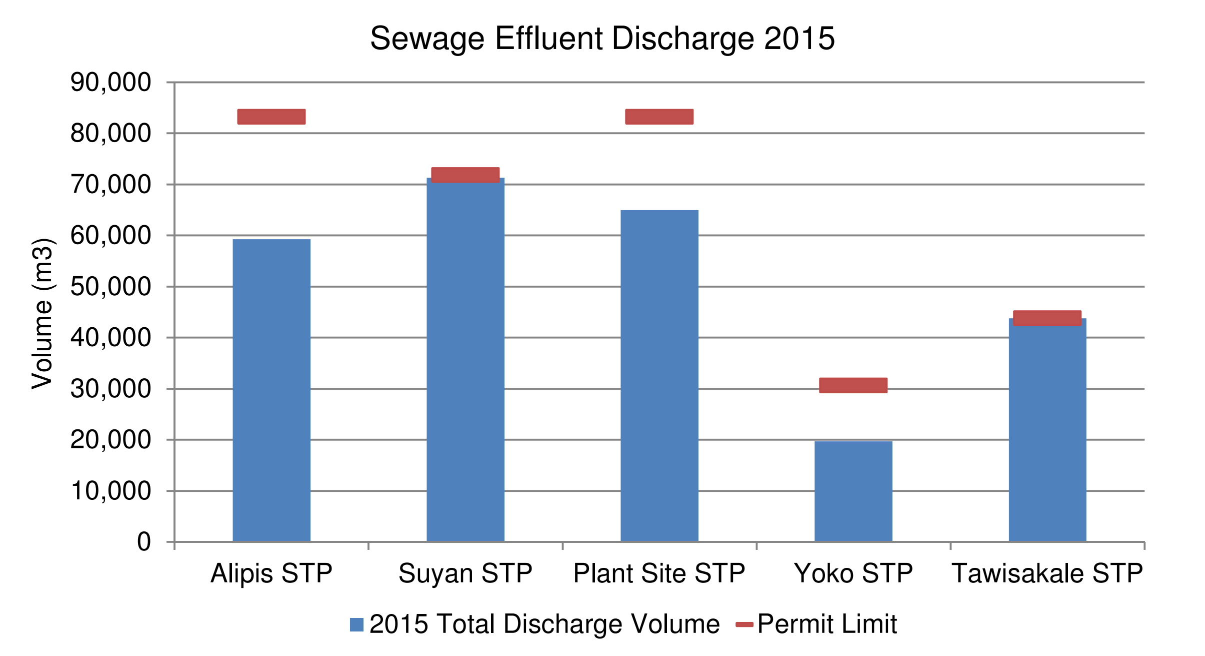



**Figure 4-56 Total annual discharge volumes of treated sewage for 2015**

The quality of the discharge from each STP is monitored for TSS, $BOD_5$ and faecal coliforms. The results of monitoring for 2015 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. The spike in TSS at the Plantsite treatment plant on 24$^{th}$ February 2015 was caused by a power outage, which resulted in inadequate treatment of effluent. 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 in September 2014 improved the competence of the operators through training. At the same time, higher level supervision and leadership were improved, which resulted in more consistent operational performance of the treatment plants in the fourth quarter of the year. PJV also has completed a specialist wastewater treatment audit of the operation of the sewage treatment plants and has completed a project to upgrade the Alipis treatment plant, which was recommended by the audit report.

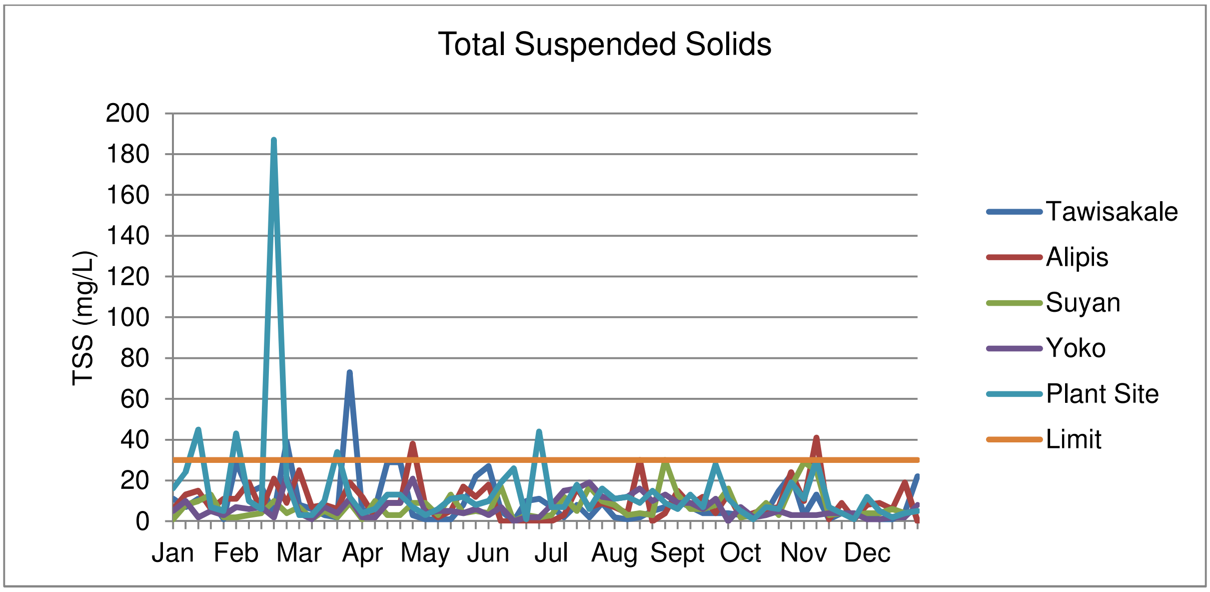



**Figure 4-57 Average monthly TSS concentration in treated sewage discharge in 2015**

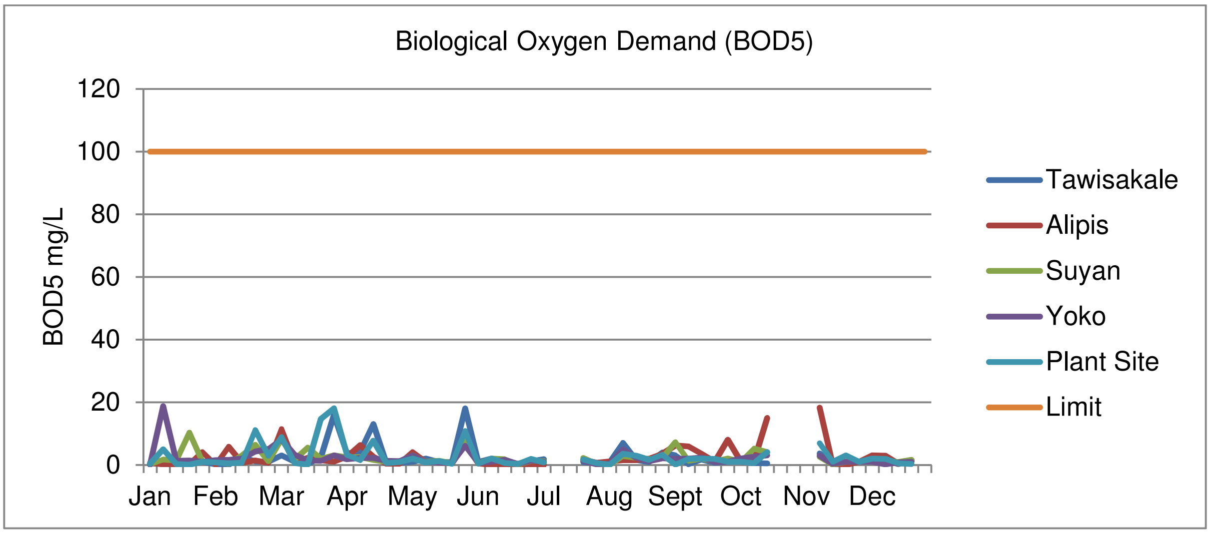



**Figure 4-58 Average monthly $BOD_5$ concentration in treated sewage discharge in 2015**

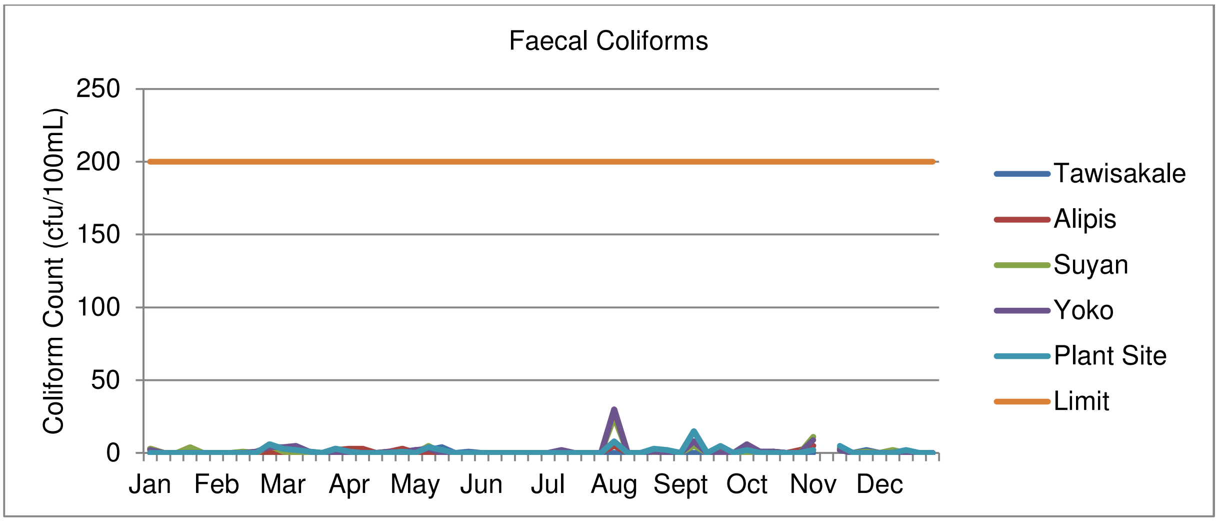



**Figure 4-59 Average monthly faecal coliform count in treated sewage discharge 2015**

### 4.11.2 Oil/Water Separator Effluent

The mine operates 19 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 contact water sampled at the mine site boundary in five months of the year. PJV is implementing a program to upgrade the capacity of some of the oil-water separators for achievement of the discharge target. In addition, PJV has increased supervision and is implementing a training program to improve the competence of operators.

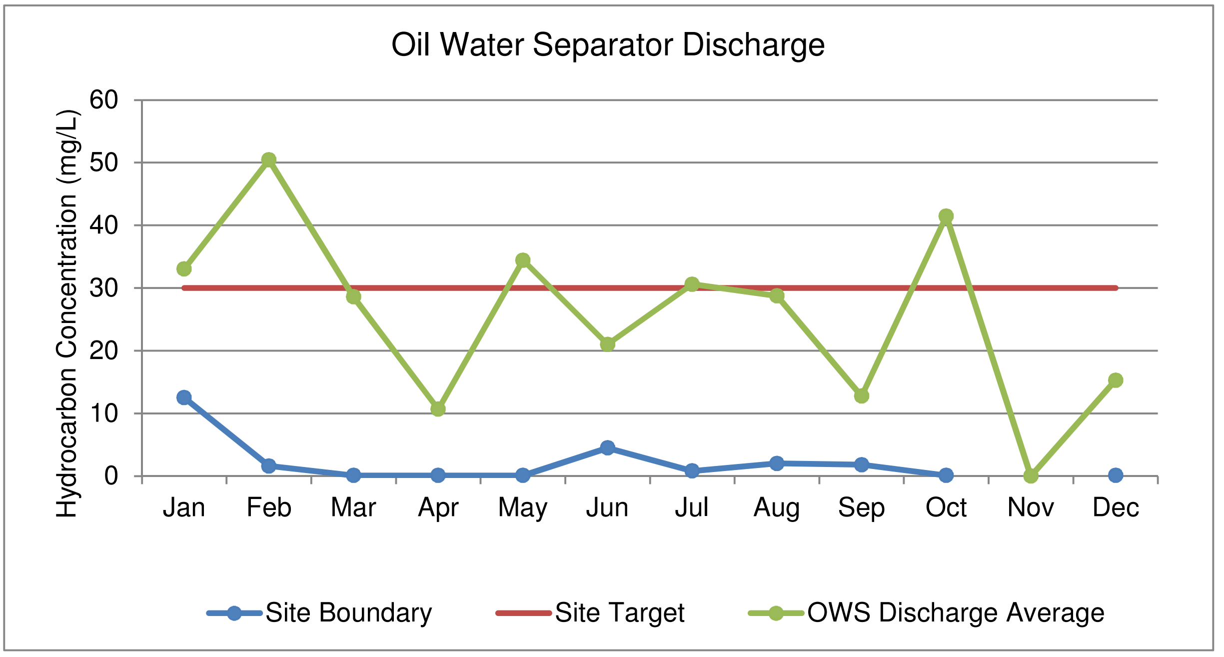



**Figure 4-60 Average monthly total hydrocarbon concentrations in oil water separator discharges 2015**

### 4.11.3 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.

#### *4.11.3.1 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 and 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 2015**

| Location | Total Rainfall run off 2015 ($Mm^3$) | Permit Limit ($Mm^3/y$) |
|---|---|---|
| Starter Dump A (DP3) | 230,000 | 1,822,000 |
| Civil crusher to Kogai Creek (DP4) | 0 | 57,000 |
| Kogai Waste Dump to Kogai Creek (DP5) | 8,048,000 | 1,681,920,000 |
| Open Pit and UG Mine drainage tunnel to Kogai Creek (DP6) | 875,000 | 12,096,000 |
| Anawe stable dump to Wendoko Creek (DP7) | 276,000 | 4,492,800 |
| Rainfall runoff from Hides to a tributary of the Tagari River (DP16) | 2,000 | 87,000 |
| **TOTAL** | **9,431,000** | **1,700,475,000** |

#### *4.11.3.2 Contact Runoff Water and Sediment Quality*

The quality of water and sediment contained in runoff from within the mining lease is dictated by the landuse 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<br>Underground mine<br>Erodible waste rock dump |
| Kaiya River downstream of Anjolek erodible dump | Erodible waste rock dump |
| Kogai Culvert | Competent waste rock dump<br>Crushing and grinding<br>Workshops<br>Sewage treatment plant<br>Hazardous substance storage |
| Kogai stable dump toe area | Competent waste rock dump |
| Lime Plant discharge | Lime processing |
| Wendoko Creek downstream of Anawe North stable dump | Competent waste rock dump |

| Monitoring site name | Land Uses |
|---|---|
| Yakatabari Creek downstream of 28 Level discharge | Underground mine<br>Workshops<br>Sewage treatment plant<br>Hazardous substance storage |
| Yunarilama/Yarik portal | Open cut mine<br>Underground mine |

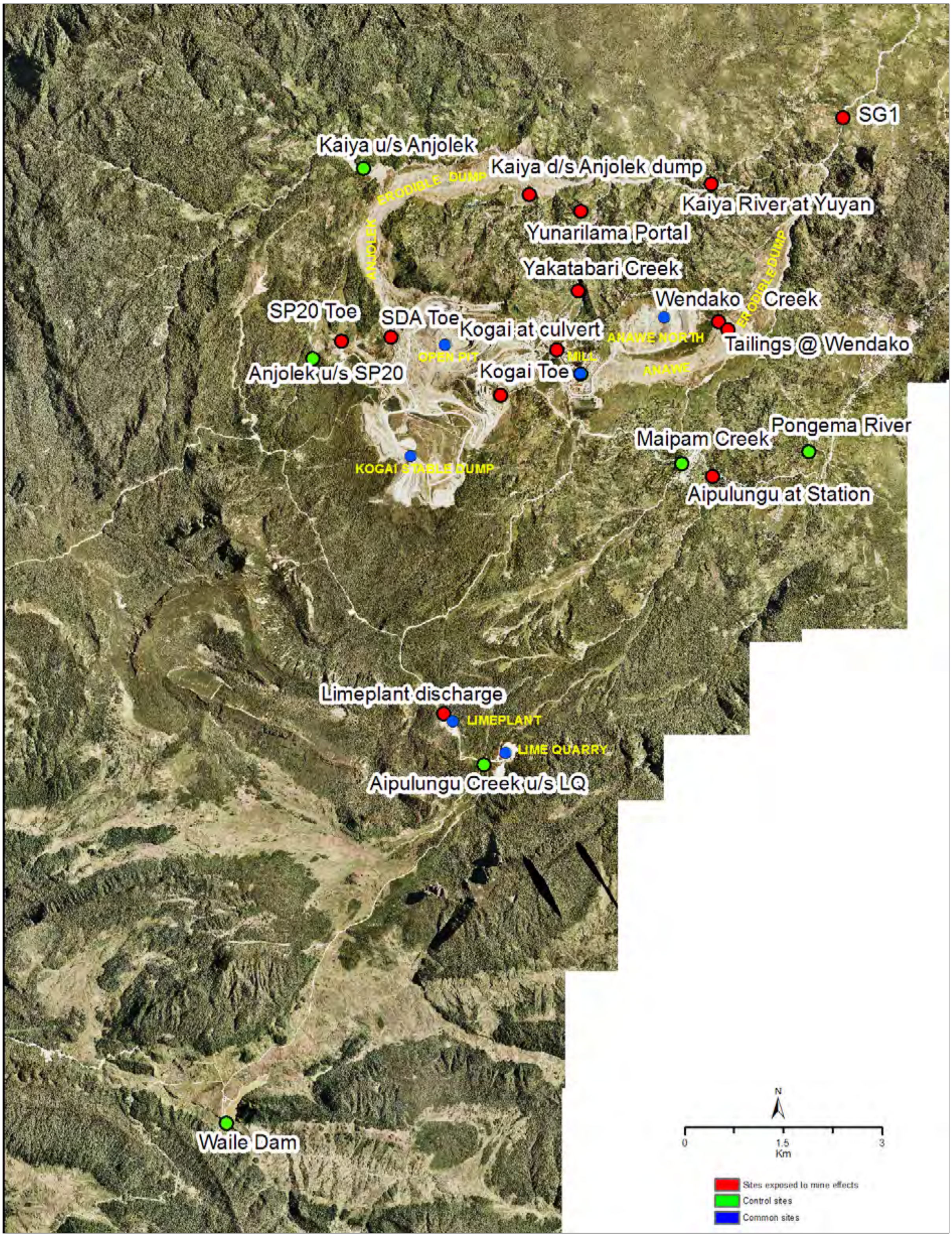



**Figure 4-61 Mine contact runoff sampling location**

Annual median values from monthly monitoring conducted in 2015 are shown in Table 4-14. 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. However the results indicate that this is not sufficient alkalinity to precipitate and adsorb cadmium and zinc, which typically require higher pH ranges than other metals to achieve complete precipitation. Discharge from the lime plant exhibits elevated pH and dissolved chromium. Runoff from Yakatabari Crk DS 28 Level exhibited elevated TSS and chromium and Yunarilama at Portal exhibited elevated TSS.

A summary of trends of water quality parameters between 2011 and 2015 in contact runoff is presented in Table 4-15, details of the statistical analysis are shown in Appendix C. The analysis shows that at 28 level the concentration of dissolved nickel has increased, at SDA toe the concentration of TSS has increased, at Kogai dump toe the concentration of dissolved cadmium and dissolved nickel and dissolved zinc has increased. At the lime plant the concentration of TSS, total chromium, total copper, total nickel, total lead and total zinc has increased, at Yakatabari Crk U/S 28 level the concentration of dissolved arsenic and total mercury has increased. At Yunarilama / Yarik Portal the concentrations of the following elements has increased: total silver, total arsenic, total cadmium, total chromium, total copper, total iron, dissolved mercury, total mercury, total nickel, total lead, total selenium and total zinc. All other elements at all other sites either reduced or remained stable over the time period.

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-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 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 2015 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^ | 7.7 | 7.6 | 7.5 | 7.7 | 7.6 | 11.2 | 7.6 | 7.6 | 7.4 |
| WAD-CN* | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Sulfate* | 220 | 57 | 59 | 170 | 622 | 2 | 1,160 | 393 | 515 |
| ALK-T* | 110 | 131 | 87 | 152 | 240 | 528 | 168 | 114 | 128 |
| TSS* | 78 | 76 | 291 | 180 | 68 | 382 | 57 | 6,273 | 8,415 |
| Hardness* | 363 | 165 | 77 | 285 | 909 | 378 | 1,283 | 352 | 610 |
| Ag-D | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Ag-T | 0.15 | 0.05 | 1.95 | 0.31 | 0.09 | 0.10 | 0.08 | 25 | 101 |
| As-D | 1.9 | 0.8 | 1.0 | 1.2 | 0.7 | 0.2 | 1.1 | 13.0 | 3.2 |
| As-T | 4.9 | 1.6 | 81 | 11 | 4.8 | 3.3 | 4.8 | 415 | 1,165 |
| Cd-D | 0.07 | 0.05 | 0.05 | 0.06 | 1.8 | 0.05 | 0.76 | 0.05 | 0.10 |
| Cd-T | 1.6 | 0.3 | 3.8 | 1.9 | 3.1 | 0.3 | 1.8 | 28 | 59 |
| Cr-D | 0.10 | 0.11 | 0.10 | 0.11 | 0.10 | 3.4 | 0.10 | 1.4 | 0.14 |
| Cr-T | 2.4 | 1.6 | 100 | 5.2 | 4.6 | 38 | 1.1 | 195 | 920 |
| Cu-D | 0.50 | 0.84 | 0.56 | 1.0 | 0.63 | 0.60 | 0.64 | 0.91 | 0.67 |
| Cu-T | 7.7 | 2.1 | 75 | 7.4 | 6.1 | 10 | 3.6 | 335 | 865 |
| Fe-D | 6.0 | 18 | 8.2 | 9.8 | 5.7 | 2.5 | 3.7 | 7.6 | 9.6 |
| Fe-T | 7,400 | 1,300 | 190,000 | 7,350 | 4,300 | 10,000 | 1,800 | 160,000 | 923,000 |
| Hg-D | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Hg-T | 0.05 | 0.05 | 0.49 | 0.06 | 0.06 | 0.05 | 0.05 | 3.8 | 13 |
| Ni-D | 6.4 | 0.70 | 0.63 | 0.74 | 2.3 | 0.5 | 1.8 | 1.6 | 4.1 |
| Ni-T | 25 | 2.8 | 104 | 5.0 | 5.8 | 12 | 3.7 | 170 | 790 |
| Pb-D | 0.10 | 0.62 | 0.17 | 0.38 | 0.52 | 0.10 | 0.26 | 1.4 | 0.46 |
| Pb-T | 27 | 9.7 | 370 | 47 | 28 | 7.1 | 13 | 2,000 | 2,850 |
| Se-D | 0.20 | 0.21 | 0.42 | 0.20 | 0.20 | 0.20 | 0.64 | 0.36 | 0.96 |
| Se-T | 0.20 | 0.21 | 2.1 | 0.42 | 0.25 | 0.27 | 0.61 | 2.9 | 13 |
| Zn-D | 12 | 6.7 | 4.0 | 10 | 350 | 0.9 | 310 | 6.6 | 6.3 |
| Zn-T | 305 | 46 | 895 | 320 | 490 | 39 | 495 | 5,460 | 10,500 |
| (shaded) | > UpRiv TV = Potential Risk | | | | | | | | |

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

**Table 4-15 Trends of water quality contact runoff 2011 - 2015 (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 | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| WAD-CN | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Sulfate | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| ALK-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| TSS | Decreased or no change | Increased | Decreased or no change | Decreased or no change | Decreased or no change | Increased | Decreased or no change | Decreased or no change | Decreased or no change |
| Hardness | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Ag-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Ag-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased |
| As-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased | Decreased or no change |
| As-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased |
| Cd-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Cd-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased |
| Cr-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Cr-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased | Decreased or no change | Decreased or no change | Increased |
| Cu-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Cu-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased | Decreased or no change | Decreased or no change | Increased |
| Fe-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Fe-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased |
| Hg-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased |
| Hg-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased | Increased |
| Ni-D | Increased | Decreased or no change | Decreased or no change | Decreased or no change | Increased | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Ni-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased | Decreased or no change | Decreased or no change | Increased |
| Pb-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Pb-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased | Decreased or no change | Decreased or no change | Increased |
| Se-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Se-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased |
| Zn-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Zn-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change | Increased | Decreased or no change | Decreased or no change | Increased |

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

D - Dissolved fraction, T - Total

**Table 4-16 Contact Sediment Quality 2015 median values** (mg/kg whole fraction)

| Parameter | 28 Level | SDA Toe | Kaiya R 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 |
|---|---|---|---|---|---|---|---|---|---|
| Ag-WAE | 1.3 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 1.1 | 0.50 |
| Ag-TD | 13 | 1.3 | 1.8 | 2.2 | 3.3 | 0.50 | 1.8 | 5.8 | 2.9 |
| As-WAE | 7.9 | 4.7 | 4.5 | 8.9 | 10 | 0.57 | 7.5 | 16 | 6.3 |
| As-TD | 250 | 81 | 72 | 120 | 130 | 5.6 | 82 | 110 | 110 |
| Cd-WAE | 1.0 | 0.70 | 0.50 | 0.69 | 1.4 | 0.50 | 1.4 | 1.4 | 0.63 |
| Cd-TD | 10 | 3.3 | 4.0 | 5.1 | 7.9 | 0.53 | 3.8 | 5.8 | 2.9 |
| Cr-WAE | 13 | 3.3 | 3.7 | 2.6 | 4.1 | 8.7 | 2.1 | 4.5 | 4.4 |
| Cr-TD | 83 | 26 | 30 | 31 | 50 | 19 | 27 | 48 | 31 |
| Cu-WAE | 18 | 5.1 | 5.2 | 4.2 | 5.9 | 2.4 | 7.2 | 13 | 5.0 |
| Cu-TD | 130 | 26 | 37 | 54 | 64 | 5.7 | 36 | 66 | 41 |
| Hg-WAE | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Hg-TD | 0.93 | 0.22 | 0.38 | 0.49 | 0.31 | 0.02 | 0.15 | 0.57 | 0.38 |
| Ni-WAE | 19 | 5.4 | 5.4 | 3.0 | 4.6 | 2.1 | 4.0 | 6.9 | 5.2 |
| Ni-TD | 68 | 27 | 35 | 30 | 38 | 6.3 | 27 | 36 | 32 |
| Pb-WAE | 140 | 98 | 120 | 100 | 160 | 3.5 | 78 | 260 | 79 |
| Pb-TD | 630 | 230 | 320 | 210 | 250 | 4.6 | 140 | 290 | 150 |
| Se-WAE | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| Se-TD | 1.0 | 0.67 | 0.95 | 0.68 | 0.57 | 0.50 | 0.80 | 0.68 | 0.71 |
| Zn-WAE | 580 | 110 | 69 | 100 | 200 | 15 | 210 | 240 | 110 |
| Zn-TD | 2,000 | 600 | 700 | 910 | 1,420 | 53 | 780 | 1,220 | 620 |
| | > UpRiv TV = Potential Risk | | | | | | | | |

WAE – Weak Acid Extractable, TD – Total Digest

## 4.12 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 7.7.

## 4.13 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 declined by 2.6% in 2015 compared to 2014, however a decreasing trend since 2009 has been maintained.

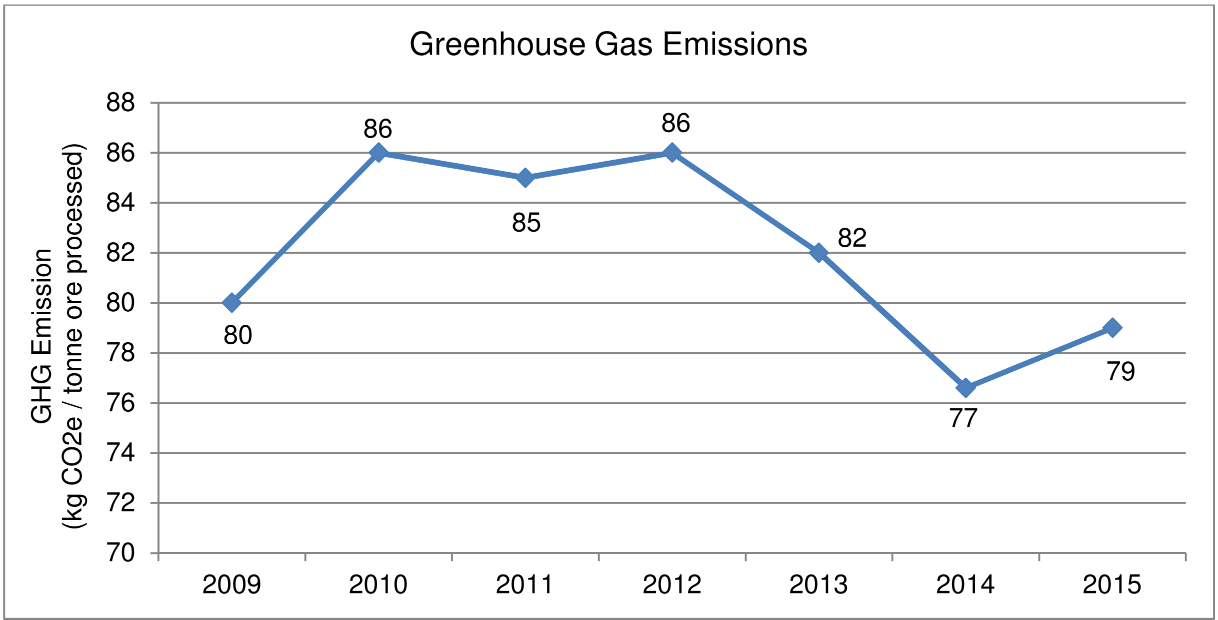



**Figure 4-62 Energy efficiency 2009 - 2015**

## 4.14 Closure Planning and Reclamation

### 4.14.1 Mine Closure Plan

In 2015 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.

### 4.14.2 Life of Mine

The Life of Mine (LOM) for Porgera mine was reviewed and revised in 2015, following the revision of the geological model reserves. Ore production and processing are expected to cease in 2027. 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.

#### 4.14.3 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:

- Fully 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.

#### 4.14.4 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.

#### 4.14.5 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 explicitly listed in the closure plan. Key people will be nominated by respective stakeholder groups to represent 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.

#### 4.14.1 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 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 2015 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 5870 tree seedlings were planted on the Kogai dump at K62 and K65. 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 2015**

| Type | Scientific Name | Local Name | Number Planted 2015 |
|---|---|---|---|
| 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** |

## 4.15 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 of each type of waste produced at the mine site. Waste oil made up 26% of the non-mineralised waste in 2015, 100% of which is re-used as fuel for heating the lime kiln. Sewage Treatment Plant sludge is disposed 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 and other metals 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.

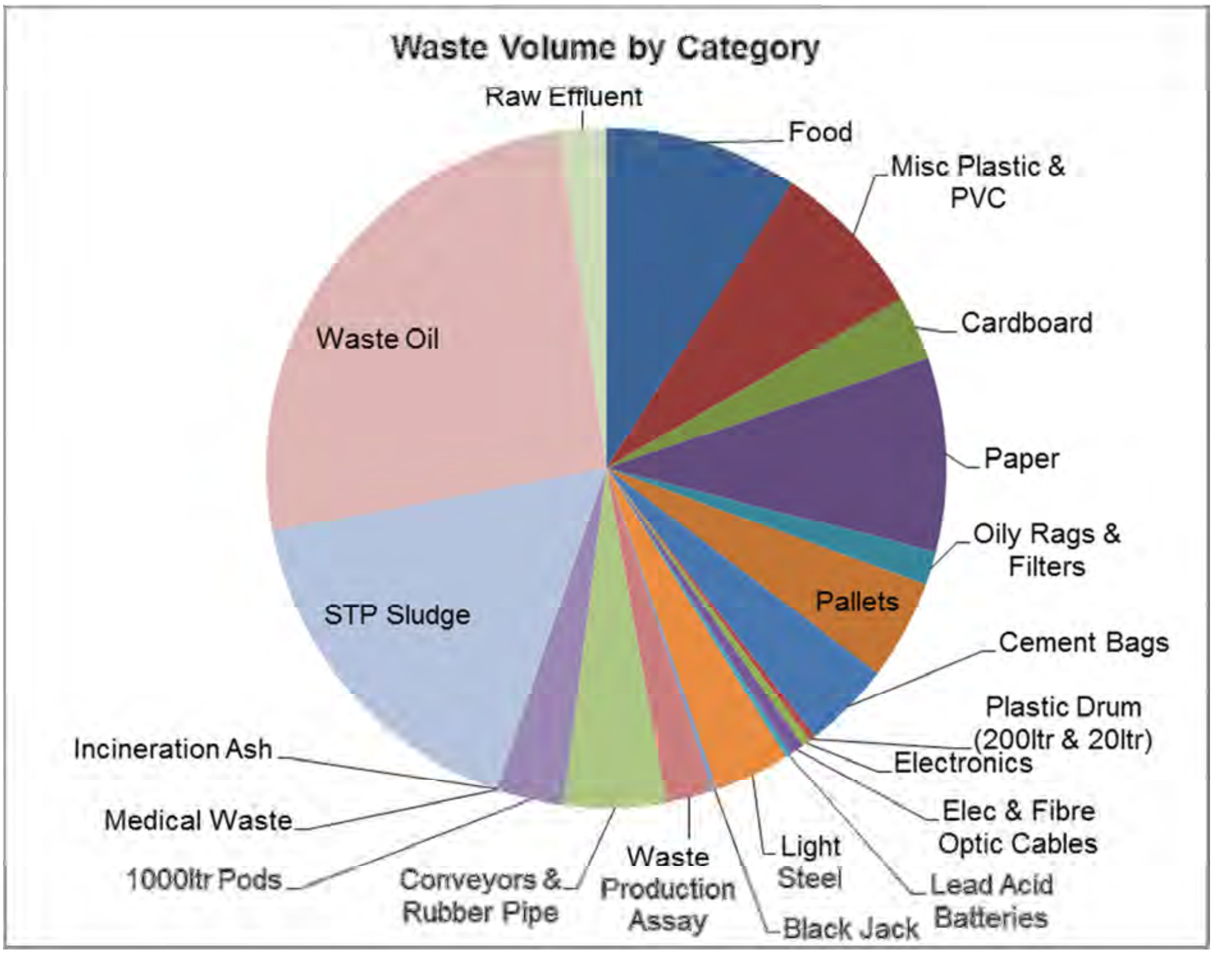



**Figure 4-63 Non-mineralised waste production by type**

# 5 BACKGROUND ENVIRONMENTAL CONDITIONS AND TVs

The environmental conditions of all natural systems will change throughout time due to natural changes 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:

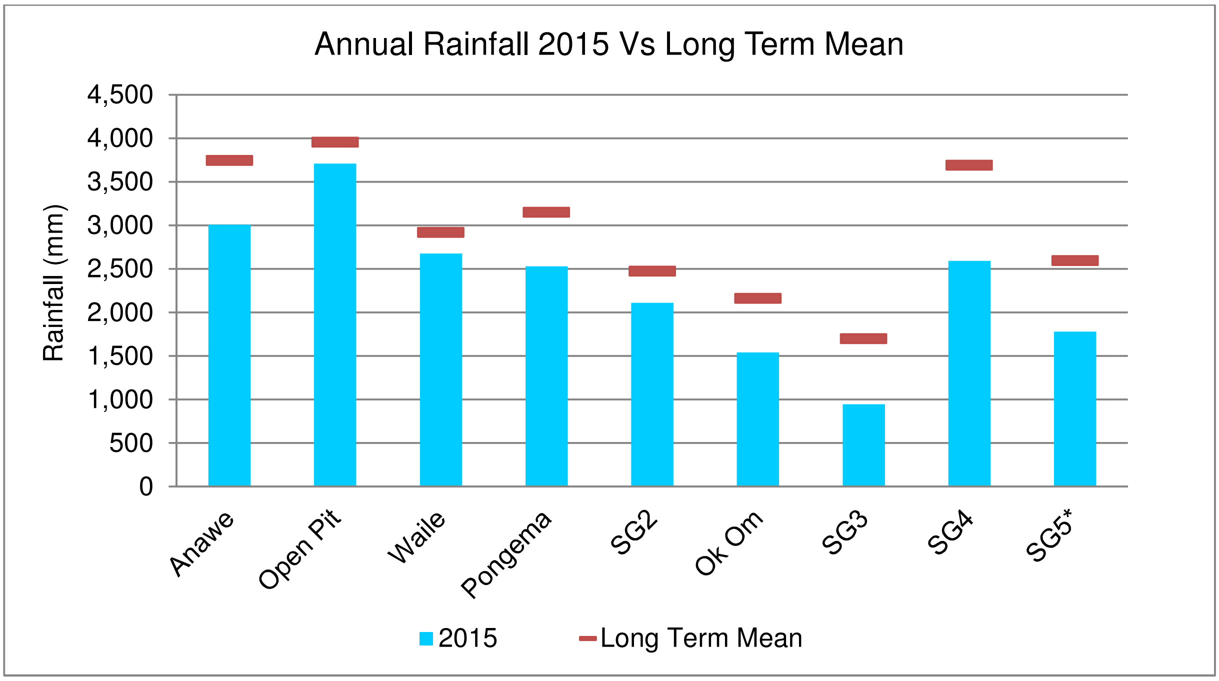
1. Quantify the climatic condition, meteorological and hydrological conditions at the mine site and within the receiving environment during 2015;
2. Describe the background environmental physical, chemical and biological conditions of aquatic ecosystems not influenced by the operation (i.e. reference site condition) and identify and quantify the natural changes at those sites during 2015 and over the history of mine operation; and
3. Establish risk assessment and impact assessment trigger values (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 2015 Rainfall in Strickland River Catchment

Figure 5-1 shows annual rainfall at stations in the upper, middle and lower Strickland catchments. 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 2015 was approximately 14% below the long term mean in the upper reach. In the middle reach (SG2, Ok Om, SG3) rainfall was about 29% below average. Rainfall was about 31% below average in the lower reach (SG4, SG5). The SG5 station was vandalised during the year which led to the loss of 18.9% of the data record.




*Incomplete data record due to equipment vandalism

**Figure 5-1 Comparison of annual rainfall (2015 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 expressed as a residual mass 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.

2015 was affected by an El Nino event that began to decline towards the end of the year. An El Nino event is defined when the ENSO falls below -8 which compares to a 2015 value of -11.3.

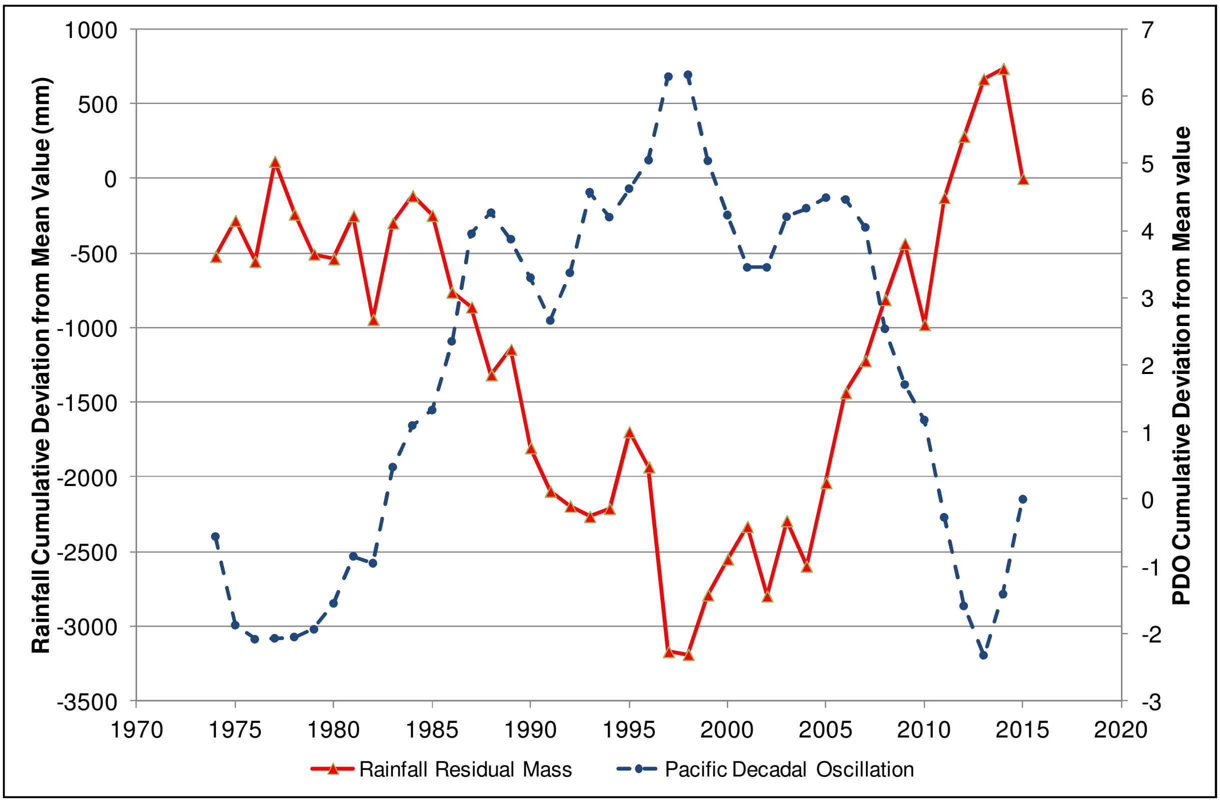



**Figure 5-2 Residual mass plots Anawe rainfall station data**

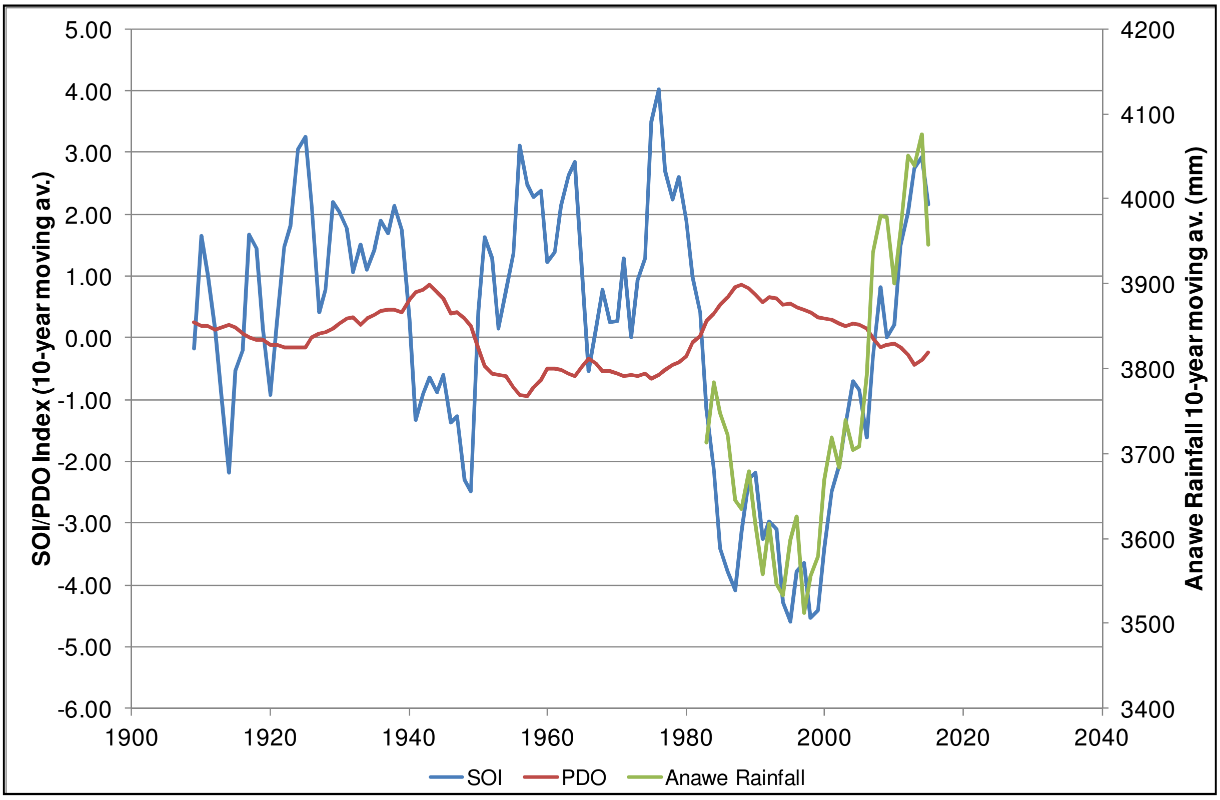



**Figure 5-3 Anawe rainfall, SOI and PDO indices on 10-y moving average**

### 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 2015**

| Parameter | Yearly total | Daily max | Daily min | Daily mean | Long-term daily mean | Std dev. (%) |
|---|---|---|---|---|---|---|
| Rainfall (mm) | 2998 | 99.2 | 0.0 | 8.3 | 10.3 | 11.4 |
| Max/Min Temp. (°C) | - | 19.5 | 8.2 | - | - | 1.9/2.1 |
| Mean Daily (°C) | - | 21.0 | 11.0 | 15.7 | 16.1 | 1.4 |
| Sunshine (hr) | 1616 | 10.5 | 0.0 | 4.5 | 4.1 | 2.1 |
| Evaporation (mm) | 1052 | 7.4 | 0.0 | 2.9 | 2.9 | 1.2 |
| Wind Run (km) | 13960 | 102.0 | 0.0 | 38.6 | 58.5 | 12.1 |

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 2015 against long-term monthly means. Annual rainfall was 2,998 mm on 293 wet days; the long-term mean annual total is 3,743 mm.

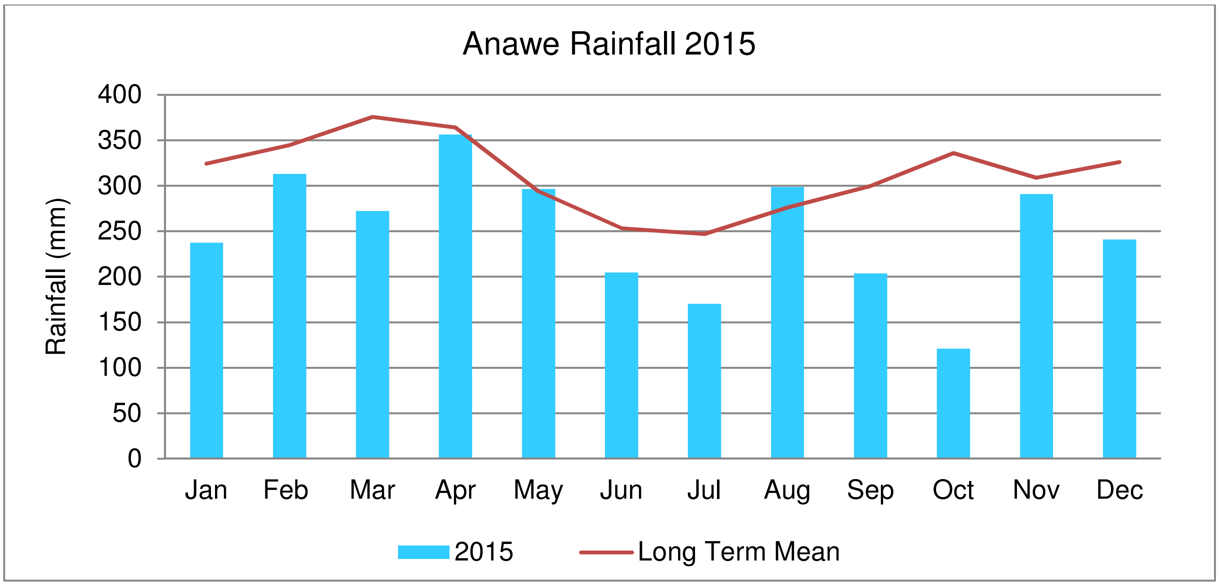



**Figure 5-4 Monthly rainfall at Anawe Plant Site during 2015 compared to long-term monthly means**

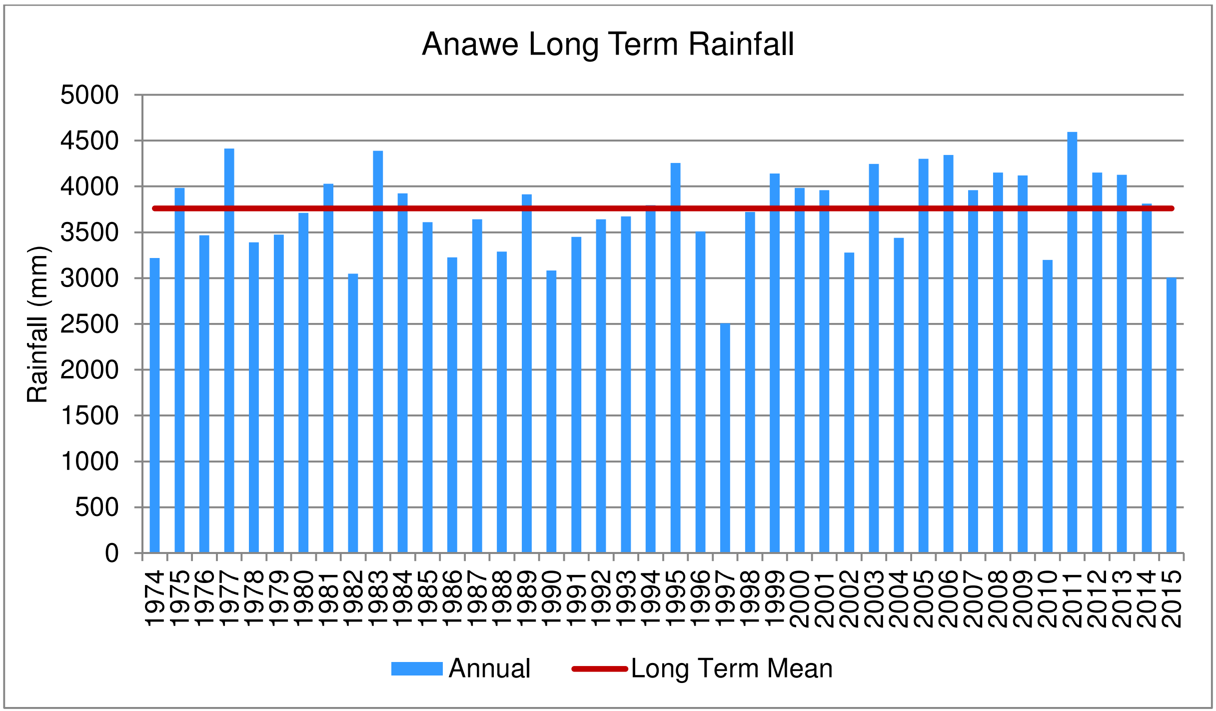



**Figure 5-5 Comparison of annual rainfall at Anawe Plant Site with long-term mean 1974 - 2015**

#### *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 3,709 mm on 296 wet days; the long-term mean annual total is 3,873 mm. Figure 5-7 shows the historical annual totals.

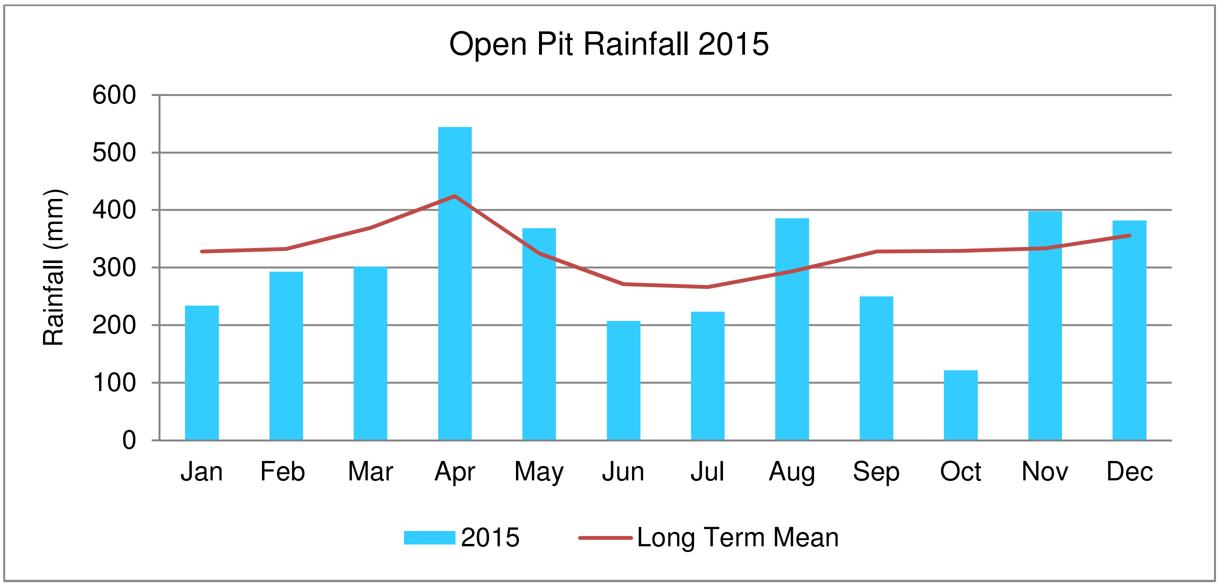



**Figure 5-6 Rainfall at Open Pit during 2015 compared to long-term monthly means**

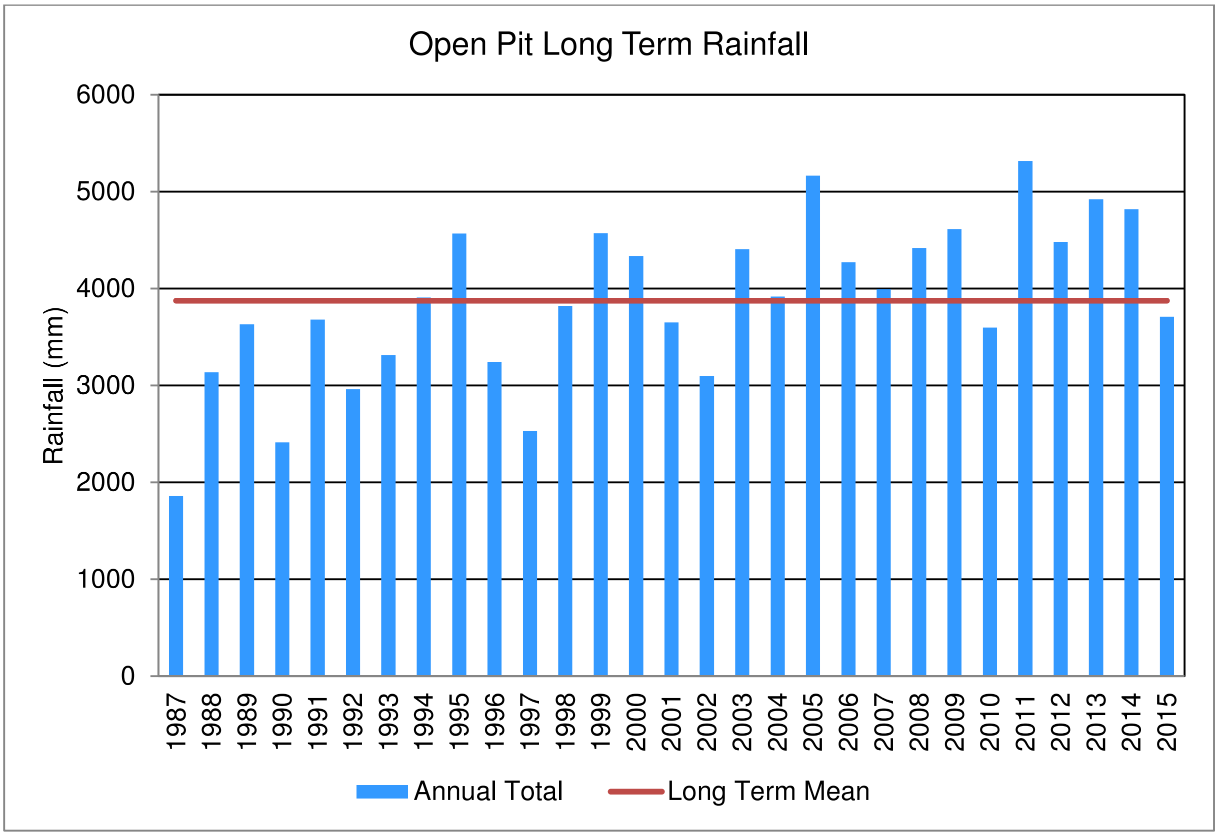



**Figure 5-7 Annual rainfall at Open Pit 1988 - 2015**

#### *5.1.3.3 Waile Creek*

Figure 5-8 shows rainfall at Waile Dam during 2015 compared to long-term monthly means. Annual rainfall was 2,677 mm on 287 wet days, long-term mean annual total is 2,906 mm.

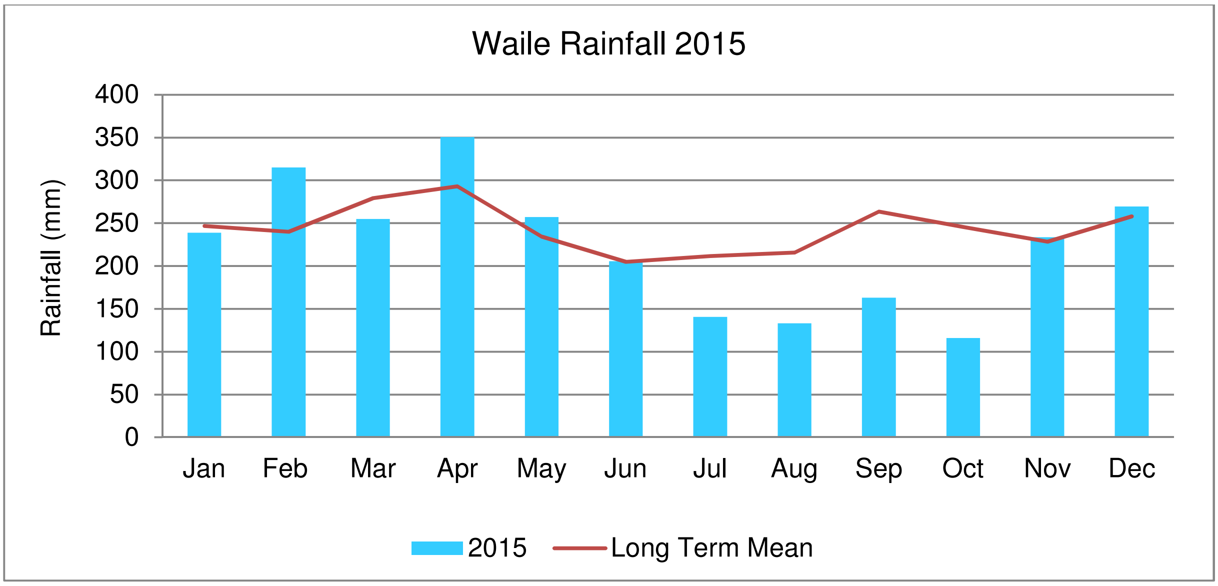



**Figure 5-8 Rainfall at Waile Dam during 2015 compared to long-term monthly means**

#### *5.1.3.4 Pongema*

Figure 5-9 shows rainfall at Suyan Camp during 2015 against long-term monthly means. Annual rainfall was 2,530 mm on 282 wet days; the long-term mean annual total is 2,942 mm.

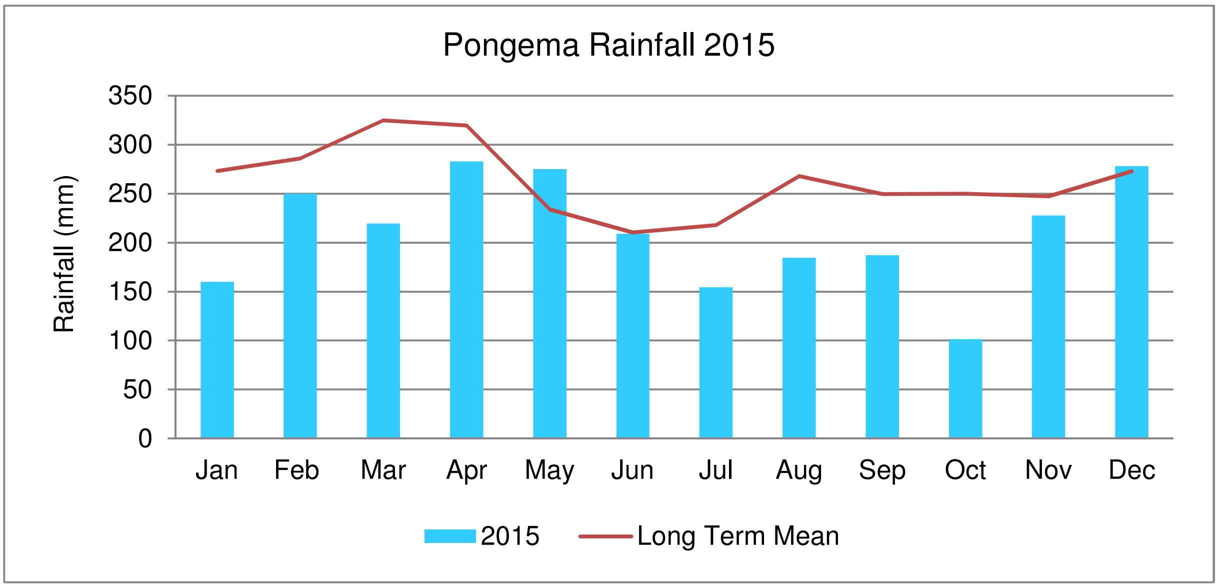



**Figure 5-9 Rainfall at Suyan Camp during 2015 compared to long-term monthly means**

#### *5.1.3.5 SG2*

Figure 5-10 shows rainfall at SG2 (Lagaip River) during the year for the months data were available plotted against long-term monthly means. Annual rainfall was 2,108 mm on 212 wet days. The long-term mean annual total is 2,043 mm.

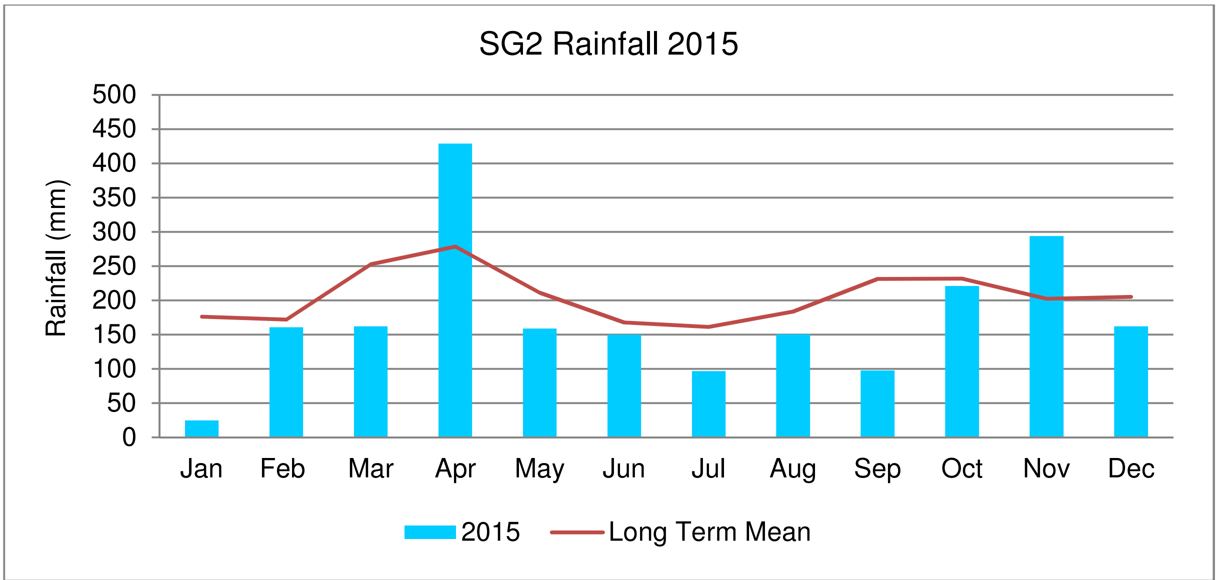



**Figure 5-10 Rainfall at SG2 during 2015 compared to long-term monthly means**

### *5.1.3.6 Ok Om*

Figure 5-11 shows rainfall at Ok Om during 2015 against long-term monthly means. Annual rainfall of 1,542 mm fell on 182 wet days; the long-term mean annual total is 2,089 mm.

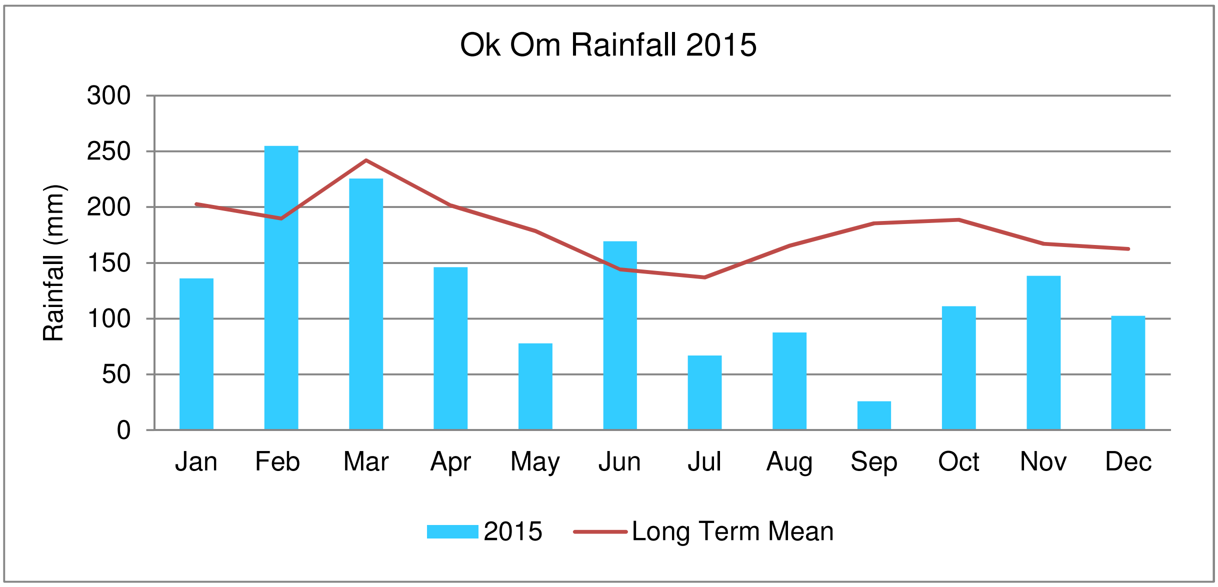



**Figure 5-11 Rainfall at Ok Om during 2015 compared to long-term monthly means**

### *5.1.3.7 SG3 (Compliance site)*

Figure 5-12 shows rainfall at the SG3 compliance site during 2015 against long-term monthly means. Annual rainfall of 947 mm fell on 158 wet days; the long-term mean annual total is 1,724 mm.

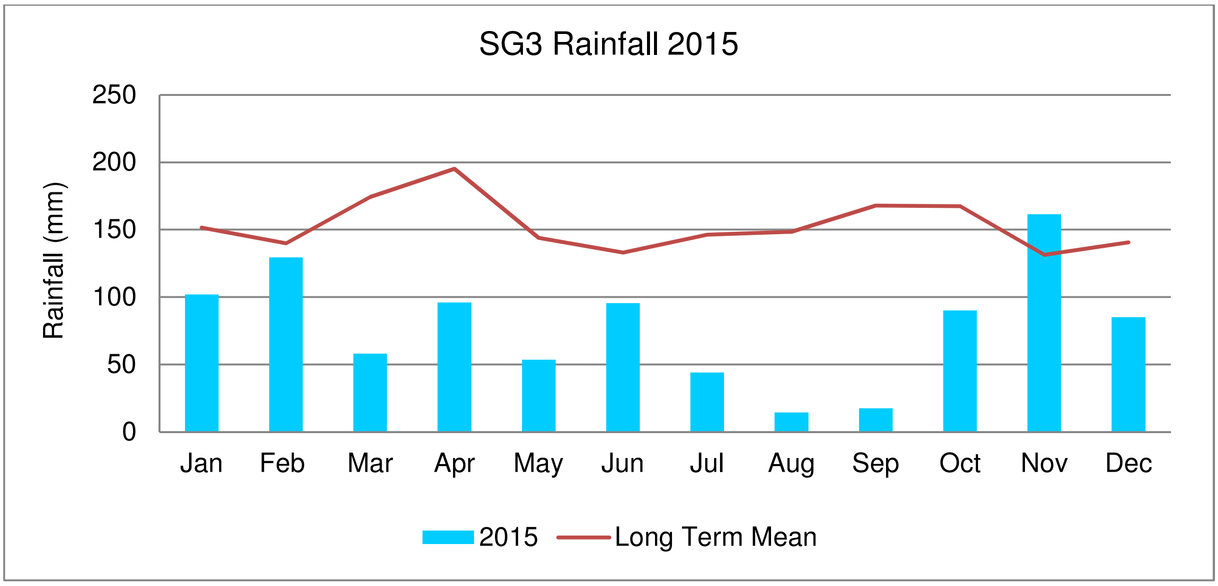



**Figure 5-12 Rainfall at SG3 during 2015 compared to long-term monthly means**

#### *5.1.3.8 SG4*

Figure 5-13 shows rainfall at SG4 in 2015 against long-term monthly means. Annual rainfall of 2,598 mm on 205 wet days was recorded against the long-term mean annual total of 3,669 mm.

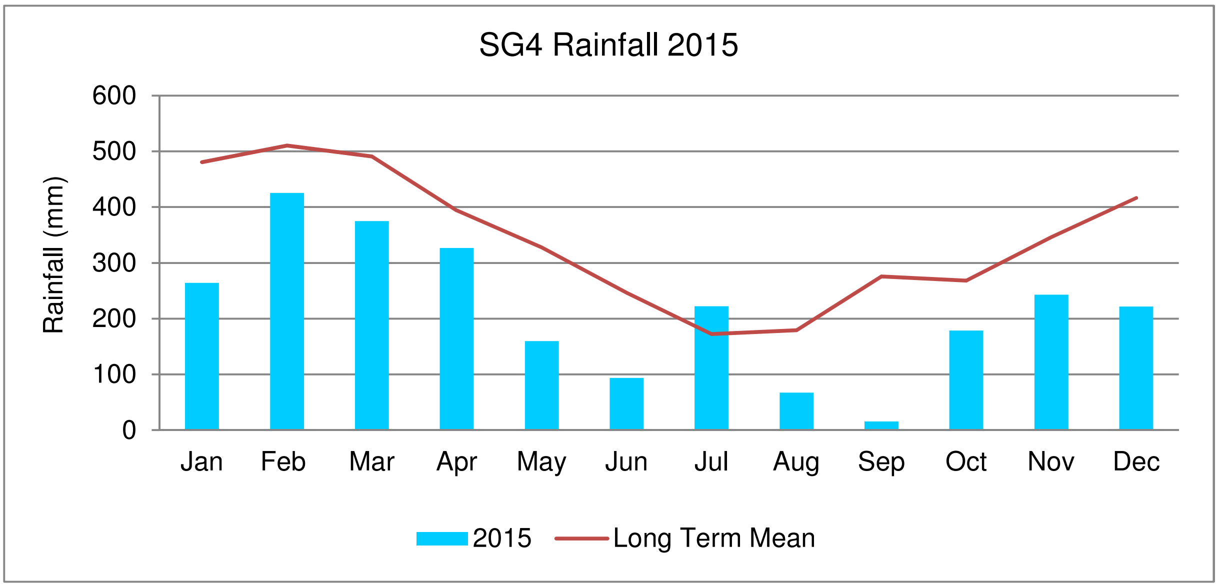
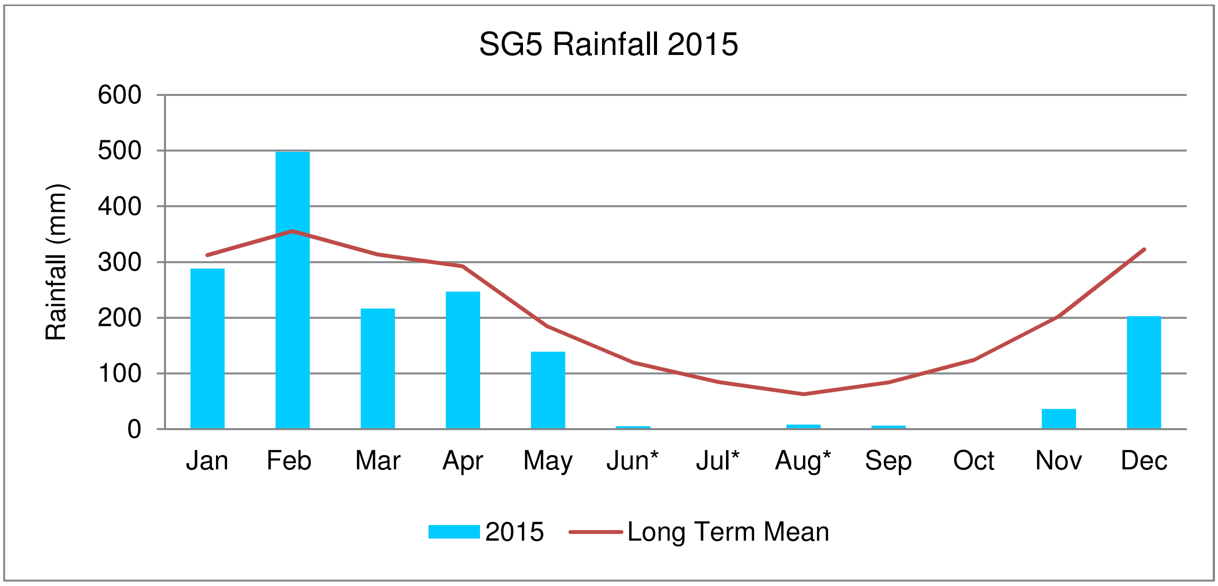



**Figure 5-13 Rainfall at SG4 during 2015 compared to long-term monthly means**

#### *5.1.3.9 SG5*

Figure 5-14 shows rainfall at SG5 during the year against long-term monthly means. Annual rainfall of 1,649 mm fell on 143 wet days, the long-term mean annual total is 2,238 mm. Very low rainfall was recorded from June to October. However, due to vandalism and logger failure, a total of 69 lost days of record was lost in June, July and August.




*Incomplete data record due to equipment vandalism

**Figure 5-14 Rainfall at SG5 during 2015 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 and therefore not influenced by the mine.

In general, flows were about 40 - 50% below average in the upper region sites of Kogai at SAG Mill and Kogai at culvert. Portal at Yunarilama was 15% above average. About 10 - 45% below average flows were recorded in the middle region, and 20-30% below average in the lower regions which is commensurate with rainfall being below average due to El Nino conditions.

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 Figure 5-16 respectively. Data records were affected by vandalism at Kogai @ Culvert, Portal @ Yunarilama and Lagaip at SG2.

**Table 5-2 Summary of flows in $m^3/s$ for riverine stations in 2015**

| Station | Days lost 2015 | Max | Mean | Min | Long-term Mean |
|---|---|---|---|---|---|
| Kogai @ SAG Mill | 0 | 0.705 | 0.260 | 0.086 | 0.70 |
| Kogai @ Culvert | 120 | 4.283 | 0.950 | 0.051 | 1.71 |
| Portal @ Yunarilama | 120 | 1.090 | 0.330 | 0.130 | 0.29 |
| Lagaip @ SG2 | 253 | 457 | 189 | 43 | 213 |
| Ok Om | 0 | 719 | 135 | 55 | 135 |
| Strickland @ SG3 | 0 | 2600 | 436 | 248 | 741 |
| Strickland @ SG4 | 0 | 6360 | 1930 | 946 | 2553 |
| Strickland @ SG5 | 0 | 4630 | 2467 | 584 | 3165 |

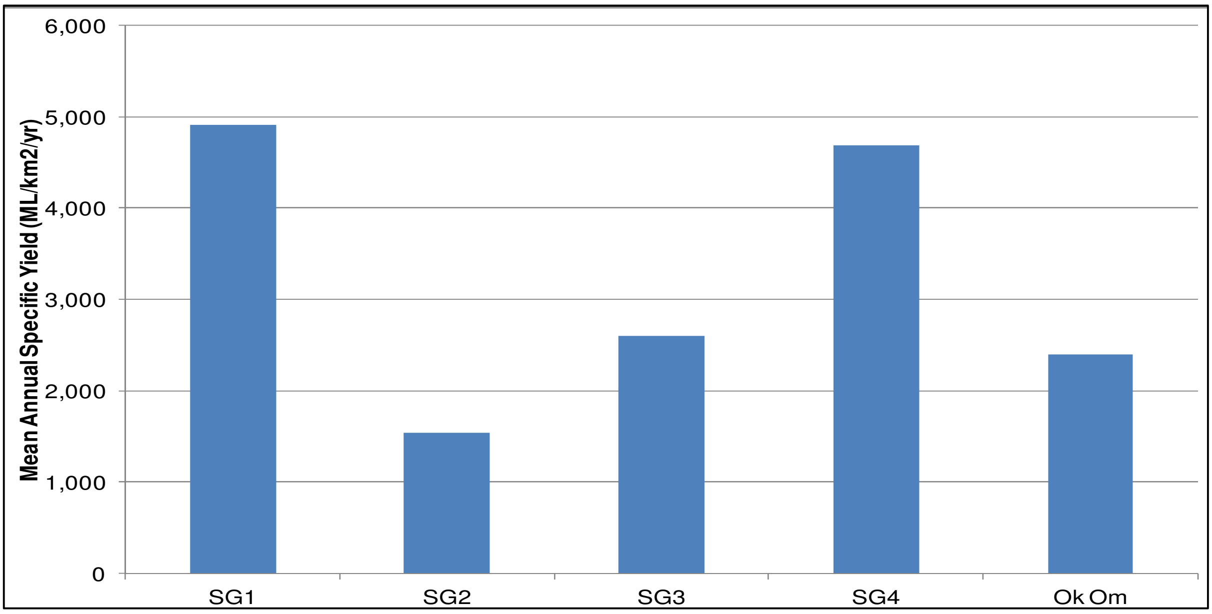



**Figure 5-15 Comparison of annual specific yield for main river gauging stations**

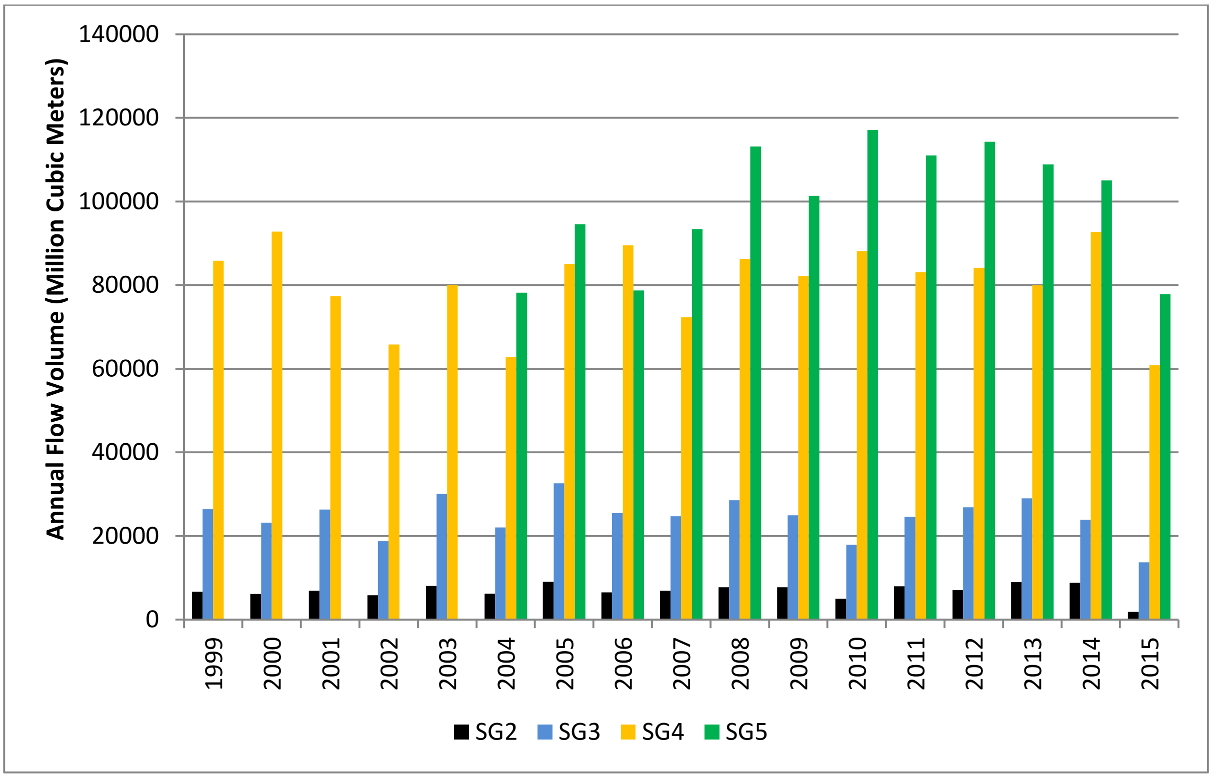



**Figure 5-16 Mean annual flow volumes for the main river gauging stations in 2015**

### 5.2.2 SG3 (Compliance site)

The total flow for the year at SG3 of 13,730 GL was approximately 36% below the long-term average of 21,470 GL. June had the highest monthly flow with 1,779 GL while October had the least with 749 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.

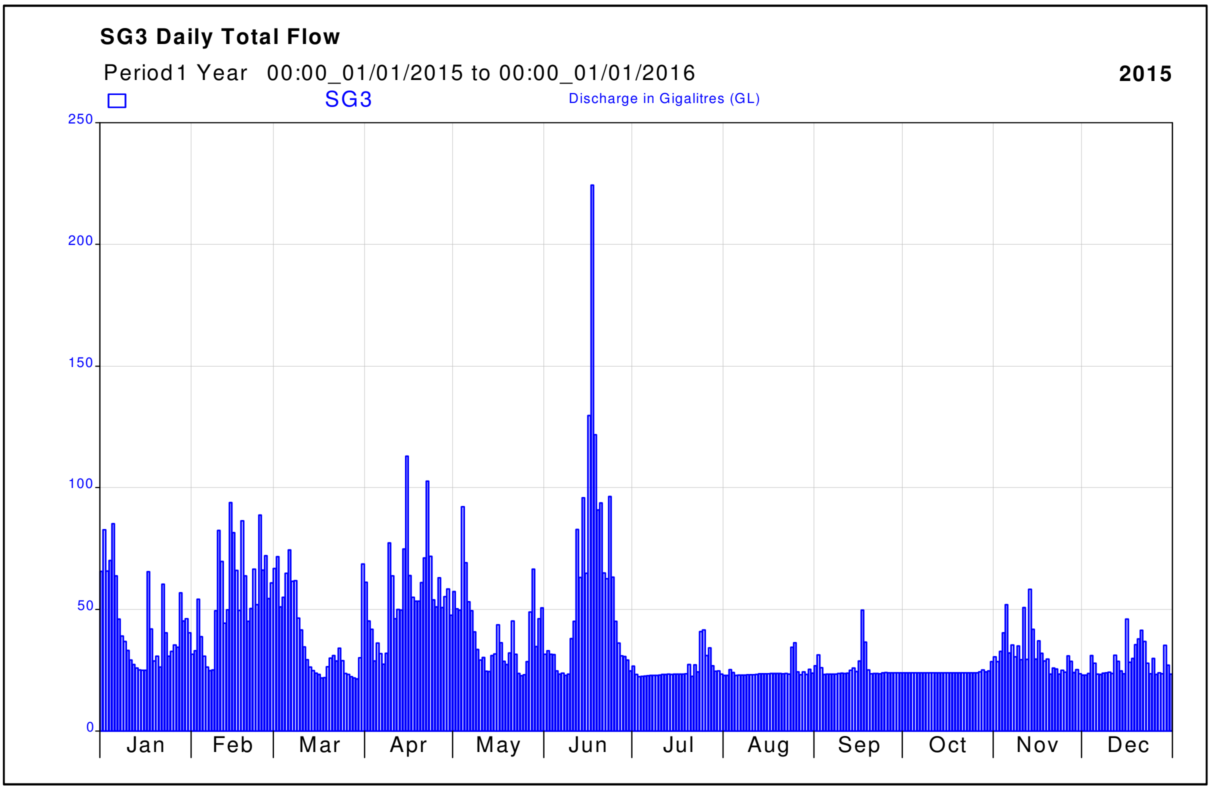



**Figure 5-17 Total daily flow (GL) at SG3 for 2015**

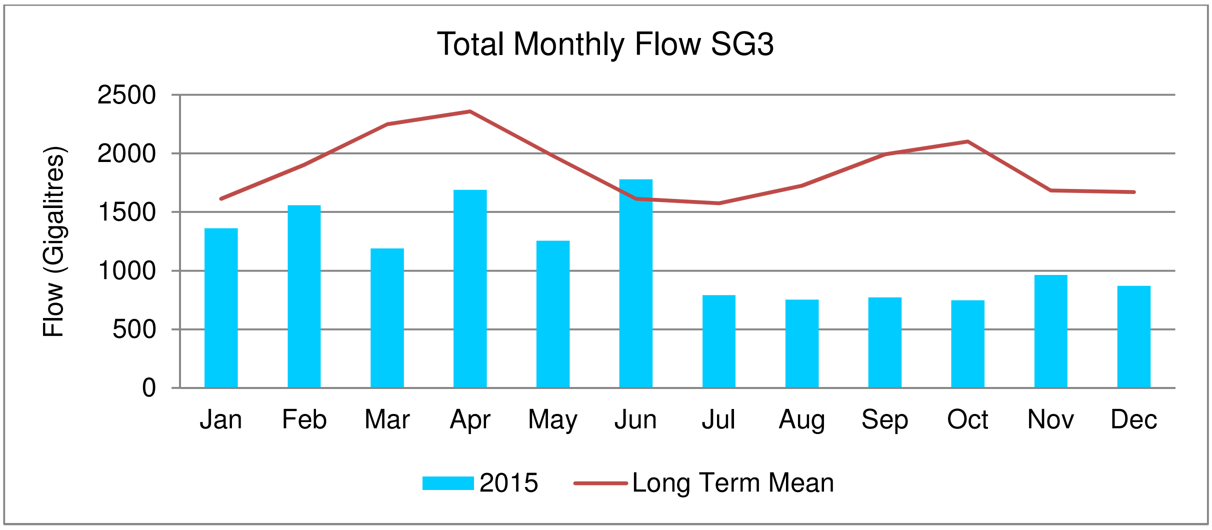



**Figure 5-18 Total monthly flow (GL) at SG3 during 2015 compared to long-term monthly means**

## 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 established trigger values 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 environmental conditions.

The site names are presented in Table 5-3 and median water quality data for 2015 are presented in Table 5-4 and shown in Figure 5-19 to Figure 5-48, with trends from 2011 - 2015 shown in Table 5-5.

**Table 5-3 Local site monitoring points**

| 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, while 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. Metal concentrations generally are low, however, background concentrations of mercury and selenium are at detectable levels throughout the historical record.

A summary of the trends between 2011 and 2015 are shown in Table 5-5, details of the statistical analysis for long-term trends are provided in Appendix C. The analysis shows that alkalinity at Aipulungu U/S Lime Plant has increased and Waile Creek alkalinity and dissolved zinc have increased. All other elements at all sites have either reduced or remained constant over the same period.

**Table 5-4 Local Reference Site Water Quality 2015 median values (µg/L except where shown)**

| Parameter | Aipulungu U/S Lime Plant | Waile Dam | Kaiya Riv U/S Anj Dump | Pongema |
|---|---|---|---|---|
| pH^ | 7.8 | 7.8 | 7.5 | 7.9 |
| WAD-CN* | 0.20 | 0.20 | 0.20 | 0.20 |
| Sulfate* | 1.0 | 1.0 | 12 | 2.0 |
| ALK-T* | 107 | 88 | 75 | 126 |
| TSS* | 18 | 13 | 85 | 35 |
| Hardness* | 110 | 79 | 67 | 134 |
| Ag-D | 0.05 | 0.05 | 0.05 | 0.05 |
| Ag-T | 0.05 | 0.05 | 0.05 | 0.05 |
| As-D | 0.15 | 0.16 | 0.24 | 0.18 |
| As-T | 0.19 | 0.20 | 0.60 | 0.24 |
| Cd-D | 0.05 | 0.05 | 0.05 | 0.05 |
| Cd-T | 0.05 | 0.05 | 0.05 | 0.05 |
| Cr-D | 0.15 | 0.15 | 0.10 | 0.15 |
| Cr-T | 0.35 | 0.20 | 1.8 | 0.71 |
| Cu-D | 0.59 | 0.50 | 0.62 | 0.50 |
| Cu-T | 0.58 | 0.50 | 1.4 | 0.71 |
| Fe-D | 16 | 54 | 23 | 10 |
| Fe-T | 140 | 165 | 1960 | 455 |
| Hg-D | 0.05 | 0.05 | 0.05 | 0.05 |
| Hg-T | 0.05 | 0.05 | 0.05 | 0.05 |
| Ni-D | 0.50 | 0.50 | 0.50 | 0.50 |
| Ni-T | 0.50 | 0.50 | 1.7 | 0.56 |
| Pb-D | 0.10 | 0.10 | 0.10 | 0.10 |
| Pb-T | 0.10 | 0.10 | 0.80 | 0.17 |
| Se-D | 0.20 | 0.20 | 0.20 | 0.20 |
| Se-T | 0.20 | 0.20 | 0.25 | 0.20 |
| Zn-D | 2.2 | 3.1 | 2.4 | 2.1 |
| Zn-T | 0.82 | 0.78 | 6.5 | 2.6 |

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

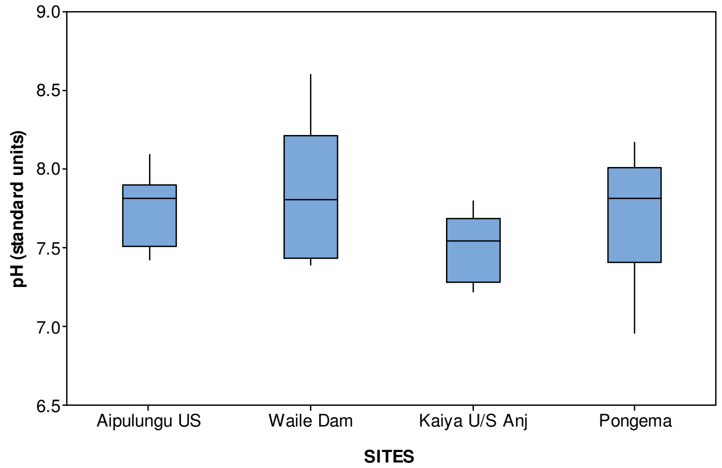



**Figure 5-19 pH in local creek runoff 2015**

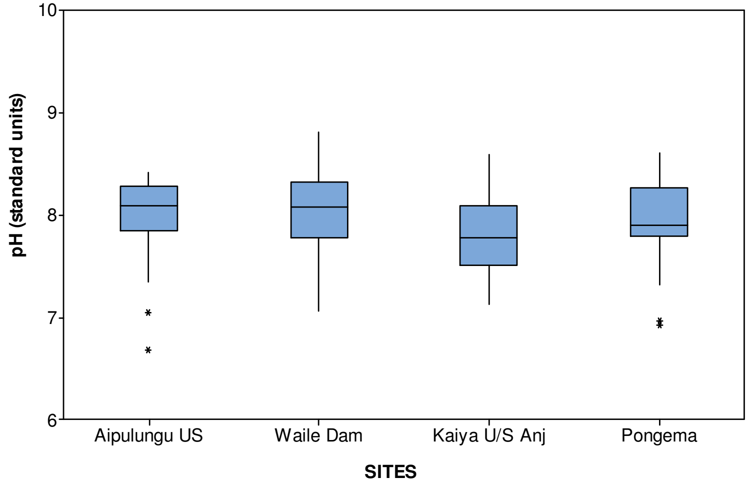



**Figure 5-20 pH in local creek runoff 2011 - 2015**

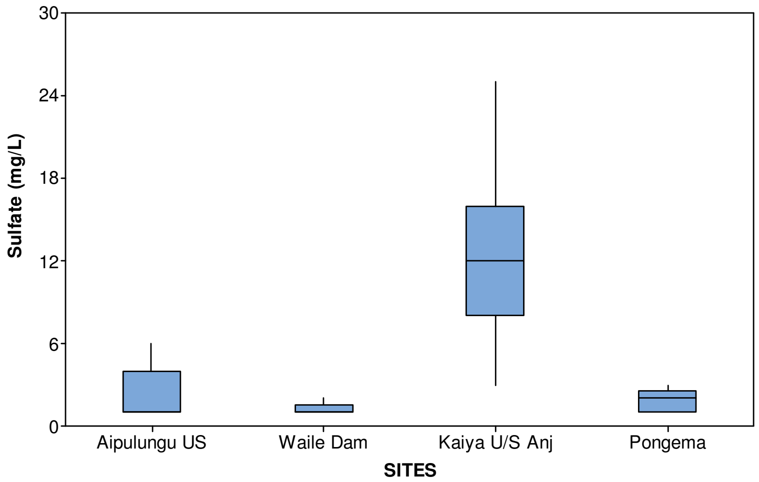



**Figure 5-21 Sulfate in local creek runoff 2015**

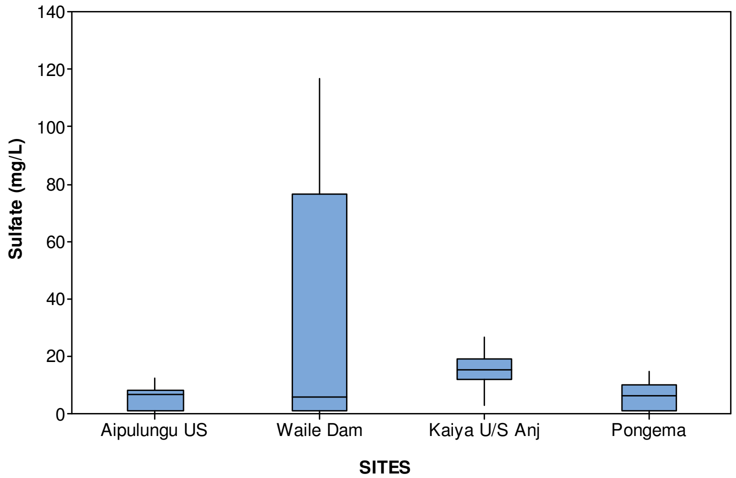



**Figure 5-22 Sulfate in local creek runoff 2011 - 2015**

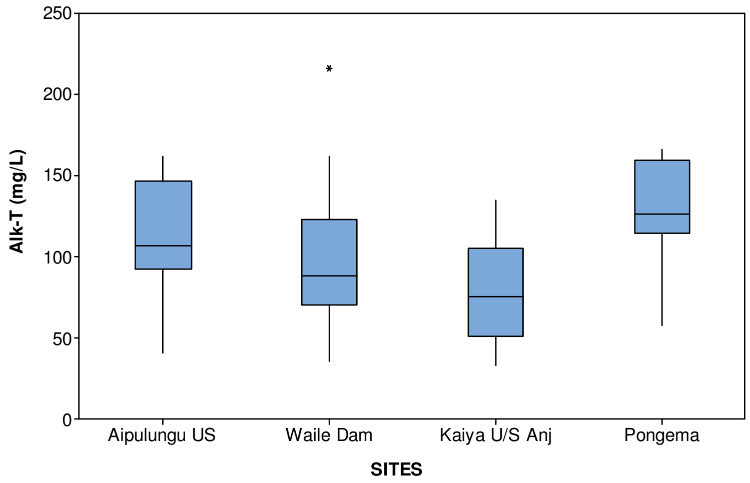



**Figure 5-23 Alkalinity in local creek runoff 2015**

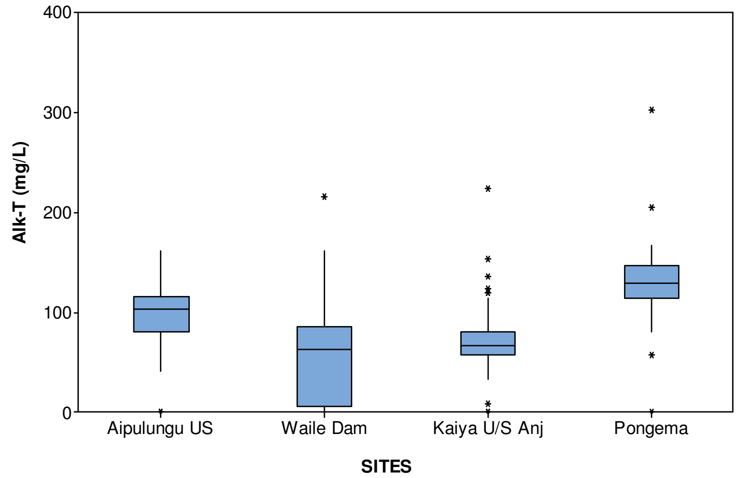



**Figure 5-24 Alkalinity in local creek runoff 2011 - 2015**

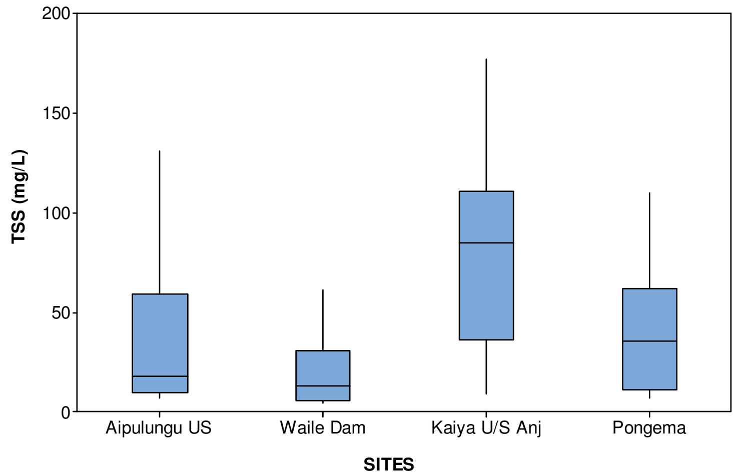



**Figure 5-25 TSS in local creek runoff 2015**

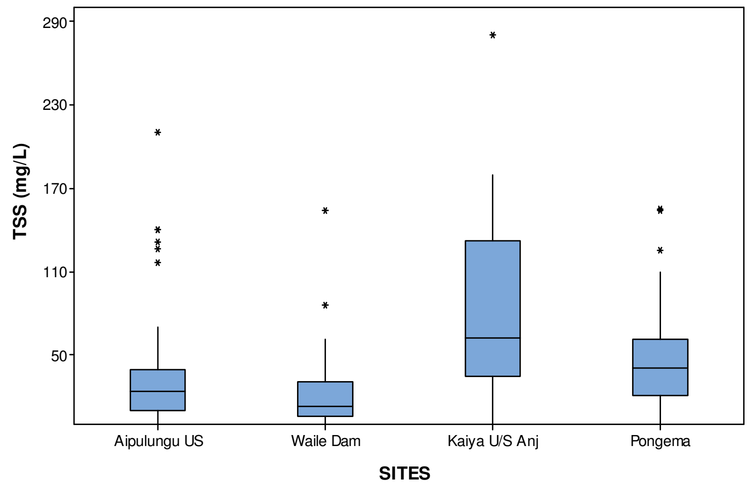



**Figure 5-26 TSS in local creek runoff 2011 - 2015**

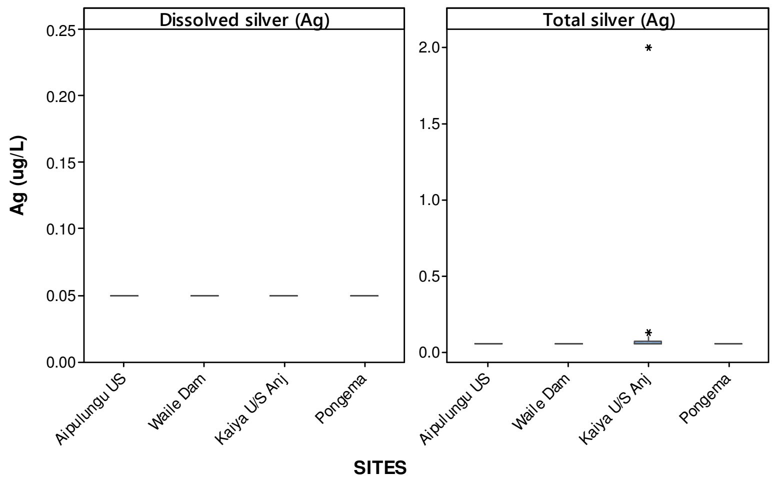



**Figure 5-27 Dissolved and total silver in local creek runoff 2015**

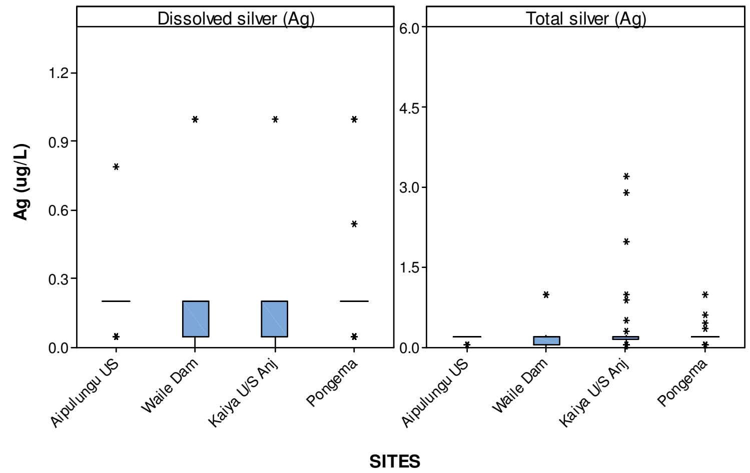



**Figure 5-28 Dissolved and total silver in local creek runoff 2011 - 2015**

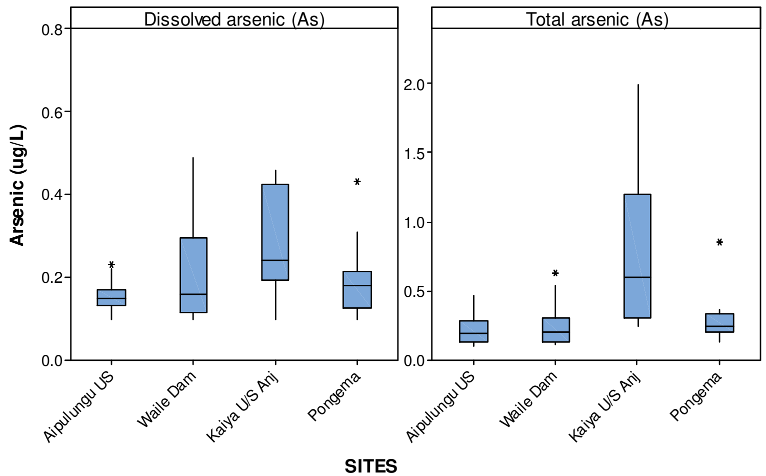



**Figure 5-29 Dissolved and total arsenic in local creek runoff 2015**

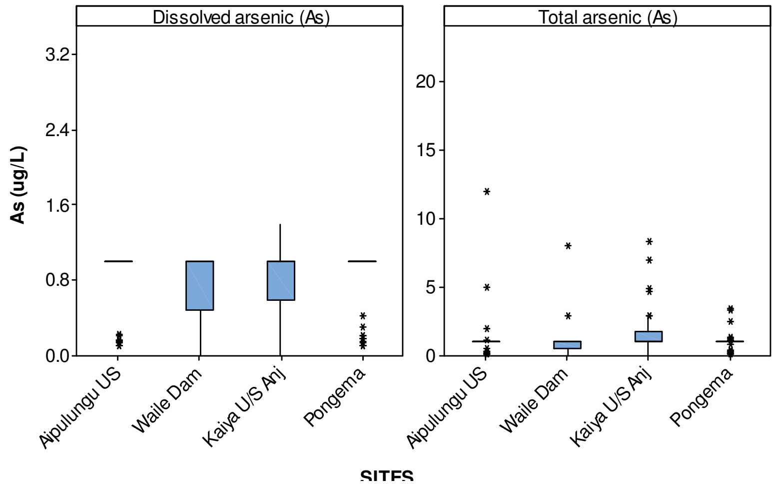



**Figure 5-30 Dissolved and total arsenic in local creek runoff 2011 - 2015**

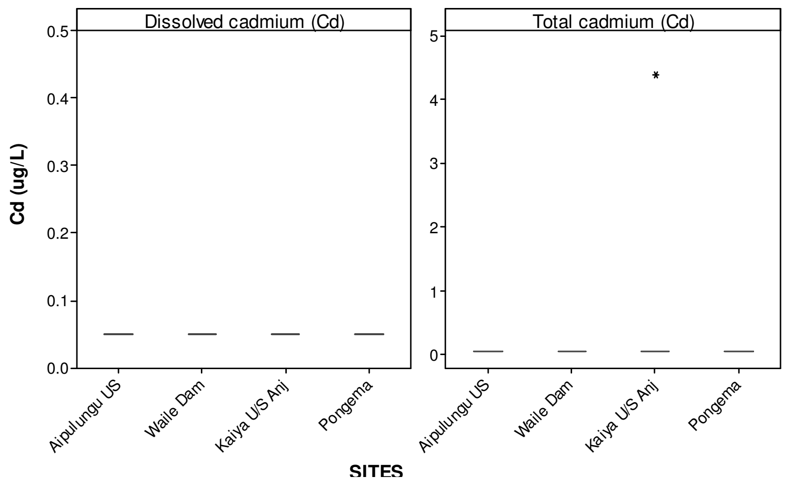



**Figure 5-31 Dissolved and total cadmium in local creek runoff 2015**

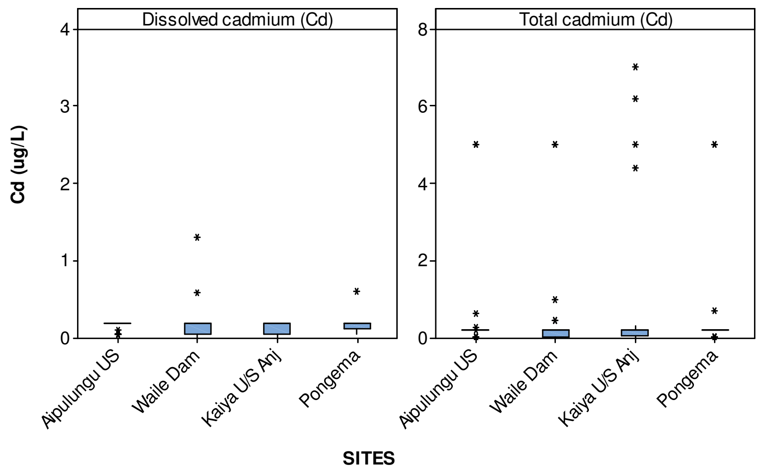



**Figure 5-32 Dissolved and total cadmium in local creek runoff 2011 - 2015**

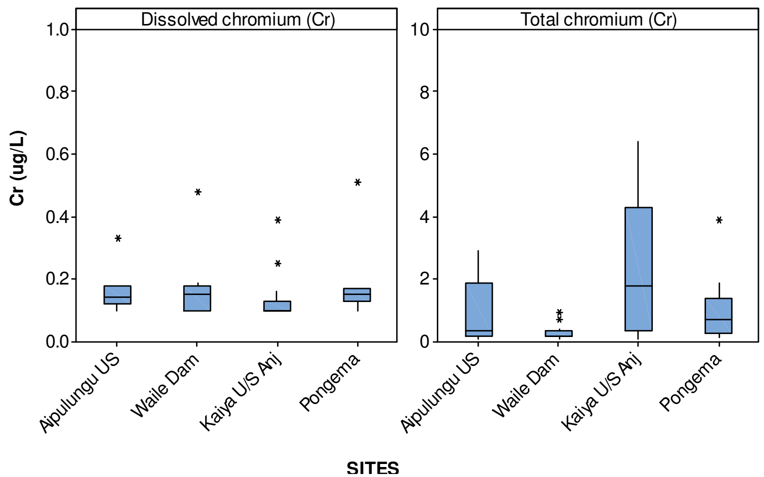



**Figure 5-33 Dissolved and total chromium in local creek runoff 2015**

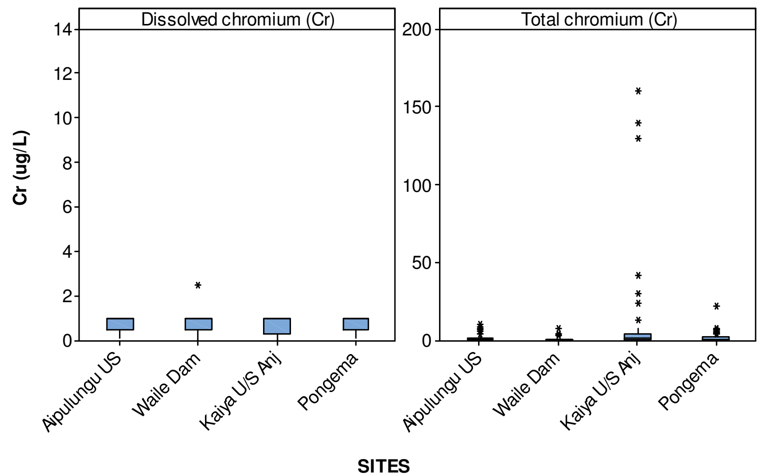



**Figure 5-34 Dissolved and total chromium in local creek runoff 2011 - 2015**

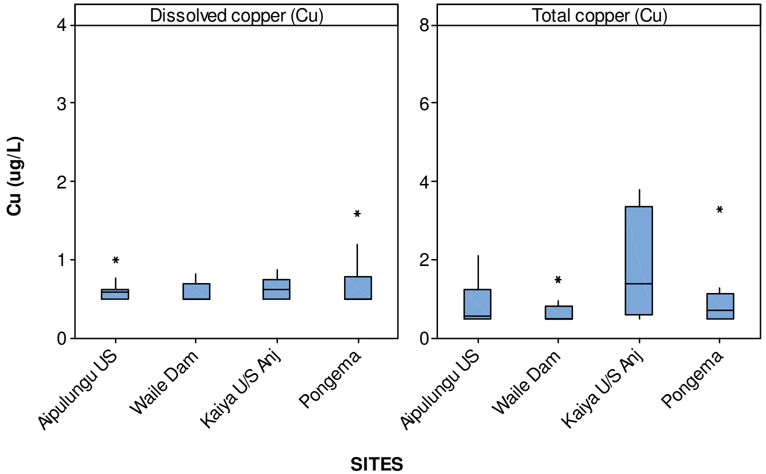



Figure 5-35 Dissolved and total copper in local creek runoff 2015

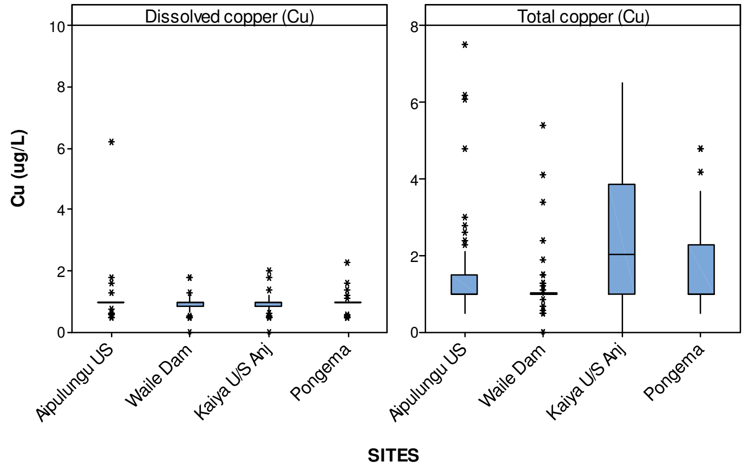



Figure 5-36 Dissolved and total copper in local creek runoff 2011 - 2015

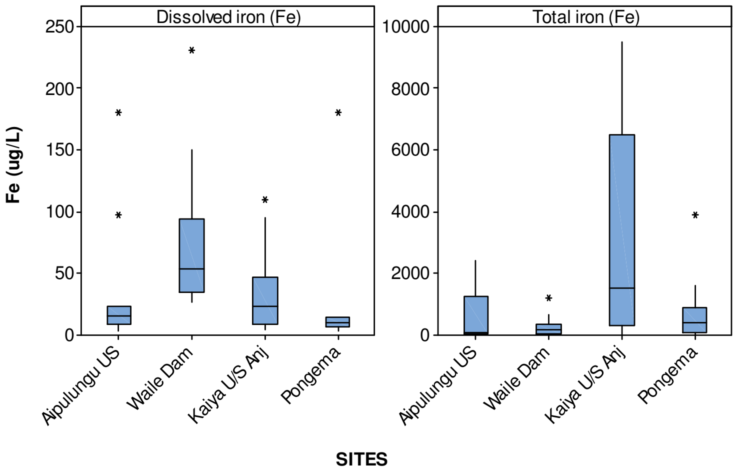



Figure 5-37 Dissolved and total iron in local creek runoff 2015

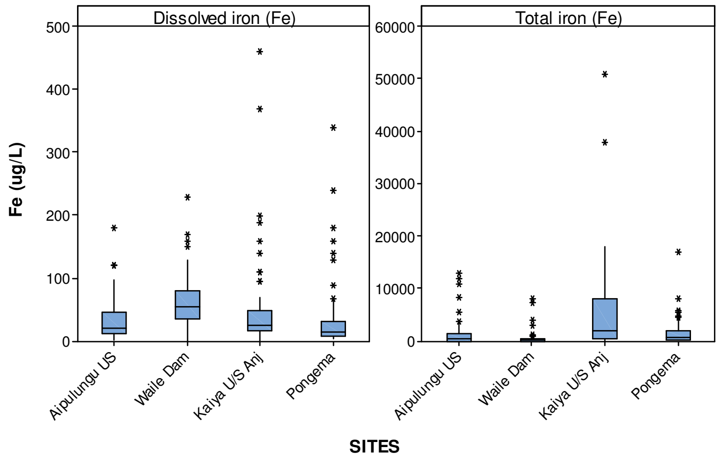



Figure 5-38 Dissolved and total iron in local creek runoff 2011 - 2015

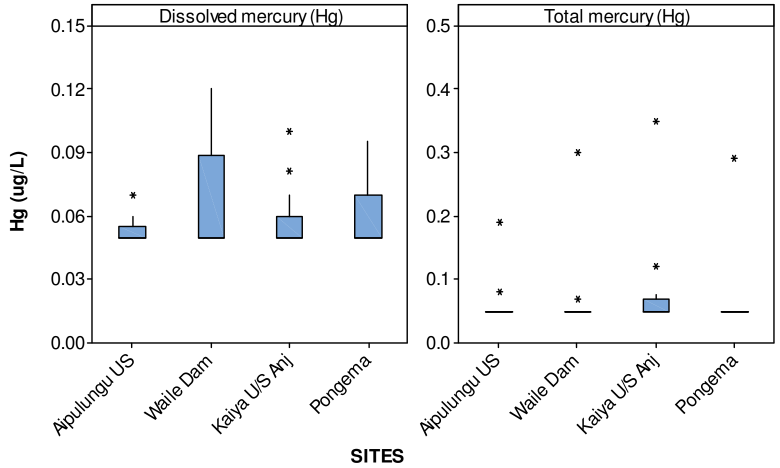



**Figure 5-39 Dissolved and total mercury in local creek runoff 2015**

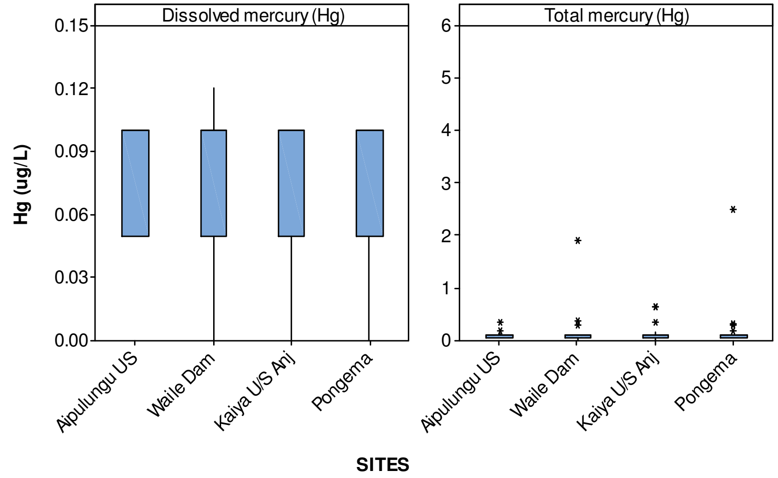



**Figure 5-40 Dissolved and total mercury in local creek runoff 2011 - 2015**

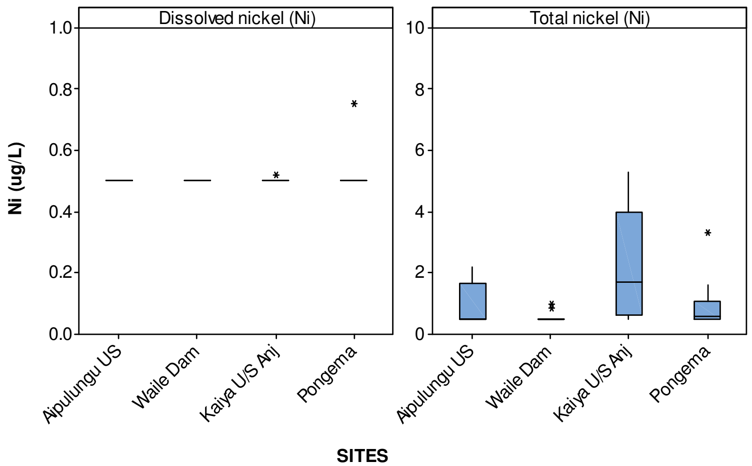



**Figure 5-41 Dissolved and total nickel in local creek runoff 2015**

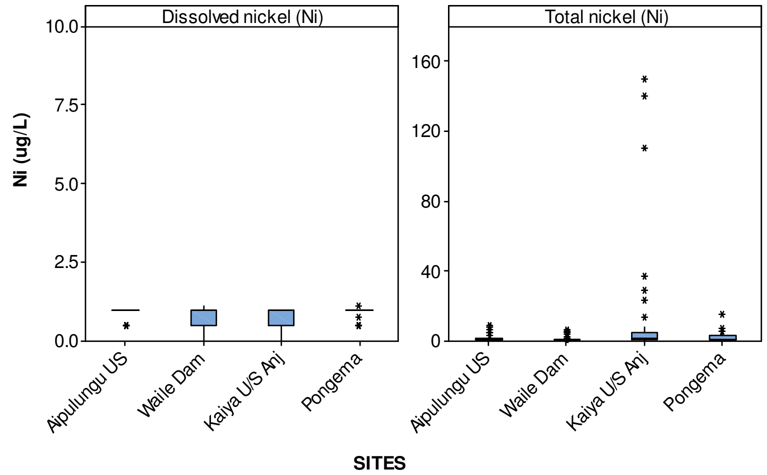



**Figure 5-42 Dissolved and total nickel in local creek runoff 2011 - 2015**

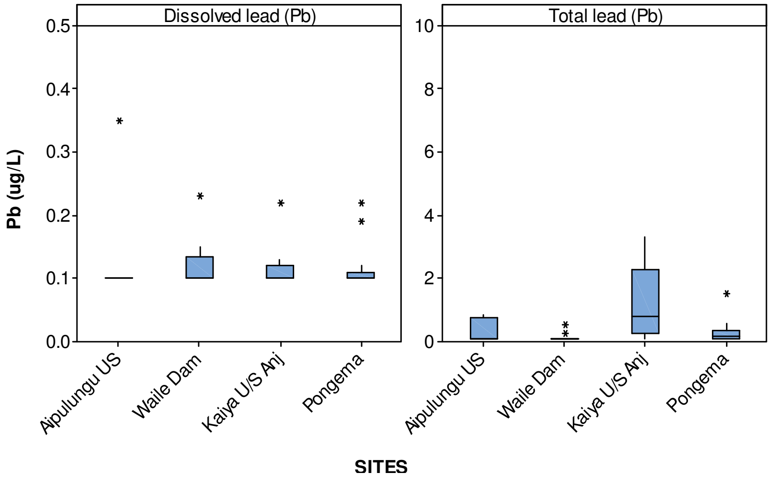



**Figure 5-43 Dissolved and total lead in local creek runoff 2015**

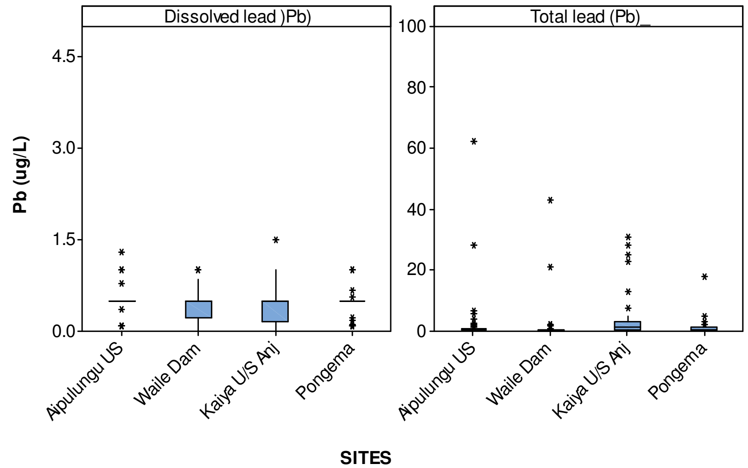



**Figure 5-44 Dissolved and total lead in local creek runoff 2011 - 2015**

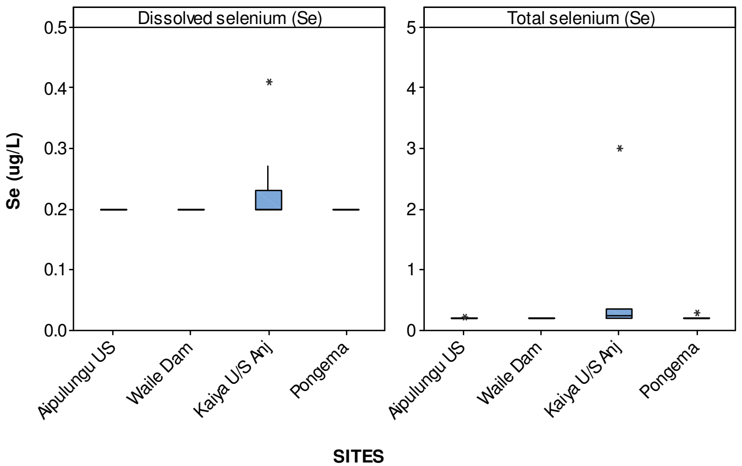



**Figure 5-45 Dissolved and total selenium in local creek runoff 2015**

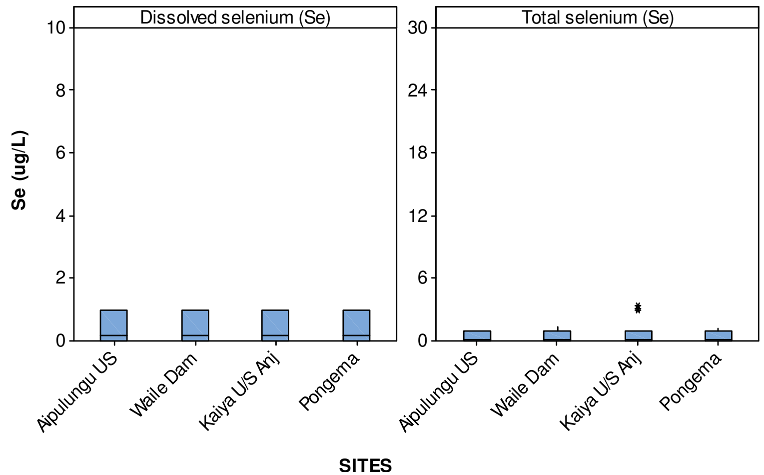



**Figure 5-46 Dissolved and total selenium in local creek runoff 2011 - 2015**

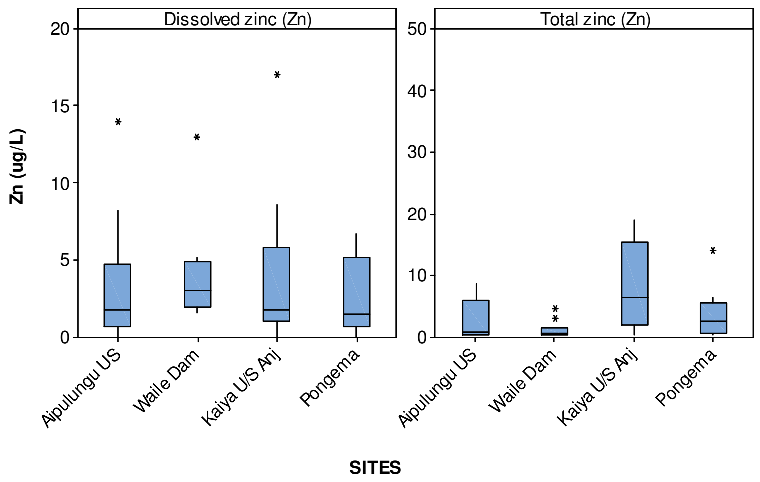



**Figure 5-47 Dissolved and total zinc in local creek runoff 2015**

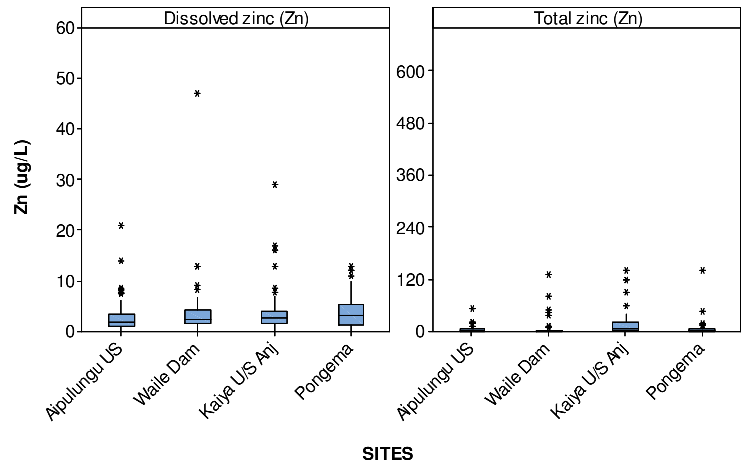



**Figure 5-48 Dissolved and total zinc in local creek runoff 2011 - 2015**

**Table 5-5 Trends of water quality in mine area runoff reference sites 2011 - 2015 as tested by Spearman Rank Correlation**

| Parameter | Aipulungu U/S Lime Plant | Waile Dam | Kaiya Riv U/S Anj Dump | Pongema |
|---|---|---|---|---|
| pH^ | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| WAD-CN* | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Sulfate* | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| ALK-T* | Increased | Increased | Decreased or no change | Decreased or no change |
| TSS* | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Hardness* | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Ag-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Ag-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| As-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| As-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Cd-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Cd-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Cr-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Cr-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Cu-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Cu-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Fe-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Fe-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Hg-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Hg-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Ni-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Ni-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Pb-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Pb-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Se-D | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Se-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |
| Zn-D | Decreased or no change | Increased | Decreased or no change | Decreased or no change |
| Zn-T | Decreased or no change | Decreased or no change | Decreased or no change | Decreased or no change |

| | |
|---|---|
| (green) | Decreased or no change over time |
| (orange) | 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 TV is higher than the ANZECC/ARMCANZ (2000) guideline for dissolved silver as no baseline data for silver are available. The ANZECC/ARMCANZ (2000) guideline values are higher than the baseline or reference TVs for dissolved arsenic, cadmium, chromium, mercury, lead and selenium. The baseline TVs are higher than the reference TV and ANZECC/ARMCANZ (2000) guideline values for TSS, dissolved copper, nickel and zinc.

In the lower river, baseline data exhibited higher pH, sulfate, concentrations of TSS, total and dissolved arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead and zinc than the lower river reference sites. This also 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 TV is higher than the ANZECC/ARMCANZ (2000) guideline for dissolved silver and cadmium, no baseline data for silver are available. The ANZECC/ARMCANZ (2000) guideline values are higher than the baseline or reference TVs for dissolved arsenic, chromium, mercury, lead, selenium and zinc. The baseline TVs are higher than the reference TV and ANZECC/ARMCANZ (2000) guideline values for dissolved copper, 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=113) | | | 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^ | 7.2 | 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* | 3 | 9 | 21 | 10 | 12 | 16 | 18 | 21 | 31 | 28 | 30 | 34 | 14.8 | 22.2 | 32.1 | | |
| Alk-T* | 63 | 89 | 121 | 110 | 117 | 122 | 110 | 150 | 263 | 96 | 106 | 124 | 106 | 117 | 169 | | |
| TSS* | 22 | 112 | 636 | 222 | 401 | 2496 | 258 | 1462 | 4874 | 743 | 1428 | 2663 | 258 | 1188 | 2837 | NA | 2837 |
| Hardness* | 61 | 86 | 110 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | | |
| Ag-D | 0.05 | 0.05 | 0.20 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.05 | 0.20 |
| Ag-T | 0.05 | 0.05 | 0.20 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | | |
| As-D | 0.4 | 0.6 | 1.0 | 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 | 1.4 | 6.3 | 1.8 | 3.5 | 11 | 2.0 | 3.7 | 10 | 4.2 | 9 | 15 | 2 | 5.5 | 13 | | |
| Cd-D | 0.05 | 0.05 | 0.20 | ND | ND | ND | 0.05 | 0.05 | 0.05 | ND | ND | ND | 0.05 | 0.05 | 0.05 | 0.4** | 0.4 |
| Cd-T | 0.05 | 0.07 | 0.20 | 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 | 0.2 | 0.3 | 0.5 | ND | ND | ND | 133 | 133 | 133 | ND | ND | ND | 0.5 | 0.5 | 0.5 | 1.0 | 1.0 |
| Cr-T | 0.8 | 6.5 | 33 | ND | ND | ND | 0.5 | 0.5 | 0.5 | ND | ND | ND | 133 | 133 | 133 | | |
| Cu-D | 0.5 | 0.8 | 1.0 | 1.1 | 1.2 | 1.4 | 0.56 | 0.9 | 7.2 | 1 | 1.7 | 4.3 | 0.98 | 1.4 | 4.1 | 1.4 | 4.1 |
| Cu-T | 0.9 | 3.5 | 27 | 5.2 | 15 | 66 | 8.8 | 41 | 146 | 7.4 | 36 | 68 | 7 | 29.4 | 81.8 | | |
| Fe-D | 5.7 | 11 | 31 | 75 | 75 | 75 | 57 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | NA | 75 |
| Fe-T* | 0.4 | 5.5 | 40 | 14 | 17 | 104 | 13 | 40 | 203 | 23 | 64 | 118 | 13 | 44 | 148 | | |
| Hg-D | 0.05 | 0.05 | 0.05 | ND | ND | ND | 0.2 | 0.2 | 0.2 | 0.05 | 0.05 | 0.05 | 0.08 | 0.125 | 0.17 | 0.6 | 0.6 |
| Hg-T | 0.05 | 0.05 | 0.09 | 0.10 | 0.10 | 0.16 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.10 | 0.10 | 0.10 | | |
| Ni-D | 0.5 | 0.5 | 1.0 | 13 | 15 | 15 | 5.7 | 9.1 | 15 | 11 | 15.7 | 23 | 10.3 | 15 | 21 | 20** | 21 |
| Ni-T | 1.0 | 6.4 | 39 | 16 | 16 | 16 | 20 | 20 | 179 | 10 | 12 | 94 | 12 | 20 | 90 | | |
| Pb-D | 0.10 | 0.10 | 0.50 | 0.30 | 0.30 | 0.64 | 0.26 | 0.30 | 0.38 | 0.3 | 0.3 | 1.3 | 0.3 | 0.3 | 1 | 8.3** | 8.3 |
| Pb-T | 0.41 | 2.00 | 13.6 | 4.36 | 12 | 160 | 6.1 | 18 | 139 | 3.6 | 23 | 59 | 4.4 | 18.8 | 82.2 | | |
| Se-D | 0.20 | 0.20 | 1.00 | ND | ND | ND | 0.07 | 0.07 | 0.07 | ND | ND | ND | 0.07 | 0.07 | 0.07 | 11 | 11 |
| Se-T | 0.20 | 0.44 | 1.00 | ND | ND | ND | 0.25 | 0.25 | 0.25 | ND | ND | ND | 0.25 | 0.25 | 0.25 | | |
| Zn-D | 1.0 | 1.6 | 3.1 | 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 | 1.8 | 12 | 89 | 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 | 7.4 | 7.6 | 7.8 | 8.0 | 8.1 | 6.0-8.0 | 6.0-8.2 |
| Sulfate* | 2 | 5 | 15 | 9.5 | 15 | 18 | | |
| ALK-T* | 55 | 78 | 105 | 83 | 93 | 101 | | |
| TSS* | 3 | 37 | 589 | 326 | 638 | 983 | NA | 983 |
| Hardness* | 26 | 56 | 73 | ND | ND | ND | | |
| Ag-D | 0.05 | 0.05 | 0.20 | ND | ND | ND | 0.05 | 0.20 |
| Ag-T | 0.1 | 0.1 | 0.2 | ND | ND | ND | | |
| As-D | 0.3 | 0.9 | 1.0 | 0.6 | 0.7 | 0.8 | 24 | 24 |
| As-T | 0.3 | 1.0 | 1.7 | 3.5 | 5.5 | 8.0 | | |
| Cd-D | 0.05 | 0.05 | 0.20 | 0.07 | 0.08 | 0.09 | 0.20 | 0.20 |
| Cd-T | 0.05 | 0.05 | 0.20 | 0.6 | 0.9 | 1.0 | | |
| Cr-D | 0.11 | 0.23 | 0.50 | 0.5 | 0.5 | 0.5 | 1.0 | 1.0 |
| Cr-T | 0.4 | 1.2 | 5.5 | 18 | 34 | 46 | | |
| Cu-D | 0.5 | 1.0 | 1.0 | 0.5 | 0.9 | 1.4 | 1.4 | 1.4 |
| Cu-T | 1.0 | 1.3 | 4.1 | 8.0 | 18 | 26 | | |
| Fe-D | 11 | 33 | 73 | 0.64 | 75 | 75 | NA | 75 |
| Fe-T* | 0.3 | 0.9 | 4.5 | 17 | 37 | 49 | | |
| Hg-D | 0.05 | 0.05 | 0.07 | ND | ND | ND | 0.60 | 0.60 |
| Hg-T | 0.05 | 0.05 | 0.10 | 0.1 | 0.1 | 0.1 | | |
| Ni-D | 0.5 | 0.6 | 1.0 | 3.6 | 10 | 15 | 11 | 15 |
| Ni-T | 0.7 | 1.4 | 5.6 | 10 | 23 | 24 | | |
| Pb-D | 0.1 | 0.2 | 0.5 | 0.3 | 0.5 | 0.7 | 2.8 | 2.8 |
| Pb-T | 0.1 | 0.5 | 1.3 | 5.6 | 10.4 | 19 | | |
| Se-D | 0.2 | 0.2 | 1.0 | 0.2 | 0.3 | 0.3 | 11 | 11 |
| Se-T | 0.2 | 0.2 | 1.0 | 0.2 | 0.2 | 0.5 | | |
| Zn-D | 1.8 | 3.3 | 5.8 | 0.5 | 1.0 | 2.9 | 8 | 8 |
| Zn-T | 1.0 | 2.3 | 11 | 28 | 68 | 94 | | |

^ 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

An analysis of the trend of median values for pH, TSS and total and dissolved metals at upper and lower river reference sites from 2011 to 2015 is presented in Table 5-8 and Table 5-9 respectively and shows that all parameters either decreased or did not change over that time period.

**Table 5-8 Trends for water quality at upper river reference sites 2011 - 2015 as determined by Spearman Rank correlation against time**

| Water Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend (2011 – 2015) |
|---|---|---|---|---|
| Upper River Ref (Trend of annual Medians from 2011 - 2015) | pH | -0.531 | <0.001 | Decreased over time |
| | TSS | -0.230 | <0.001 | Decreased over time |
| | Ag-D* | -0.813 | <0.001 | No change over time |
| | Ag-T* | -0.700 | <0.001 | No change over time |
| | As-D* | -0.792 | <0.001 | No change over time |
| | As-T | -0.269 | <0.001 | Decreased over time |
| | Cd-D* | -0.809 | <0.001 | No change over time |
| | Cd-T* | -0.737 | <0.001 | No change over time |
| | Cr-D* | -0.881 | <0.001 | No change over time |
| | Cr-T* | -0.167 | 0.012 | No change over time |
| | Cu-D* | -0.619 | <0.001 | No change over time |
| | Cu-T | -0.198 | 0.003 | Decreased over time |
| | Fe-D | -0.111 | 0.099 | No change over time |
| | Fe-T | -0.199 | 0.003 | Decreased over time |
| | Hg-D* | -0.801 | <0.001 | No change over time |
| | Hg-T* | -0.551 | <0.001 | No change over time |
| | Ni-D* | -0.742 | <0.001 | No change over time |
| | Ni-T | -0.195 | 0.004 | Decreased over time |
| | Pb-D* | -0.770 | <0.001 | No change over time |
| | Pb-T | -0.254 | <0.001 | Decreased over time |
| | Se-D* | -0.887 | <0.001 | No change over time |
| | Se-T* | -0.803 | <0.001 | No change over time |
| | Zn-D | -0.354 | <0.001 | Decreased over time |
| | Zn-T | -0.211 | 0.002 | Decreased 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 2011 - 2015 as determined by Spearman Rank correlation against time**

| Water Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Performance Assessment |
|---|---|---|---|---|
| Lower River Ref (Trend of annual Medians from 2011 - 2015) | pH | -0.319 | 0.009 | Decreased over time |
| | TSS | -0.393 | 0.001 | Decreased over time |
| | Ag-D* | -0.711 | <0.001 | No change over time |
| | Ag-T* | -0.684 | <0.001 | No change over time |
| | As-D* | -0.542 | <0.001 | No change over time |
| | As-T* | -0.419 | <0.001 | No change over time |
| | Cd-D* | -0.711 | <0.001 | No change over time |
| | Cd-T* | -0.558 | <0.001 | No change over time |
| | Cr-D* | -0.823 | <0.001 | No change over time |
| | Cr-T | -0.214 | 0.059 | No change over time |
| | Cu-D* | -0.420 | <0.001 | No change over time |
| | Cu-T | -0.478 | <0.001 | Decreased over time |
| | Fe-D | 0.211 | 0.060 | No change over time |
| | Fe-T | -0.451 | <0.001 | Decreased over time |
| | Hg-D* | -0.764 | <0.001 | No change over time |
| | Hg-T* | -0.538 | <0.001 | No change over time |
| | Ni-D* | -0.678 | <0.001 | No change over time |
| | Ni-T | -0.424 | <0.001 | Decreased over time |
| | Pb-D* | -0.680 | <0.001 | No change over time |
| | Pb-T | -0.478 | <0.001 | Decreased over time |
| | Se-D* | -0.919 | <0.001 | No change over time |
| | Se-T* | -0.892 | <0.001 | No change over time |
| | Zn-D | -0.115 | 0.310 | No change over time |
| | Zn-T | -0.415 | <0.001 | Decreased 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 site was selected as the most appropriate reference site for the ORWBs and the central and southern end of the lake. 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 TVs are higher than the baseline TV and ANZECC/ARMCANZ (2000) guideline value for TSS and dissolved silver. The baseline TV is higher than the reference TV and ANZECC/ARMCANZ (2000) guideline value for dissolved cadmium and dissolved iron. The ANZECC/ARMCANZ (2000) guideline value is higher than the baseline TV and the reference TV 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) | | | 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^ | 5.2 | 5.4 | 5.6 | 6.3 | 6.4 | 6.4 | 6.3 | 6.4 | 6.6 | 6.3 | 6.4 | 6.6 | 6.0-8.0 | 5.3-8.0 |
| Sulfate | 1.0 | 1.0 | 1.2 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | |
| ALK-T* | 5.9 | 8.5 | 11.7 | 7.7 | 8.1 | 8.8 | 7.9 | 8.1 | 8.5 | 7.8 | 8.1 | 8.7 | | |
| TSS* | 8 | 16 | 23 | 6.0 | 7.0 | 9.0 | 4.6 | 6.0 | 8.2 | 5.4 | 6.5 | 9.0 | NA | 23 |
| Hardness* | 6.8 | 7.0 | 7.0 | ND | ND | ND | ND | ND | ND | ND | ND | ND | | |
| Ag-D | 0.05 | 0.05 | 0.05 | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.05 | 0.05 |
| Ag-T | 0.05 | 0.05 | 0.05 | ND | ND | ND | ND | ND | ND | ND | ND | ND | | |
| As-D | 0.16 | 0.17 | 0.20 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 24 | 24 |
| As-T | 0.3 | 0.5 | 0.7 | 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 | 0.20 | 0.72 |
| Cd-T | 0.05 | 0.13 | 0.264 | 2.0 | 4.1 | 5.1 | 0.4 | 1.1 | 1.3 | 0.7 | 1.4 | 4.8 | | |
| Cr-D | 0.17 | 0.19 | 0.27 | 0.1 | 0.1 | 0.44 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.4 | 1.0 | 1.0 |
| Cr-T | 0.7 | 0.9 | 1.3 | 0.1 | 0.1 | 0.4 | 0.1 | 0.25 | 1.3 | 0.1 | 0.15 | 0.6 | | |
| Cu-D | 0.6 | 0.6 | 0.8 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 1.4 | 1.4 |
| Cu-T | 1.0 | 1.2 | 1.4 | 0.26 | 0.4 | 0.8 | 0.1 | 0.3 | 0.52 | 0.1 | 0.3 | 0.7 | | |
| Fe-D | 84 | 110 | 124 | 138 | 255 | 342 | 166 | 230 | 324 | 148 | 250 | 340 | NA | 340 |
| Fe-T | 436 | 940 | 2076 | 762 | 1005 | 1072 | 898 | 945 | 1024 | 898 | 980 | 1072 | | |
| Hg-D | 0.05 | 0.065 | 0.132 | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.16 | 0.16 |
| Hg-T | 0.05 | 0.05 | 0.06 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | | |
| Ni-D | 0.5 | 0.6 | 0.7 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 11 | 11 |
| Ni-T | 0.9 | 1.0 | 1.3 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | |
| Pb-D | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.7 | 0.2 | 0.2 | 0.62 | 0.2 | 0.2 | 0.7 | 3.4 | 3.4 |
| Pb-T | 0.4 | 0.5 | 0.6 | 0.5 | 1.0 | 1.9 | 0.4 | 0.8 | 1.4 | 0.38 | 0.9 | 1.7 | | |
| Se-D | 0.2 | 0.2 | 0.2 | 0.7 | 0.8 | 0.9 | 0.7 | 0.7 | 0.8 | 0.7 | 0.7 | 0.9 | 11 | 11 |
| Se-T | 0.2 | 0.33 | 0.606 | 0.9 | 0.9 | 0.9 | 0.7 | 0.8 | 1.0 | 0.7 | 0.9 | 1.0 | | |
| Zn-D | 0.9 | 1.5 | 4.0 | 0.05 | 0.05 | 0.14 | 0.05 | 0.5 | 1.0 | 0.05 | 0.08 | 0.8 | 8.0 | 8.0 |
| Zn-T | 1.6 | 2.7 | 4.1 | 1.2 | 2.0 | 2.7 | 1.3 | 2.0 | 2.88 | 1.3 | 2.0 | 2.8 | | |

^ 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

An analysis of the trend of median values for pH, TSS and total and dissolved metals at Lake Murray and ORWB reference sites from 2011 to 2015 is presented in Table 5-11 and shows that the concentrations of TSS, total copper, total iron, total nickel and total zinc increased over the time period, all other parameters either decreased or did not change over that time period.

**Table 5-11 Trends for water quality Lake Murray and ORWBs 2011 - 2015 as determined using Spearman Rank Correlation against time**

| Water Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend (2011 – 2015) |
|---|---|---|---|---|
| Lake Murray and ORWB Ref (Trend of annual Medians from 2011 - 2015) | pH | -0.370 | 0.062 | No change over time |
| | TSS | 0.877 | <0.001 | Increased over time |
| | Ag-D* | -0.779 | <0.001 | No change over time |
| | Ag-T* | -0.746 | <0.001 | No change over time |
| | As-D* | -0.235 | 0.247 | No change over time |
| | As-T | -0.936 | <0.001 | Decreased over time |
| | Cd-D* | -0.776 | <0.001 | No change over time |
| | Cd-T* | -0.602 | 0.001 | No change over time |
| | Cr-D* | -0.548 | 0.004 | No change over time |
| | Cr-T | -0.413 | 0.036 | Decreased over time |
| | Cu-D | 0.010 | 0.963 | No change over time |
| | Cu-T | 0.682 | <0.001 | Increased over time |
| | Fe-D | -0.351 | 0.079 | No change over time |
| | Fe-T | 0.522 | 0.006 | Increased over time |
| | Hg-D* | -0.675 | <0.001 | No change over time |
| | Hg-T* | -0.840 | <0.001 | No change over time |
| | Ni-D* | -0.156 | 0.448 | No change over time |
| | Ni-T | 0.482 | 0.013 | Increased over time |
| | Pb-D* | -0.686 | <0.001 | No change over time |
| | Pb-T | -0.022 | 0.915 | No change over time |
| | Se-D* | -0.553 | 0.008 | No change over time |
| | Se-T* | -0.947 | <0.001 | No change over time |
| | Zn-D | 0.387 | 0.051 | No change over time |
| | Zn-T | 0.908 | <0.001 | Increased over time |

D - Dissolved fraction, T - Total fraction

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

## 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 are used to develop 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 method is designed to better mimic the ability of an organism's digestive system to liberate metals from sediment, and therefore 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 2015, and the results are presented in Table 5-12.

Sediment quality within local creeks is dominated by the surrounding limestone geology and relatively low level of development within the catchments. The WAE and TD concentrations 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 2015 (mg/kg whole sediment)**

| | Pongema | | | Kaiya US | | | Aipulungu US | | |
|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | 20%ile | Median | 80%ile | 20%ile | Median | 80%ile | 20%ile | Median | 80%ile |
| Ag-WAE | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Ag-TD | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| As-WAE | 0.89 | 1.1 | 1.4 | 1.5 | 1.6 | 1.9 | 0.98 | 1.1 | 1.1 |
| As-TD | 3.7 | 4.0 | 4.8 | 6.3 | 7.1 | 8.1 | 2.6 | 2.7 | 2.9 |
| Cd-WAE | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Cd-TD | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Cr-WAE | 2.9 | 3.2 | 4.4 | 1.1 | 1.3 | 4.9 | 3.6 | 4.0 | 7.2 |
| Cr-TD | 16 | 18 | 24 | 23 | 25 | 29 | 27 | 32 | 32 |
| Cu-WAE | 2.3 | 2.9 | 3.8 | 4.3 | 5.6 | 8.8 | 8.7 | 8.8 | 10.4 |
| Cu-TD | 7.1 | 7.6 | 8.8 | 21 | 26 | 33 | 13 | 15 | 16 |
| Hg-WAE | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Hg-TD | 0.02 | 0.02 | 0.05 | 0.05 | 0.06 | 0.09 | 0.03 | 0.04 | 0.04 |
| Ni-WAE | 2.0 | 2.6 | 3.1 | 3.5 | 4.1 | 11 | 5.8 | 6.8 | 9.1 |
| Ni-TD | 9.8 | 10.9 | 15 | 22 | 29 | 34 | 19 | 23 | 24 |
| Pb-WAE | 3.2 | 4.3 | 5.2 | 8.3 | 9.5 | 13 | 4.4 | 5.1 | 5.3 |
| Pb-TD | 4.6 | 6.5 | 7.8 | 14 | 16 | 19 | 6.0 | 6.4 | 7.3 |
| Se-WAE | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Se-TD | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 | 0.5 | 0.5 | 0.5 |
| Zn-WAE | 13 | 16 | 19 | 18 | 22 | 48 | 26 | 29 | 39 |
| Zn-TD | 33 | 43 | 55 | 91 | 110 | 118 | 66 | 69 | 77 |

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 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 <63µm fraction typically exhibit higher concentrations of metals than the WAE metals in whole sediment fraction as the finer fraction <63µm 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 is higher than the reference TV for all metals within the upper and lower rivers. ANZECC/ARMCANZ (2000) does not provide a guideline value for selenium, so the reference TV for selenium has been adopted in the upper and lower rivers.

**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 UpRiv SED TV |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | 20%ile | Median | 80%ile | 20%ile | Median | 80%ile | | |
| Ag-WAE | 0.5 | 0.5 | 0.5 | ND | ND | ND | 1 | 1 |
| Ag-TD | 0.5 | 0.5 | 0.5 | ND | ND | ND | | |
| As-WAE | 1.4 | 1.8 | 2.2 | ND | ND | ND | 20 | 20 |
| As-TD | 8.9 | 11 | 13 | 6.5 | 10 | 14 | | |
| Cd-WAE | 0.5 | 0.5 | 0.5 | ND | ND | ND | 1.5 | 1.5 |
| Cd-TD | 0.5 | 0.5 | 0.5 | 0.06 | 0.08 | 0.10 | | |
| Cr-WAE | 1.5 | 2.8 | 6.0 | ND | ND | ND | 80 | 80 |
| Cr-TD | 21 | 35 | 130 | 28 | 31 | 33 | | |
| Cu-WAE | 3.6 | 7.1 | 11 | ND | ND | ND | 65 | 65 |
| Cu-TD | 15 | 27 | 46 | 133 | 175 | 217 | | |
| Hg-WAE | 0.01 | 0.01 | 0.01 | ND | ND | ND | 0.15 | 0.15 |
| Hg-TD | 0.03 | 0.04 | 0.07 | ND | ND | ND | | |
| Ni-WAE | 3.9 | 5.5 | 27 | ND | ND | ND | 21 | 27 |
| Ni-TD | 22 | 36 | 138 | 23 | 29 | 34 | | |
| Pb-WAE | 5.4 | 6.6 | 8.8 | ND | ND | ND | 50 | 50 |
| Pb-TD | 12 | 15 | 19 | 13 | 17 | 20 | | |
| Se-WAE | 0.50 | 0.50 | 0.50 | ND | ND | ND | NA | 0.50 |
| Se-TD | 0.50 | 0.50 | 0.53 | 0.46 | 0.50 | 0.54 | | |
| Zn-WAE | 10 | 14 | 29 | ND | ND | ND | 200 | 200 |
| Zn-TD | 67 | 90 | 100 | 92 | 113 | 133 | | |

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

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

**Table 5-14 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)**

| | LwRiv REF | | | LwRiv Baseline (<63µm) | | | ANZECC / ARMCANZ ISQG-Low | Porgera LwRiv Sed TV |
|---|---|---|---|---|---|---|---|---|
| Parameter | 20%ile | Median | 80%ile | 20%ile | Median | 80%ile | | |
| Ag-WAE | 0.5 | 0.5 | 0.5 | ND | ND | ND | 1.0 | 1.0 |
| Ag-TD | 0.5 | 0.5 | 0.5 | ND | ND | ND | | |
| As-WAE | 0.5 | 1.0 | 1.9 | ND | ND | ND | 20 | 20 |
| As-TD | 1.6 | 4.0 | 6.2 | 2.8 | 10 | 14 | | |
| Cd-WAE | 0.5 | 0.5 | 0.5 | ND | ND | ND | 1.5 | 1.5 |
| Cd-TD | 0.5 | 0.5 | 0.5 | 2.4 | 2.4 | 2.4 | | |
| Cr-WAE | 2.6 | 7.1 | 8.9 | ND | ND | ND | 80 | 80 |
| Cr-TD | 45 | 55 | 59 | 12 | 12 | 12 | | |
| Cu-WAE | 3.5 | 3.9 | 6.7 | ND | ND | ND | 65 | 65 |
| Cu-TD | 10 | 14 | 21 | 24 | 24 | 24 | | |
| Hg-WAE | 0.01 | 0.01 | 0.01 | ND | ND | ND | 0.15 | 0.15 |
| Hg-TD | 0.01 | 0.02 | 0.06 | 0.3 | 0.6 | 0.9 | | |
| Ni-WAE | 3.6 | 12 | 21 | ND | ND | ND | 21 | 21 |
| Ni-TD | 54 | 62 | 71 | 38 | 38 | 38 | | |
| Pb-WAE | 2.8 | 3.8 | 5.9 | ND | ND | ND | 50 | 50 |
| Pb-TD | 5.7 | 6.2 | 7.1 | 22 | 22 | 22 | | |
| Se-WAE | 0.5 | 0.5 | 0.5 | ND | ND | ND | NA | 0.5 |
| Se-TD | 0.5 | 0.5 | 0.5 | 0.2 | 0.2 | 0.2 | | |
| Zn-WAE | 15 | 20 | 41 | ND | ND | ND | 200 | 200 |
| Zn-TD | 78 | 100 | 136 | 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 median values for total and WAE metals at the upper river reference sites from 2013 to 2015 is presented in Table 5-15 and shows that the concentrations of WAE arsenic, WAE chromium, WAE copper 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 chromium 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 - 2015)**

| Sediment Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend (2013 – 2015) |
|---|---|---|---|---|
| Upper Riv Ref (Annual medians from 2013 – 2015) | Ag-WAE | ≤LOR | ≤LOR | No change over time |
| | Ag-TD | -0.085 | 0.240 | No change over time |
| | As-WAE | 0.328 | <0.001 | Increased over time |
| | As-TD | 0.031 | 0.665 | No change over time |
| | Cd-WAE | -0.008 | 0.929 | No change over time |
| | Cd-TD | -0.022 | 0.760 | No change over time |
| | Cr-WAE | 0.271 | 0.001 | Increased over time |
| | Cr-TD | -0.011 | 0.875 | No change over time |
| | Cu-WAE | 0.318 | <0.001 | Increased over time |
| | Cu-TD | 0.050 | 0.494 | No change over time |
| | Hg-WAE* | -0.306 | <0.001 | No change over time |
| | Hg-TD* | -0.703 | <0.001 | No change over time |
| | Ni-WAE | 0.303 | <0.001 | Increased over time |
| | Ni-TD | -0.045 | 0.536 | No change over time |
| | Pb-WAE | 0.397 | <0.001 | Increased over time |
| | Pb-TD | 0.001 | 0.994 | No change over time |
| | Se-WAE | ≤LOR | ≤LOR | No change over time |
| | Se-TD | 0.115 | 0.121 | No change over time |
| | Zn-WAE | 0.370 | <0.001 | Increased over time |
| | Zn-TD | -0.012 | 0.873 | 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 - 2015)**

| Sediment Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend (2013 – 2015) |
|---|---|---|---|---|
| Lower Riv Ref (Annual medians from 2013 – 2015) | Ag-WAE | ≤LOR | ≤LOR | No change over time |
| | Ag-TD | -0.025 | 0.844 | No change over time |
| | As-WAE | 0.252 | 0.215 | No change over time |
| | As-TD | 0.133 | 0.297 | No change over time |
| | Cd-WAE | 0.178 | 0.386 | No change over time |
| | Cd-TD | 0.211 | 0.096 | No change over time |
| | Cr-WAE | 0.223 | 0.274 | No change over time |
| | Cr-TD | 0.369 | 0.003 | Increased over time |
| | Cu-WAE | 0.258 | 0.204 | No change over time |
| | Cu-TD | 0.135 | 0.291 | No change over time |
| | Hg-WAE* | -0.308 | 0.126 | No change over time |
| | Hg-TD* | -0.779 | <0.001 | No change over time |
| | Ni-WAE | 0.212 | 0.297 | No change over time |
| | Ni-TD | 0.208 | 0.102 | No change over time |
| | Pb-WAE | 0.202 | 0.322 | No change over time |

| Sediment Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend (2013 – 2015) |
|---|---|---|---|---|
| | Pb-TD | -0.069 | 0.591 | No change over time |
| | Se-WAE | ≤LOR | ≤LOR | No change over time |
| | Se-TD | 0.106 | 0.414 | No change over time |
| | Zn-WAE | 0.469 | 0.016 | Increased over time |
| | Zn-TD | 0.098 | 0.445 | 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 <63µm fraction were measured in the baseline samples and are included for reference purposes. TVs are 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 value is higher than the reference TV. ANZECC/ARMCANZ (2000) does not provide a guideline value for selenium, so the reference TV for selenium has been adopted for the upper and lower rivers.

**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 | 0.5 | 0.5 | 0.5 | ND | ND | ND | 1.0 | 1.0 |
| Ag-TD | 0.5 | 0.5 | 0.5 | ND | ND | ND | | |
| As-WAE | 0.5 | 0.6 | 0.8 | ND | ND | ND | 20 | 20 |
| As-TD | 2.5 | 4.4 | 5.5 | 1.4 | 2.7 | 4.6 | | |
| Cd-WAE | 0.5 | 0.5 | 0.5 | ND | ND | ND | 1.5 | 1.5 |
| Cd-TD | 0.5 | 0.5 | 0.5 | 1.9 | 3.2 | 4.6 | | |
| Cr-WAE | 5.8 | 11 | 16 | ND | ND | ND | 80 | 80 |
| Cr-TD | 45 | 50 | 53 | 17 | 19 | 23 | | |
| Cu-WAE | 11 | 13 | 14 | ND | ND | ND | 65 | 65 |
| Cu-TD | 20 | 24 | 28 | 27 | 29 | 43 | | |
| Hg-WAE | 0.02 | 0.05 | 0.10 | ND | ND | ND | 0.15 | 0.15 |
| Hg-TD | 0.11 | 0.12 | 0.14 | 0.07 | 0.10 | 0.21 | | |
| Ni-WAE | 7.1 | 12 | 18 | ND | ND | ND | 21 | 21 |
| Ni-TD | 32 | 37 | 44 | 45 | 49 | 51 | | |
| Pb-WAE | 6.8 | 8.3 | 9.4 | ND | ND | ND | 50 | 50 |
| Pb-TD | 12 | 15 | 16 | 23 | 30 | 35 | | |
| Se-WAE | 0.5 | 0.5 | 0.5 | ND | ND | ND | NA | 0.5 |
| Se-TD | 0.5 | 0.5 | 1.0 | 0.1 | 0.1 | 0.2 | | |
| Zn-WAE | 29 | 51 | 66 | ND | ND | ND | 200 | 200 |
| Zn-TD | 79 | 105 | 120 | 63 | 86 | 116 | | |

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 median values for total and WAE metals at the Lake Murray and ORWB reference sites from 2013 to 2015 is presented in Table 5-18 and shows that the concentrations of TD arsenic, WAE chromium, WAE copper, TD copper, WAE nickel, WAE lead, TD lead, TD selenium, WAE zinc and TD 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 - 2015)**

| Sediment Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend (2013 – 2015) |
|---|---|---|---|---|
| Lake Murray and ORWB Ref (Annual medians from 2013 – 2015) | Ag-WAE | ≤LOR | ≤LOR | No change over time |
| | Ag-TD | ≤LOR | ≤LOR | No change over time |
| | As-WAE | 0.009 | 0.975 | No change over time |
| | As-TD | 0.720 | 0.002 | Increased over time |
| | Cd-WAE | ≤LOR | ≤LOR | No change over time |
| | Cd-TD | ≤LOR | ≤LOR | No change over time |
| | Cr-WAE | 0.835 | <0.001 | Increased over time |
| | Cr-TD | 0.461 | 0.083 | No change over time |
| | Cu-WAE | 0.720 | 0.002 | Increased over time |
| | Cu-TD | 0.813 | <0.001 | Increased over time |
| | Hg-WAE | 0.000 | 1.000 | No change over time |
| | Hg-TD | -0.335 | 0.222 | No change over time |
| | Ni-WAE | 0.752 | 0.001 | Increased over time |
| | Ni-TD | 0.406 | 0.134 | No change over time |
| | Pb-WAE | 0.807 | <0.001 | Increased over time |
| | Pb-TD | 0.682 | 0.005 | Increased over time |
| | Se-WAE | 0.445 | 0.097 | No change over time |
| | Se-TD | 0.774 | 0.001 | Increased over time |
| | Zn-WAE | 0.578 | 0.024 | Increased over time |
| | Zn-TD | 0.552 | 0.033 | Increased over time |

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

## 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 24months. 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 were all higher than the reference TVs. The USEPA guideline for selenium in fish flesh is higher than the reference or baseline TVs. As no baseline or guideline values exist for chromium in fish flesh or for all metals in prawn abdomen, the reference value in these cases has 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, copper, nickel, lead and zinc in fish flesh were all higher than the reference TVs. The USEPA guideline for selenium in fish flesh is higher than the reference or baseline TVs. As no baseline or guideline values exist for cadmium in fish flesh or for any metals in prawn abdomen, the reference value in these cases has 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 | 51 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.15 | 0.20 |
| | Prawn Ab | 61 | 0.05 | 0.07 | 0.01 | 0.01 | 0.06 | 0.09 | 7.1 | 9.3 |
| Ok Om | Fish Flesh | 55 | 0.01 | 0.02 | 0.007 | 0.01 | 0.01 | 0.02 | 0.16 | 0.23 |
| | Prawn Ab | 58 | 0.04 | 0.05 | 0.003 | 0.01 | 0.02 | 0.03 | 6.6 | 8.5 |
| Kuru | Fish Flesh | 55 | 0.01 | 0.02 | 0.004 | 0.01 | 0.01 | 0.02 | 0.15 | 0.21 |
| | Prawn Ab | 56 | 0.05 | 0.07 | 0.003 | 0.01 | 0.11 | 0.17 | 8.5 | 11 |
| Upper River Ref | Fish Flesh | 161 | 0.01 | 0.02 | 0.005 | 0.01 | 0.01 | 0.02 | 0.15 | 0.22 |
| | Prawn Ab | 175 | 0.05 | 0.06 | 0.003 | 0.01 | 0.06 | 0.11 | 7.1 | 9.8 |
| 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 | 51 | 0.07 | 0.09 | 0.01 | 0.01 | 0.01 | 0.01 | 0.26 | 0.34 | 5.2 | 6.1 |
| | Prawn Ab | 61 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.27 | 0.3 | 13 | 15 |
| Ok Om | Fish Flesh | 55 | 0.05 | 0.07 | 0.01 | 0.01 | 0.01 | 0.01 | 0.23 | 0.28 | 5.0 | 6.8 |
| | Prawn Ab | 58 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.43 | 0.51 | 14 | 15.6 |
| Kuru | Fish Flesh | 55 | 0.06 | 0.09 | 0.01 | 0.01 | 0.01 | 0.01 | 0.25 | 0.31 | 5.9 | 8.0 |
| | Prawn Ab | 56 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.36 | 0.41 | 14 | 16 |
| Upper River Ref | Fish Flesh | 161 | 0.06 | 0.09 | 0.01 | 0.01 | 0.01 | 0.01 | 0.24 | 0.31 | 5.3 | 6.9 |
| | Prawn Ab | 175 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.34 | 0.43 | 13 | 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 dw) | | 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, dw - 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 | 0.09 | 0.09 |
| | Prawn Ab | 54 | 0.06 | 0.1 | 0.01 | 0.01 | 0.04 | 0.06 | 6.6 | 11.4 |
| Tomu | Fish Flesh | 31 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.09 | 0.17 |
| | Prawn Ab | 44 | 0.06 | 0.1 | 0.01 | 0.01 | 0.03 | 0.05 | 9.7 | 11.4 |
| Lower River Ref | Fish Flesh | 32 | 0.01 | 0.01 | 0.008 | 0.01 | 0.01 | 0.01 | 0.09 | 0.17 |
| | Prawn Ab | 98 | 0.06 | 0.01 | 0.01 | 0.01 | 0.04 | 0.06 | 8.8 | 11.6 |
| Tiumsinawam 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 | - | 0.01 | - | 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 |
| Tiumsinawam 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 dw) | | 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, dw - dry weight

An analysis of the trends of median values for metals in fish flesh and prawn abdomen between 2011 and 2015 are shown in Table 5-23 to Table 5-26 and shows that the concentrations of all 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 2011 - 2015 determined by Spearman Rank correlation against time**

| Fish flesh<br>Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend (2011 – 2015) |
|---|---|---|---|---|
| Upper Riv Ref<br>(Trend of Annual Median) | As | -0.975 | 0.005 | Decreased over time |
| | Cd | -0.707 | 0.182 | No change over time |
| | Cr | <LOR | <LOR | No change over time |
| | Cu | -0.894 | 0.041 | Decreased over time |
| | Hg | <LOR | <LOR | No change over time |
| | Ni | <LOR | <LOR | No change over time |
| | Pb | <LOR | <LOR | No change over time |
| | Se | -0.894 | 0.041 | Decreased over time |
| | Zn | -0.872 | 0.054 | No change over time |

LOR - Limit of Reporting

**Table 5-24 Trends of metals in prawn abdomen for upper river reference site 2011 - 2015 determined by Spearman Rank correlation against time**

| Prawn Abdomen<br>Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend (2011 – 2015) |
|---|---|---|---|---|
| Upper Riv Ref<br>(Trend of Annual Median) | As | -0.289 | 0.638 | No change over time |
| | Cd | -0.707 | 0.182 | No change over time |
| | Cr | 0.224 | 0.718 | No change over time |
| | Cu | 0.000 | 1.000 | No change over time |
| | Hg | <LOR | <LOR | No change over time |
| | Ni | <LOR | <LOR | No change over time |
| | Pb | <LOR | <LOR | No change over time |
| | Se | -0.600 | 0.285 | No change over time |
| | Zn | <LOR | <LOR | No change over time |

LOR - Limit of Reporting

**Table 5-25 Trends of metals in fish flesh at lower river reference site 2011 - 2015 determined by Spearman Rank correlation against time**

| Fish flesh<br>Site | Element | Spearman's rho | P-Value (P=0.05) | Trend (2011 – 2015) |
|---|---|---|---|---|
| Lower Riv Ref<br>(Trend of Annual Median) | As | <LOR | <LOR | No change over time |
| | Cd | -0.707 | 0.182 | No change over time |
| | Cr | <LOR | <LOR | No change over time |
| | Cu | -0.718 | 0.172 | No change over time |
| | Hg | -0.264 | 0.668 | No change over time |
| | Ni | <LOR | <LOR | No change over time |
| | Pb | <LOR | <LOR | No change over time |
| | Se | -0.154 | 0.805 | No change over time |
| | Zn | 0.200 | 0.747 | No change over time |

LOR - Limit of Reporting

**Table 5-26 Trends of metals in prawn abdomen at lower river reference sites 2011 - 2015 determined by Spearman Rank correlation against time**

| Prawn Abdomen<br>Site | Element | Spearman's rho | P-Value (P=0.05) | Trend (2011 – 2015) |
|---|---|---|---|---|
| Lower Riv Ref<br><br>(Trend of Annual Median) | As | 0.447 | 0.450 | No change over time |
| | Cd | -0.707 | 0.182 | No change over time |
| | Cr | 0.671 | 0.215 | No change over time |
| | Cu | 0.400 | 0.505 | No change over time |
| | Hg | <LOR | <LOR | No change over time |
| | Ni | <LOR | <LOR | No change over time |
| | Pb | <LOR | <LOR | No change over time |
| | Se | -0.316 | 0.604 | No change over time |
| | Zn | 0.410 | 0.493 | No change over time |

LOR - Limit of Reporting

### 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 and prawn 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 prawn abdomen 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 prawn abdomen increased over that 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 5-27 Trends of metals in fish flesh at Lake Murray and ORWB reference sites 1999 - 2009 determined by Spearman Rank correlation against time**

| Fish Flesh<br>Site | Element | Spearman's rho | P-Value (P=0.05) | Trend (1999 – 2009) |
|---|---|---|---|---|
| LMY Ref Site (Maka)<br><br>(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

**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<br>Site | Element | Spearman's rho | P-Value (P=0.05) | Trend (1999 – 2009) |
|---|---|---|---|---|
| LMY Ref Site (Maka)<br><br>(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 Fish and Prawns

Throughout the development of the revised AER methodology for the 2013 AER, it became apparent that the dataset for biological indicators was not capable of supporting the development of impact assessment criteria in accordance with the method being applied to water, sediment and tissue metals data. The following issues have contributed to this situation:

- Inconsistent sampling methodology has been applied between sampling events and between sites over the history of the program making it difficult to compare data spatially and temporally. The assumption that equal sampling effort was being applied within and between sites could not be substantiated. Therefore the results could not continue to be assessed accurately on a catch per unit of effort bases.
- Some of the sampling methods have resulted in fatality of animals which may have been adversely affecting remaining population sizes.
- Low numbers of the target species exist at both the reference and test sites, particularly within the upper catchment. The ineffectiveness of the sampling methods, combined with the small spatial scale of sampling relative to the low density/high dispersion of the target animals results in a highly variable data set that is dominated by low or zero value results, which in turn reduces the statistical power of the data set and ultimately limits the ability of the monitoring program to statistically detect change within the ecosystem.

Application of the proposed methodology to these data would result in very low or zero values for impact criteria TVs at reference sites, which are not an appropriate benchmark for comparison with test site data as it does not provide a basis upon which to assess change at the test site.

To address this issue, Porgera began a revision of the biological monitoring program in 2014. The process included a review of current fish and prawn sampling methods with a view to achieving better standardisation between sampling events and between sites. At the time of writing the department was in the process of finalizing updated standard operating procedures for sampling, data management and reporting. It is expected to take two to three years of sampling to determine whether the revised methods for assessing fish and prawn communities has been effective in improving the dataset for fish and prawn biology.

The 2015 data were added to the historical record which includes baseline data. The data were then grouped by combining the results from all sampling methods and all indicator sub-species of fish and prawns throughout the historical data set to establish an annual median with which an historical trend could be established.

It should be noted that the grouping process is by no means ideal and carries over a high level of inherent uncertainty to the results. Therefore where possible, the presence or absence of potential impact is inferred, rather than the preferred and more robust, statistically-based conclusion of the presence or absence of actual impact.

The results presented in this section provide an indication of the trend of the biological indicators at the reference sites, which then act as a basis for inferring whether potential impact is occurring at test sites in Section 8.1.

#### *5.6.1.1 Upper and Lower River*

Trends for biological indicators of impact for the upper and lower river reference sites are presented in Table 5-29 to Table 5-32. The results show that fish richness decreased over time at the lower river reference sites, all other indicators have not changed over the time period.

**Table 5-29 Trends for fish at upper river reference sites 2011 - 2015 determined by Spearman Rank correlation against time**

| Indicator | Spearman's rho | P-Value | Trend (2011 – 2015) |
|---|---|---|---|
| Fish Abundance | 0.300 | 0.624 | No change over time |
| Fish Richness | 0.577 | 0.308 | No change over time |
| Fish Biomass | 0.100 | 0.624 | No change over time |
| Fish Condition | 0.300 | 0.624 | No change over time |

**Table 5-30 Trends for prawns at upper river reference sites 2011 - 2015 determined by Spearman Rank correlation against time**

| Indicator | Spearman's rho | P-Value | Trend (2011 – 2015) |
|---|---|---|---|
| Prawn Abundance | 0.700 | 0.188 | No change over time |
| Prawn Richness | * | * | No change over time |
| Prawn Biomass | 0.400 | 0.505 | No change over time |
| Prawn Condition | 0.900 | 0.037 | No change over time |

* Indicates all values within the data set are equal, therefore cannot support the Spearman Rank test but does indicate no significant change over time.

**Table 5-31 Trends for fish at lower river reference sites 2011 - 2015 determined by Spearman Rank correlation against time**

| Indicator | Spearman's rho | P-Value | Trend (2011 – 2015) |
|---|---|---|---|
| Fish Abundance | 0.667 | 0.219 | No change over time |
| Fish Richness | -0.894 | 0.041 | Decreased over time |
| Fish Biomass | 0.300 | 0.624 | No change over time |
| Fish Condition | 0.700 | 0.188 | No change over time |

**Table 5-32 Trends for prawns at lower river reference sites 2011 - 2015 determined by Spearman Rank correlation against time**

| Indicator | Spearman's rho | P-Value | Trend (2011 – 2015) |
|---|---|---|---|
| Prawn Abundance | -0.400 | 0.505 | No change over time |
| Prawn Richness | * | * | No change over time |
| Prawn Biomass | -0.400 | 0.505 | No change over time |
| Prawn Condition | -0.400 | 0.505 | No change over time |

* Indicates all values within the data set are equal, therefore cannot support the Spearman Rank test but does indicate no significant change over time.

#### *5.6.1.2 Lake Murray*

Biological performance assessment criteria for Lake Murray are presented in Table 5-33.

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

**Table 5-33 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 Macroinvertebrates

In 2014, PJV engaged Wetland Research and Management (WRM) to undertake a scoping study to investigate whether monitoring benthic macroinvertebrate populations within the receiving environment upstream of SG3 could provide a robust basis for impact assessment. 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. 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 2015). Macroinvertebrates are more easily sampled, function at a lower spatial scale than prawns and fish, are less mobile, 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 2015).

The initial sampling program for the study was carried out in August and September 2014, the program was repeated in August 2015. The results showed that there are rich macroinvertebrate fauna populations within the local and receiving waterways making them suitable as the basis of a sensitive ecological health monitoring program. However, given that the sampling has been conducted over only two years, the data are temporally limited and it is recommended that at least three years of data from reference sites are required to characterise temporal variability, confirm consistency in responses observed, and form an adequate baseline for developing robust SSTVs (WRM 2015). The program will be repeated in 2016 to complete the three year requirement.

# 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 and the results from other monitoring stations within the mixing zone are reported for information purposes only.

**Table 6-1 Compliance Summary 2015**

| Permit | % Compliance | Comments |
|---|---|---|
| Waste Discharge Permit<br><br>WD – L3 (121) | 97% | Averaged 97% compliance throughout 2015.<br><br>Non-compliance related to short duration exceedance of TSS concentrations in discharge from 3 of the 5 sewage treatment plants.<br><br>Note that 100% compliance was achieved throughout November and December. |
| Water Extraction Permit<br><br>WE – L3 (91) | 100% | Compliant with all eight (8) conditions. |
| **TOTAL** | **98%** | Target is 100% compliance. |

**Table 6-2 Median water quality at Upper River Test Sites against SG3 permit criteria 2015 (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** | 6 | 7.4 | 0.05 | 1.5 | 1.4 | 0.14 | 1.8 | 3.5 | 0.18 | 31 |
| **SG2** | 14 | 7.5 | 0.05 | 1.3 | 0.22 | 0.14 | 1.6 | 1.5 | 0.10 | 7.7 |
| **Wasiba** | 15 | 7.4 | 0.05 | 1.8 | 0.15 | 0.20 | 1.6 | 1.1 | 0.10 | 5.4 |
| **Wankipe** | 15 | 7.5 | 0.05 | 1.7 | 0.13 | 0.20 | 1.4 | 0.98 | 0.10 | 5.0 |
| **SG3** | 192 | 7.6 | 0.05 | 1.7 | 0.07 | 0.17 | 1.6 | 0.67 | 0.10 | 4.3 |
| **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)

# 7 RISK ASSESSMENT

## 7.1 Hydrology and Environmental Flows

### 7.1.1 Waile Creek

Figure 7-1 shows a flow duration curve for Waile Creek Dam in 2015, 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 environmental flow is maintained downstream of the dam wall when the dam is not overflowing due to leakage from the dam. During 2015, there were 27 occurrences where the dam did not overflow (of one or more days) with the longest period being 12 days.

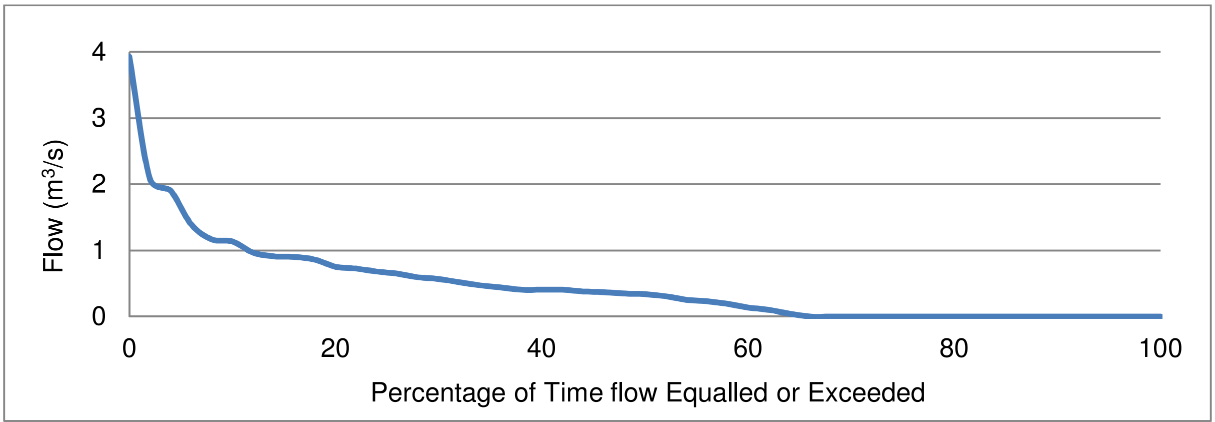



**Figure 7-1 Daily flow duration curve (estimated) for Waile Creek Dam overtopping**

### 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 50m upstream of Kogai Culvert, Kulapi Creek joins with Kogai Creek. The water extraction results in a reduction of the Kogai flow but did not result in any zero flow events within Kogai Creek.

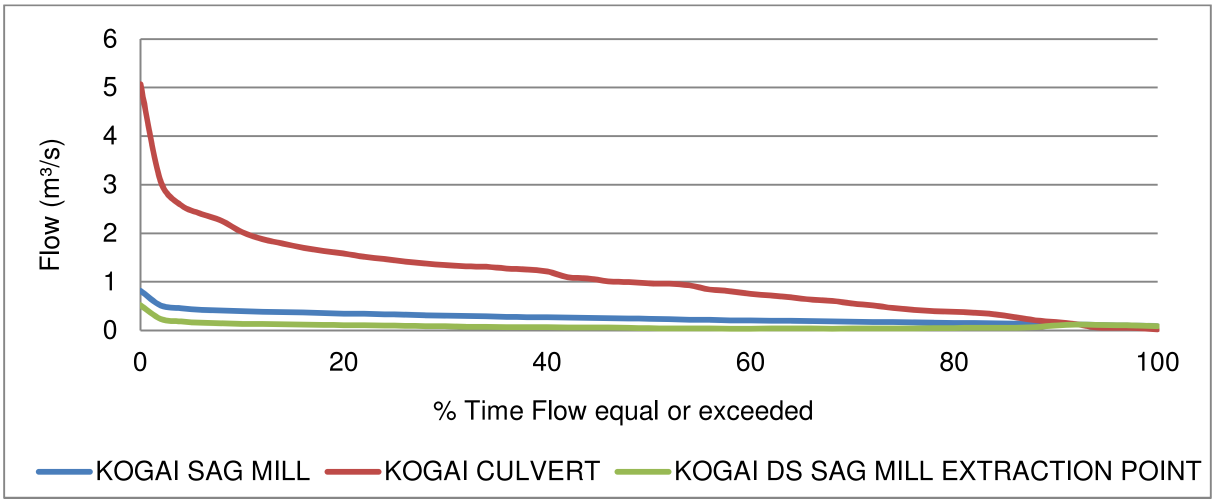



**Figure 7-2 Daily flow duration curves for Kogai Creek**

## 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 approx 5% of the tailings is retained along the Anawe erodible dump.

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 discharge; 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 2015 are shown in Figure 7-3, 2015 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 2015 was estimated by *Gumleaf* to be 20 Mt, this compares to the long term median since 1990 of approximately 43 Mt/a, and an annual load in 2014 of 31 Mt.

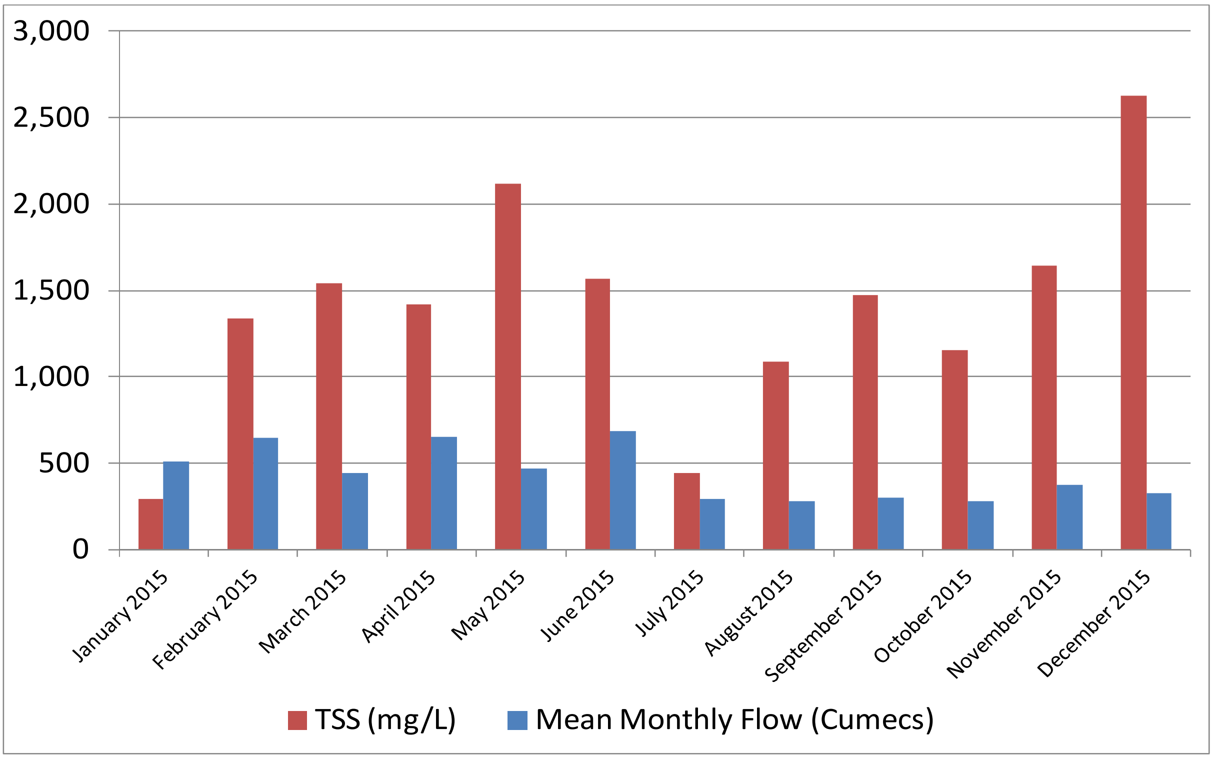



**Figure 7-3 Mean monthly TSS and flow at SG3 for 2015**

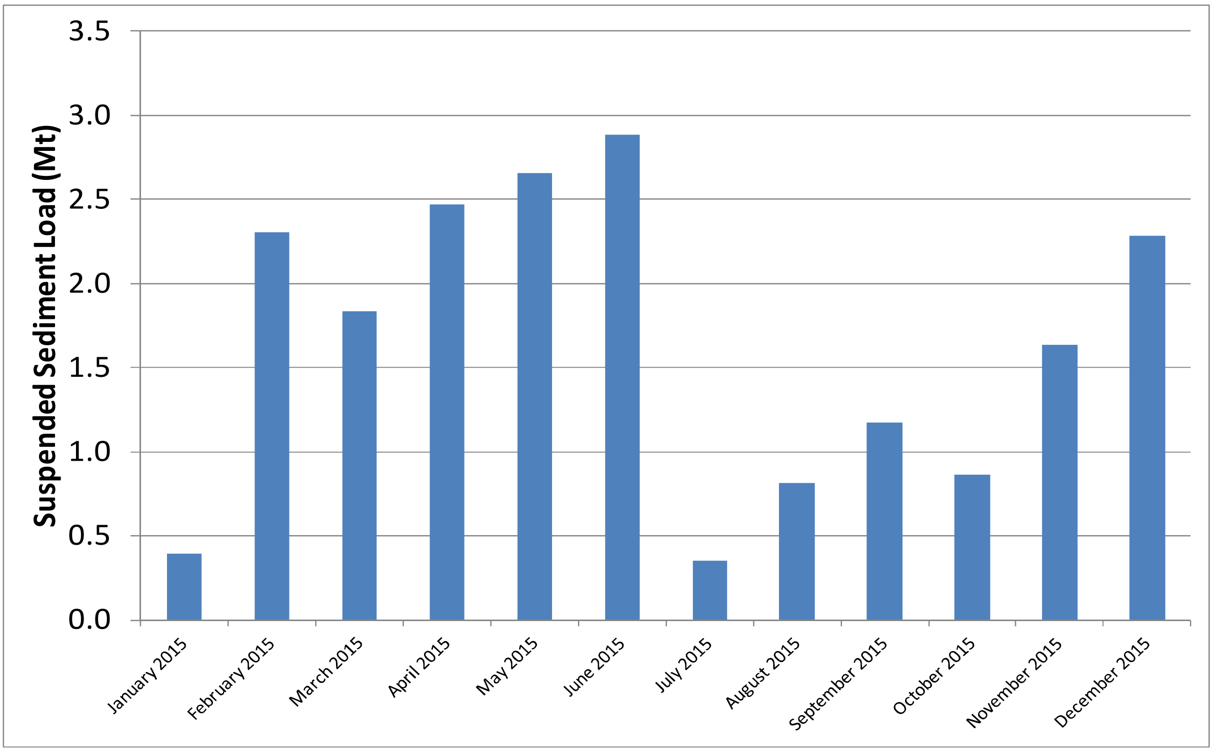



**Figure 7-4 Estimated mean monthly suspended sediment loads for SG3 (Mt)**

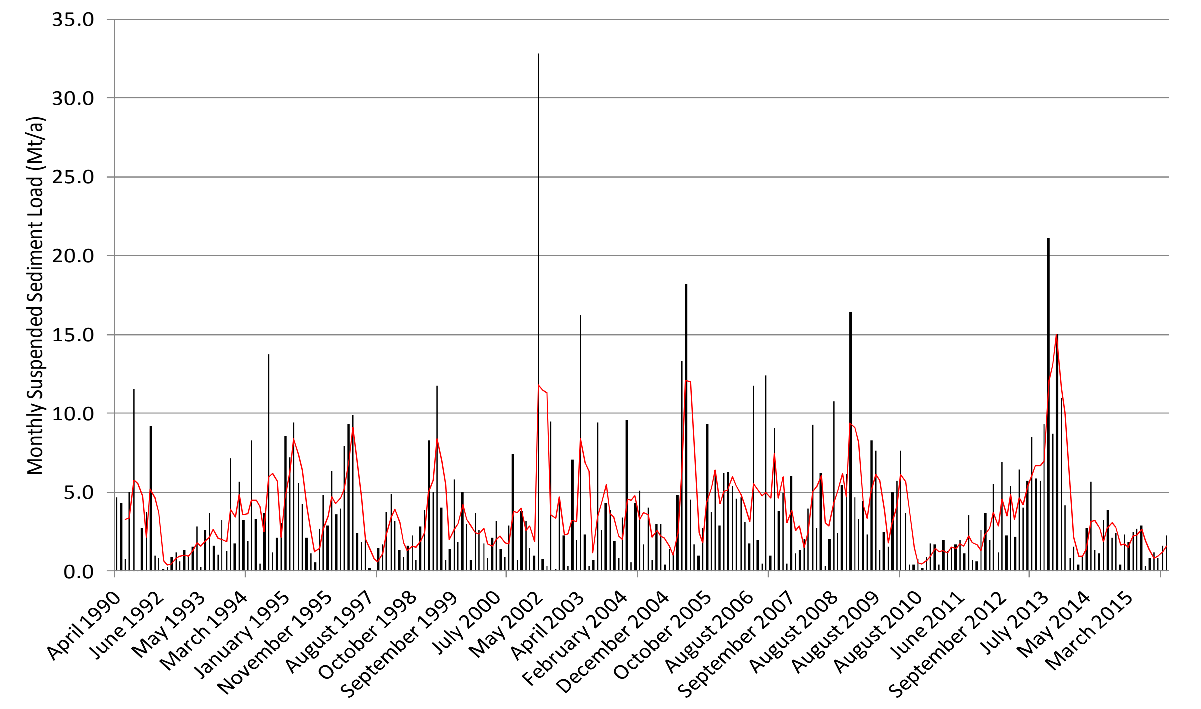
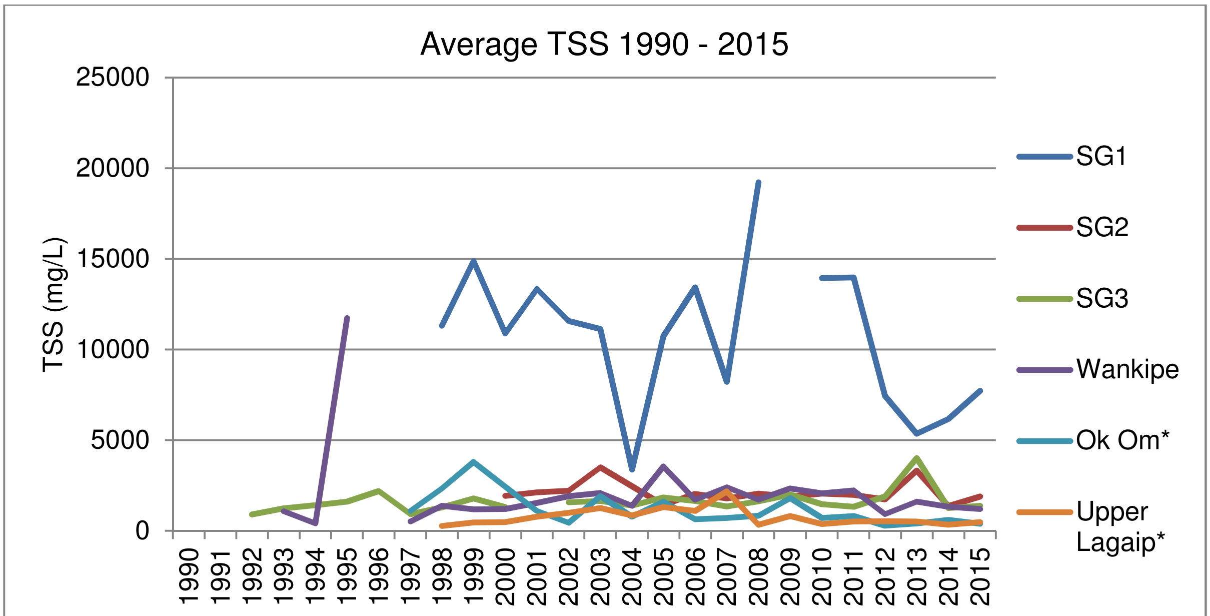



**Figure 7-5 Estimated monthly suspended sediment load (black bars) with 3-month moving average at SG3 for full record (red solid line)**

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 values at river monitoring stations upstream of SG3. All sites, reference and test, showed a reduction in TSS values compared with 2014 values, with a minor increase in TSS values for SG1 being the exception, however this is not considered significant in the context of historical variability, meaning that there was a lower contribution of natural TSS to the system compared to 2014.




* Reference site

**Figure 7-6 Historical average TSS 1990 - 2015**

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 2015 were consistent with historical volumes, and also that the natural sediment load was significantly less than 2014 and historical volumes.

As a result of consistent mine-derived load and a reduction in natural load, the proportion of total suspended sediment load that was mine-derived during 2015 at SG3 was estimated to be approximately 49% which compares to 34% in 2014 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).

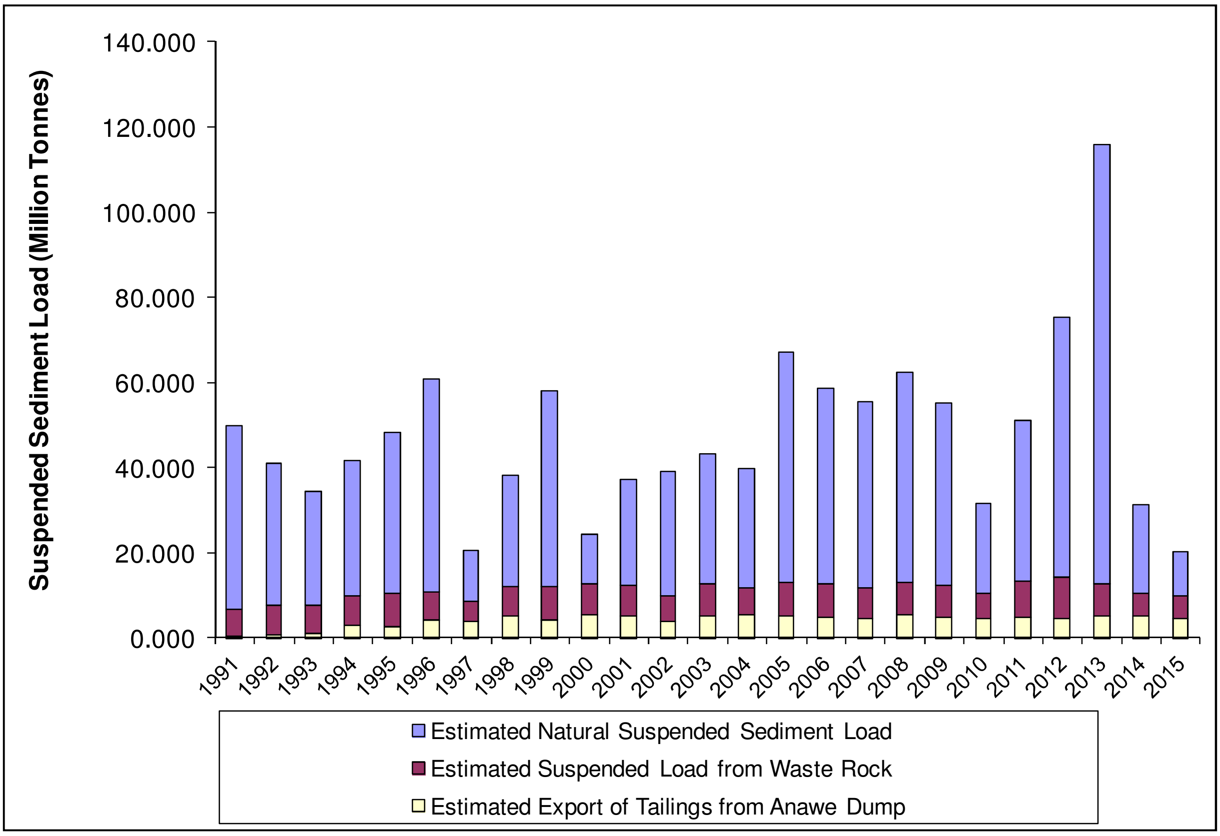



**Figure 7-7 Suspended sediment budget at SG3 since 1991**

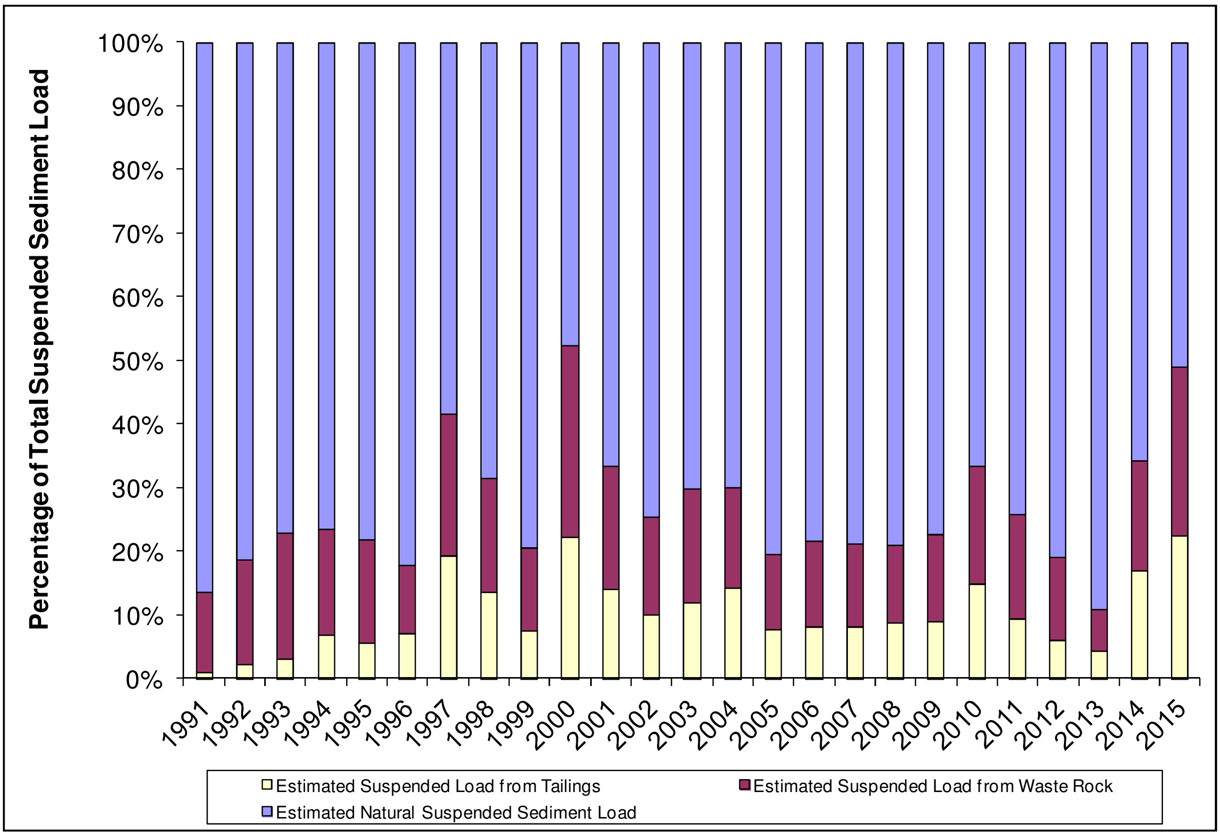



**Figure 7-8 Relative contribution of natural and mine-derived suspended sediment at SG3 (%)**

### 7.2.1 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 (8km downstream of the mine) due to a lack of community support for the monitoring program. 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 – 2015 |
| | Kaiya River upstream Yuyan Bridge | 2009 – 2015 |
| | Kaiya River downstream of Yuyan Bridge | 2009 – 2015 |
| Upper Rivers | Lagaip River at SG2 | 1990 – 2015 |
| Lower Rivers | Strickland River at PF10 | 2000 – 2015 |

Observations from previous years indicate 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 0.5m to 2m. These phases of cut-and-fill are caused by the interplay of a number of factors including sediment supply from the dump and river flow rates, which are driven by rainfall patterns. Figure 7-9, Figure 7-10 and Figure 7-11 illustrate the current situation within the Kaiya Valley, compared with past surveys. The profiles show that the 2015 bed levels are relatively low compared to levels recorded since 2010.

Figure 7-12 presents a time series of the minimum surveyed point at each cross section within the Kaiya River and is a useful metric of aggradation or degradation trends. Data for 2015 suggest that the Kaiya River between toe of the Anjolek erodible dump and the Porgera River is steady or generally in a phase of erosion, 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.

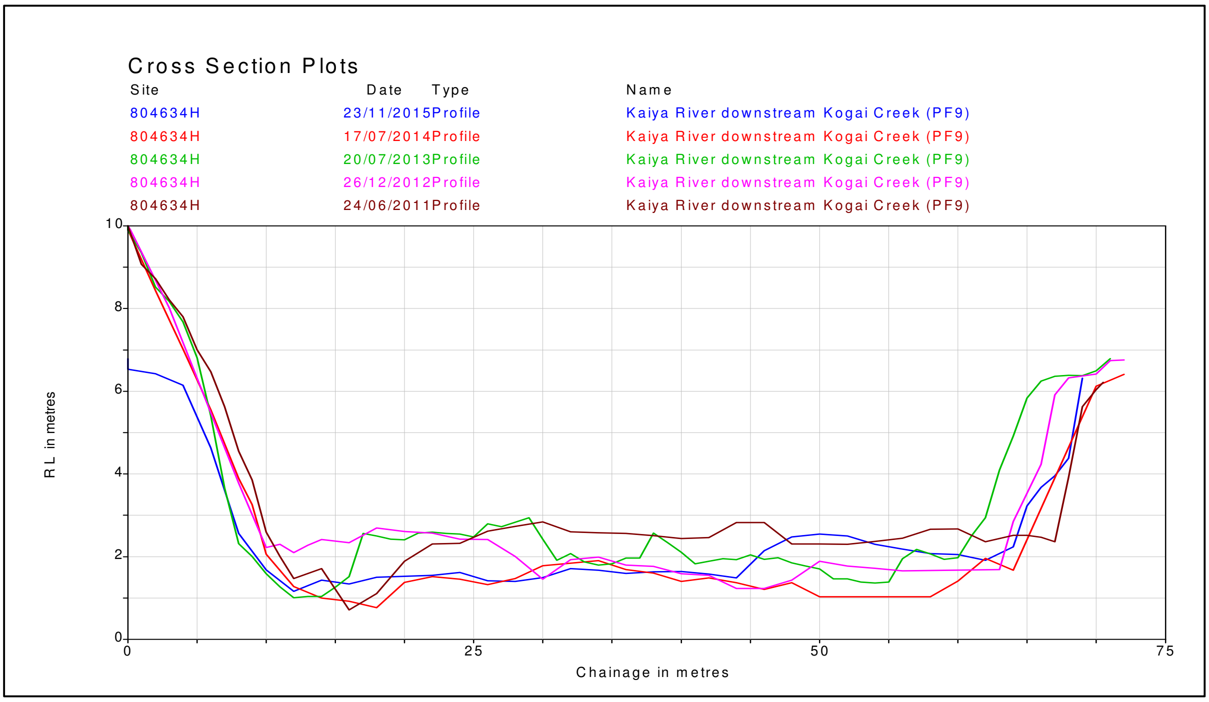



**Figure 7-9 Profile comparison (2011 - 2015) at Kaiya River downstream of Kogai Creek Confluence**

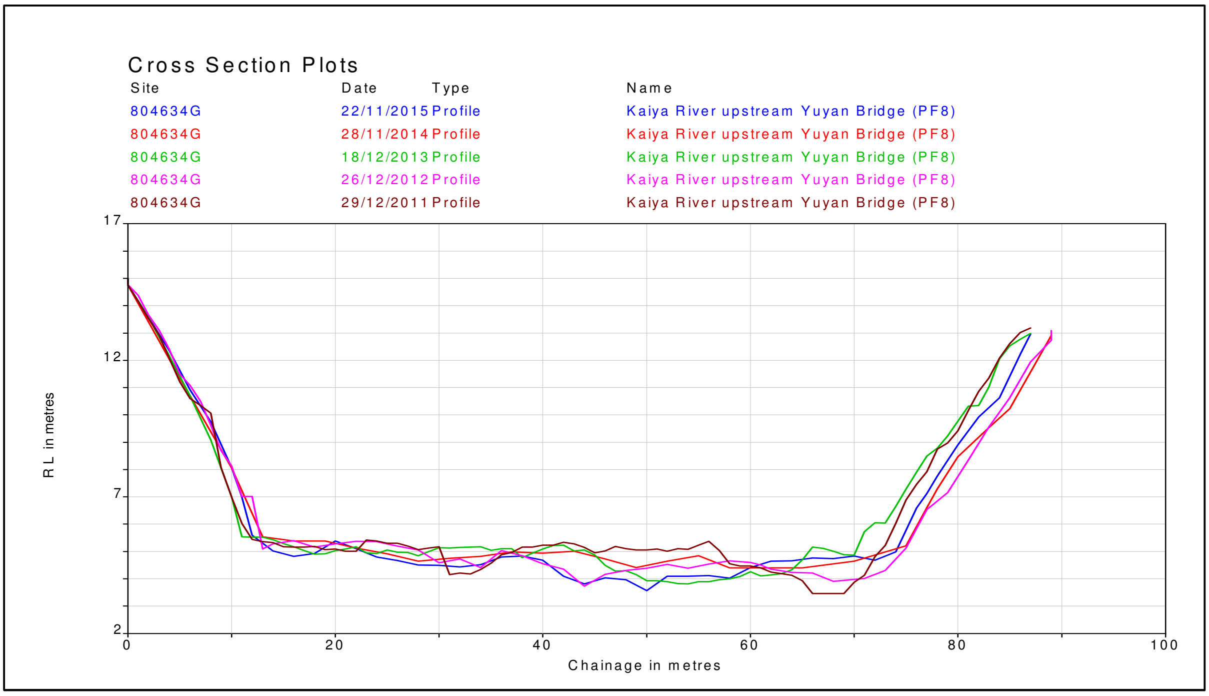



**Figure 7-10 Profile comparison (2011 - 2015) for Kaiya River upstream of Yuyan Bridge**

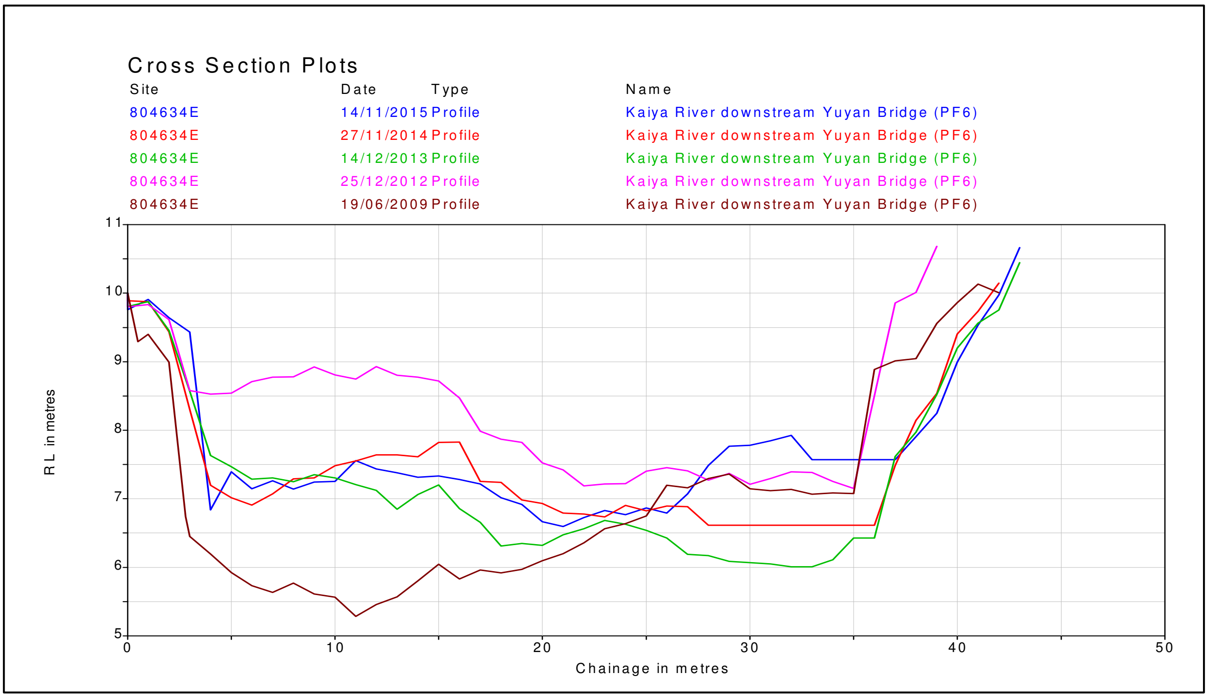



**Figure 7-11 Profile comparison (2009 - 2015) for Kaiya River downstream of Yuyan Bridge**

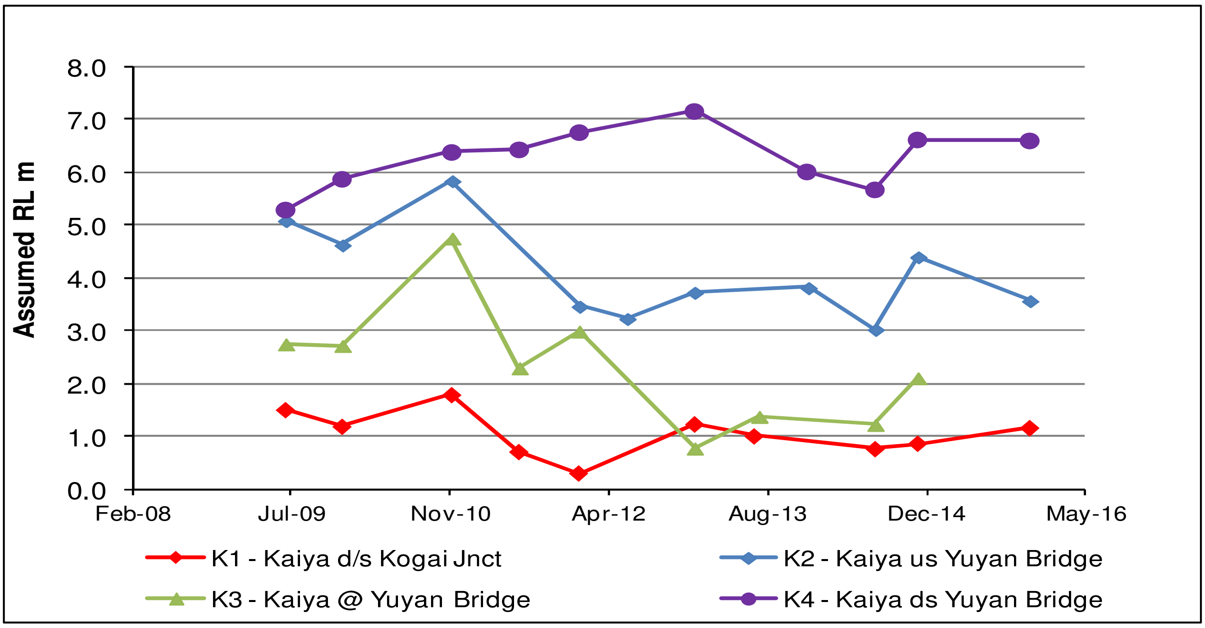



**Figure 7-12 Time series of minimum bed elevations along the Kaiya River**

As discussed in previous Annual Reports, the bed of the Porgera River at SG1 aggraded during mine construction due to initial disposal of erodible waste rock at Anawe erodible dump between about 1988 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 Figure 7-13 and indicate alternate periods of sediment aggradation and degradation over the years. Although aggradation appears to have occurred in 2015, however, in the longer term there appears to be no long term aggradation or degradation.

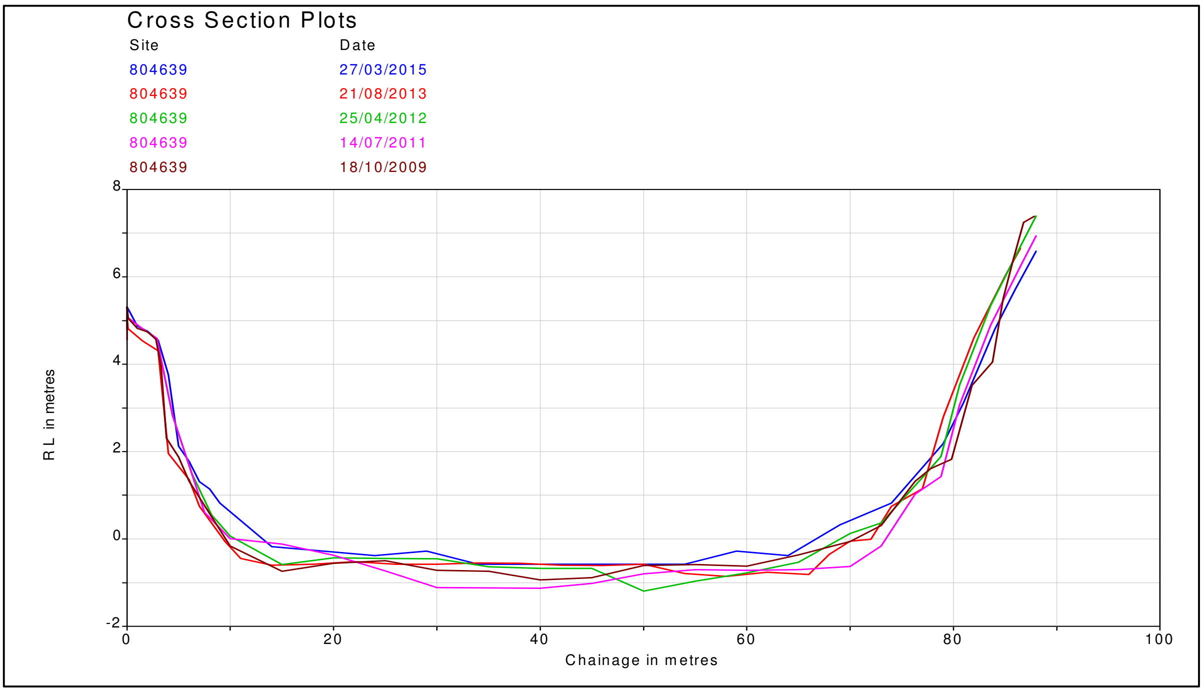



**Figure 7-13 Profile comparison (2001 - 2015) at Lagaip River at SG2**

As the river descends to the lowlands (the Fly Platform) from the upland areas, 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, 400km downstream from the mine. 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 15 years, resulting in widening of the channel by approximately 30 m, which is attributed to natural meandering processes. The 2015 survey shows that some degradation has occurred since the last survey.

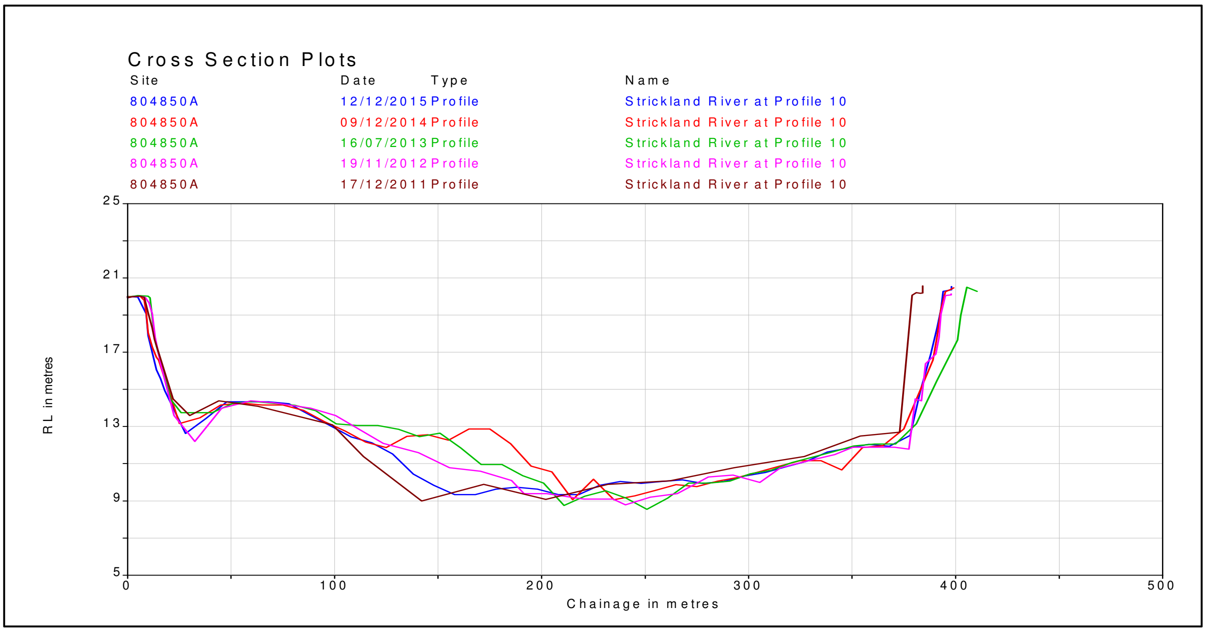



**Figure 7-14 Profile comparison (2000 - 2015) at Profile 10**

## 7.3 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 in accordance with the methodology outlined in Section 2.1. Each 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 7.3.4.

### 7.3.1 Water Quality

#### *7.3.1.1 Upper and Lower River*

The risk assessment for water quality at the upper river test sites involves comparing the 2015 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.

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 Figure 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 that the constant nature of the mine contribution causes average TSS concentrations to be elevated when compared to reference conditions, which prevents or reduces episodes of low TSS from occurring as they would in a natural system.

The assessment shows that TSS concentrations at SG1 in the upper river pose a risk to aquatic ecosystem health. SG1 is located 8 km downstream from the mine, elevated TSS at this location is due to the mine inputs of tailings and sediment from the erodible dumps and contact runoff. TSS concentrations at all other upper river and lower river test sites are significantly less than the respective TSS TVs and therefore do not pose a risk to aquatic ecosystem health.

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 risk to aquatic ecosystems is posed by concentrations of dissolved cadmium and dissolved zinc at SG1. In the lower river, risk to aquatic ecosystems is posed by dissolved copper at Bebelubi and Tiumsinawam. All other parameters at all other sites within the upper and lower rivers pose a low risk to aquatic ecosystems.

**Table 7-2 Risk assessment – median water quality results at upper river test sites in 2015 compared against UpRiv 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 | 6 | 7.4 | 6,498 | 0.05 | 1.5 | 1.4 | 0.10 | 1.8 | 14 | 0.05 | 3.5 | 0.18 | 0.25 | 31 |
| SG2 | 14 | 7.5 | 1,831 | 0.05 | 1.3 | 0.22 | 0.14 | 1.6 | 6.3 | 0.05 | 1.5 | 0.10 | 0.20 | 7.7 |
| Wasiba | 16 | 7.4 | 1,413 | 0.05 | 1.8 | 0.15 | 0.20 | 1.6 | 3.3 | 0.05 | 1.1 | 0.10 | 0.20 | 5.4 |
| Wankipe | 16 | 7.5 | 820 | 0.05 | 1.7 | 0.13 | 0.20 | 1.4 | 3.3 | 0.05 | 0.98 | 0.10 | 0.20 | 5.0 |
| SG3 | 193 | 7.6 | 1,133 | 0.05 | 1.7 | 0.07 | 0.17 | 1.6 | 4.8 | 0.05 | 0.67 | 0.10 | 0.20 | 4.3 |
| **UpRiv WQ TV** | | **6.0-8.1** | **2837** | **0.20** | **24** | **0.40** | **1.0** | **4.1** | **75** | **0.60** | **21** | **8.3** | **11** | **20** |

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

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

Note – TSM derived from 12 months data throughout 2015

**Table 7-3 Risk assessment – Median water quality results at lower river test sites in 2015 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 | 8 | 7.3 | 353 | 0.05 | 1.6 | 0.08 | 0.20 | 1.5 | 5.6 | 0.05 | 0.51 | 0.10 | 0.20 | 5.6 |
| Tiumsinawam | 8 | 7.4 | 516 | 0.05 | 1.3 | 0.07 | 0.17 | 1.4 | 13.5 | 0.05 | 0.50 | 0.11 | 0.20 | 4.9 |
| SG5 | 9 | 7.3 | 336 | 0.05 | 1.0 | 0.05 | 0.13 | 1.1 | 10 | 0.05 | 0.50 | 0.10 | 0.20 | 1.5 |
| **LwRiv WQ TV** | | **6.0-8.2** | **983** | **0.20** | **24** | **0.20** | **1.0** | **1.4** | **75** | **0.6** | **15** | **2.8** | **11** | **7.0** |

| | |
|---|---|
| | 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 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 that concentrations of TSS at Wankipe, dissolved silver at Bebelubi and TSS at SG5 have increased between 2011 and 2015, 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 2011 - 2015**

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UpRiv Ref | | | | | | | | | | | | | |
| SG1 | | | | | | | | | | | | | |
| 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 2011 - 2015**

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LwRiv Ref | | | | | | | | | | | | | |
| Bebelubi | | | | | | | | | | | | | |
| Tiumsinawam | | | | | | | | | | | | | |
| SG5 | | | | | | | | | | | | | |
| | Reduced or no change over time | | | | | | | | | | | | |
| | Increased over time | | | | | | | | | | | | |

D - Dissolved fraction

#### *7.3.1.2 Lake Murray and ORWBs*

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

The results indicate that a risk to aquatic ecosystems is posed by TSS at Avu.

**Table 7-6 Risk Assessment – Median water quality results at Lake Murray & ORWB test sites in 2015 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 | 9.0 | 0.05 | 0.31 | 0.05 | 0.10 | 0.60 | 33 | 0.05 | 0.50 | 0.10 | 0.20 | 2.5 |
| Southern Lake | 10 | 7.0 | 11 | 0.05 | 0.91 | 0.05 | 0.10 | 0.90 | 5.5 | 0.05 | 0.50 | 0.10 | 0.20 | 2.2 |
| SG6 | 4 | 6.6 | 17 | 0.05 | 0.92 | 0.05 | 0.12 | 0.96 | 14 | 0.05 | 0.50 | 0.10 | 0.20 | 2.9 |
| Kuku-fionga | 0 | No data collected in 2015 | | | | | | | | | | | | |
| Zonga-mange | 0 | No data collected in 2015 | | | | | | | | | | | | |
| Avu | 2 | 6.9 | 62 | 0.05 | 3.4 | 0.05 | 0.16 | 1.1 | 103 | 0.06 | 0.88 | 0.38 | 0.20 | 2.4 |
| **LMY and ORWB WQ TV** | | **5.3-8.0** | **23** | **0.05** | **24** | **0.72** | **1.0** | **1.4** | **340** | **0.16** | **11** | **3.4** | **11** | **8.0** |

Low risk = significantly < TV

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

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

The long-term trends presented in Appendix D, Table D-19 show that the concentrations of TSS at Central Lake, Southern Lake and Avu increased between 2011 and 2015, 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 2011 - 2015**

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LwRiv Ref | | | | | | | | | | | | | |
| Central Lake | | | | | | | | | | | | | |
| Southern Lake | | | | | | | | | | | | | |
| SG6 | | | | | | | | | | | | | |
| Avu | | | | | | | | | | | | | |

Reduced or no change over time

Increased over time

D - Dissolved fraction

### 7.3.2 Sediment Quality

#### *7.3.2.1 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 Appendix E, Table E-2 to Table E-9 and figures showing comparisons of the historical data against the TVs are shown Appendix E, Figure E-1 to Figure 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 biodiversity.

In the upper river, risk to aquatic ecosystems is posed by WAE lead at SG1, SG2, Wasiba and Wankipe. In the lower river risk is posed by WAE nickel at SG5. 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.

**Table 7-8 Risk Assessment – Median sediment quality results at upper river test sites in 2015 compared against UpRiv 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 | 6 | 0.50 | 5.5 | 0.82 | 3.8 | 6.3 | 0.01 | 5.1 | 125 | 0.50 | 114 |
| SG2 | 12 | 0.50 | 6.9 | 0.90 | 5.9 | 14 | 0.02 | 6.7 | 71 | 0.50 | 130 |
| Wasiba | 15 | 0.50 | 6.3 | 0.71 | 4.0 | 10 | 0.01 | 12 | 54 | 0.50 | 81 |
| Wankipe | 15 | 0.50 | 6.0 | 0.59 | 3.8 | 10 | 0.01 | 8.4 | 44 | 0.50 | 78 |
| SG3 | 61 | 0.50 | 3.4 | 0.50 | 6.2 | 6.5 | 0.01 | 18 | 13 | 0.50 | 44 |
| **UpRiv Sed TV** | | **1.0** | **20** | **1.5** | **80** | **65** | **0.15** | **27** | **50** | **0.50** | **200** |
| (green) | Low risk = significantly < TV | | | | | | | | | | |
| (orange) | Potential risk = significantly > TV OR not significantly different from TV | | | | | | | | | | |

WAE - Weak acid extractable

**Table 7-9 Risk Assessment – Median sediment quality results at lower river test sites in 2015 compared against LwRiv 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 | 6 | 0.50 | 3.4 | 0.50 | 6.2 | 6.5 | 0.01 | 18 | 13 | 0.50 | 44 |
| Tiumsinawam | 8 | 0.50 | 2.3 | 0.50 | 3.8 | 6.4 | 0.01 | 9.0 | 9.4 | 0.50 | 34 |
| SG5 | 8 | 0.50 | 4.2 | 0.50 | 21 | 13 | 0.01 | 38 | 19 | 0.50 | 120 |
| **LwRiv Sed TV** | | **1.0** | **20** | **1.5** | **80** | **65** | **0.20** | **21** | **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 metals in benthic sediments have been assessed between 2011 and 2015, and the results for WAE metals in whole sediment are summarised in Table 7-10 and Table 7-11 respectively, and detailed 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 were observed at the following locations: at SG1 WAE chromium and WAE nickel; at SG2 WAE arsenic, WAE chromium and WAE nickel; at Wasiba WAE cadmium; at Wankipe WAE arsenic, WAE cadmium, WAE chromium, WAE copper and WAE zinc, and at SG3 WAE arsenic, WAE cadmium, WAE chromium, WAE copper, WAE lead and WAE zinc. The concentration of all other WAE metals at all other sites have either reduced or remained unchanged between 2011 and 2015.

In the lower river, increased concentrations were observed at the following locations: at Bebelubi WAE chromium; at SG4/Tiumsinawam WAE chromium, and at SG5 WAE copper and WAE lead. The concentration of all other WAE metals in benthic have either reduced or remained unchanged between 2011 and 2015.

**Table 7-10 Comparison of trends of sediment quality at upper river reference and test sites 2011 - 2015 (whole sediment)**

| Site | Ag - WAE | As - WAE | Cd - WAE | Cr - WAE | Cu - WAE | Hg - WAE | Ni - WAE | Pb - WAE | Se - WAE | Zn - WAE |
|---|---|---|---|---|---|---|---|---|---|---|
| UpRiv 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] | [green] | [green] | [green] |
| Wasiba | [green] | [green] | [orange] | [green] | [green] | [green] | [green] | [green] | [green] | [green] |
| Wankipe | [green] | [orange] | [orange] | [orange] | [orange] | [green] | [green] | [green] | [green] | [orange] |
| SG3 | [green] | [orange] | [orange] | [orange] | [orange] | [green] | [green] | [orange] | [green] | [orange] |
| [green] | No change or reduced over time | | | | | | | | | |
| [orange] | Increased over time | | | | | | | | | |

WAE - Weak acid extractable

**Table 7-11 Comparison of trends of sediment quality at lower river reference and test sites 2011 - 2015 (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] | [green] | [green] | [green] | [green] | [green] | [green] | [green] |
| Bebelubi | [green] | [green] | [green] | [orange] | [green] | [green] | [green] | [green] | [green] | [green] |
| SG4/Tiumsinawam | [green] | [green] | [green] | [orange] | [green] | [green] | [green] | [green] | [green] | [green] |
| SG5 | [green] | [green] | [green] | [green] | [orange] | [green] | [green] | [orange] | [green] | [green] |
| [green] | No change or reduced over time | | | | | | | | | |
| [orange] | Increased over time | | | | | | | | | |

WAE - Weak acid extractable

#### *7.3.2.2 Lake Murray and ORWBs*

The results of the risk assessment for metals in sediment sampled at Lake Murray and the ORWB test sites are presented in Table 7-12Table 7-12. Detailed results of the statistical analysis are shown Appendix E, Table E-12 to Table E-17 and figures showing comparisons of the historical data against the TVs are shown in Appendix E, Figure E-23 to Figure E-32.

The risk assessment shows that risk to aquatic ecosystems is posed by WAE nickel in benthic sediment at Central Lake, Southern Lake, SG6 and Avu, and by WAE lead at Avu. The occurrence of elevated WAE nickel at these locations appears unrelated to the mine operation because the concentrations are significantly higher than the mine discharge.

**Table 7-12 Risk assessment – median sediment quality results at Lake Murray and ORWB test sites in 2015 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 | 11 | 0.50 | 1.6 | 0.50 | 20 | 17 | 0.08 | 24 | 15 | 0.50 | 86 |
| Southern Lake | 10 | 0.50 | 4.7 | 0.50 | 22 | 22 | 0.06 | 30 | 30 | 0.50 | 110 |
| SG6 | 4 | 0.5 | 8.8 | 0.50 | 21 | 22 | 0.02 | 32 | 33 | 0.50 | 120 |
| Kukufionga | 0 | No data collected in 2015 | | | | | | | | | |
| Zongamange | 0 | No data collected in 2015 | | | | | | | | | |
| Avu | 2 | 0.50 | 9.7 | 0.62 | 21 | 24 | 0.02 | 34 | 62 | 0.5 | 170 |
| **Lake Murray and ORWBs Sed TV** | | **1.0** | **20** | **1.5** | **80** | **65** | **0.15** | **21** | **50** | **0.5** | **200** |

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

WAE - Weak acid extractable

A summary of analysis of trends of WAE metals in benthic sediment between 2013 and 2014/2015 is shown in Table 7-13. Detailed results of the statistical analysis are provided in Appendix E, Table E-18.

The assessment shows increased concentrations at the following locations: at the Central Lake WAE arsenic, WAE chromium, WAE copper, WAE nickel, WAE lead and WAE zinc; at the Southern Lake WAE arsenic, WAE chromium, WAE copper, WAE nickel and WAE zinc; at SG6 WAE chromium and WAE nickel, and at Avu WAE arsenic, WAE cadmium, WAE chromium, WAE nickel and WAE zinc. The concentration of all other WAE metals in benthic sediment have either reduced or remained unchanged between 2011 and 2015.

**Table 7-13 Comparison of trends of sediment quality at Lake Murray and ORWB reference and test sites 2011 - 2015 (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 | Green | Green | Green | Orange | Orange | Green | Orange | Orange | Green | Orange |
| Central Lake | Green | Orange | Green | Orange | Orange | Green | Orange | Orange | Green | Orange |
| Southern Lake | Green | Orange | Green | Orange | Orange | Green | Orange | Green | Green | Orange |
| SG6 | Green | Green | Green | Orange | Green | Green | Orange | Green | Green | Green |
| Kukufionga * | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| Zongamange* | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| Avu | Green | Orange | Orange | Orange | Green | Green | Orange | Green | Green | Orange |
| Green | No change or reduced over time | | | | | | | | | |
| Orange | Increased over time | | | | | | | | | |

WAE - Weak acid extractable, * trend between 2013-2014

### 7.3.3 Tissue Metals

#### *7.3.3.1 Upper and Lower River*

The results of the risk assessment for concentrations of metals in tissue from prawn and fish samples collected in 2015 from riverine test sites are shown in Table 7-14 and Table 7-15 respectively. Detailed results of the statistical analysis are shown Appendix F, Table F-2 to Table F-5 and figures showing comparisons of the historical data against the TVs are shown Appendix F, Figure F-1 to Figure F-36.

The assessment shows that in the upper river, risk to aquatic ecosystems is posed by cadmium and zinc in prawn abdomen at Wasiba and by cadmium, nickel and lead at Wankipe.

In the lower river, risk to aquatic ecosystems is posed by arsenic, cadmium, nickel, selenium and zinc in prawn abdomen at Bebelubi and by cadmium, nickel and lead in prawn abdomen at Tiumsinawam.

**Table 7-14 Risk assessment – median tissue metal results at upper river test sites in 2015 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 | 0.03 | 0.003 | 0.01 | 0.15 | 0.08 | 0.01 | 0.01 | 0.32 | 4.2 |
| | Prawn Abdo | 26 | 0.04 | 0.05 | 0.02 | 6.7 | 0.01 | 0.01 | 0.02 | 0.57 | 16 |
| Wankipe | Fish Flesh | 20 | 0.02 | 0.003 | 0.01 | 0.15 | 0.06 | 0.01 | 0.01 | 0.27 | 3.7 |
| | Prawn Abdo | 26 | 0.04 | 0.01 | 0.02 | 5.6 | 0.01 | 0.02 | 0.01 | 0.38 | 13 |
| Trigger Value | Fish Flesh | | 0.20 | 0.02 | 0.02 | 0.48 | 0.09 | 0.10 | 0.17 | 2.26 | 10.4 |
| | Prawn Abdo | | 0.05 | 0.01 | 0.11 | 9.82 | 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 | | | | | | | | | | |

**Table 7-15 Risk assessment – median tissue metal results at lower river test sites in 2015 compared against LwRiv 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 | 0 | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| | Prawn Abdo | 16 | 0.12 | 0.01 | 0.02 | 8.5 | 0.01 | 0.01 | 0.01 | 0.33 | 16 |
| Tiumsinawam | Fish Flesh | 18 | 0.01 | 0.003 | 0.01 | 0.09 | 0.09 | 0.01 | 0.01 | 0.16 | 3.6 |
| | Prawn Abdo | 26 | 0.07 | 0.01 | 0.02 | 6.85 | 0.01 | 0.02 | 0.01 | 0.29 | 12 |
| Trigger Value | Fish Flesh | | 0.07 | 0.01 | 0.03 | 0.17 | 0.12 | 0.03 | 0.17 | 2.26 | 4.8 |
| | Prawn Abdo | | 0.10 | 0.01 | 0.06 | 11.6 | 0.01 | 0.01 | 0.01 | 0.31 | 16 |
| | Low risk = significantly < TV | | | | | | | | | | |
| | Potential risk = significantly > TV OR not significantly different from TV | | | | | | | | | | |

NS – Not sampled.

A summary of the analysis of trends for tissue metals in the upper and lower river between 2011 and 2015 are shown in Table 7-16 and Table 7-17, detailed results of the statistical analysis are shown in Appendix F, Table F-6 to F-9.

In the upper river test sites, the analysis shows nickel in prawn abdomen at Wankipe increased between 2011 and 2015. 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 2011 - 2015**

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

**Table 7-17 Comparison of tissue metal trends at lower river ref and test sites 2011 - 2015**

| Site | Sample | As | Cd | Cr | Cu | Hg | Ni | Pb | Se | Zn |
|---|---|---|---|---|---|---|---|---|---|---|
| LwRiv Ref | Fish Flesh | | | | | | | | | |
| | Prawn Abdo | | | | | | | | | |
| Bebelubi | Fish Flesh | | | | | | | | | |
| | Prawn Abdo | | | | | | | | | |
| Tiumsinawam | Fish Flesh | | | | | | | | | |
| | Prawn Abdo | | | | | | | | | |
| | No change or reduced over time | | | | | | | | | |
| | Increased over time | | | | | | | | | |

#### *7.3.3.2 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.

### 7.3.4 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 7-19 to Table 7-21 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.

#### *7.3.4.1 pH*

Discharge from the lime plant exhibits elevated pH as a result of rainfall runoff from the area contacting lime. The flow is relatively low compared to flows within the receiving environment and the receiving environment itself exhibits 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 93% 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, a moderate proportion of cadmium (6.1%), nickel (24%) and zinc (9.4%) were present in dissolved forms throughout 2015, the pH of receiving river waters is neutral which reduces the potential for metals to be remobilised within the water column.

#### *7.3.4.2 Total Suspended Solids*

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

The concentrations of TSS in the receiving environment at SG1 exceed the relevant TV and therefore pose a risk to the aquatic ecosystem at this location. Further downstream, the concentrations of TSS at all test sites are 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 pose a low risk to aquatic ecosystems below SG1.

TSS at Avu exceeded the TV for Lake Murray and ORWBs. Avu is an oxbow lake and in the absence of reference or baseline data for ORWBs, the TV for ORWBs has been conservatively developed based on water quality data from the northern section of Lake Murray. Conditions within the ORWBs will be influenced by surface area, depth, temperature gradients within the water column and atmosphere, wind, rainfall/runoff and human activity, all of which function on a smaller scale than within Lake Murray, and in addition water quality within the ORWB will be influenced by overflow events from the adjacent Strickland River, if the river is rising and flooding into the oxbow, then TSS will be elevated within the oxbow.

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.

A number of factors will influence the relationship between sediment and metals in both the discharge from the mine and within the receiving environment: TSS concentration, particle size distribution, pH, concentration of organic matter, sediment mineral type, the number of different metals present and the concentrations of those metals. This relationship is discussed further when assessing risks posed by metals in Section 7.3.4.3 to 7.3.4.12.

#### *7.3.4.3 Silver (Ag)*

Concentrations of dissolved silver in water and WAE silver in sediment discharged from the mine are less than the respective upper river TVs and therefore pose a low risk to the receiving environment. Concentrations of dissolved silver in water, WAE silver in benthic sediment and silver in fish and prawn tissue within the receiving environment are also less than the respective TVs indicating low risk. Overall the system wide risk posed by silver to aquatic ecosystems is considered low.

#### *7.3.4.4 Arsenic (As)*

Dissolved arsenic concentrations in contact runoff water discharged from the site pose a low risk to aquatic ecosystems downstream of the mine. This is reflected at all of the receiving environment test sites where dissolved arsenic concentrations in water also pose a low risk.

The concentration of WAE arsenic in the tailings solids is elevated compared to the upper river TV, but this is not reflected in benthic sediments within the receiving environment where WAE arsenic concentrations are less than their respective TVs and therefore pose low risk to aquatic ecosystems. WAE arsenic in benthic sediment exhibits a decreasing trend from SG2 in the upper river to Tiumsinawam in the lower river, concentrations then increase at SG5, Sth Lake, SG6 and Avu. However this increasing trend at the Lake Murray and ORWBs was not observed at Central Lake where the concentration of WAE in benthic sediment was the lowest of all the test sites in 2015.

Within the receiving environment it is expected that arsenic-enriched sediment within the tailings is diluted by natural sediments with low WAE arsenic concentrations. The size of the sediment particles and the velocity or energy of the flow throughout the receiving environment will dictate how this sediment is distributed throughout the receiving environment. In areas with high velocity, such as the upper rivers, a portion of the coarser particles will settle, especially during the falling stage of river flow following high rainfall, while the fine particles will remain in suspension. In the lower river, the finer suspended sediment particles will be deposited in the river channel and from the portion of river water entering the floodplain, Lake Murray and ORWBs where flow velocities reduce. This is shown in Table 7-18 where the average proportion of total sediment within each region that is classified as fine sediment (<63μm) increases as the rivers flow out of highlands and down to the lower river flood plain, Lake Murray and the ORWBs.

It is possible that a portion of the coarse fraction of arsenic-enriched tailings particles is settling in the upper river, and a portion of the fine fraction of arsenic enriched tailings particles remains in suspension in the upper river and begins to settle in the lower river at SG5, and southern Lake Murray and Avu. Similar trends were observed for WAE copper, WAE lead and WAE zinc in benthic sediment during 2015. This is consistent with CSIRO (1996) which concluded that treated tailings and incompetent waste rock are discharged from the mine predominantly as fine (more than 80% is <65μm in diameter) and that these fines are transported to the lower Strickland River, the Strickland/Fly floodplain and to the Fly River estuary. Tailings are the most metal-enriched fine fraction, so riverine transport of tailings is the major source of environmental risk (CSIRO 1996).

It is also possible that there is an additional non-PJV related source contributing metal-enriched sediment to the system which has not been identified by the PJV environmental monitoring program. It is most likely that a combination of these factors is contributing to the low WAE arsenic concentration in benthic sediment throughout the receiving environment.

In 2015 PJV continued the investigation into the behavior of metals within the receiving environment.

**Table 7-18 Average proportion of total sediment fine sediment (<63µm) in the upper rivers, lower rivers and Lake Murray and ORWBs**

| Region | Average Proportion of Total Sediment in the Fine Fraction (% <63µm) |
|---|---|
| Upper River | 37.8 |
| Lower River | 57.5 |
| Lake Murray and ORWBs | 87.6 |

Note - Calculated using 2015 data from test and reference sites within each region.

Arsenic in prawn abdomen at Bebelubi is statistically significantly greater than the lower river TV and confirms that arsenic is bioaccumulating at a higher rate than at the reference site at this location and poses a risk. It is notable however, that at Tiumsinawam some 60 km downstream from Bebelubi, arsenic concentration in prawn abdomen (0.07 mg/kg) was significantly less than the respective TV (0.10 mg/kg), indicating low risk. The exposure of prawns to arsenic typically occurs via contact with or ingestion of dissolved arsenic in water, WAE arsenic in benthic sediment or via the food web. Additionally, given the possibility that a proportion of arsenic-enriched tailings sediment will remain in suspension along the receiving river system, it is conceivable that arsenic associated with suspended sediment is an additional pathway of exposure for prawns at Bebelubi. Concentrations of dissolved arsenic in water and WAE arsenic in benthic sediment at Bebelubi are low risk, which indicates that a combination of arsenic associated with suspended sediment and arsenic within the food web are possibly contributing to elevated arsenic in prawn abdomen at this location.

It could be expected that prawns in the upper river at Wasiba and Wankipe would also exhibit elevated arsenic in abdomen tissue given that they are likely to be exposed to higher concentrations of arsenic in suspended sediment and the food web than prawns at Bebelubi. The factors for this inconsistency are not understood, however a contributing factor may be that different species of prawn are used for tissue analysis in the upper river (*Macrobrachium handschini*) and the lower river (*Macrobrachium rosenbergii*), with potentially different feeding habits and assimilative capacities. It should be noted that the concentrations of all metals within prawn and fish tissue at all sites within the upper and lower rivers are 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 7.6.

Overall, given that arsenic in prawn abdomen at Bebelubi is the only indicator of arsenic that exceeded a TV and that this was not observed 60 km downstream at Tiumsinawam, the system-wide risk posed by arsenic to aquatic ecosystems is considered low.

#### *7.3.4.5 Cadmium (Cd)*

Dissolved cadmium in tailings, and mine contact runoff water from Kogai Dump Toe and Wendoko D/S Anawe Nth pose a potential risk to the receiving environment, and this is reflected by elevated dissolved cadmium in water at SG1, approx 8km downstream of the mine on the Porgera River. However, at all sites downstream of SG1, dissolved cadmium concentrations in water pose low risk and exhibit a decreasing concentration with increasing distance from the mine. A combination of dilution and adsorption to particulate matter within the receiving environment rapidly reduces the concentration of dissolved cadmium in water.

WAE cadmium in tailings solids poses a potential risk to the receiving environment, however the concentrations of WAE cadmium in benthic sediment at all test sites within the receiving environment were significantly less than the TV indicating low risk. It is reasonable to expect that cadmium enriched tailings sediment is diluted by natural sediments with low WAE cadmium concentrations. The fine fraction of cadmium enriched tailings sediments and enriched sediment resulting from the adsorption of dissolved cadmium in water will remain in suspension during river transport and a portion will settle in the lower river and ORWBs. However, it is also possible that there is an additional non-PJV related source contributing metal enriched sediment to the system which has not been identified by the PJV environmental monitoring program. It is most likely that a combination of these factors is contributing to the low WAE cadmium concentration in benthic sediment throughout the receiving environment.

Cadmium in prawn abdomen at Wasiba is significantly greater than the upper river TV, while cadmium in prawn abdomen at Wankipe, Bebelubi and Tiumsinawam are not significantly different from their respective TVs, all results indicate potential 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 are 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 7.6.

The behavior of cadmium within the receiving environment is the subject of ongoing investigation. However, given the low concentrations of dissolved cadmium in water and WAE cadmium in benthic sediment, and that cadmium in prawn abdomen at Wasiba was the only indicator which was statistically significantly greater than the TV downstream from SG1, the system-wide risk posed by cadmium to aquatic ecosystems is considered low.

#### *7.3.4.6 Chromium (Cr)*

The concentration of dissolved chromium in water discharged from the lime plant and Yakatabari D/S 28 level are elevated and pose a potential risk to the receiving environment. Within the receiving environment, the concentrations of dissolved chromium in water, WAE chromium in benthic sediment and chromium in fish flesh and prawn abdomen pose low risk.

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

#### *7.3.4.7 Copper (Cu)*

Dissolved copper in tailings poses a potential risk to the receiving environment. Dissolved copper at all upper river test sites pose low risk. In the lower river at Bebelubi, the median dissolved copper concentration in water during 2015 is higher than the TV and at Tiumsinawam, the median dissolved copper concentration in water during 2015 is equal to the TV, both indicating potential risk. Statistical tests could not be applied for the lower river sites due to the low sample size (n). A combination of dilution and adsorption to particulate matter within the receiving environment rapidly reduces the concentration of dissolved copper in water. Earlier studies of copper speciation (Apte, 1995) and Cresswell (2013) showed that the majority of dissolved copper was present in non-labile form, and no ecotoxicological effects on aquatic life were expected.

WAE copper in tailings solids is elevated and poses a potential risk to the receiving environment. However, concentrations of WAE copper in benthic sediment at all test sites within the upper and lower river and Lake Murray and ORWBs are low risk. WAE copper in benthic sediment exhibits a decreasing trend from SG2 in the upper river to Tiumsinawam in the lower river, concentrations then increase at SG5, central and southern Lake Murray, SG6 and Avu.

It is reasonable to expect that copper-enriched tailings sediment is diluted by natural sediments with low WAE copper concentrations. The fine fraction of copper-enriched tailings sediments and enriched sediment resulting from the adsorption of dissolved copper from water will remain in suspension during river transport and a portion will settle in the lower river, southern and central Lake Murray and ORWBs. However, it is also possible that there is an additional non-PJV related source contributing metal enriched sediment to the system which has not been identified by the PJV environmental monitoring program. It is most likely that a combination of these factors is contributing to the WAE copper concentration in benthic sediment throughout the receiving environment.

Copper concentrations in fish flesh and prawn abdomen at all test sites are below their respective TVs and are low risk.

Overall, given the low concentrations of dissolved copper in water, WAE copper in benthic sediment and copper in fish flesh and prawn abdomen, the system-wide risk of copper to aquatic ecosystems is considered low.

#### *7.3.4.8 Mercury (Hg)*

The concentrations of dissolved mercury in water discharged from the mine are 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 is elevated in tailings sediment and poses a potential risk to the receiving environment. However, WAE concentrations of mercury in benthic sediment throughout the receiving environment are low and pose low risk.

The concentration of mercury in fish flesh and prawn abdomen throughout the receiving environment poses low risk to aquatic ecosystems.

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

#### *7.3.4.9 Nickel (Ni)*

The concentration of dissolved nickel in tailings poses a potential risk to aquatic ecosystems downstream of the mine. However, the concentration of dissolved nickel at all receiving environment sites poses low risk. A combination of dilution and adsorption to particulate matter within the receiving environment rapidly reduces the concentration of dissolved nickel in water.

WAE nickel in sediment discharged from the site is highest in tailings solids, however none of the discharge sites exceed the TV and therefore all pose a low risk to the aquatic ecosystem in the receiving environment. WAE nickel in benthic sediment within the upper rivers is also low risk. Concentrations of WAE nickel in benthic sediment display an increasing trend with distance from the mine, concentrations at Bebelubi and Tiumsinawam in the lower river are low risk, but at SG5 further downstream, WAE nickel concentrations increase significantly to exceed the lower river TV, and also exceed the concentration in tailings solids. Similarly, concentrations of WAE nickel in benthic sediment in central and southern Lake Murray and Avu exceed the TV for Lake Murray and ORWBs, and are also greater than concentrations in the tailings solids.

It is possible that a proportion of the dissolved nickel in water that is adsorbed to sediment, and along with a proportion of nickel-enriched tailings solids are contributing to WAE nickel concentrations in benthic sediment in the lower river, Lake Murray and ORWBs. WAE nickel in sediment is being contributed to the system from the upper river reference sites and it is also possible that elevated WAE nickel in benthic sediment at SG5 and Lake Murray and ORWBs is the result of contributions of enriched WAE nickel in sediment to the lower Strickland River from non-PJV related sources which have not been identified by the PJV environmental monitoring program. Nickel is included in the ongoing investigation of the behavior of metals within the receiving environment.

Nickel is elevated in prawn abdomen at Wankipe in the upper river and at Bebelubi in the lower river but not significantly different from their respective TVs, and at Tiumsinawam in the lower river, nickel in prawn abdomen is greater than the TV. These results indicate that nickel is bioaccumulating in prawn abdomen at a greater rate than at respective reference sites and poses potential risk to aquatic ecosystems at these locations.

Overall, given the elevated concentrations of dissolved nickel in tailings, the potential risk indicated by elevated WAE nickel in benthic sediment at SG5 and Lake Murray and ORWBs, the potential risk indicated by nickel in prawn abdomen at Bebelubi and Tiumsinawam, nickel is considered to pose a potential system-wide risk to aquatic ecosystems. Further investigation is required to determine the concentration of WAE nickel in the fine fraction of tailings sediment and the relative contribution of tailings to the WAE nickel concentrations in lower river benthic sediments.

#### *7.3.4.10 Lead (Pb)*

Concentration of dissolved lead in water discharged from the site poses low risk, and is reflected by low concentrations of dissolved lead in water, and therefore low risk to aquatic ecosystems throughout the receiving environment.

Sediment with WAE lead concentrations greater than the upper river TV is discharged from a number of sites, the highest being Yakatabari DS 28 Level and the lowest being tailings solids. In the upper river, the concentrations of WAE lead in benthic sediment pose a risk to aquatic ecosystems at SG1, SG2, Wasiba and Wankipe, the latter being not significantly different from the TV. From SG1 downstream to Tiumsinawam, the concentration of WAE lead in benthic sediment exhibits a decreasing trend with increasing distance from the mine. Concentrations then increase at SG5, central and southern Lake Murray and SG6, but remain less than their respective TVs. WAE lead concentrations at Avu are greater than the TV for Lake Murray and ORWBs indicating potential risk to aquatic ecosystems at this location.

It is possible that lead enriched fine sediment from the mine is being transported to the lower Strickland River, Lake Murray and ORWBs. It is also possible that there are non-PJV related inputs of WAE lead in benthic sediment in the system. Lead is included in the ongoing investigation of the behavior of metals within the receiving environment.

Lead in prawn abdomen at Wasiba was significantly greater than the TV, and at Wankipe and Tiumsinawam was not significantly different from their respective TVs, indicating 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 are 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 7.6.

Overall, 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 SG1, SG2, Wasiba, Wankipe and Avu, the potential risk indicated by lead in prawn abdomen at Wasiba, Wankipe and Tiumsinawam, lead is considered to pose a potential system-wide risk to aquatic ecosystems.

#### *7.3.4.11 Selenium (Se)*

Dissolved selenium in water and WAE selenium in sediment discharged from the site are both below the respective upper river TVs and therefore pose 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 in prawn abdomen at Wasiba was significantly greater than the TV, and at Bebelubi was not significantly different from the TV, indicating 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 are 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 7.6.

Overall, given the low concentration of dissolved selenium in water and WAE selenium in mine-derived sediments and throughout the receiving environment, and selenium in prawn abdomen at

Wasiba and Bebelubi are the only indication of potential risk, the system-wide risk of selenium is considered low.

#### *7.3.4.12 Zinc (Zn)*

The concentrations of dissolved zinc in tailings and in water discharged from Kogai Dump Toe and Wendoko D/S Anawe Nth are greater than the upper river TV and pose potential risk to aquatic ecosystems in the receiving environment. This is reflected by elevated dissolved zinc in water at SG1 which exceeds the upper river TV and indicates potential risk. From SG2 in the upper river downstream to the lower river and Lake Murray and ORWBs, dissolved zinc in water poses low risk and shows decreasing concentrations with increasing distance from the mine. A combination of dilution and adsorption to particulate matter within the receiving environment rapidly reduces the concentration of dissolved zinc in water.

Sediment with WAE zinc concentrations greater than the upper river TV is discharged from a number of sites, the highest being tailings solids and the lowest being Kogai Dump Toe. However, concentrations of WAE zinc in benthic sediment at all test sites within the receiving environment are below their respective TVs and therefore pose low risk. From SG1 downstream to Tiumsinawam, the concentration of WAE zinc in benthic sediment decreases with increasing distance from the mine. Concentrations then increase at SG5, central and southern Lake Murray, SG6 and Avu.

It is possible that a proportion of the dissolved zinc in water that is adsorbed to sediment, along with a proportion of zinc enriched tailings solids contributed to WAE zinc concentrations in benthic sediment in the lower river, and Lake Murray and ORWBs. It is also possible that elevated WAE zinc in benthic sediment at SG5 and Lake Murray and ORWBs is the result of contributions of enriched WAE zinc in sediment to the lower Strickland River from non-PJV related sources which have not been identified by the PJV environmental monitoring program. Zinc is included in the ongoing investigation of the behavior of metals within the receiving environment.

Zinc concentrations in prawn abdomen at Wasiba and Bebelubi are not significantly different from their respective TVs, indicating potential risk to aquatic ecosystems at these locations.

Overall, given the low concentration of dissolved zinc in water downstream from SG1, low WAE zinc concentrations in sediment throughout the receiving environment, and that the zinc concentrations in prawn abdomen at Wasiba and Bebelubi are not significantly different from their respective TVs, the system-wide risk of zinc to aquatic ecosystems is considered low.

**Table 7-19 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 2015 (µg/L except where shown)**

| 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 | 161,000 | 0.05 | 0.29 | 73 | 0.10 | 30 | 0.10 | 1,600 | 0.10 | 2.4 | 19,000 |
| | 28 Level | 7.7 | 78 | 0.05 | 1.9 | 0.07 | 0.10 | 0.50 | 0.05 | 6.4 | 0.10 | 0.20 | 12 |
| | SDA Toe | 7.6 | 76 | 0.05 | 0.8 | 0.05 | 0.11 | 0.84 | 0.05 | 0.70 | 0.62 | 0.21 | 6.7 |
| | Kaiya Riv D/S Anj Dump | 7.5 | 291 | 0.05 | 1.0 | 0.05 | 0.10 | 0.56 | 0.05 | 0.63 | 0.17 | 0.42 | 4.0 |
| | Kogai Culvert | 7.7 | 180 | 0.05 | 1.2 | 0.06 | 0.11 | 1.0 | 0.05 | 0.74 | 0.38 | 0.20 | 10 |
| | Kogai dump toe | 7.6 | 68 | 0.05 | 0.7 | 1.8 | 0.10 | 0.63 | 0.05 | 2.3 | 0.52 | 0.20 | 350 |
| | Lime Plant | 11.2 | 382 | 0.05 | 0.2 | 0.05 | 3.4 | 0.60 | 0.05 | 0.50 | 0.10 | 0.20 | 0.90 |
| | Wendoko Crk D/S Anawe Nth | 7.6 | 57 | 0.05 | 1.1 | 0.76 | 0.10 | 0.64 | 0.05 | 1.8 | 0.26 | 0.64 | 310 |
| | Yakatabari D/S 28 Level | 7.6 | 6,273 | 0.05 | 13.0 | 0.05 | 1.4 | 0.91 | 0.05 | 1.6 | 1.4 | 0.36 | 6.6 |
| | Yunarilama/Yarik @ Portal | 7.4 | 8,415 | 0.05 | 3.2 | 0.10 | 0.14 | 0.67 | 0.05 | 4.1 | 0.46 | 0.96 | 6.3 |
| Upper River | SG1 | 7.4 | 6,498 | 0.05 | 1.5 | 1.4 | 0.10 | 1.8 | 0.05 | 3.5 | 0.18 | 0.25 | 31 |
| | SG2 | 7.5 | 1,831 | 0.05 | 1.3 | 0.22 | 0.14 | 1.6 | 0.05 | 1.5 | 0.10 | 0.20 | 7.7 |
| | Wasiba | 7.4 | 1,413 | 0.05 | 1.8 | 0.15 | 0.20 | 1.6 | 0.05 | 1.1 | 0.10 | 0.20 | 5.4 |
| | Wankipe | 7.5 | 820 | 0.05 | 1.7 | 0.13 | 0.20 | 1.4 | 0.05 | 0.98 | 0.10 | 0.20 | 5.0 |
| | SG3 | 7.6 | 1,133 | 0.05 | 1.7 | 0.07 | 0.17 | 1.6 | 0.05 | 0.67 | 0.10 | 0.20 | 4.3 |
| Lower River | Bebelubi | 7.3 | 353 | 0.05 | 1.6 | 0.08 | 0.20 | 1.5 | 0.05 | 0.51 | 0.10 | 0.20 | 5.6 |
| | Tiumsinawam | 7.4 | 516 | 0.05 | 1.3 | 0.07 | 0.17 | 1.4 | 0.05 | 0.50 | 0.11 | 0.20 | 4.9 |
| | SG5 | 7.3 | 336 | 0.05 | 1.0 | 0.05 | 0.13 | 1.1 | 0.05 | 0.50 | 0.10 | 0.20 | 1.5 |
| Lake Murray and ORWBs | Central Lake | 6.6 | 9.0 | 0.05 | 0.31 | 0.05 | 0.10 | 0.60 | 0.05 | 0.50 | 0.10 | 0.20 | 2.5 |
| | Southern Lake | 7.0 | 11 | 0.05 | 0.91 | 0.05 | 0.10 | 0.90 | 0.05 | 0.50 | 0.10 | 0.20 | 2.2 |
| | SG6 | 6.6 | 17 | 0.05 | 0.92 | 0.05 | 0.12 | 0.96 | 0.05 | 0.50 | 0.10 | 0.20 | 2.9 |
| | Kukufionga | No data collected in 2015 | | | | | | | | | | | |
| | Zongamange | No data collected in 2015 | | | | | | | | | | | |
| | Avu | 6.9 | 62 | 0.05 | 3.4 | 0.05 | 0.16 | 1.1 | 0.06 | 0.88 | 0.38 | 0.20 | 2.4 |

^ std units, * mg/L

**Table 7-20 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 2015 (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 | 0.50 | 74 | 4.0 | 22 | 84 | 0.16 | 22 | 74 | 0.50 | 680 |
| | 28 Level | 1.3 | 7.9 | 1.0 | 13 | 18 | 0.01 | 19 | 140 | 0.50 | 580 |
| | SDA Toe | 0.50 | 4.7 | 0.70 | 3.3 | 5.1 | 0.01 | 5.4 | 98 | 0.50 | 110 |
| | Kaiya Riv D/S Anj Dump | 0.50 | 4.5 | 0.50 | 3.7 | 5.2 | 0.01 | 5.4 | 120 | 0.50 | 69 |
| | Kogai Culvert | 0.50 | 8.9 | 0.69 | 2.6 | 4.2 | 0.01 | 3.0 | 100 | 0.50 | 100 |
| | Kogai dump toe | 0.50 | 10 | 1.4 | 4.1 | 5.9 | 0.01 | 4.6 | 160 | 0.50 | 200 |
| | Lime Plant | 0.50 | 0.57 | 0.50 | 8.7 | 2.4 | 0.01 | 2.1 | 3.5 | 0.50 | 15 |
| | Wendoko Crk D/S Anawe Nth | 0.50 | 7.5 | 1.4 | 2.1 | 7.2 | 0.01 | 4.0 | 78 | 0.50 | 210 |
| | Yakatabari DS 28 Level | 1.1 | 16 | 1.4 | 4.5 | 13 | 0.01 | 6.9 | 260 | 0.50 | 240 |
| | Yunarilama/Yarik @ Portal | 0.50 | 6.3 | 0.63 | 4.4 | 5.0 | 0.01 | 5.2 | 79 | 0.50 | 110 |
| Upper River | SG1 | 0.50 | 5.5 | 0.82 | 3.8 | 6.3 | 0.01 | 5.1 | 125 | 0.50 | 114 |
| | SG2 | 0.50 | 6.9 | 0.90 | 5.9 | 14 | 0.02 | 6.7 | 71 | 0.50 | 130 |
| | Wasiba | 0.50 | 6.3 | 0.71 | 4.0 | 10 | 0.01 | 12 | 54 | 0.50 | 81 |
| | Wankipe | 0.50 | 6.0 | 0.59 | 3.8 | 10 | 0.01 | 8.4 | 44 | 0.50 | 78 |
| | SG3 | 0.50 | 3.4 | 0.50 | 6.2 | 6.5 | 0.01 | 18 | 13 | 0.50 | 44 |
| Lower River | Bebelubi | 0.50 | 3.4 | 0.50 | 6.2 | 6.5 | 0.01 | 18 | 13 | 0.50 | 44 |
| | Tiumsinawam | 0.50 | 2.3 | 0.50 | 3.8 | 6.4 | 0.01 | 9.0 | 9.4 | 0.50 | 34 |
| | SG5 | 0.50 | 4.2 | 0.50 | 21 | 13 | 0.01 | 38 | 19 | 0.50 | 120 |
| Lake Murray and ORWBs | Central Lake | 0.50 | 1.6 | 0.50 | 20 | 17 | 0.08 | 24 | 15 | 0.50 | 86 |
| | Southern Lake | 0.50 | 4.7 | 0.50 | 22 | 22 | 0.06 | 30 | 30 | 0.50 | 110 |
| | SG6 | 0.50 | 8.8 | 0.50 | 21 | 22 | 0.02 | 32 | 33 | 0.50 | 120 |
| | Kukufionga | No data collected in 2015 | | | | | | | | | |
| | Zongamange | No data collected in 2015 | | | | | | | | | |
| | Avu | 0.50 | 9.7 | 0.62 | 21 | 24 | 0.02 | 34 | 62 | 0.5 | 170 |

WAE – Weak acid extraction

**Table 7-21 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 2015**

| 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 | 7.4 | 1,413 | 0.05 | 1.8 | 0.15 | 0.20 | 1.6 | 0.05 | 1.1 | 0.10 | 0.20 | 5.4 |
| | | Sed-WAE | mg/kg | - | - | 0.50 | 6.3 | 0.71 | 4.0 | 10 | 0.01 | 12 | 54 | 0.50 | 81 |
| | | Fish Flesh | mg/kg | - | - | - | 0.03 | 0.003 | 0.01 | 0.15 | 0.08 | 0.01 | 0.01 | 0.32 | 4.2 |
| | | Prawn Abdo | mg/kg | - | - | - | 0.04 | 0.05 | 0.02 | 6.7 | 0.01 | 0.01 | 0.02 | 0.57 | 16 |
| | Wankipe | Water-D | µg/L | 7.5 | 820 | 0.05 | 1.7 | 0.13 | 0.20 | 1.4 | 0.05 | 0.98 | 0.10 | 0.20 | 5.0 |
| | | Sed-WAE | mg/kg | - | - | 0.50 | 6.0 | 0.59 | 3.8 | 10 | 0.01 | 8.4 | 44 | 0.50 | 78 |
| | | Fish Flesh | mg/kg | - | - | - | 0.02 | 0.003 | 0.01 | 0.15 | 0.06 | 0.01 | 0.01 | 0.27 | 3.7 |
| | | Prawn Abdo | mg/kg | - | - | - | 0.04 | 0.01 | 0.02 | 5.6 | 0.01 | 0.02 | 0.01 | 0.38 | 13 |
| Lower River | Bebelubi | Water-D | µg/L | 7.3 | 353 | 0.05 | 1.6 | 0.08 | 0.20 | 1.5 | 0.05 | 0.51 | 0.10 | 0.20 | 5.6 |
| | | Sed-WAE | mg/kg | - | - | 0.50 | 3.4 | 0.50 | 6.2 | 6.5 | 0.01 | 18 | 13 | 0.50 | 44 |
| | | Fish Flesh | mg/kg | - | - | - | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| | | Prawn Abdo | mg/kg | - | - | - | 0.12 | 0.01 | 0.02 | 8.5 | 0.01 | 0.01 | 0.01 | 0.33 | 16 |
| | Tiumsina wam | Water-D | µg/L | 7.4 | 516 | 0.05 | 1.3 | 0.07 | 0.17 | 1.4 | 0.05 | 0.50 | 0.11 | 0.20 | 4.9 |
| | | Sed-WAE | mg/kg | - | - | 0.50 | 2.3 | 0.50 | 3.8 | 6.4 | 0.01 | 9.0 | 9.4 | 0.50 | 34 |
| | | Fish Flesh | mg/kg | - | - | - | 0.01 | 0.003 | 0.01 | 0.09 | 0.09 | 0.01 | 0.01 | 0.16 | 3.6 |
| | | Prawn Abdo | mg/kg | - | - | - | 0.07 | 0.01 | 0.02 | 6.85 | 0.01 | 0.02 | 0.01 | 0.29 | 12 |

* std units; * mg/L

## 7.4 Local Water Supplies

Participatory sampling of local village water supplies was carried out at four Special Mining Lease Villages (Yarik, Apalaka, Panadaka and Kulapi) in September 2015 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 including tanks, a drum and two springs, 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 on Figure 7-15.

The samples were prepared at the PJV onsite laboratory for dispatch to external laboratories. Samples for biological analysis were sent to SGS laboratory in Port Moresby, Papua New Guinea, while samples requiring trace metals tests were sent to National Measurement Institute (NMI) laboratory in Sydney, Australia. Physico-chemical analyses were conducted at the onsite laboratory.

**Table 7-22 Sampling sites for Local Village Water Supplies 2015**

| Sites | Name on map | Easting | Northing |
|---|---|---|---|
| Market Store | NA | NA | NA |
| Apalaka H1 Tank | AP_H1 | 9397663 | 731732 |
| Apalaka H2 Tank | AP_H2 | 9397668 | 731751 |
| Yarik H1 Tank | YR_H1 | 9397172 | 732549 |
| Yarik H2 Tank | YR_H2 | 9397157 | 732803 |
| Yarik H3 Tank | YR_H3 | 9397392 | 732845 |
| Yarik School Tank | Yarik School | 9397325 | 733329 |
| Kulapi V1 H1 drum | KL_V1H1 | 9394334 | 733261 |
| Kulapi V2 H 1 tank | KL_V2H1 | 9394495 | 733045 |
| Kulapi V4 H1 tank | KL_V4H1 | 9394700 | 732772 |
| Panadaka 1 Joseph and Rueben Kiala Tank | PA_V1H8 | 9395580 | 733706 |
| Panadaka 1 Joseph Kiala Tank | PA_V1H9 | 9395509 | 733541 |
| Panadaka 1 Bilip Aile Tank | PA_V1H6 | 9395610 | 733666 |
| Panadaka 1 Panda Ekepa Tank | PA_V1H3 | 9395508 | 733674 |
| Panadaka 1 Catholic Church Tank | PA_V1H2 | 9395447 | 733689 |
| Panadaka 1 John Pokean Tank | PA_V1H5 | 9395598 | 733582 |
| Panadaka 1 Roselyn Pokean Tank | PA_V1H7 | 9395618 | 733682 |
| Panadaka 1 United Church Tank | PA_V1H10 | 9395573 | 733761 |
| Panadaka 1 Jack Inji Tank | PA_V1H1 | 9395455 | 733689 |
| Panadaka 1 Neslon Nai Tank | PA_V1H11 | 9395447 | 733606 |
| Panadaka 1 Bus David Yandapa Tank | PA_V1H4 | 9895578 | 733584 |
| Panadaka 2 Timothy Kerene Tank | PA_V2H4 | 9395743 | 733784 |
| Panadaka 2 Nickson Yambu Tank | PA_V2H2 | 9395857 | 733795 |
| Panadaka 2 Akena Pawa Tank | PA_V2H1 | 939577 | 733837 |

| Sites | Name on map | Easting | Northing |
|---|---|---|---|
| Panadaka 2 Tomson Kuna Tank | PA_V2H3 | 9395786 | 733792 |
| Wendako Spring | Wendako Spring | 9394941 | 734120 |
| Alipis Tank 1 | AL_T1 | 9395686 | 733348 |
| Alipis Tank 2 | AL_H2 | 9395775 | 733346 |
| Alipis Tank 3 | AL_H3 | 9395775 | 733346 |

The water quality test results for raw drinking water sites are presented in Table 7-23 and Table 7-24 and show the following exceedances of the PNG Raw Drinking Water Standard: low pH at 3 tanks; elevated alkalinity at Wendako Spring; elevated total solids at two tanks; elevated turbidity at 1 tank and bacterial contamination at 13 locations. Dissolved metals were very low in all of the water supplies sampled. The high number of water supply samples with bacterial contamination is very surprising given the very low level of contamination observed in the previous two years. The poor water quality is considered to be related to the drought conditions and very low water levels in the tanks, with some at or near empty during sampling in September. This restricted the ability to flush the taps adequately before sample collection and bacteria on the tap surface is likely a significant source of contamination. PJV will investigate this issue and will ensure that the taps are sterilized before sample collection for bacteriological analysis.

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.

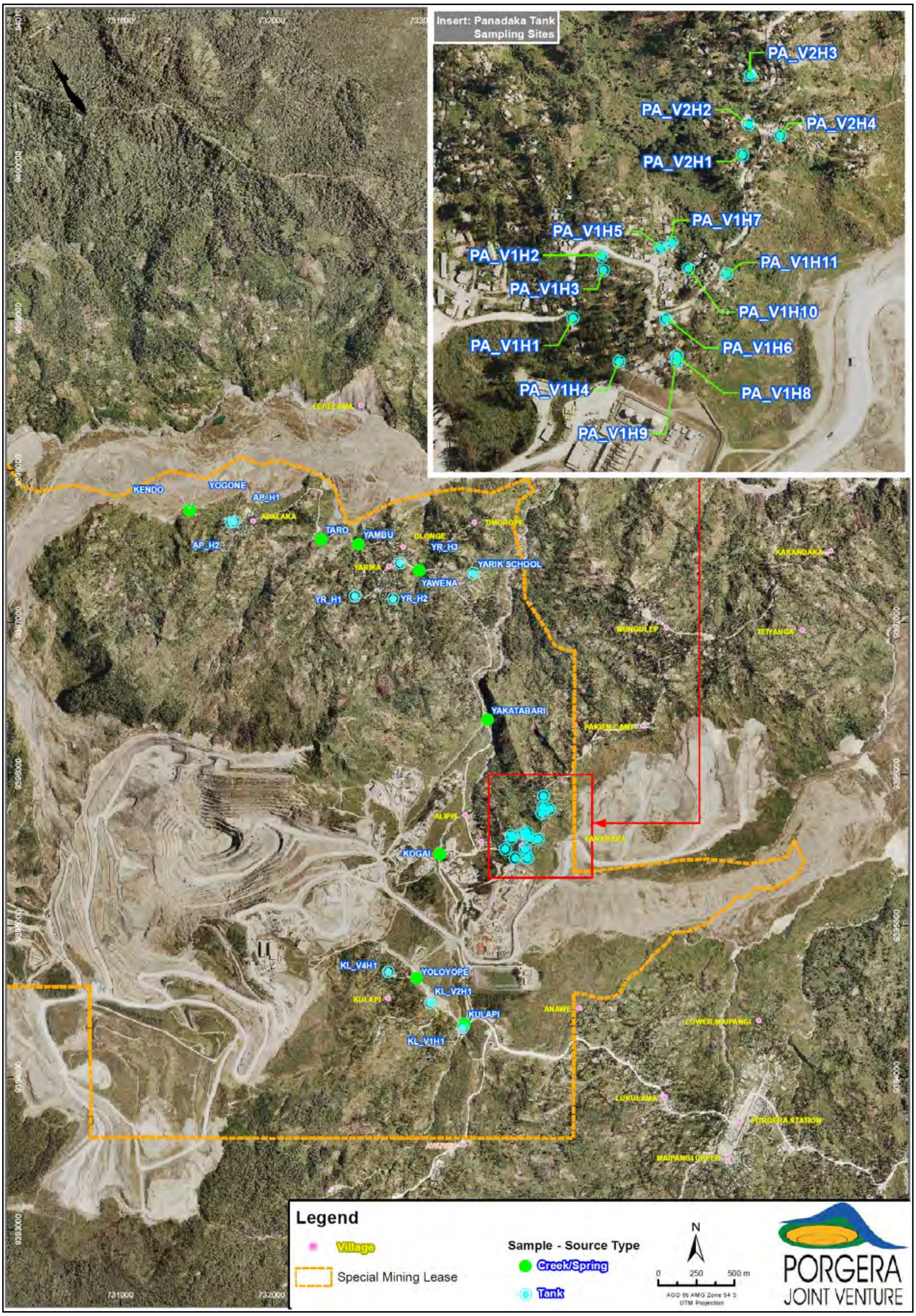



**Figure 7-15 Sampling sites for local village water supplies**

**Table 7-23 Physiochemical and biological water quality at drinking water sites against PNG Raw Drinking Water Quality Standard 2015**

| Site | pH | Conductivity | TSS | Sulfate | Chloride | Alkalinity | Total Solids | Turbidity | Color | Faecal Coliforms | Total Coliforms |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Units | SU | (µS/cm) | mg/L | mg/L | mg/L | mg/L | mg/L | NTU | hazen | (cfu/100mL) | (cfu/100mL) |
| Market Store | 6.1 | 11 | 2.0 | 1.0 | 2.7 | 14 | 10 | 0.2 | 5 | 1.0 | 15 |
| Apalaka H1 Tank | 5.3 | 12 | 1.0 | 2.0 | 3.4 | 11 | 5.0 | 1.2 | 5 | 0 | 2 |
| Apalaka H2 Tank | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Yarik H1 Tank | 7.0 | 8.5 | 11 | 1.0 | 2.7 | 11 | 180 | 1.1 | 5 | 0 | NR |
| Yarik H2 Tank | 6.6 | 7.7 | 0.0 | 0.0 | 2.7 | 11 | 5.0 | 1.3 | 5 | 20 | 23 |
| Yarik H3 Tank | 6.2 | 12 | 11 | 7.0 | 2.7 | 25 | 5.0 | 1.3 | 5 | 6.0 | 111 |
| Yarik School Tank | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Kulapi V1H1 Drum | 7.1 | 35 | 1.0 | 0.0 | 3.4 | 25 | 5.0 | 1.3 | 5 | 0 | 0 |
| Kulapi V2H1 Tank | 7.2 | 14 | 7.0 | 0.0 | 3.4 | 22 | 5.0 | 1.5 | 5 | 1.0 | 1 |
| Kulapi V4H1 Tank | 6.9 | 10 | 0.0 | 0.0 | 2.7 | 11 | 5.0 | 1.1 | 5 | 25 | 29 |
| Panandaka 1 J and R Kiala | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panandaka 1 Joseph Kiala | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panadaka 1 Bilip Aile Tank | 7.1 | 11 | 0.0 | 1.0 | 3.4 | 14 | 5.0 | 1.6 | 5 | 3.0 | 5 |
| Panandaka 1 P Ekepa | 7.4 | 14 | 0.0 | 1.0 | 2.7 | 11 | 5.0 | 1.4 | 5 | 26 | 30 |
| Panadaka 1 Cath Ch Tank | 7.8 | 17 | 10 | 6.0 | 4.7 | 16 | 5.0 | 1.3 | 5 | 0 | 3 |
| Panandaka 1 J Pokean | 6.8 | 85 | 1010 | 1.0 | 2.7 | 47 | 1200 | 90 | 5 | 3.0 | 121 |
| Panandaka 1 R Pokean | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panadaka 1 1 U Ch Tank | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panandaka 1 Jack Inji | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panandaka 1 Nelson Nai | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panadaka 1 BDY Tank | 7.1 | 18 | 0.0 | 1.0 | 2.7 | 19 | 5.0 | 1.5 | 5 | 2.0 | 3 |
| Panandaka 2 T Kerene | 6.5 | 15 | 1.0 | 1.0 | 2.7 | 11 | 5.0 | 1.5 | 5 | 27 | 64 |
| Panandaka 2 N Yambu | 6.8 | 14 | 0.0 | 0.0 | 2.7 | 14 | 5.0 | 1.2 | 5 | 0 | 12 |
| Panandaka 2 Akena Pawa | 6.9 | 17 | 0.0 | 1.0 | 2.7 | 14 | 5.0 | 1.2 | 5 | 1 | 1 |
| Panandaka 2 T Kuna | 6.7 | 7.8 | 0.0 | 0.0 | 2.7 | 14 | 5.0 | 1.2 | 5 | 40 | 61 |
| Wendako Spring | 7.3 | 360 | 4.0 | 5.0 | 3.4 | 216 | 150 | 2.3 | 5 | 99 | 101 |
| Alipis Tank 1 | 7.5 | 16 | 5.0 | 1.0 | 2.7 | 14 | 5.0 | 1.5 | 5 | 0 | 0 |
| Alipis Tank 2 | 7.2 | 15 | 9.0 | 1.0 | 2.7 | 11 | 5.0 | 1.1 | 5 | 0 | 0 |
| Alipis Tank 3 | 7.0 | 19 | 1.0 | 1.0 | 2.7 | 14 | 5.0 | 1.2 | 5 | 0 | 3.0 |
| **PNG (1984)** | **6.5 - 9.2** | **-** | **-** | **250** | **250** | **200** | **500** | **<5** | **15** | **0** | **<10** |

| | |
|---|---|
| (green) | Compliant |
| (orange) | Non-compliant |

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

NS - Not Sampled, NA - Not Applicable

**Table 7-24 Metal concentrations at drinking water sites against PNG Raw Drinking Water Quality Standard 2015 (ug/L)**

| Site | As | | Cd | | Cu | | Pb | | Hg | | Ni | | Se | | Zn | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | T | D | T | D | T | D | T | D | T | D | T | D | T | D | T |
| Market Store | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Apalaka H1 Tank | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Apalaka H2 Tank | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Yarik H1 Tank | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Yarik H2 Tank | 0.3 | 0.2 | 0.1 | 0.1 | 2.1 | 1.9 | 0.3 | 0.2 | 0.05 | 0.05 | 0.5 | 0.5 | 0.2 | 0.2 | 160 | 160 |
| Yarik H3 Tank | 0.1 | 0.1 | 0.1 | 0.14 | 0.5 | 0.5 | 0.1 | 0.1 | 0.05 | 0.05 | 0.5 | 0.5 | 0.2 | 0.2 | 390 | 410 |
| Yarik School Tank | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Kulapi V1H1 Drum | 0.13 | 0.1 | 0.1 | 0.1 | 0.5 | 0.5 | 0.1 | 0.1 | 0.05 | 0.05 | 0.5 | 0.5 | 0.2 | 0.2 | 710 | 660 |
| Kulapi V2H1 Tank | 0.1 | 0.1 | 0.1 | 0.1 | 0.5 | 0.5 | 0.1 | 0.1 | 0.05 | 0.05 | 0.5 | 0.5 | 0.2 | 0.2 | 110 | 100 |
| Kulapi V4H1 Tank | 0.1 | 0.13 | 0.1 | 0.1 | 0.5 | 0.5 | 0.2 | 0.2 | 0.05 | 0.05 | 0.5 | 0.5 | 0.2 | 0.2 | 260 | 240 |
| Panandaka 1 J and R Kiala | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panandaka 1 Joseph Kiala | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panadaka 1 Bilip Aile Tank | 0.1 | 0.15 | 0.1 | 0.1 | 2.6 | 2.6 | 0.2 | 0.1 | 0.05 | 0.05 | 0.5 | 0.5 | 0.2 | 0.2 | 490 | 460 |
| Panandaka 1 P Ekepa | 0.1 | 0.1 | 0.1 | 0.1 | 1.3 | 0.9 | 0.2 | 0.1 | 0.05 | 0.05 | 0.5 | 0.5 | 0.2 | 0.2 | 1440 | 1400 |
| Panadaka 1 Cath Ch Tank | 0.1 | 0.13 | 0.1 | 0.1 | 1.6 | 1.5 | 0.3 | 0.2 | 0.05 | 0.05 | 0.5 | 0.5 | 0.2 | 0.2 | 1490 | 1520 |
| Panandaka 1 J Pokean | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panandaka 1 R Pokean | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panadaka 1 1 U Ch Tank | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panandaka 1 Jack Inji | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panandaka 1 Nelson Nai | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panadaka 1 BDY Tank | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panandaka 2 T Kerene | 0.6 | 0.6 | 0.1 | 0.1 | 3.3 | 3.5 | 0.5 | 0.7 | 0.05 | 0.05 | 0.5 | 0.5 | 0.2 | 0.2 | 850 | 830 |
| Panandaka 2 N Yambu | 0.4 | 0.4 | 0.1 | 0.1 | 3.2 | 3.1 | 0.2 | 0.2 | 0.05 | 0.05 | 0.5 | 0.5 | 0.2 | 0.2 | 370 | 340 |
| Panandaka 2 Akena Pawa | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Panandaka 2 T Kuna | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Wendako Spring | 0.1 | 0.2 | 0.1 | 0.1 | 0.5 | 0.5 | 0.1 | 0.1 | 0.05 | 0.05 | 0.5 | 0.5 | 0.2 | 0.2 | 5.7 | 2.3 |
| Alipis Tank 1 | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Alipis Tank 2 | 0.3 | 0.6 | 0.1 | 0.4 | 0.7 | 1.1 | 1.9 | 20 | 0.05 | 0.05 | 0.5 | 0.5 | 0.2 | 0.2 | 1230 | 2200 |
| Alipis Tank 3 | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| **PNG (1984)** | **7** | **NA** | **2** | **NA** | **1,000** | **NA** | **10** | **NA** | **1** | **NA** | **20** | **NA** | **10** | **NA** | **3,000** | **NA** |

| | |
|---|---|
| (green) | Compliant |
| (orange) | Non-compliant |

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

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

## 7.5 Water-based activities

Various water-based activities undertaken by local community's results in contact with water: gold panning, bathing, 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 2015 are 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 cadmium, dissolved iron, dissolved nickel and dissolved zinc in tailings exceed the guideline values and therefore indicate potential risk to anyone exposed to the undiluted tailings slurry.

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 with contact with water - gold panning, bathing, 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 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 2015 median receiving water quality values with recreational exposure guidelines (µg/L)**

| 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 | 47 | 6.4 | 0.05 | 0.29 | 73 | 0.10 | 30 | 5,400 | 0.10 | 1,600 | 0.10 | 2.4 | 19,000 |
| SG1 | 6 | 7.4 | 0.05 | 1.5 | 1.4 | 0.1 | 1.8 | 14.3 | 0.05 | 3.5 | 0.18 | 0.25 | 31 |
| SG2 | 14 | 7.5 | 0.05 | 1.3 | 0.22 | 0.14 | 1.6 | 6.3 | 0.05 | 1.5 | 0.10 | 0.20 | 7.7 |
| Wasiba | 15 | 7.4 | 0.05 | 1.8 | 0.15 | 0.20 | 1.6 | 3.3 | 0.05 | 1.1 | 0.10 | 0.20 | 5.4 |
| Wankipe | 15 | 7.5 | 0.05 | 1.7 | 0.13 | 0.20 | 1.4 | 3.3 | 0.05 | 0.98 | 0.10 | 0.20 | 5.0 |
| SG3 | 192 | 7.6 | 0.05 | 1.7 | 0.07 | 0.17 | 1.6 | 4.8 | 0.05 | 0.67 | 0.10 | 0.20 | 4.3 |
| **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

## 7.6 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 2015 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 | 0.03 | 0.003 | 0.01 | 0.15 | 0.08 | 0.01 | 0.01 | 0.32 | 4.2 |
| | Prawn Abdo | 26 | 0.04 | 0.05 | 0.02 | 6.7 | 0.01 | 0.01 | 0.01 | 0.57 | 16 |
| Wankipe | Fish Flesh | 20 | 0.02 | 0.003 | 0.01 | 0.15 | 0.06 | 0.01 | 0.01 | 0.27 | 3.7 |
| | Prawn Abdo | 26 | 0.04 | 0.01 | 0.02 | 5.6 | 0.01 | 0.02 | 0.01 | 0.38 | 13 |
| Bebelubi | Fish Flesh | 0 | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| | Prawn Abdo | 16 | 0.12 | 0.01 | 0.02 | 8.5 | 0.01 | 0.01 | 0.01 | 0.33 | 16 |
| Tium-sinawam | Fish Flesh | 18 | 0.01 | 0.003 | 0.01 | 0.09 | 0.09 | 0.01 | 0.01 | 0.16 | 3.6 |
| | Prawn Abdo | 26 | 0.07 | 0.01 | 0.02 | 6.85 | 0.01 | 0.02 | 0.01 | 0.29 | 12 |
| **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** |
| (green) | Compliant | | | | | | | | | | |
| (orange) | 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

## 7.7 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 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.

**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

As discussed in Section 2.6, the inherent variability of the historical data set for biological indicators does not support the assessment method used for water, sediment and tissue metal, whereby impact assessment criteria are generated using the most recent 24-month data set, and test site medians (TSMs) are generated from the 2015 data set.

Therefore, to improve the applicability of the data, the historical data set has been amalgamated to identify long-term trends for each of the biological indicators, and impact assessment has been conducted based on a comparison of indicators between reference and test sites. However, it should be noted that this process has resulted in a considerable degree of uncertainty associated with the conclusions as the data can only provide an indication of impact, and not an absolute determination of impact. Consequently the findings are limited to prediction of whether potential impact is or is not indicated.

Porgera is continuing to improve its biological monitoring program to provide a more robust data set for biological indicators to support future assessments.

## 8.1 Fish and Prawns

### 8.1.1 Upper and Lower River

The results of the impact assessment at upper and lower river test sites are presented in Table 8-1 and Table 8-2 respectively.

The results show that in the upper river, no potential impact was indicated at Wasiba and Wankipe over time compared to the trends observed at reference sites.

In the lower river, potential impact was indicated at Bebelubi in the form of a reduced trend of prawn condition over time compared to the trend observed at reference sites, there was no potential impact indicated at Tiumsinawam.

**Table 8-1 Impact assessment – based on the trend of the annual median of biological indicators at upper river test sites relative to the trend of the annual median of biological indicators at upper river reference sites from 2011 - 2015 using Spearman Rank Test.**

| Site | Indicator | rho | P-Value | Impact assessment |
|---|---|---|---|---|
| Upper River Ref | Fish Abundance | 0.300 | 0.624 | No significant change over time |
| | Fish Richness | 0.577 | 0.308 | No significant change over time |
| | Fish Biomass | 0.100 | 0.624 | No significant change over time |
| | Fish Condition | 0.300 | 0.624 | No significant change over time |
| | Prawn Abundance | 0.700 | 0.188 | No significant change over time |
| | Prawn Richness | * | * | No significant change over time |
| | Prawn Biomass | 0.400 | 0.505 | No significant change over time |
| | Prawn Condition | 0.900 | 0.037 | No significant change over time |

| Site | Indicator | rho | P-Value | Impact assessment |
|---|---|---|---|---|
| Wasiba | Fish Abundance | 0.500 | 0.391 | No potential impact indicated |
| | Fish Richness | 0.577 | 0.308 | No potential impact indicated |
| | Fish Biomass | 0.900 | 0.037 | No potential impact indicated |
| | Fish Condition | 0.500 | 0.391 | No potential impact indicated |
| | Prawn Abundance | 0.900 | 0.037 | No potential impact indicated |
| | Prawn Richness | * | * | No potential impact indicated |
| | Prawn Biomass | 0.400 | 0.505 | No potential impact indicated |
| | Prawn Condition | 1.000 | * | No potential impact indicated |
| Wankipe | Fish Abundance | 0.300 | 0.624 | No potential impact indicated |
| | Fish Richness | 0.224 | 0.718 | No potential impact indicated |
| | Fish Biomass | 0.500 | 0.391 | No potential impact indicated |
| | Fish Condition | 0.700 | 0.188 | No potential impact indicated |
| | Prawn Abundance | 0.700 | 0.188 | No potential impact indicated |
| | Prawn Richness | * | * | No potential impact indicated |
| | Prawn Biomass | 0.700 | 0.188 | No potential impact indicated |
| | Prawn Condition | -0.300 | 0.624 | No potential impact indicated |

* Indicates all values within the data set are equal, therefore cannot support the Spearman Rank test but does indicate no significant change over time.

**Table 8-2 Impact assessment – based on the trend of the annual median of biological indicators at lower river test sites relative to the trend of the annual median of biological indicators at lower river reference sites from 2011 - 2015 using Spearman Rank Test.**

| Site | Indicator | rho | P-Value | Impact assessment |
|---|---|---|---|---|
| Lower River Ref | Fish Abundance | 0.667 | 0.219 | No significant change over time |
| | Fish Richness | -0.894 | 0.041 | Significant decrease over time |
| | Fish Biomass | 0.300 | 0.624 | No significant change over time |
| | Fish Condition | 0.700 | 0.188 | No significant change over time |
| | Prawn Abundance | -0.400 | 0.505 | No significant change over time |
| | Prawn Richness | * | * | No significant change over time |
| | Prawn Biomass | -0.400 | 0.505 | No significant change over time |
| | Prawn Condition | -0.400 | 0.505 | No significant change over time |
| Bebelubi | Fish Abundance | -0.564 | 0.322 | No potential impact indicated |
| | Fish Richness | -0.667 | 0.219 | No potential impact indicated |
| | Fish Biomass | -0.700 | 0.188 | No potential impact indicated |
| | Fish Condition | 0.900 | 0.037 | No potential impact indicated |
| | Prawn Abundance | -0.600 | 0.285 | No potential impact indicated |
| | Prawn Richness | 0.671 | 0.215 | No potential impact indicated |
| | Prawn Biomass | -0.600 | 0.285 | No potential impact indicated |
| | Prawn Condition | -0.900 | 0.037 | Potential impact indicated |

| Site | Indicator | rho | P-Value | Impact assessment |
|---|---|---|---|---|
| Tiumsinawam | Fish Abundance | 0.300 | 0.624 | No potential impact indicated |
| | Fish Richness | -0.359 | 0.553 | No potential impact indicated |
| | Fish Biomass | 0.300 | 0.624 | No potential impact indicated |
| | Fish Condition | 0.800 | 0.104 | No potential impact indicated |
| | Prawn Abundance | 0.200 | 0.747 | No potential impact indicated |
| | Prawn Richness | 0.671 | 0.215 | No potential impact indicated |
| | Prawn Biomass | -0.200 | 0.747 | No potential impact indicated |
| | Prawn Condition | 0.000 | 1.000 | No potential impact indicated |

* Indicates all values within the data set are equal, therefore cannot support the Spearman Rank test but does indicate no significant change over time.

### 8.1.2 Lake Murray

The results of impact assessment at Lake Murray are presented in Table 8-3for data recorded from 1993-2009. No potential impact was indicated at either of the test sites as evidenced by no difference in trend between the test and reference site for any of the indicators.

**Table 8-3 Impact assessment – based on the trend of the annual median of biological indicators at Lake Murray and ORWB test sites relative to the trend of the annual median of biological indicators at Lake Murray and ORWB reference sites from 1993 - 2009 using Spearman Rank Test.**

| Site | Indicator | rho | P-Value | Impact assessment |
|---|---|---|---|---|
| Lake Murray ORWBs Ref | Fish Abundance | -0.164 | 0.558 | No significant change over time |
| | Fish Richness | 0.087 | 0.759 | No significant change over time |
| | Fish Biomass | 0.111 | 0.694 | No significant change over time |
| | Fish Condition | -0.446 | 0.095 | No significant change over time |
| Central Lake | Fish Abundance | 0.441 | 0.058 | No potential impact indicated |
| | Fish Richness | 0.534 | 0.018 | No potential impact indicated |
| | Fish Biomass | 0.358 | 0.132 | No potential impact indicated |
| | Fish Condition | 0.425 | 0.070 | No potential impact indicated |
| Southern Lake | Fish Abundance | 0.061 | 0.789 | No potential impact indicated |
| | Fish Richness | 0.263 | 0.237 | No potential impact indicated |
| | Fish Biomass | -0.037 | 0.871 | No potential impact indicated |
| | Fish Condition | 0.185 | 0.411 | No potential impact indicated |

# 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 Environmental Management System (EMS), which is certified to ISO 14001 and has the objectives of consistently and effectively achieve compliance with legal obligations, mitigate risk and continually improve 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 2015 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.

The operational and environmental aspects of the mine in 2015 were comparable in most respects to previous years, with the exception of a significant increase in the volume of erodible waste rock that was disposed to Anjolek erodible dump, associated with mining Stage 5C at the pit rim.

The site achieved compliance with an average of 97% of the conditions of the environmental permits. Non-compliance related to elevated TSS in discharge from 3 of the 5 sewage treatment plants on at least one occasion throughout the year. The site achieved 100% compliance throughout November and December of 2015 and maintains a target of 100% compliance. Water quality at compliance point SG3 on the Strickland River was compliant with permit requirements throughout 2015.

Background environmental conditions in 2015 were characterised by a strong El Niño event which resulted in the second lowest annual rainfall total at the PJV Anawe plant site since 1974, and subsequently below average flow in the upper and lower rivers. Given that inputs from the mine are relatively consistent from year to year, particularly in recent history, the behavior of mine inputs throughout the receiving environment is largely dictated by flow rates of rivers within the receiving environment. Lower flows result in lower rates of dilution of mine inputs within the receiving environment.

Baseline water quality in the upper, lower rivers and Lake Murray indicates 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 show 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, lower rivers and Lake Murray indicates naturally elevated background concentrations of some metals were present downstream of the mine prior to the PJV commencing operations. Sediment quality data from reference sites show 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 reflect 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.

Risk assessment is performed by developing trigger values for physical and chemical parameters in water, benthic sediment, tissue metal and air using baseline, reference and guideline values which act as a benchmark for assessing concentrations in discharge and/or at test sites potentially influenced by mine discharge. Where an indicator 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.

The results of the risk assessment show that the low rainfall and subsequent low river flows that were experienced in 2015 due to the strong El Niño event, have decreased the moderating influence  river flows on the operation's environmental aspects within the receiving environment.

Low rainfall resulted in insufficient water supply from Waile Creek Dam and the ore processing plant was shut down for a number of days in 2015. Baseflow into the dam maintained a seep at the toe of the dam wall that releases approximately 100l/s to the downstream environment. Downstream of the water extraction point at Kogai Creek, flow was maintained throughout the year, albeit at a reduced rate at times due to low rainfall periods. Water extraction for the mine supply is considered to present low environmental risk because environmental flows were maintained in Waile and Kogai creeks.

Inputs from the mine in 2015 were consistent with recent years, with the exception of a slight reduction in sediment load from the erodible dumps to the river system, due to lower rainfall. Consistent input from the mine and lower flows in the receiving environment resulted in lower dilution rates with water and sediment from natural inputs. This is evidenced by higher TSS concentrations at SG1 compared to previous years and an increase in the proportion of mine derived TSS at SG3.

Within the receiving environment however, the increased proportion of mine derived TSS did not result in increased risk due to the physical effects of TSS. TSS concentrations at SG1 and Avu were above their respective TVs and therefore indicated potential risk at those locations. SG1 is 8km downstream of the mine and at the very upper extent of the receiving environment. The exceedance at Avu is not considered to represent significant risk, given the low suitability of the Lake Murray and ORWBs TV. Therefore, these exceedances are not considered representative of system-wide risk, and so overall the physical risk posed by TSS concentrations in water is considered low. However, the behavior of sediment and particulate metals within the receiving environment is an important consideration when assessing chemical risks.

Metals discharged from the minesite 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 behavior 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.<br><br>Bioavailable to aquatic organisms exposed to elevated dissolved concentrations of metals in the water column and in sediment pore water. |

| Metal form in discharge | Behaviour in receiving environment |
|---|---|
| Mineralised particulate - strongly bound in coarse fraction (>63µm) | Settle as benthic sediment in the upper river sections of the receiving environment.<br>Low bioavailability to aquatic organisms.<br>Low risk of re-mobilisation within the receiving environment due to alkaline conditions. |
| Mineralised particulate - strongly bound in fine fraction (<63µm) | 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.<br>Low bioavailability to aquatic organisms.<br>Low risk of re-mobilisation within the receiving environment due to alkaline conditions. |
| Particulate - weakly bound/adsorbed to coarse fraction (>63µm) | Settle as benthic sediment in the upper sections of the receiving environment.<br>Potentially bioavailable to aquatic organisms exposed to benthic sediment at discharge points and within the upper river.<br>Low risk of re-mobilisation within the receiving environment due to alkaline conditions. |
| Particulate - weakly bound/adsorbed to fine fraction (<63µm) | 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.<br>Potentially bioavailable to aquatic organisms exposed to suspended sediment in the water column throughout the entire receiving environment and to benthic sediment in the lower river, Lake Murray and ORWBs.<br>Low risk of re-mobilisation within the receiving environment due to alkaline conditions |

Concentrations of dissolved cadmium, copper, nickel and zinc are elevated in tailings, and concentrations of dissolved cadmium and zinc are elevated in discharge from Kogai and Anawe North competent waste rock dumps. Within the receiving environment the only elevated concentrations that are considered to pose potential risk are dissolved cadmium and zinc observed at SG1, 8km downstream of the mine. Downstream of SG1 the concentrations of dissolved metals pose low risk. This pattern suggests that concentrations of dissolved metals discharged from the site are reduced upon entering the receiving environment as a result of combination of dilution and adsorption to particulate matter.

There are two sources of mine-derived particulate metals within the receiving environment: particulate metals discharged from the site and particulate metals that are formed within the receiving environment from dissolved metals discharged from the site. The behavior of particulate metals within the receiving environment is dictated to a large degree by particle size, which will determine whether the particle will settle or remain in suspension. The strength of the bond formed between the metal and the particle, will determine whether the metal is weak acid extractable (WAE) or strongly bound and extractable only by strong acid digest (TD). The risk assessment focussed on WAE metals as these are the bioavailable fraction and therefore present a potential risk to the receiving environment.

The risk assessment concluded that potential risk was posed by: tailings sediment containing elevated WAE arsenic, cadmium, copper, lead, and zinc; sediment discharged from Kogai and Anawe North competent dumps containing elevated WAE lead and zinc; and sediment discharged from a number of other locations containing elevated WAE lead and zinc.

Within the receiving environment, WAE nickel in benthic sediment posed a risk at SG5, central and southern Lake Murray, SG6 and Avu, which are the furthest monitoring points downstream of the mine. WAE nickel concentrations in benthic sediment increased with increasing distance from the mine, which also was observed for WAE chromium, although WAE chromium concentrations did not pose a risk to the receiving environment. Given that the concentrations of WAE nickel in sediment discharged from the mine are relatively low, this trend suggests several possible explanations: that WAE nickel is enriched primarily in the fine fraction of tailings sediment; that nickel enrichment of the fine fraction of natural sediments is potentially occurring due to dissolved nickel adsorbing to fine, suspended sediment within the receiving water column; there is a natural source of nickel enriched fine sediment that has not been identified by the PJV monitoring program, and the fine sediment remains in suspension until reaching the lower sections of the river system, Lake Murray and ORWBs, where it settles and contributes to benthic sediment.

The risk assessment also showed that WAE lead in benthic sediment posed a risk to the receiving environment in the upper river at SG1, SG2, Wasiba and Wankipe, and in the ORWB Avu. WAE lead concentrations in sediment decreased from SG1 downstream to SG3 and then increased at SG5, SG6 and Avu. A similar pattern was observed for WAE arsenic, WAE cadmium, WAE copper and WAE zinc although WAE lead was the only metal to pose a risk. The concentration gradient suggests that lead is associated with both the coarse and fine fractions, with the coarse fraction settling in the upper river and the fine fraction remaining in suspension until reaching the lower sections of the river system, Lake Murray and ORWBs, where it settles as benthic sediment.

Concentrations of metals in fish tissue were low throughout the upper and lower rivers exhibiting low risk. Concentrations of metals in prawn abdomen indicated risk in the upper river at Wasiba and Wankipe, and in the lower river at Bebelubi and Tiumsinawam. However in most cases the metal concentrations in prawn tissue were not significantly different from the TV, so although potential risk is indicated, overall the aquatic ecosystem risk as a result of metals accumulation in prawn abdomen is considered low.

In addition to risks posed to the receiving environment, the operations 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 through dermal contact with undiluted tailings as a result of low pH and elevated concentrations of dissolved cadmium, iron, nickel and zinc. Fish and prawns at Wasiba and Wankipe in the upper river, and Bebelubi and Tiumsinawam in the lower river are fit for human consumption.

Additionally, localised risks to air quality are posed by elevated concentrations of oxides of nitrogen from the Anawe Generator and elevated particulate matter in discharge 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. | Tailings discharge:<br>- Elevated dissolved nickel in slurry<br>- Elevated WAE lead in solids<br>Contact runoff:<br>- 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. |
| Local water supplies | Low risk | |
| Water-based activities | Potential risk – limited to undiluted tailings at discharge point within SML and LMPs. | Tailings discharge :<br>- Low pH<br>- Elevated dissolved cadmium, iron, nickel and zinc. |
| Fish and prawn consumption | Low risk | |
| Air quality | Potential risk – limited to within SML and LMPs. | Power generation Anawe:<br>- Elevated $NO_x$ emissions from Anawe generator.<br>Lime production:<br>- Elevated particulate matter emissions from lime kiln. |

Impact assessment is performed based on biological indicators of aquatic ecosystem health at reference sites to confirm whether risks are resulting in actual impact to aquatic ecosystems. Potential impact is indicated where the trend of a biological indicator at a test site is declining relative to the trend at a reference site. Within the upper rivers, biological indicators show that potential impact is not occurring. In the lower rivers potential impact is indicated by a reduction in prawn condition at Bebelubi relative to the lower river reference sites, all other indicators show no potential impact. Biological monitoring in Lake Murray has not occurred since 2009 due to a lack of community support, data collected between 1993 and 2009 indicates no potential impact in Lake Murray.

Overall, the environmental performance of the operation in 2015 has been consistent with recent years. The site achieved a high level of compliance with legal obligations and the scope and magnitude of environmental aspects were consistent with recent years. An increase in risk to the receiving environment was noted in 2015, driven by consistent inputs from the mine coupled with reduced river flows and natural sediment inputs throughout the upper and lower rivers system resulting from the strong El Niño event which occurred throughout 2015. However, the condition of the receiving environment 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 2014 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 lower river, Lake Murray and ORWB reference and test sites;
2. Continue to investigate potential bioaccumulation pathways for contaminants of concern within the receiving environment;
3. Continue to improve the methods for sampling fish and prawn populations to improve catch rates, reduce within-site variability, therefore improving consistency and increasing statistical power;
4. Continue to conduct an annual macroinvertebrate survey to establish a robust data set, with the aim of incorporating macroinvertebrates as an additional indicator of impact into future annual environment reports;
5. Continue to revise the QA/QC procedures associated with tissue metal sampling;

**Reduce Environmental Risk and Impact and Improve Performance**

6. Continue to investigate options for reducing the bioavailability of metals within the receiving environment;
7. Continue to implement the Waste Rock Management Plan to minimise the release of metalliferous drainage from the competent waste rock dumps.

**Communication and Engagement**

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

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## APPENDIX A. BOX PLOTS EXPLAINED

In a box plot, shown in Figure A-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) |

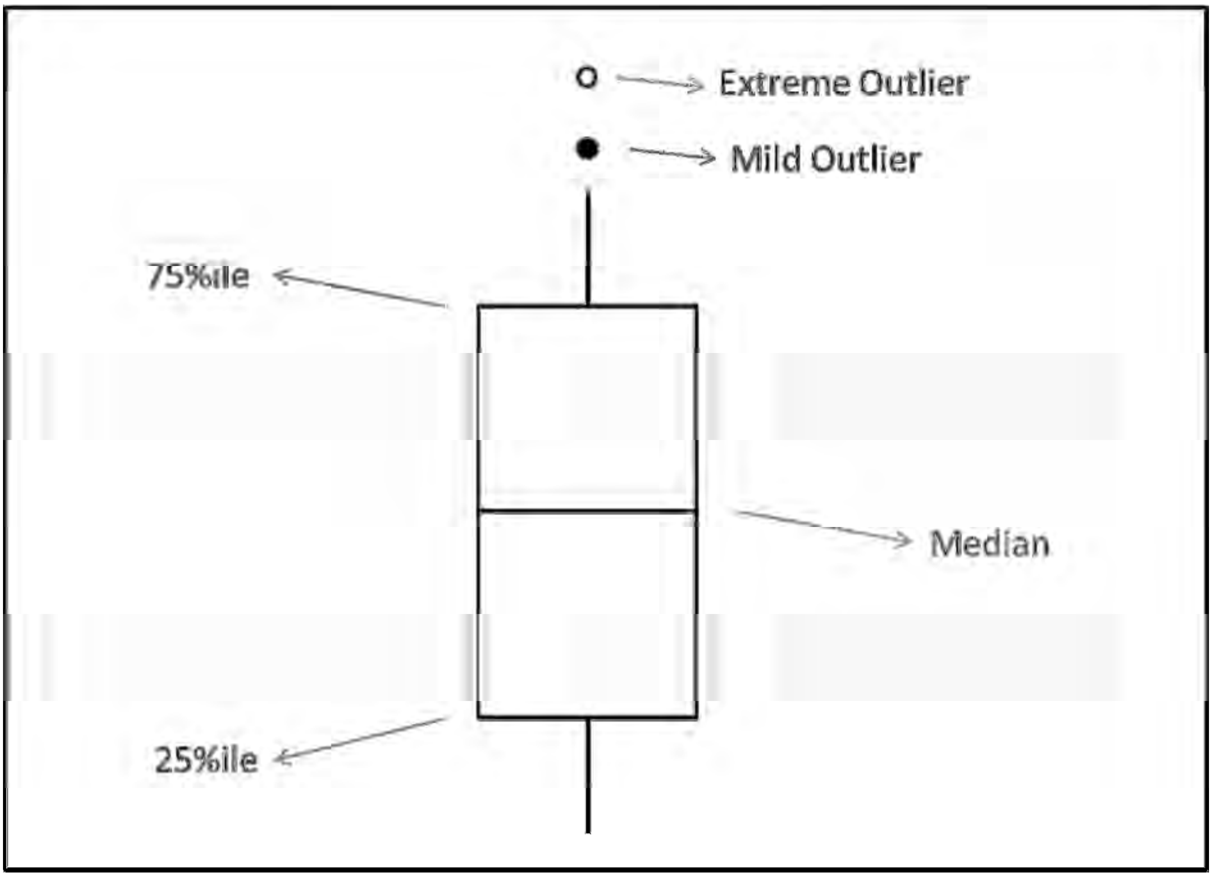



**Figure A-1 Box Plot**

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 B. QA/QC

Collection of environmental monitoring data is performed by the PJV Environment Department. The team consists of 19 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 2015 was performed by the National Measurement Institute (NMI) in Sydney Australia. NMI 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 & 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 B-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 B-1.

**Table B-1 QA/QC Samples – Water and Sediment Quality**

| QA/QC Sample | Purpose | Sample rate | Acceptance Criteria |
|---|---|---|---|
| Combined field, method and transport blank<br><br>(water only) | Test for contamination during field work, sample preparation and transport.<br><br>Test for accuracy of laboratory analytical method. | 1 blank per sample batch | ≤ LOR for each analyte |
| Field duplicate | Test repeatability of laboratory analytical method. | 1 duplicate for every 8 samples (minimum 1 per batch) | ± 44% of primary sample |
| NMI lab duplicate | Test repeatability of laboratory analytical method. | 1 blank per sample batch | ± 44% of primary sample |
| NMI lab control sample | Test influence of sample preparation and analysis on recovery. | 1 blank per sample batch | 75% – 120% recovery |
| NMI matrix spike | Test influence of sample preparation and analysis on recovery. | 1 blank per sample batch | 75% – 120% recovery |

The results of QA/QC samples from water quality sampling at SG3 in 2015 are shown in Table B-2 and indicate good performance for the majority of QA/QC samples across the majority of parameters. The exception is the performance of the combined blank for dissolved zinc, where 18% of results exceeded the LOR. This indicates that zinc contamination of the blank occurred during the sample collection, transport and analysis process. It should be noted that the highest concentration recorded was four-times the LOR and is considered extremely low. However, SOPs and training are being revised to ensure the risk of contamination is minimised.

**Table B-2 2015 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 | 96 | 100 | 92 | 100 | 82 | 96 | 100 |
| CRM | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Field Duplicate | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 92 | 100 |
| NMI Duplicate | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| NMI Lab Control Sample | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| NMI Matrix Spike | 100 | 100 | 100 | 100 | 100 | 92 | 100 | 100 | 100 | 100 | 100 | 100 |

D = Dissolved fraction

The results of QA/QC samples from sediment quality sampling at SG3 in 2015 are shown in Table B-3 and indicate good performance of all samples for all parameters with the exception of field duplicates for copper and lead. The cause of poor performance of copper and lead duplicates is not known, however the review of SOPs and increased focus on training and competency is expected in improve the QA/QC performance and will facilitate a more timely investigation of non-compliant QA/QC results.

**Table B-3 2015 Sediment quality QA/QC sample results SG3**

| | % Within Acceptable Criteria | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Type** | **Ag - WAE** | **As - WAE** | **Cd - WAE** | **Cr - WAE** | **Cu - WAE** | **Hg - WAE** | **Ni - WAE** | **Pb - WAE** | **Se - WAE** | **Zn - WAE** |
| Field Duplicate | 97 | 90 | 93 | 90 | 87 | 90 | 90 | 77 | 100 | 90 |
| NMI Duplicate | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| NMI Matrix Spike | 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 2015 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 B-4. The results showed good performance across most analysis, with the exception of oil and grease, pH and TSS.

**Table B-4 Proficiency testing results 2015**

| **Date** | **Analyte** | **Lab result** | **MU** | **Median** | **NORM IQR** | **CV (%)** | **n** | **z-score** |
|---|---|---|---|---|---|---|---|---|
| March 2015 | Oil & Grease | 30.1 | 0.3 | 71.7 | 7.41 | 10.3 | 41 | -5.61 |
| | | 22.8 | 0.3 | 44.0 | 5.00 | 11.4 | 39 | -4.24 |
| April 2015 | Alkalinity | 62.9 | 24 | 50.80 | 4.34 | 8.5 | 47 | 2.79 |
| | Chloride | 103 | 9.4 | 94.8 | 2.48 | 2.6 | 47 | 3.3 |
| | Conductivity | 516 | 32 | 507 | 10.4 | 2.0 | 57 | 0.87 |
| | Sulphate | 32 | 2.6 | 32.5 | 1.52 | 4.7 | 47 | -0.33 |
| | Total Dissolved Solids | 333 | 4.9 | 328.5 | 19.1 | 5.8 | 42 | 0.24 |
| | Total Solids | 361 | 90 | 334 | 22.2 | 6.7 | 38 | 1.21 |
| July 2015 | Sulphate | 13.7 | 5.0 | 13.3 | 0.52 | 3.9 | 49 | 0.77 |
| | Conductivity | 292.8 | 5.0 | 294.0 | 7.8 | 2.6 | 63 | -0.15 |
| | pH – potable | 6.11 | 0.5 | 6.69 | 0.089 | 1.3 | 67 | -6.52 |
| | pH - standard | 7.22 | 0.2 | 7.16 | 0.044 | 0.6 | 67 | 1.35 |
| | Colour | 22.5 | 5 | 21 | 3.2 | 15.4 | 34 | 0.46 |
| August 2015 | BOD | 89.0 | 25.3 | 89.9 | | | 30 | na |
| | COD | 124 | 15 | 146 | 9.5 | 6.5 | 30 | -2.33 |
| August 2015 | Total Solids | 544 | 40 | 541 | 14.1 | 2.6 | 33 | 0.21 |
| | Total Solids | 328 | 40 | 358 | 14.8 | 4.1 | 33 | -2.02 |
| | Total Suspended Solids | 48 | 10 | 45.5 | 4.45 | 9.8 | 45 | 0.56 |
| | Total Suspended Solids | 73.2 | 10 | 97.6 | 5.93 | 5.1 | 45 | -4.11 |
| September 2015 | WAD-CN | 0.080 | 0.008 | 0.1060 | 0.0158 | 14.9 | 20 | -1.65 |
| | WAD-CN | 4.50 | 0.2 | 5.28 | 0.445 | 8.4 | 20 | -1.75 |

| | |
|---|---|
| (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 B-5.

**Table B-5 QA/QC samples – tissue metals**

| QA/QC Sample | Purpose | Sample rate | Acceptance Criteria |
|---|---|---|---|
| Field reference sample<br>(Fish flesh of known concentration) | Test for contamination during field work, sample preparation and transport.<br>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.<br>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 2015 are shown in Table B-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 copper, nickel and zinc 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 B-6 2015 Tissue metal QA/QC sample results**

| | % Within Acceptable Criteria | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | n | As | Cd | Cr | Cu | Hg | Ni | Pb | Se | Zn |
| Field Duplicate | 16 | 88 | 88 | 81 | 88 | 100 | 69 | 100 | 100 | 100 |
| Field Reference Sample | 43 | 68 | 100 | 42 | 86 | 95 | 74 | 100 | 100 | 86 |
| NMI Blank | 10 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| NMI Duplicate | 10 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| NMI Lab Control Sample | 10 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| NMI Matrix Spike | 10 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

### Internal Quality Audits

Internal audits are performed at six-monthly intervals to assess the department's compliance with the Porgera Monitoring Auditing and Reporting Plan and associated SOPs. The findings of the audits are captured in a corrective action log.

The monitoring and reporting program is also subject to ISO 14001 external audits, International Cyanide Management Code external audits and Barrick Corporate external audits.

### 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 C. BOX PLOTS AND TRENDS OF MINE AREA RUNOFF WATER QUALITY 1994 – 2015

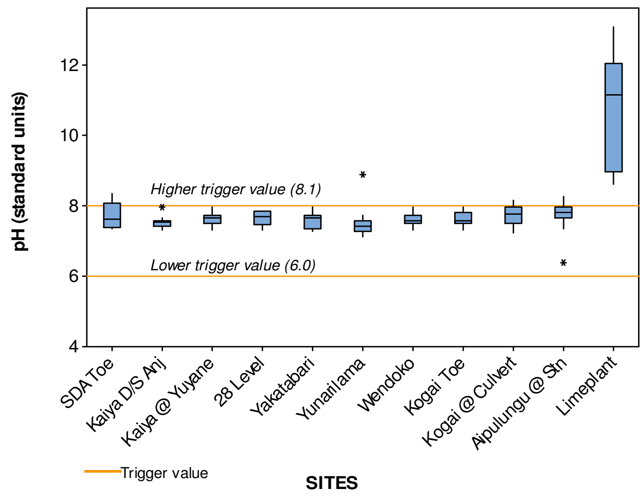



**Figure C-1 pH in mine contact runoff 2015**

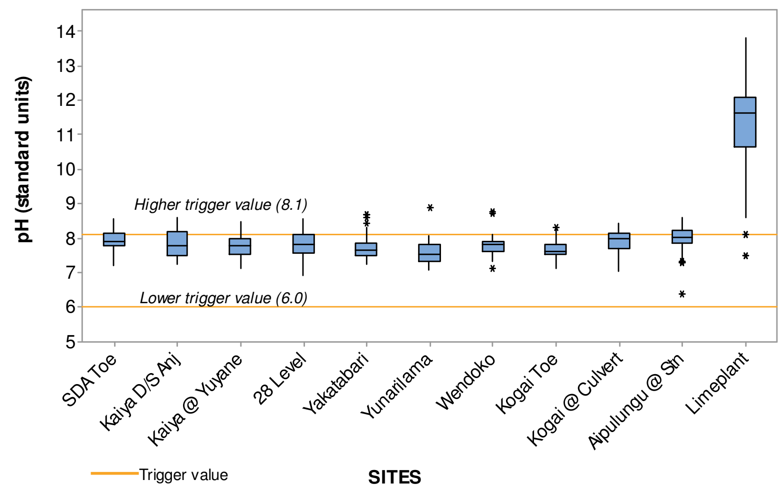



**Figure C-2 pH in mine contact runoff 2011 - 2015**

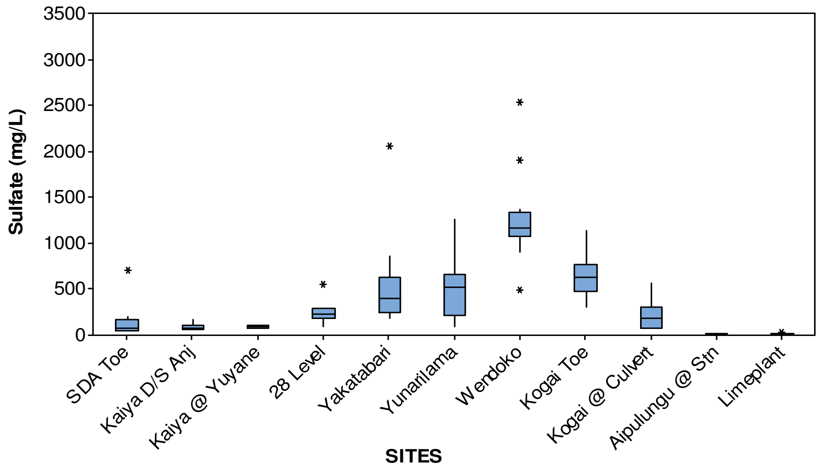



**Figure C-3 Sulfate in mine contact runoff 2015**

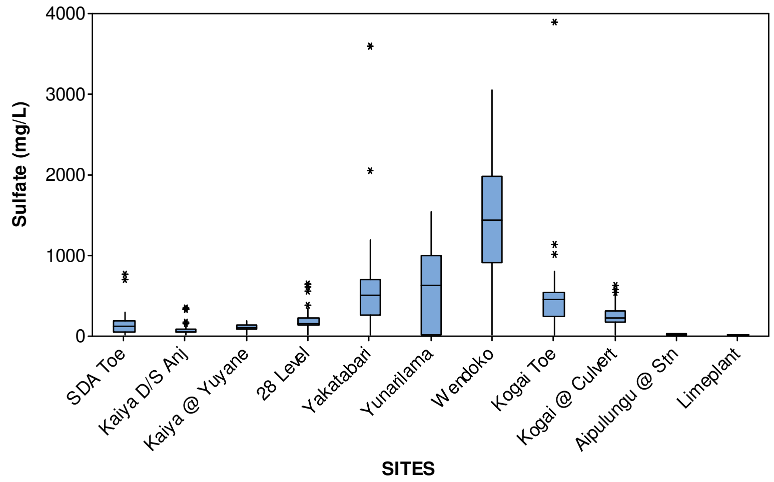



**Figure C-4 Sulfate in mine contact runoff 2011 - 2015**

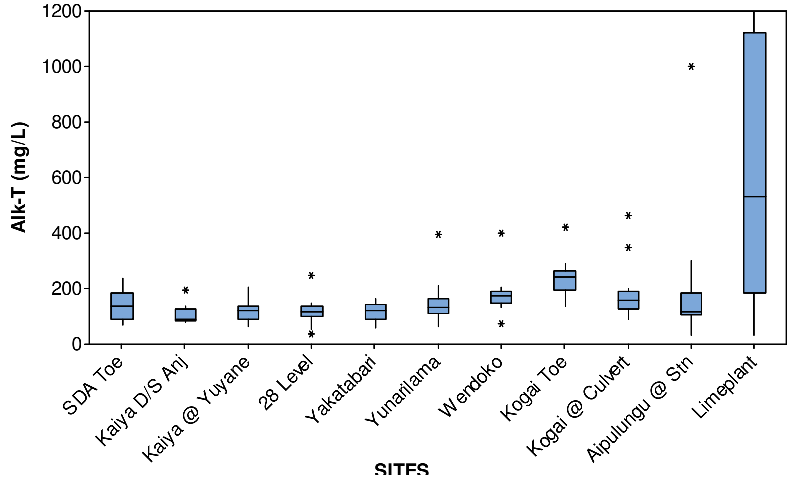



**Figure C-5 Alkalinity of contact runoff 2015**

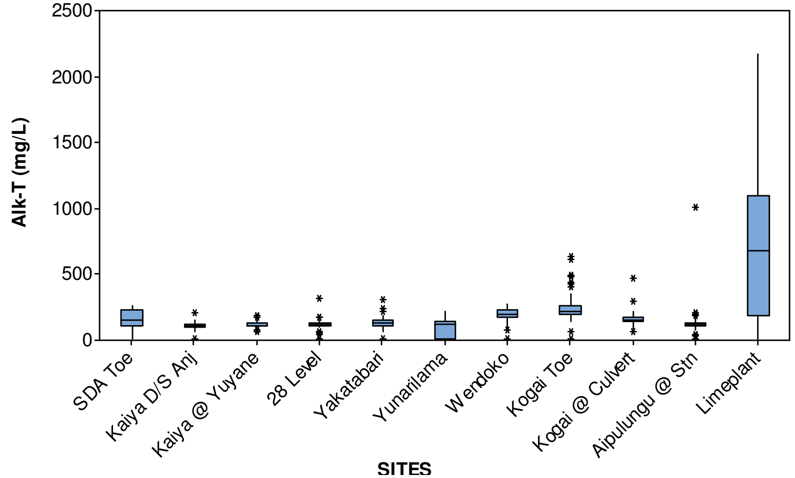



**Figure C-6 Alkalinity of contact runoff 2011 - 2015**

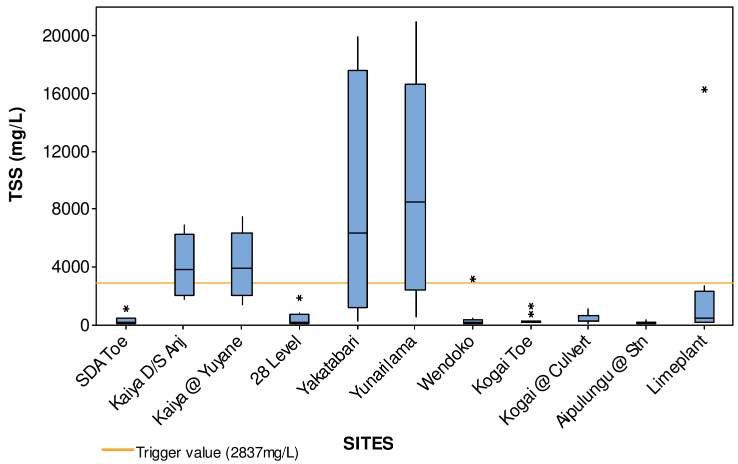



**Figure C-7 TSS in contact runoff 2015**

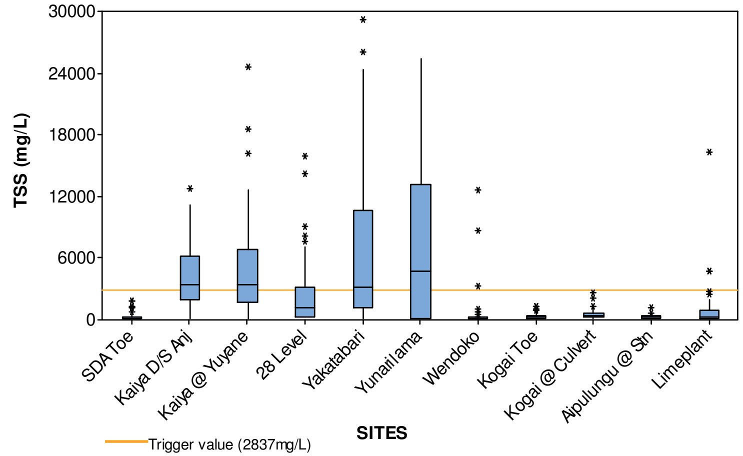



**Figure C-8 TSS in contact runoff 2011 - 2015**

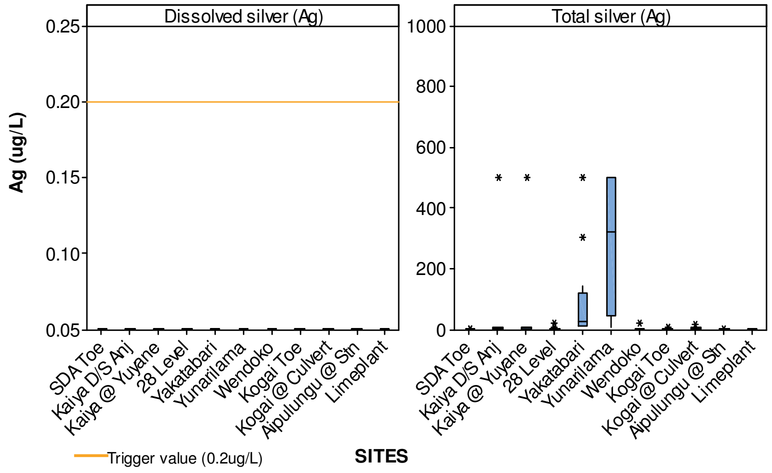



**Figure C-9 Dissolved and total silver in contact runoff 2015**

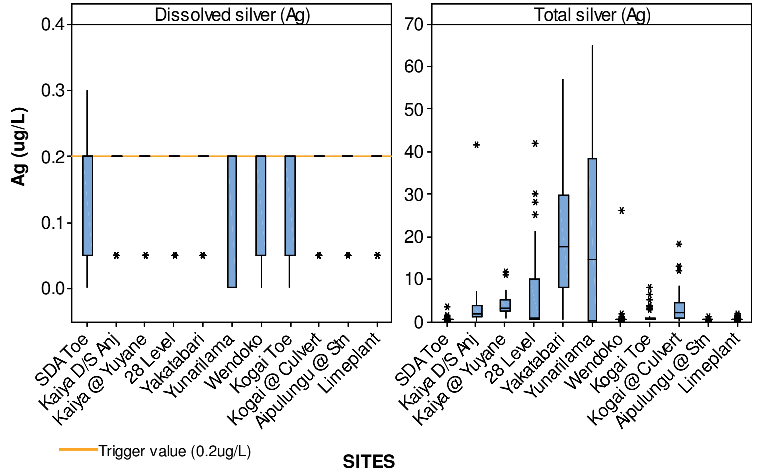



**Figure C-10 Dissolved and total silver in contact runoff 2011 - 2015**

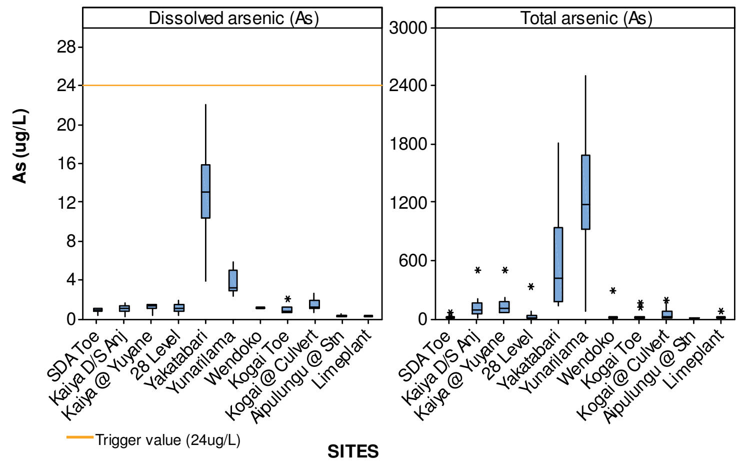



**Figure C-11 Dissolved and total arsenic in contact runoff 2015**

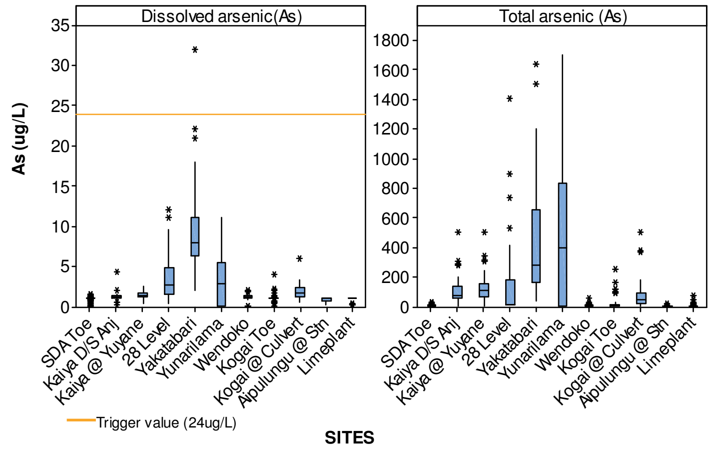



**Figure C-12 Dissolved and total arsenic in contact runoff 2011 - 2015**

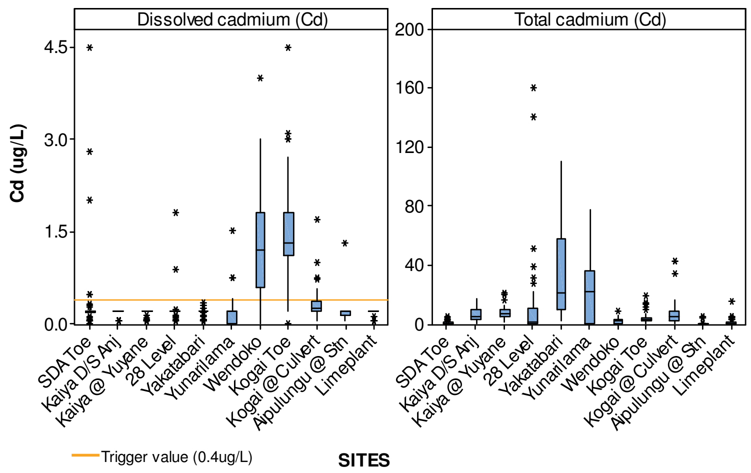



**Figure C-13 Dissolved and total cadmium in contact runoff 2015**

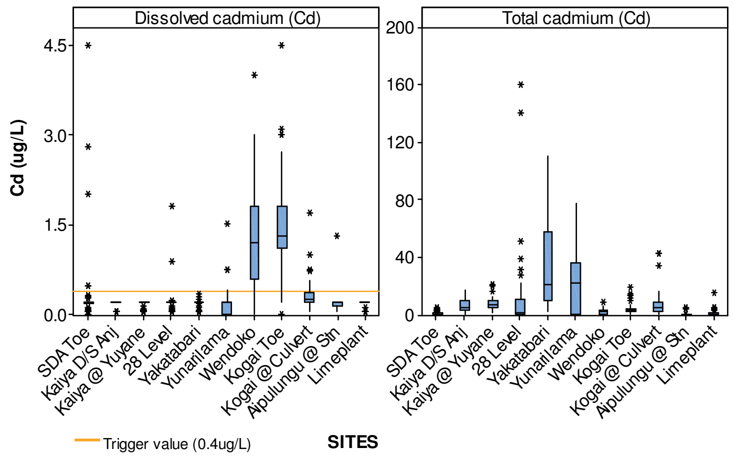



**Figure C-14 Dissolved and total cadmium contact runoff 2011 - 2015**

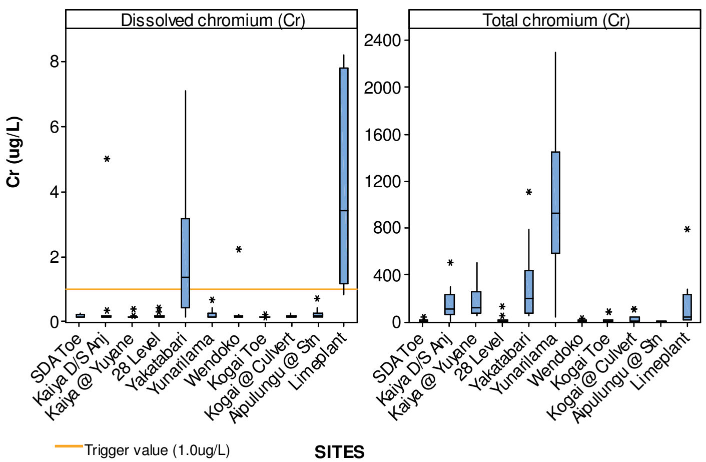



**Figure C-15 Dissolved and total chromium in contact runoff 2015**

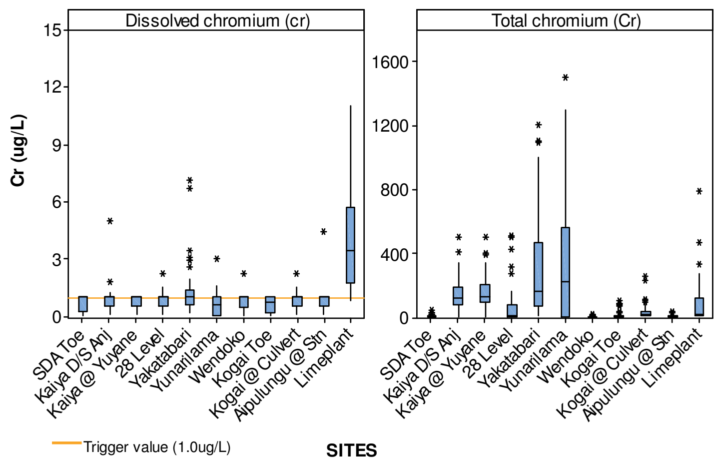



**Figure C-16 Dissolved and total chromium in contact runoff 2011 - 2015**

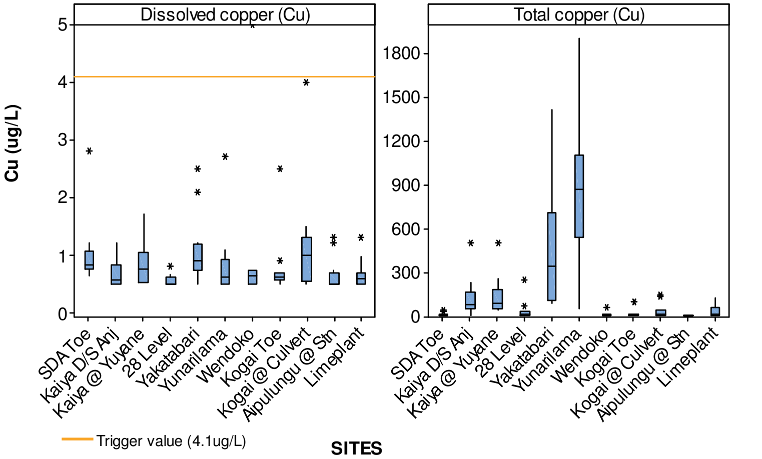



**Figure C-17 Dissolved and total copper in contact runoff 2015**

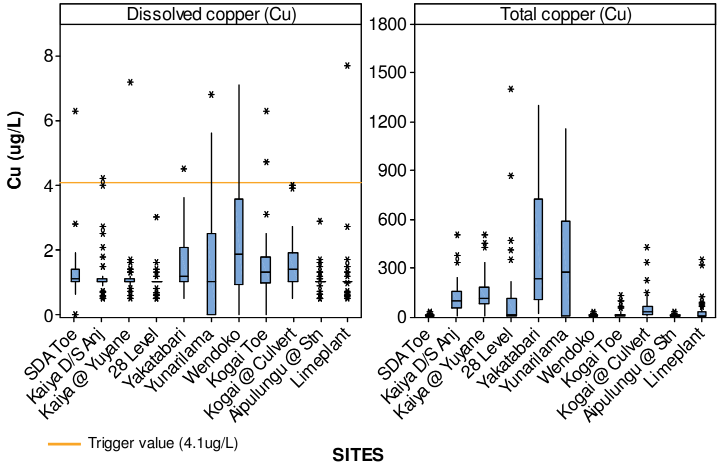



**Figure C-18 Dissolved and total copper contact runoff 2011 - 2015**

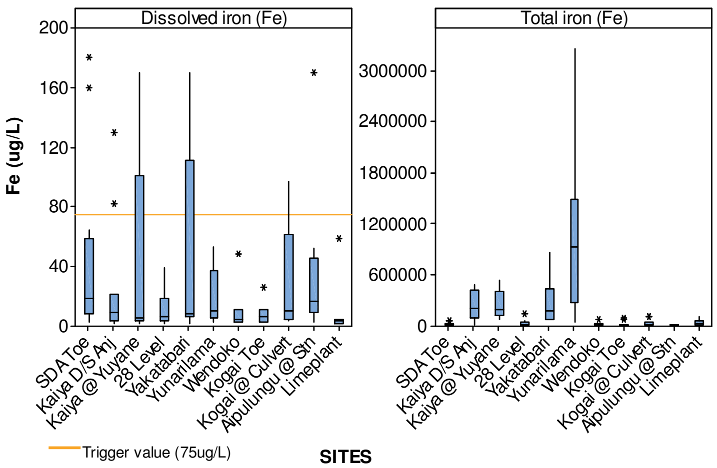



**Figure C-19 Dissolved and total iron in contact runoff 2015**

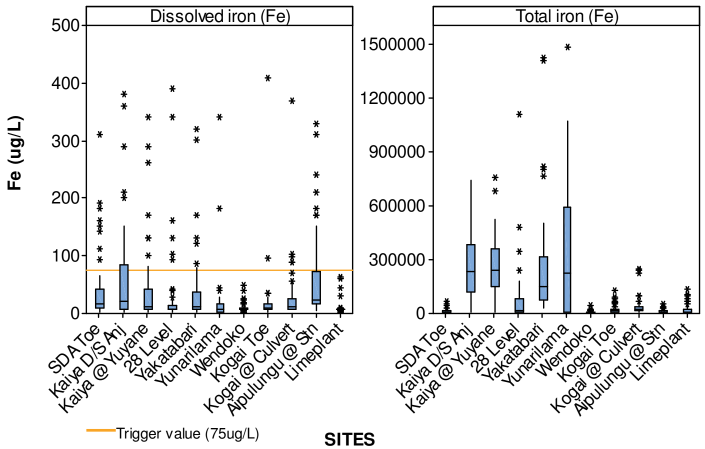



**Figure C-20 Dissolved and total iron in contact runoff 2011 - 2015**

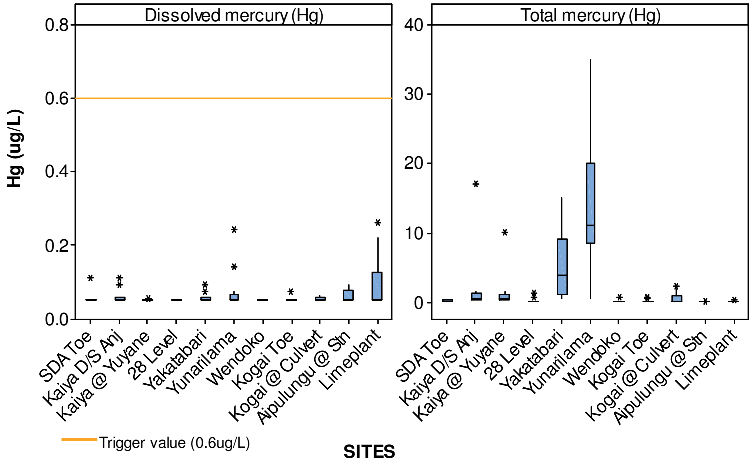



**Figure C-21 Dissolved and total mercury in contact runoff 2015**

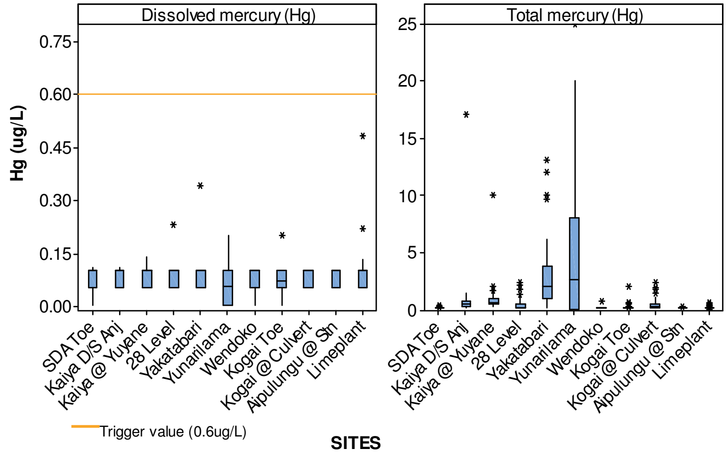



**Figure C-22 Dissolved and total mercury in contact runoff 2011 - 2015**

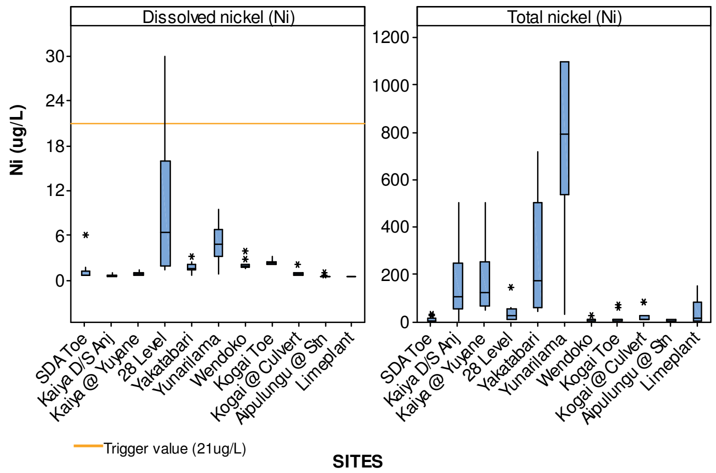



**Figure C-23 Dissolved and total nickel in contact runoff 2015**

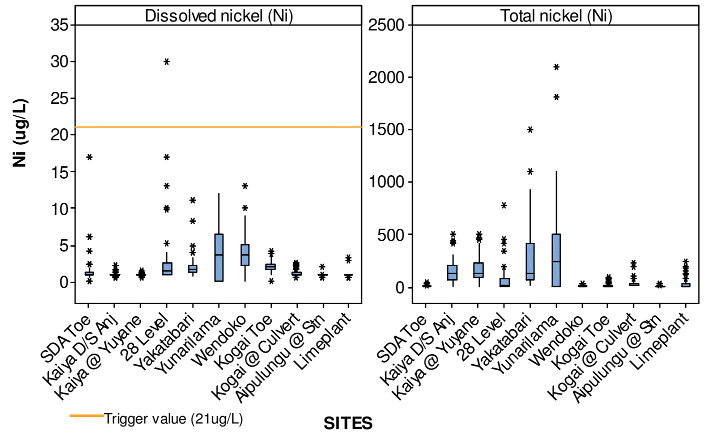



**Figure C-23 Dissolved and total nickel in contact runoff 2011 - 2015**

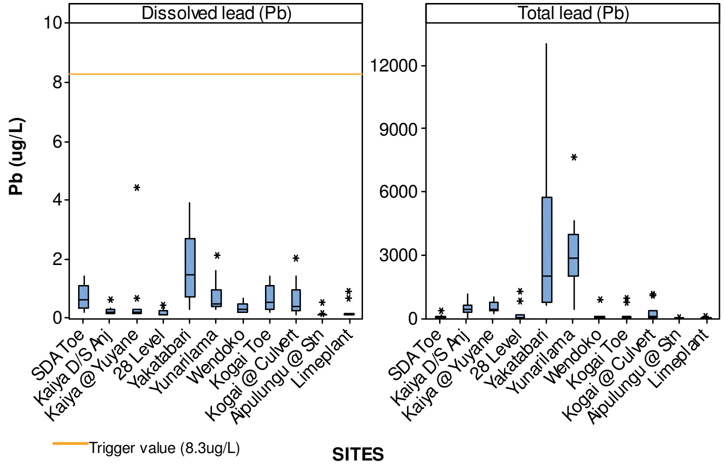



**Figure C-24 Dissolved and total lead in contact runoff 2015**

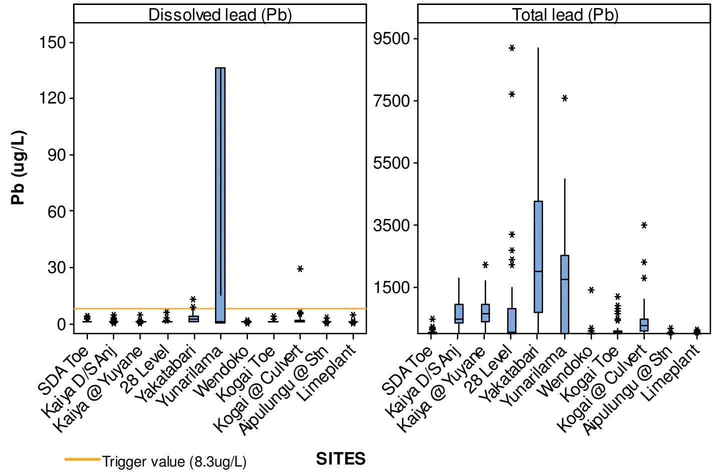



**Figure C-25 Dissolved and total lead contact runoff 2011 - 2015**

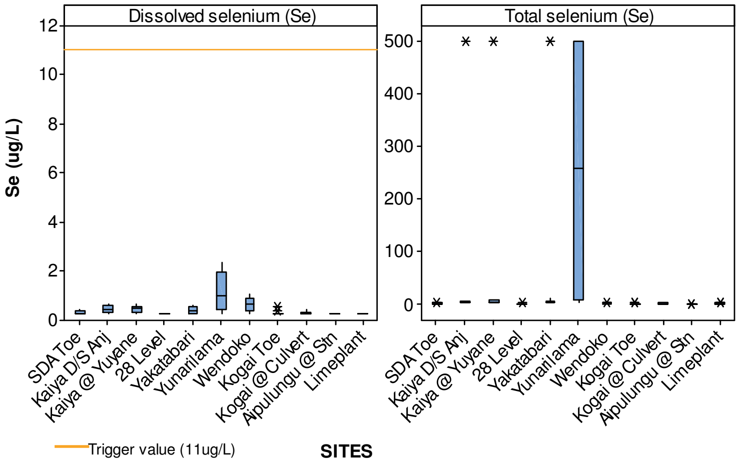



**Figure C-25 Dissolved and total selenium in contact runoff 2015**

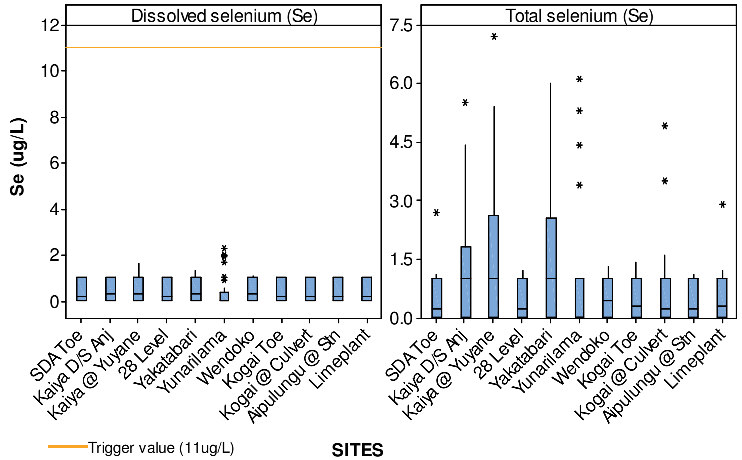



**Figure C-26 Dissolved and total selenium in contact runoff 2011 - 2015**

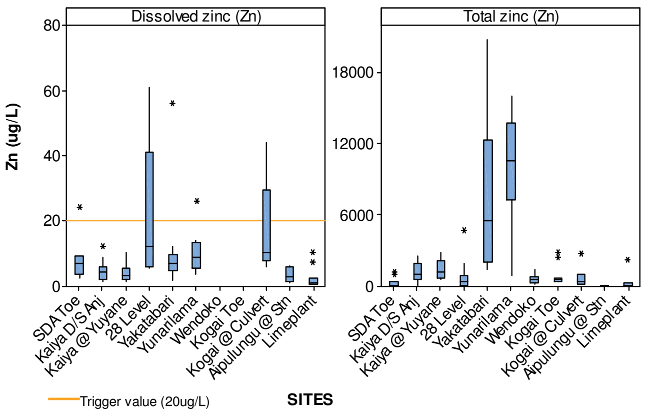



**Figure C-27 Dissolved and total zinc in contact runoff 2015**

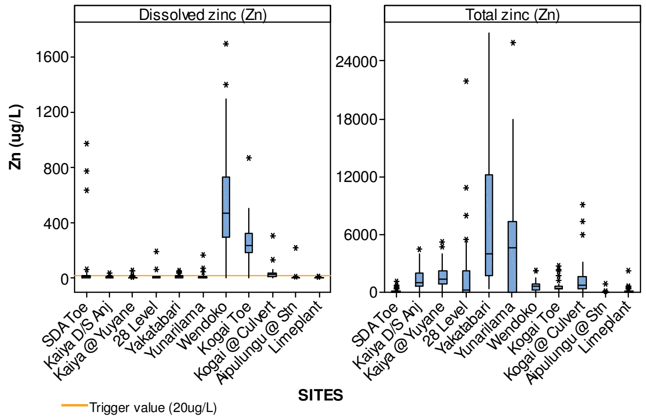



**Figure C-28 Dissolved and total zinc in contact runoff 2011 - 2015**

**Table C-1 SDA Toe 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.574 | <0.001 | Decrease |
| Sulfate | -0.495 | <0.001 | Decrease |
| ALK-T | -0.218 | 0.117 | Decrease |
| TSS | 0.267 | 0.053 | Increase |
| Ag-D* | -0.726 | <0.001 | No change |
| Ag-T* | -0.253 | 0.068 | No change |
| As-D* | -0.481 | <0.001 | No change |
| As-T | 0.061 | 0.665 | No change |
| Cd-D* | -0.659 | <0.001 | No change |
| Cd-T | -0.144 | 0.416 | No change |
| Cr-D* | -0.984 | <0.001 | No change |
| Cr-T | -0.056 | 0.693 | No change |
| Cu-D* | -0.465 | <0.001 | No change |
| Cu-T | -0.017 | 0.904 | No change |
| Fe-D | 0.097 | 0.491 | No change |
| Fe-T | 0.039 | 0.781 | No change |
| Hg-D* | -0.742 | <0.001 | No change |
| Hg-T* | -0.419 | 0.002 | No change |
| Ni-D* | -0.436 | 0.001 | No change |
| Ni-T | 0.026 | 0.856 | No change |
| Pb-D* | -0.367 | 0.007 | No change |
| Pb-T | -0.054 | 0.699 | No change |
| Se-D* | -0.822 | <0.001 | No change |
| Se-T* | -0.700 | <0.001 | No change |
| Zn-D | -0.334 | 0.016 | Decrease |
| Zn-T | -0.002 | 0.989 | 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 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.730 | <0.001 | Decrease |
| Sulfate | 0.162 | 0.267 | No change |
| ALK-T | 0.026 | 0.858 | No change |
| TSS | -0.327 | 0.020 | Decrease |
| Ag-D* | -0.775 | <0.001 | No change |
| Ag-T | -0.156 | 0.268 | No change |
| As-D* | -0.118 | 0.404 | No change |
| As-T | -0.321 | 0.020 | Decrease |
| Cd-D* | -0.760 | <0.001 | No change |
| Cd-T | -0.321 | 0.020 | Decrease |
| Cr-D* | -0.750 | <0.001 | No change |
| Cr-T | -0.324 | 0.019 | Decrease |
| Cu-D* | -0.628 | <0.001 | No change |
| Cu-T | -0.393 | 0.004 | Decrease |
| Fe-D | -0.259 | 0.064 | No change |
| Fe-T | -0.456 | 0.001 | Decrease |
| Hg-D* | -0.733 | <0.001 | No change |
| Hg-T* | 0.039 | 0.784 | No change |
| Ni-D* | -0.629 | <0.001 | No change |
| Ni-T | -0.347 | 0.012 | Decrease |
| Pb-D* | -0.618 | <0.001 | No change |
| Pb-T | -0.462 | 0.001 | Decrease |
| Se-D* | -0.823 | <0.001 | No change |
| Se-T | 0.105 | 0.583 | No change |
| Zn-D | 0.057 | 0.691 | No change |
| Zn-T | -0.433 | 0.001 | Decrease |

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 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.593 | <0.001 | Decrease |
| Sulfate | -0.545 | <0.001 | Decrease |
| ALK-T | 0.074 | 0.600 | No change |
| TSS | -0.190 | 0.182 | No change |
| Ag-D* | -0.753 | <0.001 | No change |
| Ag-T | -0.147 | 0.298 | No change |
| As-D | -0.021 | 0.885 | No change |
| As-T | -0.097 | 0.493 | No change |
| Cd-D* | -0.753 | <0.001 | No change |
| Cd-T | -0.277 | 0.047 | Decrease |
| Cr-D* | -0.841 | <0.001 | No change |
| Cr-T | -0.180 | 0.201 | No change |
| Cu-D* | -0.276 | 0.048 | No change |
| Cu-T | -0.346 | 0.012 | Decrease |
| Fe-D | -0.163 | 0.248 | No change |
| Fe-T | -0.376 | 0.007 | Decrease |
| Hg-D* | -0.844 | <0.001 | No change |
| Hg-T | -0.080 | 0.571 | No change |
| Ni-D* | -0.249 | 0.076 | No change |
| Ni-T | -0.275 | 0.048 | Decrease |
| Pb-D* | -0.431 | 0.001 | No change |
| Pb-T | -0.447 | 0.001 | Decrease |
| Se-D* | -0.816 | <0.001 | No change |
| Se-T | 0.080 | 0.672 | No change |
| Zn-D | 0.052 | 0.716 | No change |
| Zn-T | -0.267 | 0.056 | 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-4 28 Level 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.335 | 0.012 | Decrease |
| Sulfate | 0.244 | 0.078 | No change |
| ALK-T | -0.058 | 0.672 | No change |
| TSS | -0.661 | <0.001 | Decrease |
| Ag-D* | -0.744 | <0.001 | No change |
| Ag-T* | -0.598 | <0.001 | No change |
| As-D | -0.826 | <0.001 | Decrease |
| As-T | -0.540 | <0.001 | Decrease |
| Cd-D | -0.219 | 0.105 | No change |
| Cd-T | -0.419 | 0.001 | Decrease |
| Cr-D* | -0.872 | <0.001 | No change |
| Cr-T | -0.872 | <0.001 | Decrease |
| Cu-D* | -0.675 | <0.001 | No change |
| Cu-T | -0.437 | 0.001 | Decrease |
| Fe-D | -0.134 | 0.324 | No change |
| Fe-T | -0.447 | 0.001 | Decrease |
| Hg-D* | -0.847 | <0.001 | No change |
| Hg-T* | -0.489 | <0.001 | No change |
| Ni-D | 0.542 | <0.001 | Increase |
| Ni-T | -0.350 | 0.008 | Decrease |
| Pb-D* | -0.636 | <0.001 | No change |
| Pb-T | -0.497 | <0.001 | Decrease |
| Se-D* | -0.864 | <0.001 | No change |
| Se-T* | -0.655 | <0.001 | No change |
| Zn-D | 0.251 | 0.064 | No change |
| Zn-T | -0.421 | 0.001 | Decrease |

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 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.370 | 0.006 | Decrease |
| Sulfate | -0.345 | 0.012 | Decrease |
| ALK-T | -0.226 | 0.100 | No change |
| TSS | -0.137 | 0.324 | No change |
| Ag-D* | -0.749 | <0.001 | No change |
| Ag-T | 0.040 | 0.771 | No change |
| As-D | 0.382 | 0.004 | Increase |
| As-T | -0.080 | 0.563 | No change |
| Cd-D* | -0.589 | <0.001 | No change |
| Cd-T | 0.020 | 0.884 | No change |
| Cr-D | 0.015 | 0.911 | No change |
| Cr-T | -0.106 | 0.443 | No change |
| Cu-D* | -0.392 | 0.003 | No change |
| Cu-T | -0.047 | 0.731 | No change |
| Fe-D | -0.003 | 0.985 | No change |
| Fe-T | -0.184 | 0.182 | No change |
| Hg-D* | -0.770 | <0.001 | No change |
| Hg-T | 0.316 | 0.019 | Increase |
| Ni-D | -0.075 | 0.586 | No change |
| Ni-T | -0.146 | 0.289 | No change |
| Pb-D | -0.094 | 0.494 | No change |
| Pb-T | -0.036 | 0.794 | No change |
| Se-D* | -0.770 | <0.001 | No change |
| Se-T | 0.120 | 0.507 | No change |
| Zn-D | -0.062 | 0.654 | No change |
| Zn-T | -0.036 | 0.792 | 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 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.498 | 0.002 | Decrease |
| Sulfate | -0.651 | <0.001 | Decrease |
| ALK-T | 0.140 | 0.402 | No change |
| TSS | -0.116 | 0.487 | No change |
| Ag-D* | -0.852 | <0.001 | No change |
| Ag-T | 0.678 | <0.001 | Increase |
| As-D | -0.223 | 0.177 | No change |
| As-T | 0.558 | <0.001 | Increase |
| Cd-D* | -0.369 | 0.023 | No change |
| Cd-T | 0.485 | 0.002 | Increase |
| Cr-D* | -0.795 | <0.001 | No change |
| Cr-T | 0.545 | <0.001 | Increase |
| Cu-D* | -0.585 | <0.001 | No change |
| Cu-T | 0.539 | <0.001 | Increase |
| Fe-D | -0.118 | 0.478 | No change |
| Fe-T | 0.346 | 0.036 | Increase |
| Hg-D* | -0.606 | <0.001 | Increase |
| Hg-T | 0.599 | <0.001 | Increase |
| Ni-D | -0.064 | 0.703 | No change |
| Ni-T | 0.527 | 0.001 | Increase |
| Pb-D* | -0.786 | <0.001 | No change |
| Pb-T | 0.367 | 0.024 | Increase |
| Se-D* | -0.185 | 0.476 | No change |
| Se-T | 0.674 | 0.003 | Increase |
| Zn-D | 0.132 | 0.435 | No change |
| Zn-T | 0.449 | 0.005 | Increase |

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 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.440 | 0.001 | Decrease |
| Sulfate | -0.219 | 0.119 | No change |
| ALK-T | -0.550 | <0.001 | Decrease |
| TSS | -0.038 | 0.786 | No change |
| Ag-D* | -0.758 | <0.001 | No change |
| Ag-T* | -0.347 | 0.010 | No change |
| As-D | -0.552 | <0.001 | Decrease |
| As-T | -0.097 | 0.486 | No change |
| Cd-D* | -0.464 | <0.001 | No change |
| Cd-T | -0.459 | <0.001 | Decrease |
| Cr-D* | -0.796 | <0.001 | No change |
| Cr-T* | -0.227 | 0.099 | No change |
| Cu-D* | -0.607 | <0.001 | No change |
| Cu-T | -0.364 | 0.007 | Decrease |
| Fe-D | -0.072 | 0.608 | No change |
| Fe-T | -0.107 | 0.446 | No change |
| Hg-D* | -0.860 | <0.001 | No change |
| Hg-T* | -0.475 | <0.001 | No change |
| Ni-D | -0.795 | <0.001 | Decrease |
| Ni-T | -0.524 | <0.001 | Decrease |
| Pb-D* | -0.553 | <0.001 | No change |
| Pb-T | -0.106 | 0.446 | No change |
| Se-D* | -0.780 | <0.001 | No change |
| Se-T* | -0.713 | <0.001 | No change |
| Zn-D | -0.655 | <0.001 | Decrease |
| Zn-T | -0.591 | <0.001 | Decrease |

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 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | 0.044 | 0.767 | No change |
| Sulfate | 0.257 | 0.075 | No change |
| ALK-T | -0.192 | 0.187 | No change |
| TSS | 0.048 | 0.745 | No change |
| Ag-D* | -0.770 | <0.001 | No change |
| Ag-T* | -0.292 | 0.041 | No change |
| As-D* | -0.206 | 0.155 | No change |
| As-T | 0.048 | 0.742 | No change |
| Cd-D | 0.335 | 0.019 | Increase |
| Cd-T | 0.252 | 0.081 | No change |
| Cr-D* | -0.905 | <0.001 | No change |
| Cr-T | -0.015 | 0.917 | No change |
| Cu-D | -0.435 | 0.002 | No change |
| Cu-T | -0.056 | 0.701 | No change |
| Fe-D | -0.210 | 0.147 | No change |
| Fe-T | 0.021 | 0.888 | No change |
| Hg-D* | -0.835 | <0.001 | No change |
| Hg-T* | -0.462 | 0.001 | No change |
| Ni-D | 0.451 | 0.001 | Increase |
| Ni-T | 0.019 | 0.896 | No change |
| Pb-D | -0.032 | 0.828 | No change |
| Pb-T | -0.001 | 0.997 | No change |
| Se-D* | -0.847 | <0.001 | No change |
| Se-T* | -0.708 | <0.001 | No change |
| Zn-D | 0.396 | 0.005 | Increase |
| Zn-T | 0.163 | 0.264 | 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-9 Kogai at Culvert 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.397 | 0.002 | Decrease |
| Sulfate | -0.527 | <0.001 | Decrease |
| ALK-T | -0.169 | 0.209 | No change |
| TSS | -0.080 | 0.556 | No change |
| Ag-D* | -0.770 | <0.001 | No change |
| Ag-T | -0.183 | 0.173 | No change |
| As-D | -0.322 | 0.014 | Decrease |
| As-T | -0.249 | 0.061 | No change |
| Cd-D* | -0.456 | <0.001 | No change |
| Cd-T | -0.169 | 0.210 | No change |
| Cr-D* | -0.864 | <0.001 | No change |
| Cr-T | -0.107 | 0.427 | No change |
| Cu-D | -0.343 | 0.009 | Decrease |
| Cu-T | -0.177 | 0.187 | No change |
| Fe-D | 0.028 | 0.839 | No change |
| Fe-T | -0.017 | 0.903 | No change |
| Hg-D* | -0.836 | <0.001 | No change |
| Hg-T* | 0.005 | 0.970 | No change |
| Ni-D* | -0.355 | 0.007 | No change |
| Ni-T | -0.159 | 0.238 | No change |
| Pb-D* | -0.415 | 0.001 | No change |
| Pb-T | -0.235 | 0.079 | No change |
| Se-D* | -0.840 | <0.001 | No change |
| Se-T* | -0.506 | 0.003 | No change |
| Zn-D | -0.328 | 0.014 | Decrease |
| Zn-T | -0.208 | 0.121 | 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 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.578 | <0.001 | Decrease |
| Sulfate | -0.653 | <0.001 | Decrease |
| ALK-T | 0.176 | 0.194 | No change |
| TSS | -0.301 | 0.024 | Decrease |
| Ag-D* | -0.759 | <0.001 | No change |
| Ag-T* | -0.740 | <0.001 | No change |
| As-D* | -0.710 | <0.001 | No change |
| As-T* | -0.385 | 0.003 | No change |
| Cd-D* | -0.676 | <0.001 | No change |
| Cd-T* | -0.709 | <0.001 | No change |
| Cr-D* | -0.855 | <0.001 | No change |
| Cr-T | -0.282 | 0.034 | Decrease |
| Cu-D* | -0.456 | <0.001 | No change |
| Cu-T | -0.360 | 0.006 | Decrease |
| Fe-D | -0.213 | 0.111 | No change |
| Fe-T | -0.320 | 0.016 | Decrease |
| Hg-D* | -0.803 | <0.001 | No change |
| Hg-T* | -0.772 | <0.001 | No change |
| Ni-D* | -0.716 | <0.001 | No change |
| Ni-T | -0.332 | 0.012 | Decrease |
| Pb-D* | -0.665 | <0.001 | No change |
| Pb-T | -0.285 | 0.032 | Decrease |
| Se-D* | -0.602 | <0.001 | No change |
| Se-T* | -0.597 | <0.001 | No change |
| Zn-D | -0.341 | 0.010 | Decrease |
| Zn-T | -0.317 | 0.016 | Decrease |

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 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.246 | 0.070 | No change |
| Sulfate | -0.445 | 0.001 | Decrease |
| ALK-T | -0.191 | 0.162 | No change |
| TSS | 0.284 | 0.037 | Increase |
| Ag-D* | -0.774 | <0.001 | No change |
| Ag-T | -0.224 | 0.097 | No change |
| As-D* | -0.722 | <0.001 | No change |
| As-T | 0.221 | 0.102 | No change |
| Cd-D* | -0.682 | <0.001 | No change |
| Cd-T | 0.026 | 0.848 | No change |
| Cr-D | 0.076 | 0.576 | No change |
| Cr-T | 0.342 | 0.010 | Increase |
| Cu-D* | -0.503 | <0.001 | No change |
| Cu-T | 0.277 | 0.039 | Increase |
| Fe-D* | -0.462 | <0.001 | No change |
| Fe-T | 0.253 | 0.062 | No change |
| Hg-D* | -0.482 | <0.001 | No change |
| Hg-T* | -0.368 | 0.005 | No change |
| Ni-D* | -0.630 | <0.001 | No change |
| Ni-T | 0.267 | 0.046 | Increase |
| Pb-D* | -0.364 | 0.006 | No change |
| Pb-T | 0.290 | 0.030 | Increase |
| Se-D* | -0.864 | <0.001 | No change |
| Se-T* | -0.564 | <0.001 | No change |
| Zn-D | -0.137 | 0.320 | No change |
| Zn-T | 0.300 | 0.024 | Increase |

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 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.408 | 0.002 | Decrease |
| Sulfate | -0.623 | <0.001 | Decrease |
| ALK-T | 0.311 | 0.021 | Increase |
| TSS | -0.082 | 0.555 | No change |
| Ag-D* | -0.675 | <0.001 | No change |
| Ag-T* | -0.729 | <0.001 | No change |
| As-D* | -0.716 | <0.001 | No change |
| As-T* | -0.657 | <0.001 | No change |
| Cd-D* | -0.699 | <0.001 | No change |
| Cd-T* | -0.714 | <0.001 | No change |
| Cr-D* | -0.752 | <0.001 | No change |
| Cr-T* | -0.447 | <0.001 | No change |
| Cu-D* | -0.557 | <0.001 | No change |
| Cu-T* | -0.468 | <0.001 | No change |
| Fe-D | -0.302 | 0.022 | Decrease |
| Fe-T | -0.435 | 0.001 | Decrease |
| Hg-D* | -0.821 | <0.001 | No change |
| Hg-T* | -0.638 | <0.001 | No change |
| Ni-D* | -0.729 | <0.001 | No change |
| Ni-T* | -0.363 | 0.006 | No change |
| Pb-D* | -0.657 | <0.001 | No change |
| Pb-T* | -0.393 | 0.003 | No change |
| Se-D* | -0.864 | <0.001 | No change |
| Se-T* | -0.834 | <0.001 | No change |
| Zn-D | -0.152 | 0.263 | Decrease |
| Zn-T | -0.374 | 0.004 | Decrease |

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 Dam 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.371 | 0.004 | Decrease |
| Sulfate | -0.822 | <0.001 | Decrease |
| ALK-T | 0.736 | <0.001 | Increase |
| TSS | 0.205 | 0.124 | No change |
| Ag-D* | -0.766 | <0.001 | No change |
| Ag-T* | -0.767 | <0.001 | No change |
| As-D* | -0.730 | <0.001 | No change |
| As-T* | 0.710 | <0.001 | No change |
| Cd-D* | -0.647 | <0.001 | No change |
| Cd-T* | -0.720 | <0.001 | No change |
| Cr-D* | -0.870 | <0.001 | No change |
| Cr-T* | -0.783 | <0.001 | No change |
| Cu-D* | -0.593 | <0.001 | No change |
| Cu-T* | -0.497 | <0.001 | No change |
| Fe-D | 0.011 | 0.937 | No change |
| Fe-T | -0.444 | 0.001 | Decrease |
| Hg-D* | -0.724 | <0.001 | No change |
| Hg-T* | -0.693 | <0.001 | No change |
| Ni-D* | -0.715 | <0.001 | No change |
| Ni-T* | -0.555 | <0.001 | No change |
| Pb-D* | -0.697 | <0.001 | No change |
| Pb-T* | -0.583 | <0.001 | No change |
| Se-D* | -0.874 | <0.001 | No change |
| Se-T* | -0.830 | <0.001 | No change |
| Zn-D | 0.256 | 0.054 | Increase |
| Zn-T | -0.501 | <0.001 | Decrease |

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 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.558 | <0.001 | Decrease |
| Sulfate | -0.401 | 0.003 | Decrease |
| ALK-T | 0.210 | 0.128 | No change |
| TSS | -0.260 | 0.058 | No change |
| Ag-D* | -0.770 | <0.001 | No change |
| Ag-T* | -0.645 | <0.001 | No change |
| As-D* | -0.582 | <0.001 | No change |
| As-T* | -0.498 | <0.001 | No change |
| Cd-D* | -0.713 | <0.001 | No change |
| Cd-T* | -0.713 | <0.001 | No change |
| Cr-D* | -0.886 | <0.001 | No change |
| Cr-T* | -0.293 | 0.030 | No change |
| Cu-D* | -0.638 | <0.001 | No change |
| Cu-T* | -0.330 | 0.014 | No change |
| Fe-D | -0.233 | 0.087 | No change |
| Fe-T | -0.348 | 0.010 | Decrease |
| Hg-D* | -0.788 | <0.001 | No change |
| Hg-T* | -0.574 | <0.001 | No change |
| Ni-D* | -0.758 | <0.001 | No change |
| Ni-T | -0.267 | 0.049 | Decrease |
| Pb-D* | -0.754 | <0.001 | No change |
| Pb-T | -0.396 | 0.003 | Decrease |
| Se-D* | -0.847 | <0.001 | No change |
| Se-T* | -0.769 | <0.001 | No change |
| Zn-D | -0.026 | 0.853 | No change |
| Zn-T | -0.300 | 0.026 | Decrease |

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 2011 - 2015 (trend of annual median)**

| Parameter | Spearman's rho | P-Value (P=0.05) | Trend |
|---|---|---|---|
| pH | -0.596 | <0.001 | Decrease |
| Sulfate | -0.589 | <0.001 | Decrease |
| ALK-T | 0.048 | 0.716 | No change |
| TSS | 0.020 | 0.879 | No change |
| Ag-D* | -0.751 | <0.001 | No change |
| Ag-T* | -0.710 | <0.001 | No change |
| As-D* | -0.723 | <0.001 | No change |
| As-T* | -0.657 | <0.001 | No change |
| Cd-D* | -0.681 | <0.001 | No change |
| Cd-T* | -0.751 | <0.001 | No change |
| Cr-D* | -0.850 | <0.001 | No change |
| Cr-T* | -0.355 | 0.005 | No change |
| Cu-D* | -0.437 | <0.001 | No change |
| Cu-T* | -0.412 | 0.001 | No change |
| Fe-D | -0.211 | 0.105 | No change |
| Fe-T | -0.351 | 0.006 | Decrease |
| Hg-D* | -0.801 | <0.001 | No change |
| Hg-T* | -0.580 | <0.001 | No change |
| Ni-D* | -0.703 | <0.001 | No change |
| Ni-T* | -0.450 | <0.001 | No change |
| Pb-D* | -0.704 | <0.001 | No change |
| Pb-T* | -0.485 | <0.001 | No change |
| Se-D* | -0.874 | <0.001 | No change |
| Se-T* | -0.833 | <0.001 | No change |
| Zn-D | -0.393 | 0.002 | Decrease |
| Zn-T | -0.389 | 0.002 | Decrease |

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 2015 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 | 11 | 11 | 7.7 | LowerTV<TSM<UpTV | Step 1/2 | 6.0-8.1 | 0.002 | LOW |
| TSS | 12 | 12 | 78 | TSM < TV | Step 1 | 2837 | 0.001 | LOW |
| Ag-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.2 | 0.001 | LOW |
| As-D | 12 | 12 | 0.92 | TSM < TV | Step 1 | 24 | 0.001 | LOW |
| Cd-D | 12 | 12 | 0.07 | TSM < TV | Step 1 | 0.4 | 0.112 | POTENTIAL |
| Cr-D | 12 | 12 | 0.10 | 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 | 6.0 | TSM < TV | Step 1 | 75 | 0.019 | LOW |
| Hg-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.6 | 0.001 | LOW |
| Ni-D | 12 | 12 | 6.4 | TSM < TV | Step 1 | 21 | 0.033 | LOW |
| Pb-D | 12 | 12 | 0.10 | TSM < TV | Step 1 | 8.3 | 0.001 | LOW |
| Se-D | 12 | 12 | 0.20 | TSM < TV | Step 1 | 11 | 0.001 | LOW |
| Zn-D | 11 | 11 | 12 | TSM < TV | Step 1 | 20 | 0.412 | LOW |

**Table C-17 Anjolek SDA 2015 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 | 10 | 1 | 7.7 | LowerTV<TSM<UpTV | Step 1/2 | 6.0-8.1 | 0.018/ 0.03 | LOW |
| TSS | 11 | 11 | 63 | TSM < TV | Step 1 | 2837 | 0.002 | LOW |
| Ag-D | 11 | 11 | 0.05 | TSM < TV | Step 1 | 0.2 | 0.002 | LOW |
| As-D | 11 | 11 | 0.80 | TSM < TV | Step 1 | 24 | 0.002 | LOW |
| Cd-D | 11 | 11 | 0.10 | TSM < TV | Step 1 | 0.4 | 0.002 | LOW |
| Cr-D | 11 | 11 | 0.75 | TSM < TV | Step 1 | 1.0 | 0.002 | LOW |
| Cu-D | 11 | 11 | 22 | TSM < TV | Step 1 | 4.1 | 0.002 | LOW |
| Fe-D | 11 | 11 | 0.05 | TSM < TV | Step 1 | 75 | 0.153 | POTENTIAL |
| Hg-D | 11 | 11 | 0.05 | TSM < TV | Step 1 | 0.6 | 0.002 | LOW |
| Ni-D | 11 | 11 | 0.66 | TSM < TV | Step 1 | 21 | 0.002 | LOW |
| Pb-D | 11 | 11 | 0.63 | TSM < TV | Step 1 | 8.3 | 0.002 | LOW |
| Se-D | 11 | 11 | 0.20 | TSM < TV | Step 1 | 11 | 0.002 | LOW |
| Zn-D | 10 | 1 | 6.8 | TSM < TV | Step 1 | 20 | 0.051 | LOW |

**Table C-18 Kaiya at Yuyan Bridge 2015 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 | 7.62 | LowerTV <TSM<UpTV | Step 1 | 6.0-8.1 | 0.002 | LOW |
| TSS | 12 | 12 | 3850 | TSM ≥ TV | Step 2 | 2837 | 0.240 | POTENTIAL |
| Ag-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.2 | 0.001 | LOW |
| As-D | 12 | 12 | 1.25 | TSM < TV | Step 1 | 24 | 0.01 | LOW |
| Cd-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.4 | 0.001 | LOW |
| Cr-D | 12 | 12 | 0.10 | TSM < TV | Step 1 | 1.0 | 0.001 | LOW |
| Cu-D | 12 | 12 | 0.76 | TSM < TV | Step 1 | 4.1 | 0.001 | LOW |
| Fe-D | 12 | 12 | 5.0 | TSM < TV | Step 1 | 75 | 0.128 | POTENTIAL |
| Hg-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.6 | 0.001 | LOW |
| Ni-D | 12 | 12 | 0.77 | TSM < TV | Step 1 | 21 | 0.001 | LOW |
| Pb-D | 12 | 12 | 0.19 | TSM < TV | Step 1 | 8.3 | 0.001 | LOW |
| Se-D | 12 | 12 | 0.43 | TSM < TV | Step 1 | 11 | 0.001 | LOW |
| Zn-D | 11 | 11 | 3.1 | TSM < TV | Step 1 | 20 | 0.002 | LOW |

**Table C-19 Kaiya River d/s Anjolek Erodible Dump 2015 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 | 7.50 | LowerTV <TSM<UpTV | Step 1 | 6.0-8.1 | 0.002 | LOW |
| TSS | 12 | 12 | 3763 | TSM ≥ TV | Step 2 | 2837 | 0.085 | POTENTIAL |
| Ag-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.2 | 0.001 | LOW |
| As-D | 12 | 12 | 0.995 | 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 | 12 | 0.10 | TSM < TV | Step 1 | 1.0 | 0.019 | LOW |
| Cu-D | 12 | 12 | 0.56 | TSM < TV | Step 1 | 4.1 | 0.001 | LOW |
| Fe-D | 12 | 12 | 8.2 | TSM < TV | Step 1 | 75 | 0.003 | LOW |
| Hg-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.6 | 0.001 | LOW |
| Ni-D | 12 | 12 | 0.63 | TSM < TV | Step 1 | 21 | 0.001 | LOW |
| Pb-D | 12 | 12 | 0.17 | TSM < TV | Step 1 | 8.3 | 0.001 | LOW |
| Se-D | 12 | 12 | 0.42 | TSM < TV | Step 1 | 11 | 0.001 | LOW |
| Zn-D | 11 | 11 | 4.0 | TSM < TV | Step 1 | 20 | 0.002 | LOW |

**Table C-20 Kogai Culvert 2015 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 / 0.002 | LOW |
| TSS | 13 | 13 | 180 | TSM < TV | Step 1 | 2837 | 0.001 | LOW |
| Ag-D | 13 | 13 | 0.05 | TSM < TV | Step 1 | 0.2 | 0.001 | LOW |
| As-D | 13 | 13 | 1.2 | TSM < TV | Step 1 | 24 | 0.001 | LOW |
| Cd-D | 13 | 13 | 0.06 | TSM < TV | Step 1 | 0.4 | 0.003 | LOW |
| Cr-D | 13 | 13 | 0.11 | TSM < TV | Step 1 | 1.0 | 0.001 | LOW |
| Cu-D | 13 | 13 | 1.0 | TSM < TV | Step 1 | 4.1 | 0.001 | LOW |
| Fe-D | 13 | 13 | 9.8 | TSM < TV | Step 1 | 75 | 0.02 | LOW |
| Hg-D | 13 | 13 | 0.05 | TSM < TV | Step 1 | 0.6 | 0.001 | LOW |
| Ni-D | 13 | 13 | 0.74 | TSM < TV | Step 1 | 21 | 0.001 | LOW |
| Pb-D | 13 | 13 | 0.38 | TSM < TV | Step 1 | 8.3 | 0.001 | LOW |
| Se-D | 13 | 13 | 0.20 | TSM < TV | Step 1 | 11 | 0.001 | LOW |
| Zn-D | 12 | 12 | 10.3 | TSM < TV | Step 1 | 20 | 0.305 | POTENTIAL |

**Table C-21 Kogai Stable Dump Toe Area 2015 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 | 11 | 11 | 7.78 | LowerTV <TSM<UpTV | Step 1 | 6.0-8.1 | 0.002 | LOW |
| TSS | 12 | 12 | 68 | TSM < TV | Step 1 | 2837 | 0.001 | LOW |
| Ag-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.2 | 0.001 | LOW |
| As-D | 12 | 12 | 0.72 | TSM < TV | Step 1 | 24 | 0.001 | LOW |
| Cd-D | 12 | 12 | 1.75 | TSM ≥ TV | Step 2 | 0.4 | 0.001 | POTENTIAL |
| Cr-D | 12 | 12 | 0.10 | TSM < TV | Step 1 | 1.0 | 0.001 | LOW |
| Cu-D | 12 | 12 | 0.63 | TSM < TV | Step 1 | 4.1 | 0.001 | LOW |
| Fe-D | 12 | 12 | 5.7 | TSM < TV | Step 1 | 75 | 0.019 | LOW |
| Hg-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.6 | 0.001 | LOW |
| Ni-D | 12 | 12 | 2.3 | TSM < TV | Step 1 | 21 | 0.001 | LOW |
| Pb-D | 12 | 12 | 0.52 | TSM < TV | Step 1 | 8.3 | 0.001 | LOW |
| Se-D | 12 | 12 | 0.20 | TSM < TV | Step 1 | 11 | 0.001 | LOW |
| Zn-D | 11 | 11 | 350 | TSM ≥ TV | Step 2 | 20 | 0.002 | POTENTIAL |

**Table C-22 Lime Plant Discharge 2015 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 | 11 | 11 | 11.15 | TSM ≥ TV | Step 2 | 6.0-8.1 | 0.002 | POTENTIAL |
| TSS | 12 | 12 | 382 | TSM < TV | Step 1 | 2837 | 0.019 | LOW |
| Ag-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.2 | 0.001 | LOW |
| As-D | 12 | 12 | 0.19 | 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 | 3.4 | TSM ≥ TV | Step 2 | 1.0 | 0.003 | POTENTIAL |
| Cu-D | 12 | 12 | 0.60 | 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 | 0.05 | 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 | 8.3 | 0.001 | LOW |
| Se-D | 12 | 12 | 0.20 | TSM < TV | Step 1 | 11 | 0.001 | LOW |
| Zn-D | 11 | 11 | 0.88 | TSM < TV | Step 1 | 20 | 0.002 | LOW |

**Table C-23 Wendoko Creek d/s Anawe Nth 2015 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 | 7.57 | LowerTV <TSM<UpTV | Step 1 | 6.0-8.1 | 0.002 | LOW |
| TSS | 12 | 12 | 57 | TSM < TV | Step 1 | 2837 | 0.002 | LOW |
| Ag-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.2 | 0.001 | LOW |
| As-D | 12 | 12 | 1.05 | TSM < TV | Step 1 | 24 | 0.001 | LOW |
| Cd-D | 12 | 12 | 0.76 | TSM ≥ TV | Step 2 | 0.4 | 0.008 | POTENTIAL |
| Cr-D | 12 | 12 | 0.10 | TSM < TV | Step 1 | 1.0 | 0.019 | LOW |
| Cu-D | 12 | 12 | 0.64 | TSM < TV | Step 1 | 4.1 | 0.002 | LOW |
| Fe-D | 12 | 12 | 3.6 | TSM < TV | Step 1 | 75 | 0.019 | LOW |
| Hg-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.6 | 0.001 | LOW |
| Ni-D | 12 | 12 | 1.8 | TSM < TV | Step 1 | 21 | 0.001 | LOW |
| Pb-D | 12 | 12 | 0.26 | TSM < TV | Step 1 | 8.3 | 0.001 | LOW |
| Se-D | 12 | 12 | 0.64 | TSM < TV | Step 1 | 11 | 0.001 | LOW |
| Zn-D | 11 | 11 | 310 | TSM ≥ TV | Step 2 | 20 | 0.002 | POTENTIAL |

**Table C-24 Yakatabari Creek d/s 28 level 2015 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 | 11 | 11 | 7.63 | LowerTV <TSM<UpTV | Step 1 | 6.0-8.1 | 0.002 | LOW |
| TSS | 12 | 12 | 6237 | TSM ≥ TV | Step 2 | 2837 | 0.046 | POTENTIAL |
| Ag-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.2 | 0.001 | LOW |
| As-D | 12 | 12 | 13 | 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 | 12 | 1.35 | TSM ≥ TV | Step 2 | 1.0 | 0.128 | POTENTIAL |
| Cu-D | 12 | 12 | 0.95 | TSM < TV | Step 1 | 4.1 | 0.001 | LOW |
| Fe-D | 12 | 12 | 7.5 | TSM < TV | Step 1 | 75 | 0.163 | LOW |
| Hg-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.6 | 0.001 | LOW |
| Ni-D | 12 | 12 | 1.60 | TSM < TV | Step 1 | 21 | 0.001 | LOW |
| Pb-D | 12 | 12 | 1.43 | TSM < TV | Step 1 | 8.3 | 0.002 | LOW |
| Se-D | 12 | 12 | 0.36 | TSM < TV | Step 1 | 11 | 0.001 | LOW |
| Zn-D | 12 | 12 | 6.6 | TSM < TV | Step 1 | 20 | 0.028 | POTENTIAL |

**Table C-25 Yunarilama at Portal 2015 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 | 11 | 11 | 7.4 | LowerTV <TSM<UpTV | Step 1 | 6.0-8.1 | 0.012 / 0.002 | LOW |
| TSS | 11 | 11 | 8415 | TSM ≥ TV | Step 2 | 2837 | 0.010 | POTENTIAL |
| Ag-D | 11 | 11 | 0.05 | TSM < TV | Step 1 | 0.2 | 0.001 | LOW |
| As-D | 12 | 12 | 3.15 | TSM < TV | Step 1 | 24 | 0.001 | LOW |
| Cd-D | 12 | 12 | 0.19 | TSM < TV | Step 1 | 0.4 | 0.001 | LOW |
| Cr-D | 12 | 12 | 0.13 | TSM < TV | Step 1 | 1.0 | 0.001 | LOW |
| Cu-D | 12 | 12 | 0.62 | TSM < TV | Step 1 | 4.1 | 0.001 | LOW |
| Fe-D | 12 | 12 | 9.6 | TSM < TV | Step 1 | 75 | 0.019 | LOW |
| Hg-D | 12 | 12 | 0.05 | TSM < TV | Step 1 | 0.6 | 0.001 | LOW |
| Ni-D | 12 | 12 | 4.7 | TSM < TV | Step 1 | 21 | 0.001 | LOW |
| Pb-D | 12 | 12 | 0.46 | TSM < TV | Step 1 | 8.3 | 0.001 | LOW |
| Se-D | 12 | 12 | 0.96 | TSM < TV | Step 1 | 11 | 0.001 | LOW |
| Zn-D | 12 | 12 | 8.7 | TSM < TV | Step 1 | 20 | 0.003 | LOW |

**Table C-26 Tailings Slurry 2015 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 | 47 | 46 | 6.4 | Lower TV < TSM < Higher TV | Step 1 / 2 | 6.0-8.1 | <0.001/<0.001 | LOW |
| TSS | 47 | NA | 161000 | TSM > TV | Step 2 | 2837 | NA | POTENTIAL |
| Ag-D | 47 | 47 | 0.05 | TSM < TV | Step 1 | 0.2 | <0.001 | LOW |
| As-D | 47 | 47 | 0.29 | TSM < TV | Step 1 | 24 | <0.001 | LOW |
| Cd-D | 47 | NA | 73 | TSM > TV | Step 2 | 0.4 | NA | POTENTIAL |
| Cr-D | 47 | 47 | 0.10 | TSM < TV | Step 1 | 1.0 | <0.001 | LOW |
| Cu-D | 47 | NA | 30 | TSM > TV | Step 2 | 4.1 | NA | POTENTIAL |
| Fe-D | 47 | NA | 5400 | TSM > TV | Step 2 | 75 | NA | POTENTIAL |
| Hg-D | 47 | 47 | 0.10 | TSM < TV | Step 1 | 0.6 | <0.001 | LOW |
| Ni-D | 47 | NA | 1600 | TSM > TV | Step 2 | 21 | NA | POTENTIAL |
| Pb-D | 47 | 47 | 0.10 | TSM < TV | Step 1 | 8.3 | <0.001 | LOW |
| Se-D | 47 | 47 | 2.4 | TSM < TV | Step 1 | 11 | <0.001 | LOW |
| Zn-D | 47 | NA | 1900 | TSM > TV | Step 2 | 20 | NA | POTENTIAL |

**Table C-28 Tailings Solids 2015 median against upper river 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 | 27 | 27 | 0.5 | TSM < TV | Step 1 | 1 | <0.001 | LOW |
| As- WAE | 27 | NA | 74 | TSM > TV | Step 2 | 20 | NA | POTENTIAL |
| Cd- WAE | 27 | NA | 4.0 | TSM > TV | Step 2 | 1.5 | NA | POTENTIAL |
| Cr- WAE | 27 | 27 | 22 | TSM < TV | Step 1 | 80 | <0.001 | LOW |
| Cu- WAE | 27 | NA | 84 | TSM > TV | Step 2 | 65 | NA | POTENTIAL |
| Hg- WAE | 27 | NA | 0.16 | TSM > TV | Step 2 | 0.15 | NA | POTENTIAL |
| Ni- WAE | 27 | 26 | 22 | TSM < TV | Step 1 | 27 | <0.001 | LOW |
| Pb- WAE | 27 | NA | 74 | TSM > TV | Step 2 | 50 | NA | POTENTIAL |
| Se- WAE | 27 | NA | 0.5 | TSM = TV | Step 3 | 0.50 | NA | LOW |
| Zn- WAE | 27 | NA | 680 | TSM > TV | Step 2 | 200 | NA | 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 2015 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 | 6 | 6 | 7.4 | Lower TV < TSM < Upper TV | Step 1/2 | 6.0-8.1 | NA | LOW |
| TSS* | 6 | 6 | 6498 | TSM > TV | Step 2 | 2837 | NA | POTENTIAL |
| Ag-D* | 6 | 6 | 0.05 | TSM < TV | Step 1 | 0.2 | NA | LOW |
| As-D* | 6 | 6 | 1.5 | TSM < TV | Step 1 | 24 | NA | LOW |
| Cd-D* | 6 | 6 | 1.4 | TSM > TV | Step 2 | 0.4 | NA | POTENTIAL |
| Cr-D* | 6 | 6 | 0.14 | TSM < TV | Step 1 | 1.0 | NA | LOW |
| Cu-D* | 6 | 6 | 1.8 | TSM < TV | Step 1 | 4.1 | NA | LOW |
| Fe-D* | 6 | 6 | 14 | TSM < TV | Step 1 | 75 | NA | LOW |
| Hg-D* | 6 | 6 | 0.05 | TSM < TV | Step 1 | 0.6 | NA | LOW |
| Ni-D* | 6 | 6 | 3.5 | TSM < TV | Step 1 | 21 | NA | LOW |
| Pb-D* | 6 | 6 | 0.18 | TSM < TV | Step 1 | 8.3 | NA | LOW |
| Se-D* | 6 | 6 | 0.25 | TSM < TV | Step 1 | 11 | NA | LOW |
| Zn-D * | 6 | 6 | 31 | TSM > TV | Step 2 | 20 | NA | POTENTIAL |

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

**Table D-4 Water quality upper river test sites - SG2 2015 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 | 14 | 13 | 7.5 | Lower TV < TSM < Upper TV | Step 1/2 | 6.0-8.1 | 0.001 / 0.001 | LOW |
| TSS | 14 | 14 | 1831 | TSM < TV | Step 1 | 2837 | 0.002 | LOW |
| Ag-D | 14 | 14 | 0.05 | TSM < TV | Step 1 | 0.2 | 0.001 | LOW |
| As-D | 14 | 14 | 1.3 | TSM < TV | Step 1 | 24 | 0.001 | LOW |
| Cd-D | 14 | 13 | 0.22 | TSM < TV | Step 1 | 0.4 | 0.050 | LOW |
| Cr-D | 14 | 14 | 0.14 | TSM < TV | Step 1 | 1.0 | 0.009 | LOW |
| Cu-D | 14 | 14 | 1.6 | TSM < TV | Step 1 | 4.1 | 0.001 | LOW |
| Fe-D | 14 | 14 | 6.3 | TSM < TV | Step 1 | 75 | 0.009 | LOW |
| Hg-D | 14 | 14 | 0.05 | TSM < TV | Step 1 | 0.6 | 0.001 | LOW |
| Ni-D | 14 | 14 | 1.5 | TSM < TV | Step 1 | 21 | 0.001 | LOW |
| Pb-D | 14 | 14 | 0.10 | TSM < TV | Step 1 | 8.3 | 0.001 | LOW |
| Se-D | 14 | 14 | 0.20 | TSM < TV | Step 1 | 11 | 0.001 | LOW |
| Zn-D | 14 | 13 | 7.7 | TSM < TV | Step 1 | 20 | 0.002 | LOW |

**Table D-5 Water quality upper river test sites - Wasiba 2015 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 | 16 | 15 | 7.4 | Lower TV < TSM < Upper TV | Step 1/2 | 6.0-8.1 | <0.001 / <0.001 | LOW |
| TSS | 16 | 15 | 1413 | TSM < TV | Step 1 | 2837 | <0.001 | LOW |
| Ag-D | 16 | 16 | 0.05 | TSM < TV | Step 1 | 0.2 | <0.001 | LOW |
| As-D | 16 | 16 | 1.8 | TSM < TV | Step 1 | 24 | <0.001 | LOW |
| Cd-D | 16 | 16 | 0.15 | TSM < TV | Step 1 | 0.4 | 0.004 | LOW |
| Cr-D | 16 | 16 | 0.20 | TSM < TV | Step 1 | 1.0 | 0.004 | LOW |
| Cu-D | 16 | 16 | 1.6 | TSM < TV | Step 1 | 4.1 | 0.001 | LOW |
| Fe-D | 16 | 16 | 3.3 | TSM < TV | Step 1 | 75 | <0.001 | LOW |
| Hg-D | 16 | 16 | 0.05 | TSM < TV | Step 1 | 0.6 | <0.001 | LOW |
| Ni-D | 16 | 16 | 1.1 | TSM < TV | Step 1 | 21 | <0.001 | LOW |
| Pb-D | 16 | 16 | 0.10 | TSM < TV | Step 1 | 8.3 | <0.001 | LOW |
| Se-D | 16 | 16 | 0.20 | TSM < TV | Step 1 | 11 | <0.001 | LOW |
| Zn-D | 16 | 16 | 5.4 | TSM < TV | Step 1 | 20 | <0.001 | LOW |

**Table D-6 Water quality upper river test sites - Wankipe 2015 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 | 16 | 15 | 7.5 | Lower TV < TSM < Upper TV | Step ½ | 6.0-8.1 | <0.001 / <0.001 | LOW |
| TSS | 16 | 15 | 820 | TSM < TV | Step 1 | 2837 | 0.001 | LOW |
| Ag-D | 16 | 16 | 0.05 | TSM < TV | Step 1 | 0.2 | <0.001 | LOW |
| As-D | 16 | 16 | 1.7 | TSM < TV | Step 1 | 24 | <0.001 | LOW |
| Cd-D | 16 | 16 | 0.13 | TSM < TV | Step 1 | 0.4 | <0.001 | LOW |
| Cr-D | 16 | 16 | 0.20 | TSM < TV | Step 1 | 1.0 | <0.001 | LOW |
| Cu-D | 16 | 16 | 1.4 | TSM < TV | Step 1 | 4.1 | <0.001 | LOW |
| Fe-D | 16 | 16 | 3.3 | TSM < TV | Step 1 | 75 | 0.004 | LOW |
| Hg-D | 16 | 16 | 0.05 | TSM < TV | Step 1 | 0.6 | <0.001 | LOW |
| Ni-D | 16 | 16 | 0.98 | TSM < TV | Step 1 | 21 | <0.001 | LOW |
| Pb-D | 16 | 16 | 0.10 | TSM < TV | Step 1 | 8.3 | <0.001 | LOW |
| Se-D | 16 | 16 | 0.20 | TSM < TV | Step 1 | 11 | <0.001 | LOW |
| Zn-D | 16 | 16 | 5.0 | TSM < TV | Step 1 | 20 | <0.001 | LOW |

**Table D-7 Water quality upper river test sites - SG3 2015 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 | 193 | 192 | 7.6 | Lower TV < TSM < Upper TV | Step 1 / 2 | 6.0-8.1 | <0.001 /<0.001 | LOW |
| TSS | 193 | 192 | 1133 | TSM < TV | Step 1 | 2837 | <0.001 | LOW |
| Ag-D | 193 | 193 | 0.05 | TSM < TV | Step 1 | 0.2 | <0.001 | LOW |
| As-D | 193 | 193 | 1.7 | TSM < TV | Step 1 | 24 | <0.001 | LOW |
| Cd-D | 193 | 193 | 0.07 | TSM < TV | Step 1 | 0.4 | <0.001 | LOW |
| Cr-D | 193 | 177 | 0.17 | TSM < TV | Step 1 | 1.0 | <0.001 | LOW |
| Cu-D | 193 | 177 | 1.6 | TSM < TV | Step 1 | 4.1 | <0.001 | LOW |
| Fe-D | 193 | 193 | 4.8 | TSM < TV | Step 1 | 75 | <0.001 | LOW |
| Hg-D | 193 | 193 | 0.05 | TSM < TV | Step 1 | 0.6 | <0.001 | LOW |
| Ni-D | 193 | 193 | 0.67 | TSM < TV | Step 1 | 21 | <0.001 | LOW |
| Pb-D | 193 | 193 | 0.10 | TSM < TV | Step 1 | 8.3 | <0.001 | LOW |
| Se-D | 193 | 193 | 0.20 | TSM < TV | Step 1 | 11 | <0.001 | LOW |
| Zn-D | 193 | 161 | 4.3 | TSM < TV | Step 1 | 20 | <0.001 | LOW |

**Table D-8 Water quality lower river test sites - Bebelubi 2015 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* | 8 | 8 | 7.3 | Lower TV < TSM < Upper TV | Step 1 / 2 | 6.0-8.2 | NA | LOW |
| TSS* | 8 | 8 | 353 | TSM < TV | Step 1 | 983 | NA | LOW |
| Ag-D* | 8 | 8 | 0.05 | TSM < TV | Step 1 | 0.2 | NA | LOW |
| As-D* | 8 | 8 | 1.6 | TSM < TV | Step 1 | 24 | NA | LOW |
| Cd-D* | 8 | 8 | 0.08 | TSM < TV | Step 1 | 0.2 | NA | LOW |
| Cr-D* | 8 | 8 | 0.20 | TSM < TV | Step 1 | 1 | NA | LOW |
| Cu-D* | 8 | 8 | 1.5 | TSM > TV | Step 2 | 1.4 | NA | POTENTIAL |
| Fe-D* | 8 | 8 | 5.6 | TSM < TV | Step 1 | 75 | NA | LOW |
| Hg-D* | 8 | 8 | 0.05 | TSM < TV | Step 1 | 0.6 | NA | LOW |
| Ni-D* | 8 | 8 | 0.51 | TSM < TV | Step 1 | 15 | NA | LOW |
| Pb-D* | 8 | 8 | 0.10 | TSM < TV | Step 1 | 2.8 | NA | LOW |
| Se-D* | 8 | 8 | 0.20 | TSM < TV | Step 1 | 11 | NA | LOW |
| Zn-D* | 8 | 8 | 5.6 | TSM < TV | Step 1 | 7 | NA | LOW |

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

**Table D-9 Water quality lower river test sites - SG4/Tiumsinawam 2015 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 |
|---|---|---|---|---|---|---|---|---|
| Tiumsinawam | N | N (Test) | Median | Result | Go to | | | |
| pH* | 8 | 8 | 7.4 | Lower TV < TSM < Upper TV | Step 1 / 2 | 6.0-8.2 | NA | LOW |
| TSS* | 8 | 8 | 516 | TSM < TV | Step 1 | 983 | NA | LOW |
| Ag-D* | 8 | 8 | 0.05 | TSM < TV | Step 1 | 0.2 | NA | LOW |
| As-D* | 8 | 8 | 1.3 | TSM < TV | Step 1 | 24 | NA | LOW |
| Cd-D* | 8 | 8 | 0.07 | TSM < TV | Step 1 | 0.2 | NA | LOW |
| Cr-D* | 8 | 8 | 0.17 | TSM < TV | Step 1 | 1 | NA | LOW |
| Cu-D* | 8 | 8 | 1.4 | TSM = TV | Step 2 | 1.4 | NA | POTENTIAL |
| Fe-D* | 8 | 8 | 13.5 | TSM < TV | Step 1 | 75 | NA | LOW |
| Hg-D* | 8 | 8 | 0.05 | TSM < TV | Step 1 | 0.6 | NA | LOW |
| Ni-D* | 8 | 8 | 0.5 | TSM < TV | Step 1 | 15 | NA | LOW |
| Pb-D* | 8 | 8 | 0.11 | TSM < TV | Step 1 | 2.8 | NA | LOW |
| Se-D* | 8 | 8 | 0.20 | TSM < TV | Step 1 | 11 | NA | LOW |
| Zn-D* | 8 | 8 | 4.9 | TSM < TV | Step 1 | 7 | NA | LOW |

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

**Table D-10 Water quality lower river test sites - SG5 2015 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* | 9 | 9 | 7.3 | Lower TV < TSM < Upper TV | Step 1 / 2 | 6.0-8.2 | NA | LOW |
| TSS* | 9 | 9 | 336 | TSM < TV | Step 1 | 983 | NA | LOW |
| Ag-D* | 5 | 5 | 0.05 | TSM < TV | Step 1 | 0.2 | NA | LOW |
| As-D* | 9 | 9 | 1.0 | TSM < TV | Step 1 | 24 | NA | LOW |
| Cd-D* | 9 | 9 | 0.05 | TSM < TV | Step 1 | 0.2 | NA | LOW |
| Cr-D* | 9 | 9 | 0.13 | TSM < TV | Step 1 | 1.0 | NA | LOW |
| Cu-D* | 9 | 9 | 1.1 | TSM < TV | Step 1 | 1.4 | NA | LOW |
| Fe-D* | 9 | 9 | 10 | TSM < TV | Step 1 | 75 | NA | LOW |
| Hg-D* | 9 | 9 | 0.05 | TSM < TV | Step 1 | 0.6 | NA | LOW |
| Ni-D* | 9 | 9 | 0.50 | TSM < TV | Step 1 | 15 | NA | LOW |
| Pb-D* | 9 | 9 | 0.10 | TSM < TV | Step 1 | 2.8 | NA | LOW |
| Se-D* | 9 | 9 | 0.20 | TSM < TV | Step 1 | 11 | NA | LOW |
| Zn-D* | 9 | 9 | 1.5 | TSM < TV | Step 1 | 7 | NA | LOW |

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

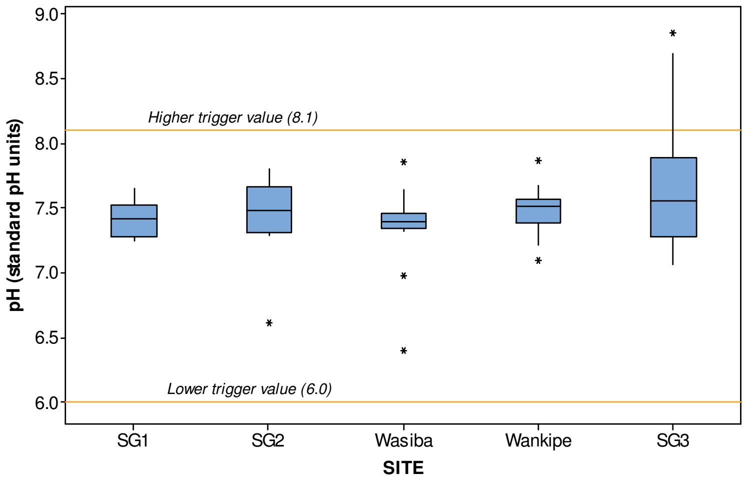



**Figure D-1 pH in water upper river test sites 2015**

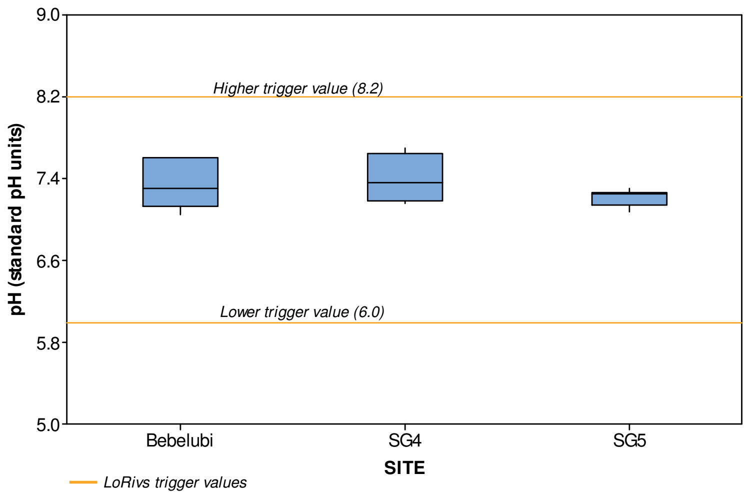



**Figure D-2 pH in water at lower river test sites 2015**

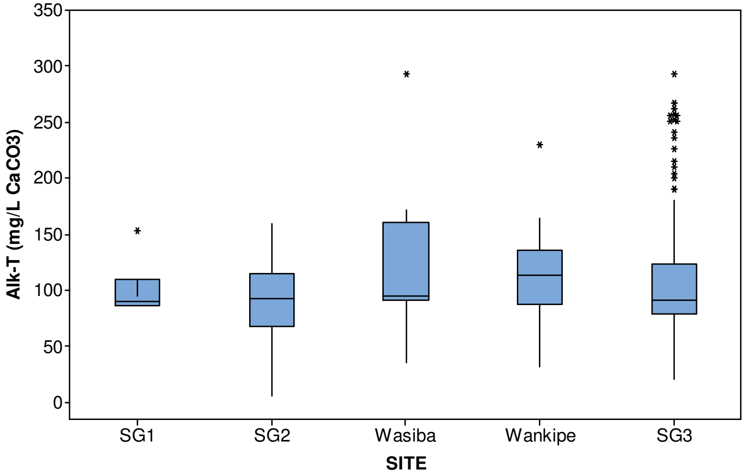



**Figure D-3 Alkalinity in water upper river test sites 2015**

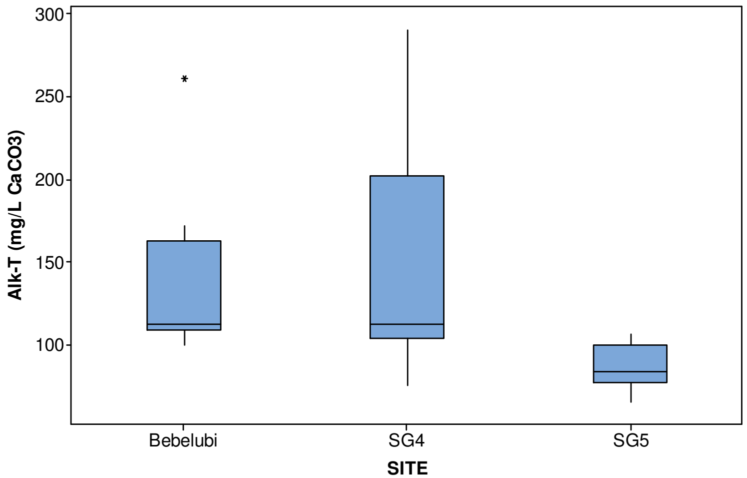



**Figure D-4 Alkalinity in water lower river test sites 2015**

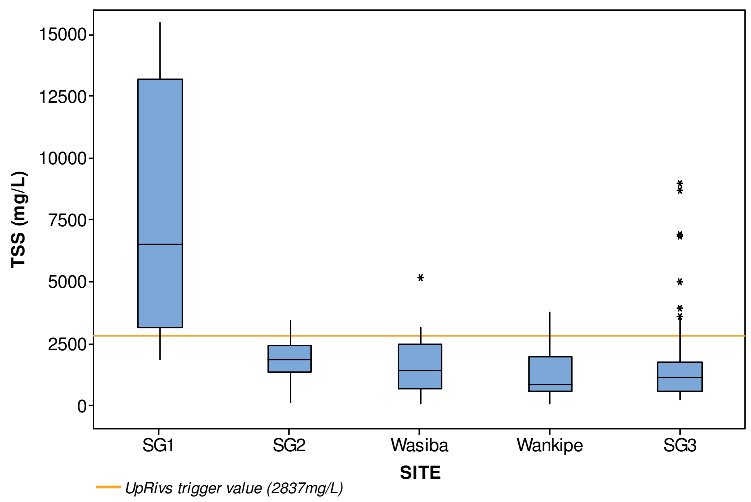



**Figure D-5 TSS in water upper river test sites 2015**

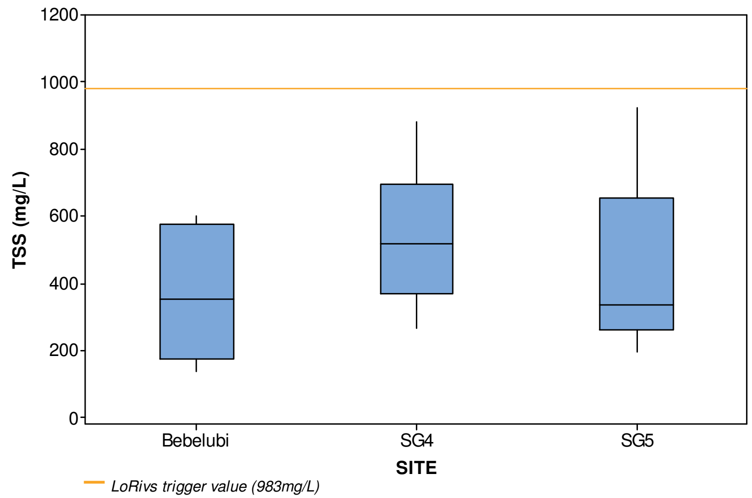



**Figure D-6 TSS in water lower river test sites 2015**

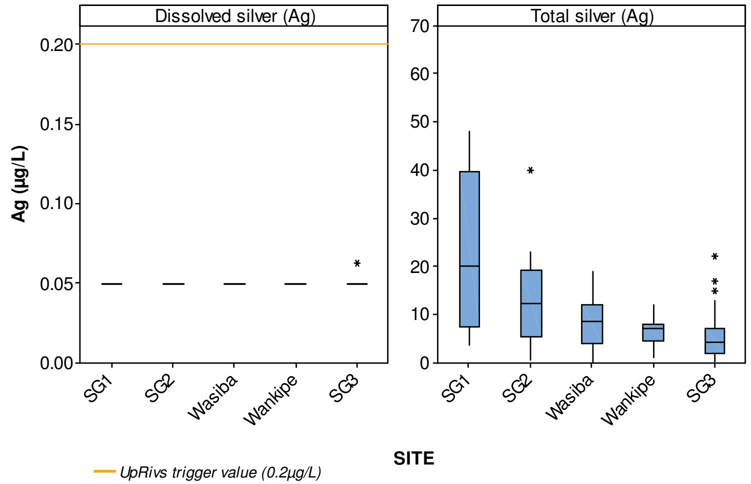



**Figure D-7 Silver in water upper river test sites 2015**

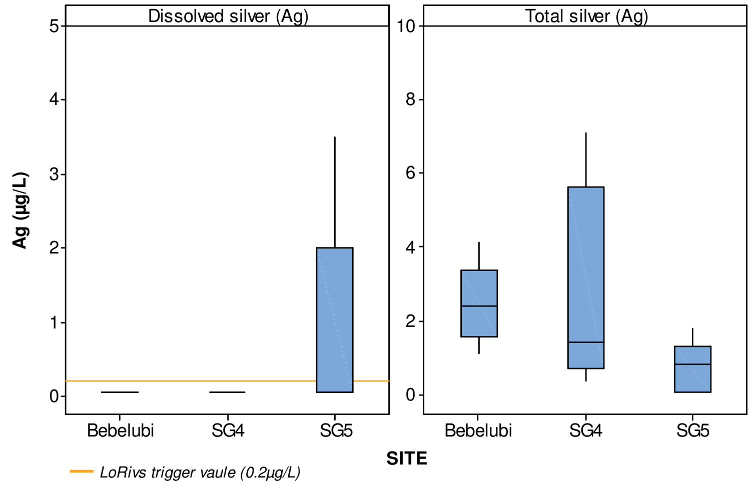



**Figure D-8 Silver in water lower river test sites 2015**

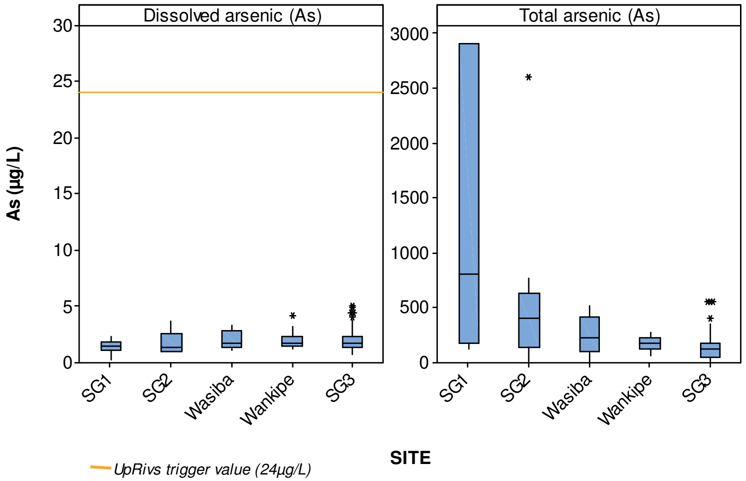



**Figure D-9 Arsenic in water upper river test sites 2015**

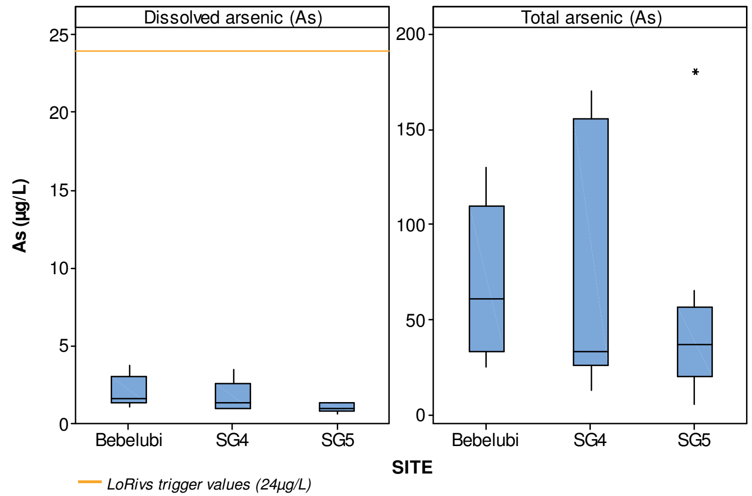



**Figure D-10 Arsenic in water lower river test sites 2015**

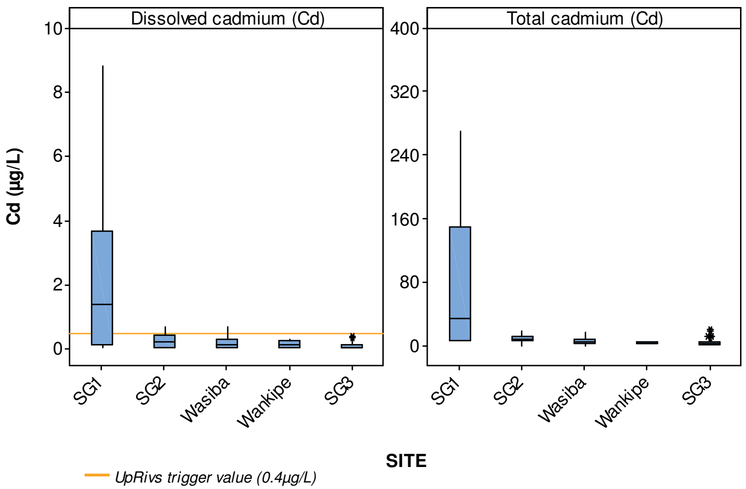



**Figure D-11 Cadmium in water upper river test sites 2015**

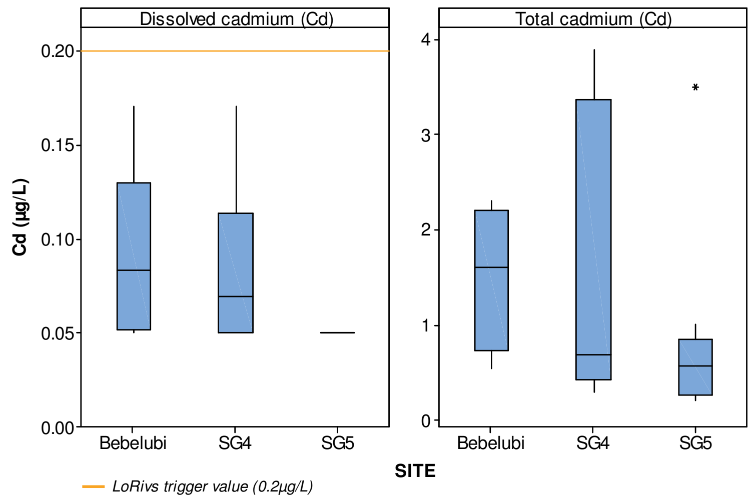



**Figure D-12 Cadmium in water lower river test sites 2015**

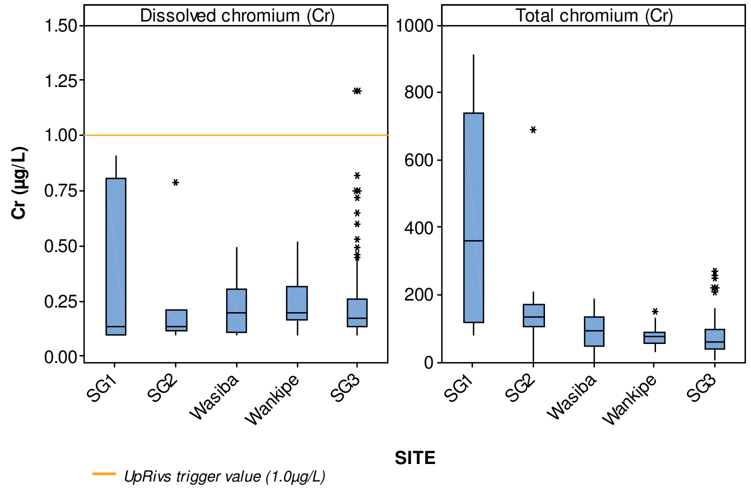



**Figure D-13 Chromium in water upper river test sites 2015**

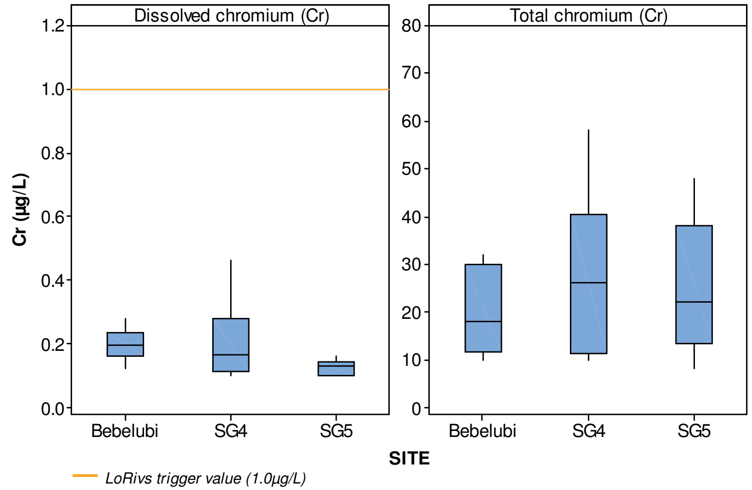



**Figure D-14 Chromium in water lower river test sites 2015**

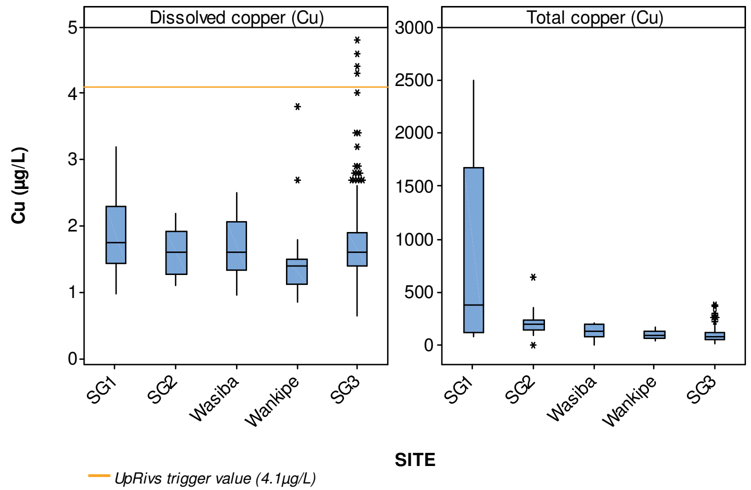



**Figure D-15 Copper in water upper river test sites 2015**

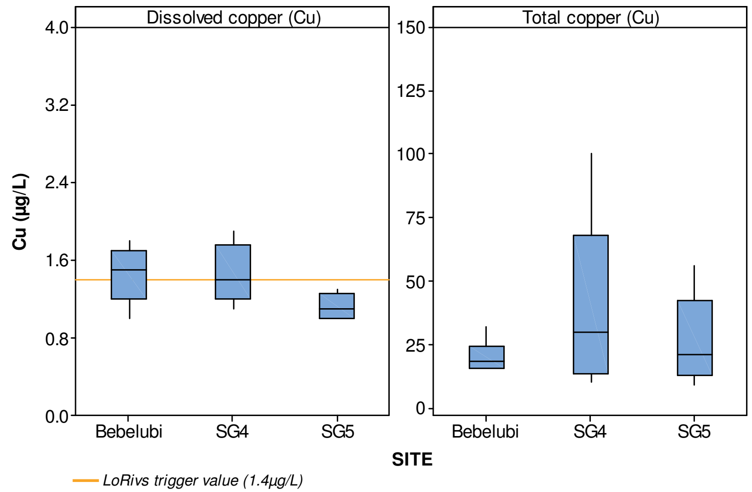



**Figure D-16 Copper in water lower river test sites 2015**

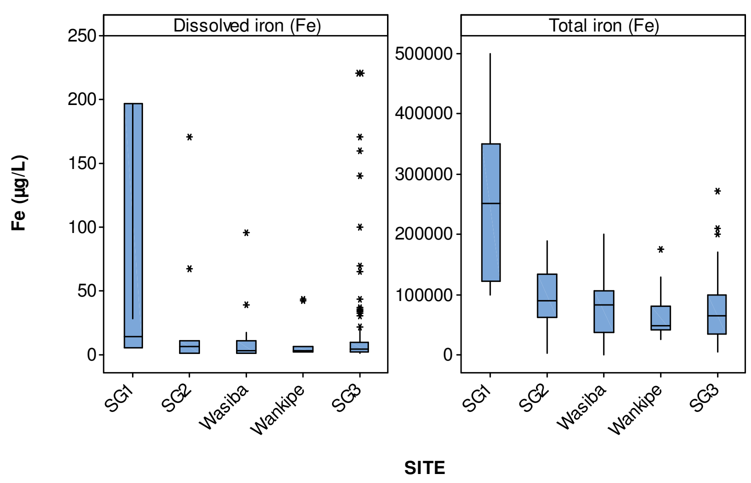



Figure D-17 Iron in water upper river test sites 2015

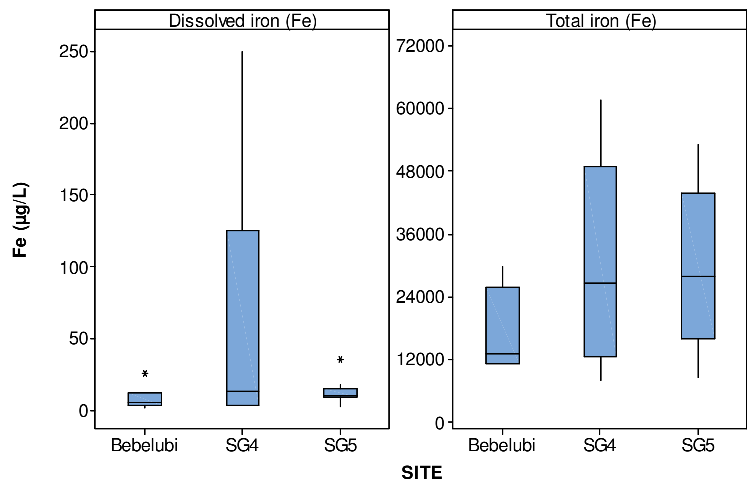



Figure D-18 Iron in water lower river test sites 2015

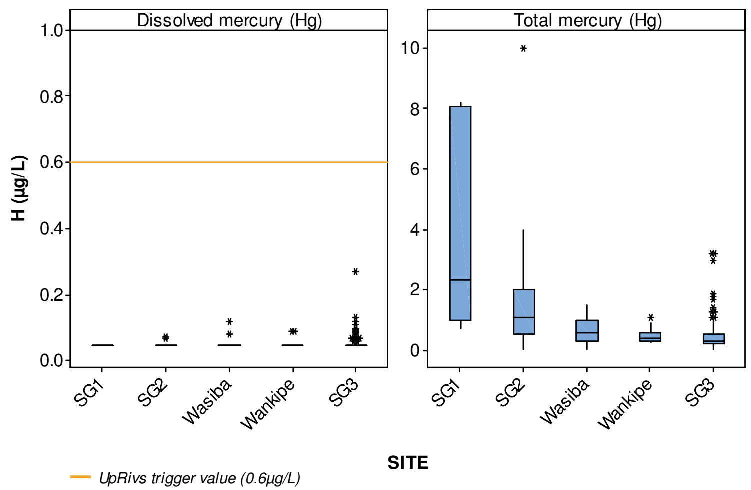



Figure D-19 Mercury in water upper river test sites 2015

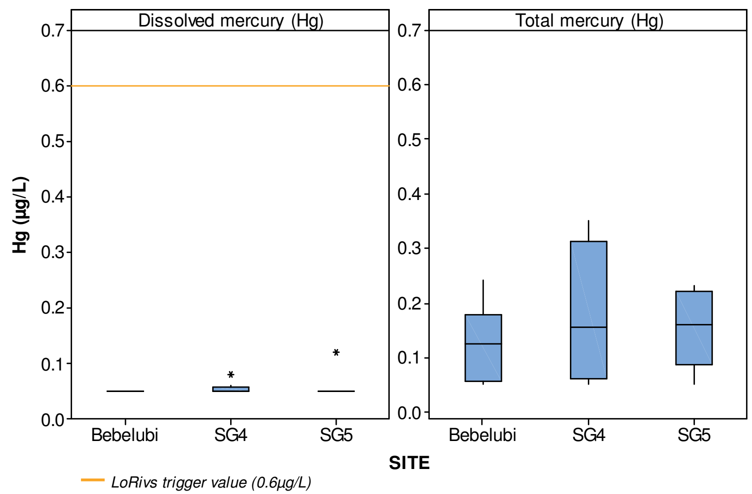



Figure D-20 Mercury in water lower river test sites 2015

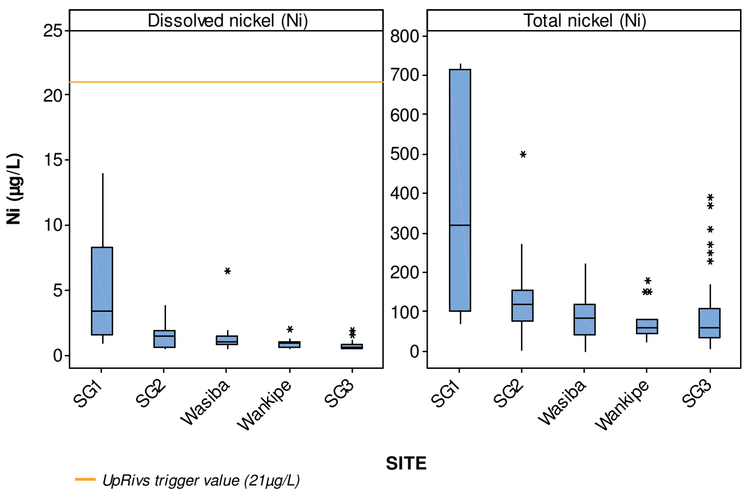



**Figure D-21 Nickel in water upper river test sites 2015**

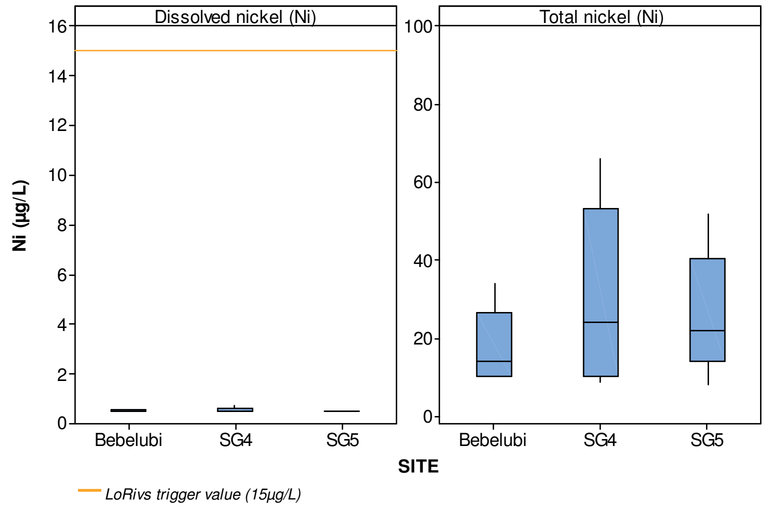



**Figure D-22 Nickel in water lower river test sites 2015**

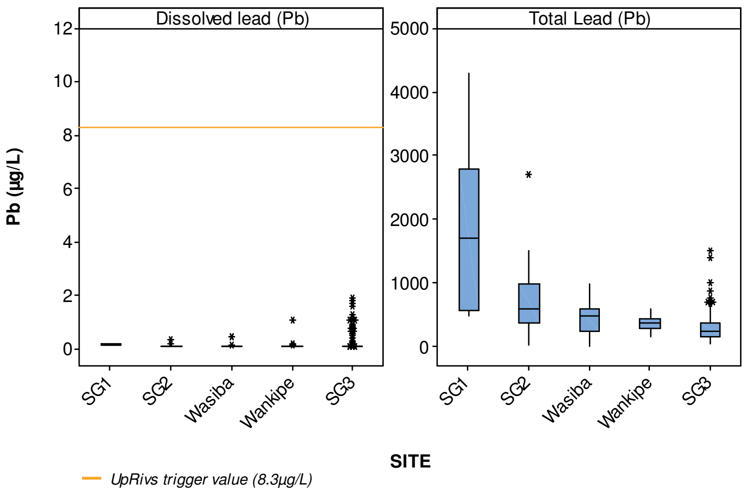



**Figure D-23 Lead in water upper river test sites 2015**

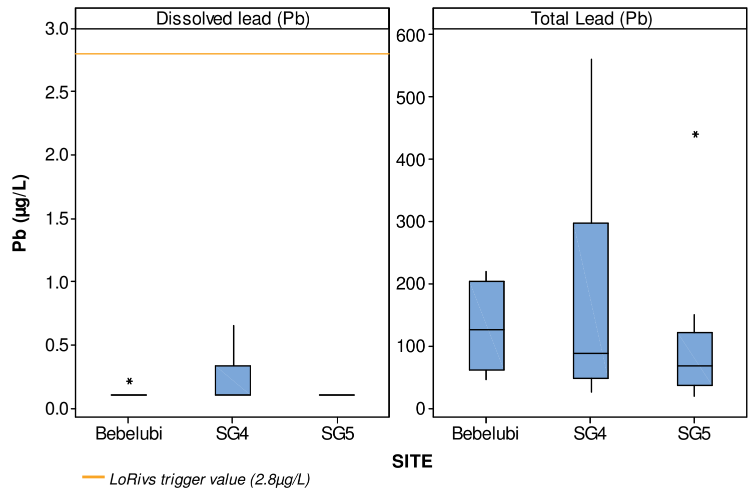



**Figure D-24 Lead in water lower river test sites 2015**

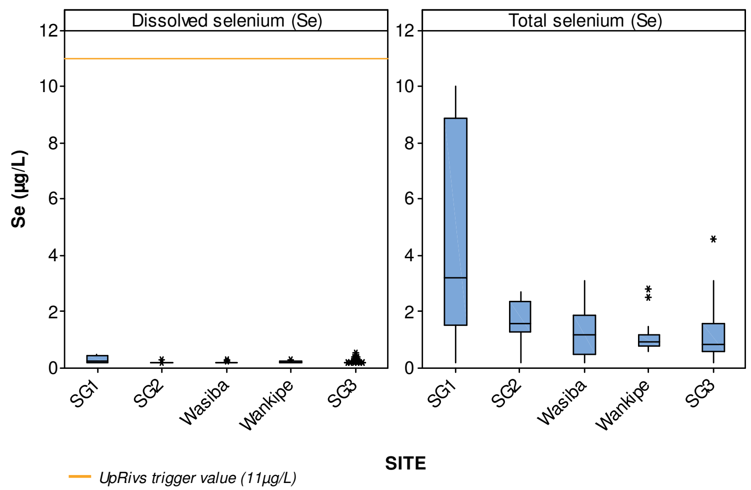



Figure D-25 Selenium in water upper river test sites 2015

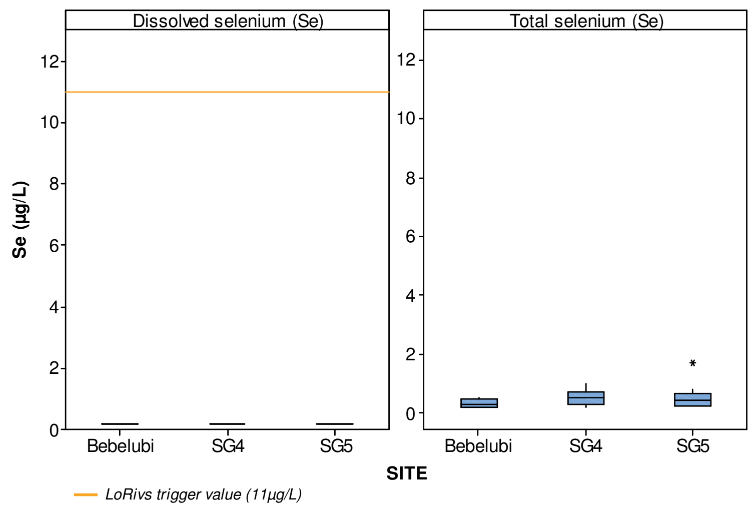



Figure D-26 Selenium in water lower river test sites 2015

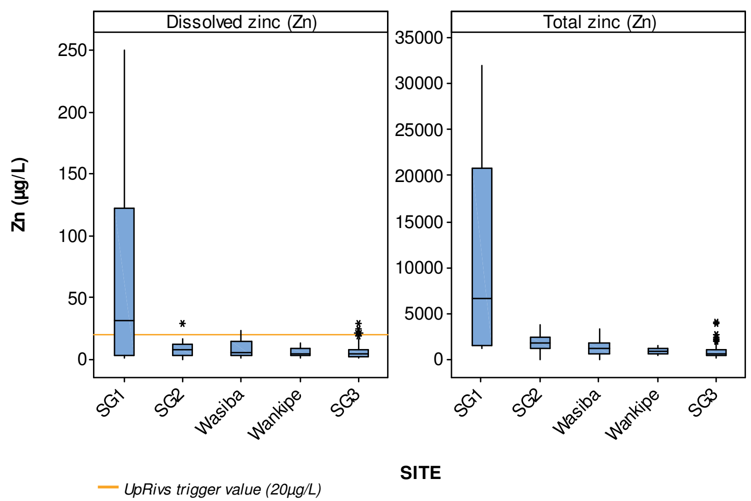



Figure D-27 Zinc in water upper river test sites 2015

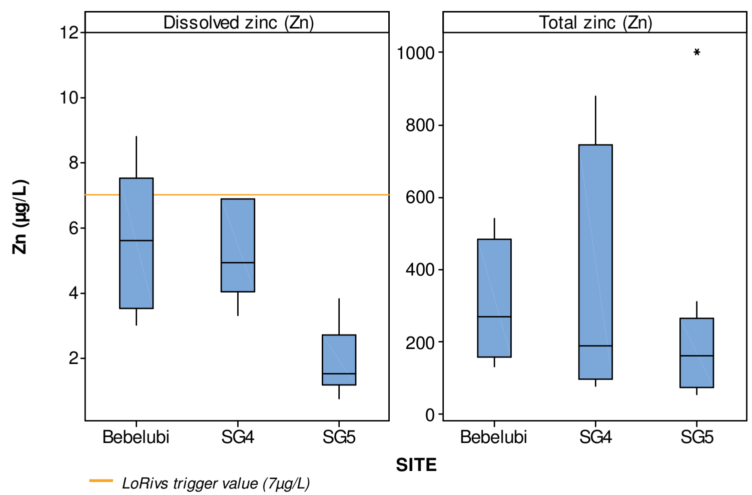



Figure D-28 Zinc in water lower river test sites 2015

**Table D-11 Performance assessment – Based on the trend of the annual median of water quality indicators at upper river test sites relative to the trend of the annual median of water quality indicators at upper river reference sites throughout the history of the operation using Spearman Rank Test.**

| Water Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend 2011 - 2015 |
|---|---|---|---|---|
| SG1 (Trend of Annual Medians from 2011 - 2015) | pH | -0.638 | <0.001 | Reduced over time |
| | TSS | -0.431 | 0.003 | Reduced over time |
| | Ag-D | -0.506 | <0.001 | Reduced over time |
| | As-D | -0.139 | 0.362 | No change over time |
| | Cd-D | 0.182 | 0.232 | No change over time |
| | Cr-D | -0.831 | <0.001 | Reducing over time |
| | Cu-D | -0.072 | 0.638 | No change over time |
| | Fe-D | 0.017 | 0.912 | No change over time |
| | Hg-D | -0.697 | <0.001 | Reduced over time |
| | Ni-D | 0.225 | 0.137 | No change over time |
| | Pb-D | -0.475 | <0.001 | Reduced over time |
| | Se-D | -0.713 | <0.001 | Reduced over time |
| | Zn-D | 0.191 | 0.209 | No change over time |
| SG2 (Trend of Annual Medians from 2011 - 2015) | pH | -0.471 | <0.001 | Reduced over time |
| | TSS | 0.033 | 0.816 | No change over time |
| | Ag-D | -0.817 | <0.001 | Reduced over time |
| | As-D | -0.151 | 0.284 | No change over time |
| | Cd-D | -0.110 | 0.439 | No change over time |
| | Cr-D | -0.772 | <0.001 | Reduced over time |
| | Cu-D | -0.169 | 0.230 | No change over time |
| | Fe-D | -0.220 | 0.117 | No change over time |
| | Hg-D | -0.837 | <0.001 | Reduced over time |
| | Ni-D | 0.201 | 0.153 | No change over time |
| | Pb-D | -0.717 | <0.001 | Reduced over time |
| | Se-D | -0.909 | <0.001 | Reduced over time |
| | Zn-D | -0.220 | 0.121 | No change over time |
| Wasiba (Trend of Annual Medians from 2011 - 2015) | pH | -0.085 | <0.001 | Reduced over time |
| | TSS | 0.159 | 0.449 | No change over time |
| | Ag-D* | -0.906 | <0.001 | No change over time |
| | As-D* | 0.355 | 0.075 | No change over time |
| | Cd-D* | -0.246 | 0.226 | No change over time |
| | Cr-D* | -0.756 | <0.001 | No change over time |
| | Cu-D* | 0.233 | 0.253 | No change over time |
| | Fe-D | -0.312 | 0.121 | No change over time |
| | Hg-D* | 0.228 | 0.263 | No change over time |
| | Ni-D* | 0.270 | 0.182 | No change over time |
| | Pb-D* | -0.790 | <0.001 | No change over time |
| | Se-D | -0.808 | <0.001 | Reduced over time |
| | Zn-D | 0.248 | 0.222 | No change over time |

| Water Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend 2011 - 2015 |
|---|---|---|---|---|
| Wankipe (Trend of Annual Medians from 2011 - 2015) | pH | 0.126 | 0.357 | No change over time |
| | TSS | 0.328 | 0.016 | Increased over time |
| | Ag-D* | 0.411 | 0.002 | No change over time |
| | As-D* | 0.292 | 0.029 | No change over time |
| | Cd-D* | 0.025 | 0.855 | No change over time |
| | Cr-D* | 0.011 | 0.937 | No change over time |
| | Cu-D* | -0.146 | 0.282 | No change over time |
| | Fe-D | -0.305 | 0.022 | Reduced over time |
| | Hg-D* | 0.177 | 0.192 | No change over time |
| | Ni-D* | -0.207 | 0.126 | No change over time |
| | Pb-D* | -0.029 | 0.834 | No change over time |
| | Se-D | -0.518 | <0.001 | Reduced over time |
| | Zn-D | -0.067 | 0.624 | No change over time |
| SG3 (Trend of Annual Medians from 2011 - 2015) | pH | -0.597 | <0.001 | Reduced over time |
| | TSS | -0.122 | <0.001 | Reduced over time |
| | Ag-D | -0.671 | <0.001 | Reduced over time |
| | As-D* | 0.133 | <0.001 | No change over time |
| | Cd-D | -0.506 | <0.001 | Reduced over time |
| | Cr-D | -0.828 | <0.001 | Reduced over time |
| | Cu-D* | 0.252 | <0.001 | No change over time |
| | Fe-D | -0.108 | <0.001 | Reduced over time |
| | Hg-D | -0.815 | <0.001 | Reduced over time |
| | Ni-D | -0.640 | <0.001 | Reduced over time |
| | Pb-D | -0.550 | <0.001 | Reduced over time |
| | Se-D | -0.841 | <0.001 | Reduced over time |
| | Zn-D | -0.083 | 0.016 | Reduced over time |

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

**Table D-12 Performance assessment – Based on the trend of the annual median of water quality indicators at lower river test sites relative to the trend of the annual median of water quality indicators at lower river reference sites throughout the history of the operation using Spearman Rank Test.**

| Water Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend 2011 - 2015 |
|---|---|---|---|---|
| Bebelubi (Trend of Annual Medians from 2011 - 2015) | pH | -0.627 | <0.001 | Reducing over time |
| | TSS | -0.342 | 0.045 | Reducing over time |
| | Ag-D | -0.706 | <0.001 | Reducing over time |
| | As-D | 0.467 | 0.002 | Increasing over time |
| | Cd-D | -0.701 | <0.001 | Reducing over time |
| | Cr-D | -0.858 | <0.001 | Reducing over time |
| | Cu-D | 0.180 | 0.261 | No change over time |
| | Fe-D | 0.075 | 0.642 | No change over time |
| | Hg-D | -0.776 | <0.001 | Reducing over time |
| | Ni-D | -0.617 | <0.001 | Reducing over time |
| | Pb-D | -0.642 | <0.001 | Reducing over time |
| | Se-D | -0.888 | <0.001 | Reducing over time |
| | Zn-D | 0.225 | 0.157 | No change over time |
| Tiumsinawam (Trend of Annual Medians from 2011 - 2015) | pH | -0.694 | <0.001 | Reducing over time |
| | TSS | -0.343 | 0.047 | Reducing over time |
| | Ag-D | -0.730 | <0.001 | Reducing over time |
| | As-D | 0.048 | 0.776 | No change over time |
| | Cd-D | -0.724 | <0.001 | Reducing over time |
| | Cr-D | -0.903 | <0.001 | Reducing over time |
| | Cu-D | 0.224 | 0.183 | No change over time |
| | Fe-D | 0.324 | 0.051 | No change over time |
| | Hg-D | -0.838 | <0.001 | Reducing over time |
| | Ni-D | -0.725 | <0.001 | Reducing over time |
| | Pb-D | -0.543 | <0.001 | Reducing over time |
| | Se-D | -0.919 | <0.001 | Reducing over time |
| | Zn-D | 0.578 | <0.001 | Reducing over time |
| SG5 (Trend of Annual Medians from 2011 - 2015) | pH | 0.248 | 0.321 | No change over time |
| | TSS | 0.675 | 0.003 | Increasing over time |
| | Ag-D | -0.747 | 0.001 | Reducing over time |
| | As-D* | 0.197 | 0.418 | No change over time |
| | Cd-D | -0.688 | 0.001 | Reducing over time |
| | Cr-D* | -0.124 | 0.613 | No change over time |
| | Cu-D* | 0.615 | 0.005 | No change over time |
| | Fe-D | -0.633 | 0.004 | Reducing over time |
| | Hg-D | -0.702 | 0.001 | Reducing over time |
| | Ni-D | -0.688 | 0.001 | Reducing over time |
| | Pb-D* | -0.432 | 0.065 | No change over time |
| | Se-D* | ≤LOR | ≤LOR | No change over time |
| | Zn-D | 0.235 | 0.333 | 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 2015 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 | 9.0 | TSM < TV | Step 1 | 23 | 0.028 | LOW |
| Ag-D | 11 | NA | 0.05 | TSM = TV | Step 3 | 0.05 | NA | LOW |
| As-D | 11 | 11 | 0.31 | 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 | 0.10 | TSM < TV | Step 1 | 1 | 0.002 | LOW |
| Cu-D | 11 | 11 | 0.60 | TSM < TV | Step 1 | 1.4 | 0.002 | LOW |
| Fe-D | 11 | 11 | 33 | TSM < TV | Step 1 | 340 | 0.002 | LOW |
| Hg-D | 11 | 11 | 0.05 | TSM < TV | Step 1 | 0.16 | 0.002 | 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 | 2.5 | TSM < TV | Step 1 | 8 | 0.002 | LOW |

**Table D-14 Water quality Lake Murray and ORWBs test sites - South Lake Murray 2015 median (µg/L)**

| Test Site | | | | Initial Assessment | | TV | Statistical Test Result (P=0.05) | Risk Assessment |
|---|---|---|---|---|---|---|---|---|
| Southern Lake | N | N (Test) | Median | Result | Go to | | | |
| pH | 10 | 10 | 7.0 | Lower TV < TSM < Upper TV | Step 1 / 2 | 5.3-8.0 | 0.003 / 0.003 | LOW |
| TSS | 10 | 10 | 11 | TSM < Upper TV | Step 1 | 23 | 0.007 | LOW |
| Ag-D | 10 | NA | 0.05 | TSM = TV | Step 3 | 0.05 | NA | LOW |
| As-D | 10 | 10 | 0.91 | 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 | 0.10 | TSM < Upper TV | Step 1 | 1 | 0.003 | LOW |
| Cu-D | 10 | 10 | 0.90 | TSM < Upper TV | Step 1 | 1.4 | 0.003 | LOW |
| Fe-D | 10 | 10 | 5.5 | TSM < Upper TV | Step 1 | 340 | 0.003 | LOW |
| Hg-D | 10 | 10 | 0.05 | TSM < Upper TV | Step 1 | 0.16 | 0.003 | 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 | 2.2 | TSM < Upper TV | Step 1 | 8 | 0.003 | LOW |

**Table D-15 Water quality Lake Murray and ORWBs test sites - SG6 2015 median (µg/L)**

| Test Site | | | | Initial Assessment | | TV | Statistical Test Result (P=0.05) | Risk Assessment |
|---|---|---|---|---|---|---|---|---|
| SG6 | N | N (Test) | Median | Result | Go to | | | |
| pH | 4 | 4 | 6.6 | Lower TV < TSM < Upper TV | Step 1 / 2 | 5.3-8.0 | 0.005 / 0.005 | LOW |
| TSS* | 4 | 3 | 17 | TSM < Upper TV | Step 1 | 23 | 0.605 | LOW |
| Ag-D | 4 | NA | 0.05 | TSM = TV | Step 3 | 0.05 | NA | LOW |
| As-D | 4 | 4 | 0.92 | TSM < Upper TV | Step 1 | 24 | 0.050 | LOW |
| Cd-D | 4 | 4 | 0.05 | TSM < Upper TV | Step 1 | 0.72 | 0.050 | LOW |
| Cr-D | 4 | 4 | 0.12 | TSM < Upper TV | Step 1 | 1 | 0.050 | LOW |
| Cu-D* | 4 | 4 | 0.96 | TSM < Upper TV | Step 1 | 1.4 | 0.101 | LOW |
| Fe-D | 4 | 4 | 14 | TSM < Upper TV | Step 1 | 340 | 0.050 | LOW |
| Hg-D | 4 | 4 | 0.05 | TSM < Upper TV | Step 1 | 0.16 | 0.050 | LOW |
| Ni-D | 4 | 4 | 0.5 | TSM < Upper TV | Step 1 | 11 | 0.050 | LOW |
| Pb-D | 4 | 4 | 0.10 | TSM < Upper TV | Step 1 | 3.4 | 0.050 | LOW |
| Se-D | 4 | 4 | 0.20 | TSM < Upper TV | Step 1 | 11 | 0.050 | LOW |
| Zn-D* | 4 | 4 | 2.9 | TSM < Upper TV | Step 1 | 8 | 0.101 | LOW |

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

**Table D-16 Water quality Lake Murray and ORWBs test sites - Kukufionga 2015 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 | | | | | | 5.3-8.0 | | No data collected in 2015 therefore Wilcoxon for risk assessment not performed |
| TSS | | | | | | 23 | | |
| Ag-D | | | | | | 0.05 | | |
| As-D | | | | | | 24 | | |
| Cd-D | | | | | | 0.72 | | |
| Cr-D | | | | | | 1 | | |
| Cu-D | | | | | | 2.5 | | |
| Fe-D | | | | | | 340 | | |
| Hg-D | | | | | | 0.16 | | |
| Ni-D | | | | | | 11 | | |
| Pb-D | | | | | | 3.4 | | |
| Se-D | | | | | | 11 | | |
| Zn-D | | | | | | 8 | | |

**Table D-17 Water quality Lake Murray and ORWBs test sites - Zongamange 2015 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 | | | | | | 5.3-8.0 | | No data collected in 2015 therefore Wilcoxon for risk assessment not performed |
| TSS | | | | | | 23 | | |
| Ag-D | | | | | | 0.05 | | |
| As-D | | | | | | 24 | | |
| Cd-D | | | | | | 0.72 | | |
| Cr-D | | | | | | 1 | | |
| Cu-D | | | | | | 2.5 | | |
| Fe-D | | | | | | 340 | | |
| Hg-D | | | | | | 0.16 | | |
| Ni-D | | | | | | 11 | | |
| Pb-D | | | | | | 3.4 | | |
| Se-D | | | | | | 11 | | |
| Zn-D | | | | | | 8 | | |

**Table D-18 Water quality Lake Murray and ORWBs test sites - Avu 2015 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* | 2 | 2 | 6.9 | Lower TV < TSM < Upper TV | Step 1 / 2 | 5.3-8.0 | 0.186 / 0.186 | LOW |
| TSS | 2 | 2 | 62 | TSM > TV | Step 2 | 23 | 0.186 | POTENTIAL |
| Ag-D* | 2 | 0 | 0.05 | TSM = TV | Step 3 | 0.05 | NA | LOW |
| As-D* | 2 | 2 | 3.4 | TSM < TV | Step 1 | 24 | 0.186 | LOW |
| Cd-D* | 2 | 2 | 0.05 | TSM < TV | Step 1 | 0.72 | 0.186 | LOW |
| Cr-D* | 2 | 2 | 0.16 | TSM < TV | Step 1 | 1 | 0.186 | LOW |
| Cu-D* | 2 | 2 | 1.1 | TSM < TV | Step 1 | 1.4 | 0.184 | LOW |
| Fe-D* | 2 | 2 | 103 | TSM < TV | Step 1 | 340 | 0.186 | LOW |
| Hg-D* | 2 | 2 | 0.06 | TSM < TV | Step 1 | 0.16 | 0.186 | LOW |
| Ni-D* | 2 | 2 | 0.88 | TSM < TV | Step 1 | 11 | 0.186 | LOW |
| Pb-D* | 2 | 2 | 0.38 | TSM < TV | Step 1 | 3.4 | 0.186 | LOW |
| Se-D* | 2 | 2 | 0.20 | TSM < TV | Step 1 | 11 | 0.186 | LOW |
| Zn-D* | 2 | 2 | 2.4 | TSM < TV | Step 1 | 8 | 0.186 | LOW |

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

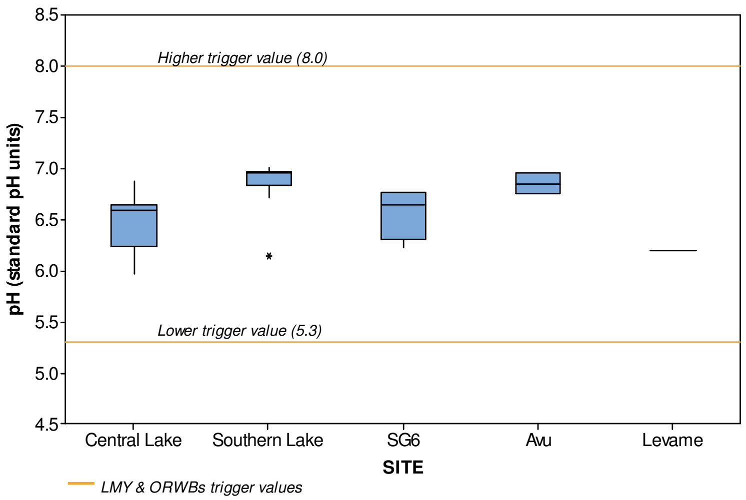



Figure D-29 pH in water Lake Murray and ORWBs test sites 2015

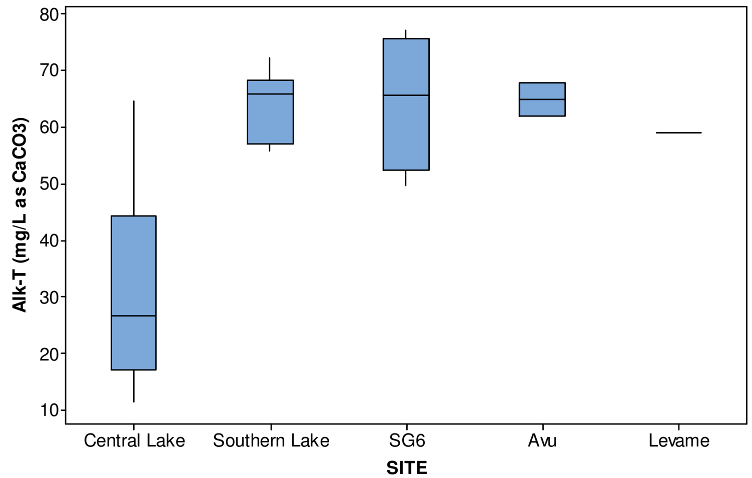



Figure D-30 Alkalinity in water Lake Murray and ORWBs test sites 2015

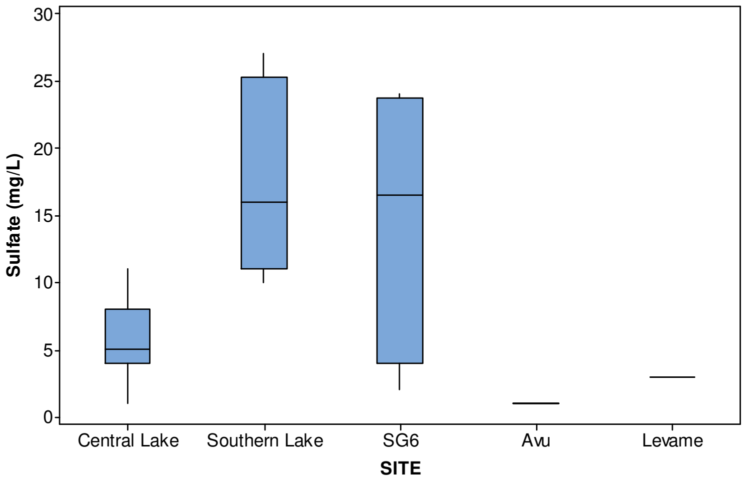



Figure D-31 Sulfate in water Lake Murray and ORWBs test sites 2015

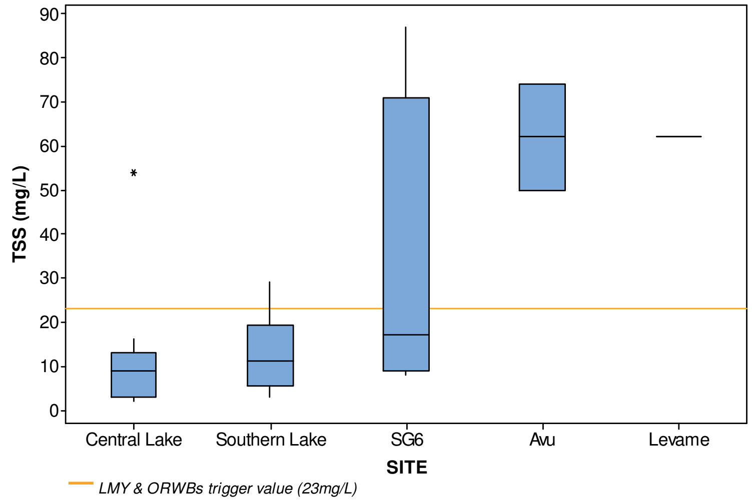



Figure D-32 TSS in water Lake Murray and ORWBs test sites 2015

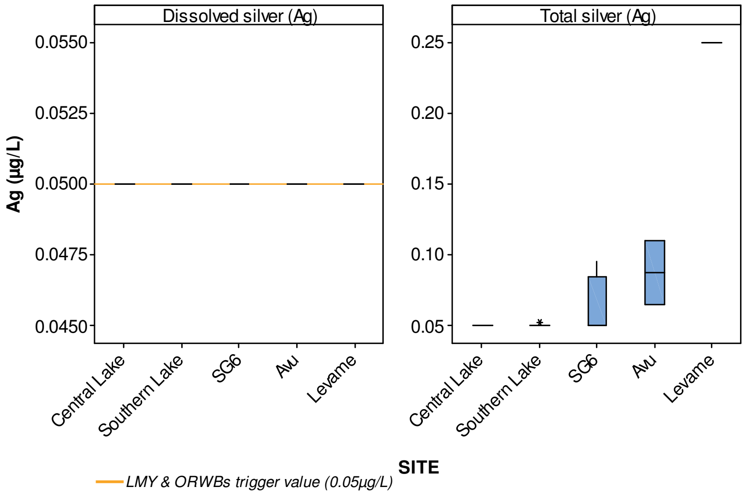



**Figure D-33 Silver in water Lake Murray and ORWBs test sites 2015**

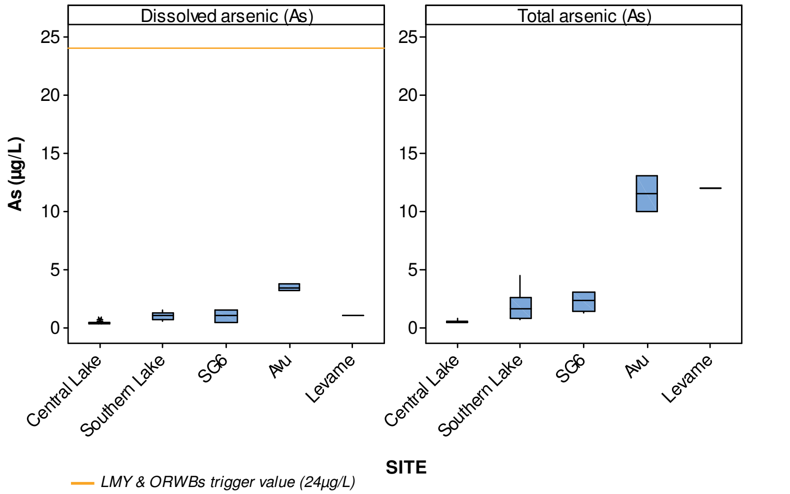



**Figure D-34 As in water Lake Murray and ORWBs test sites 2015**

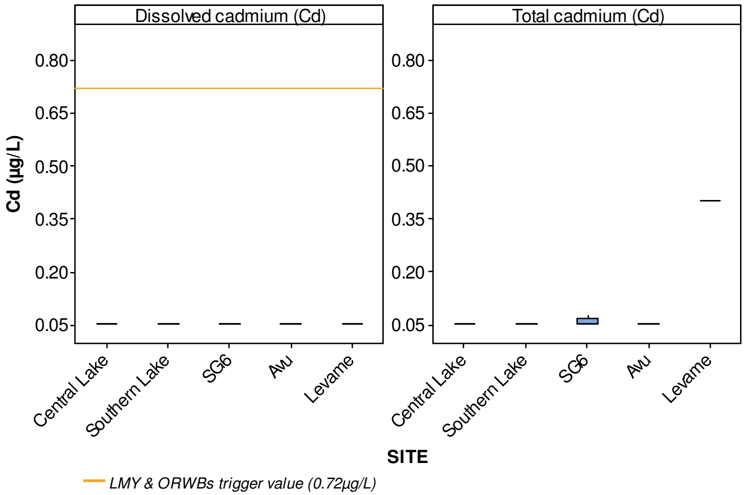



**Figure D-35 Cadmium in water Lake Murray and ORWBs test sites 2015**

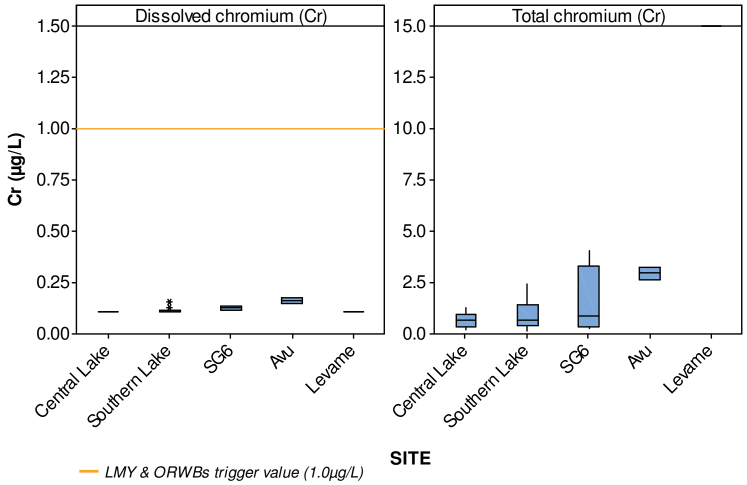



**Figure D-36 Cr in water Lake Murray and ORWBs test sites 2015**

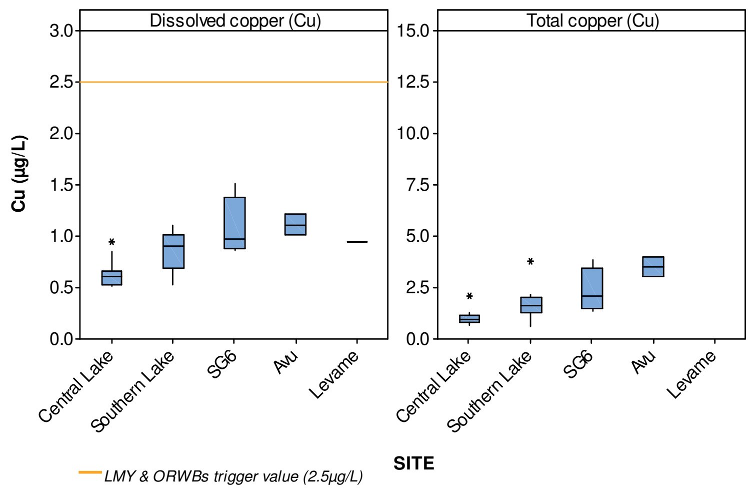



**Figure D-37 Copper in water Lake Murray and ORWBs test sites 2015**

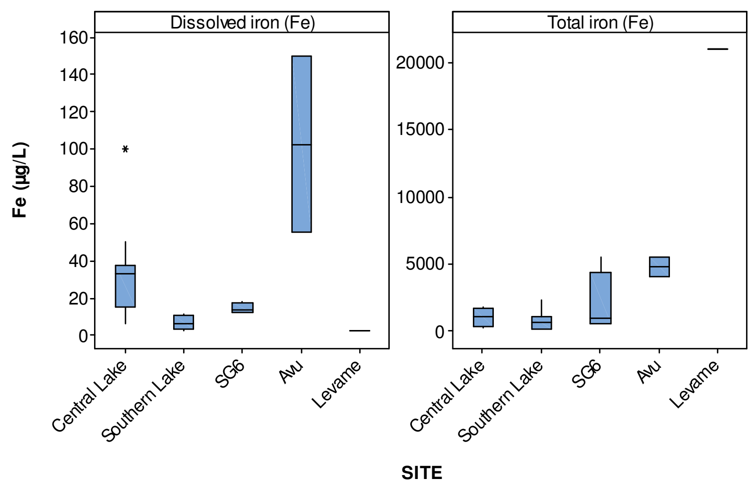



**Figure D-38 Iron in water Lake Murray and ORWBs test sites 2015**

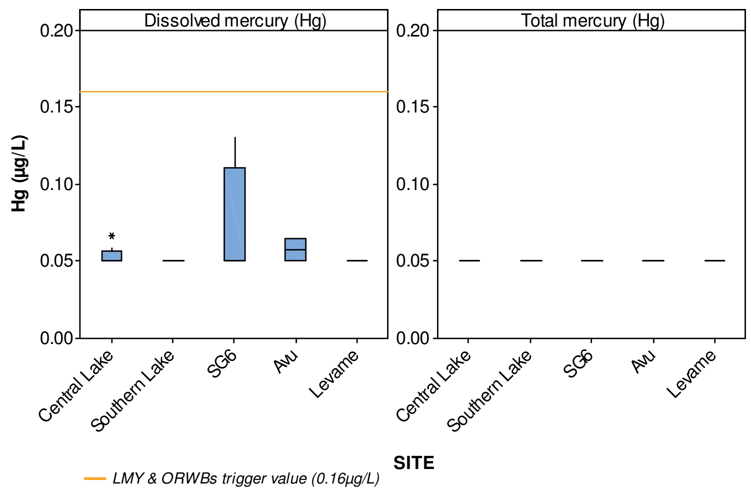



**Figure D-39 Mercury in water Lake Murray and ORWBs test sites 2015**

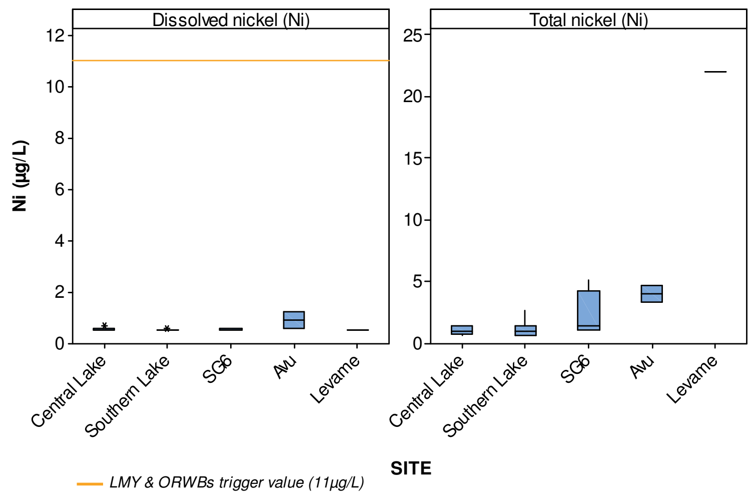



**Figure D-40 Nickel in water Lake Murray and ORWBs test sites 2015**

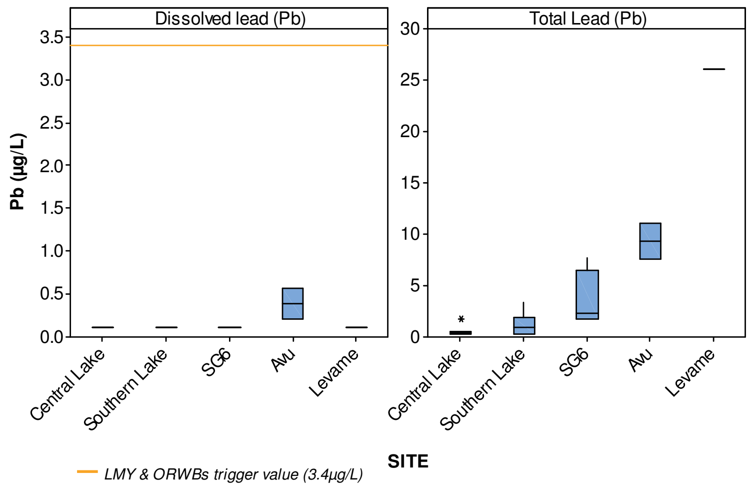



Figure D-41 Lead in water Lake Murray and ORWBs test sites 2015

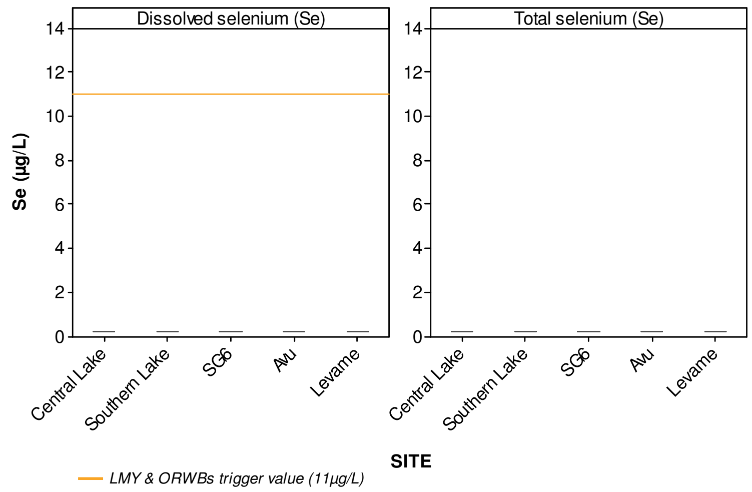



Figure D-42 Selenium in water Lake Murray and ORWBs test sites 2015

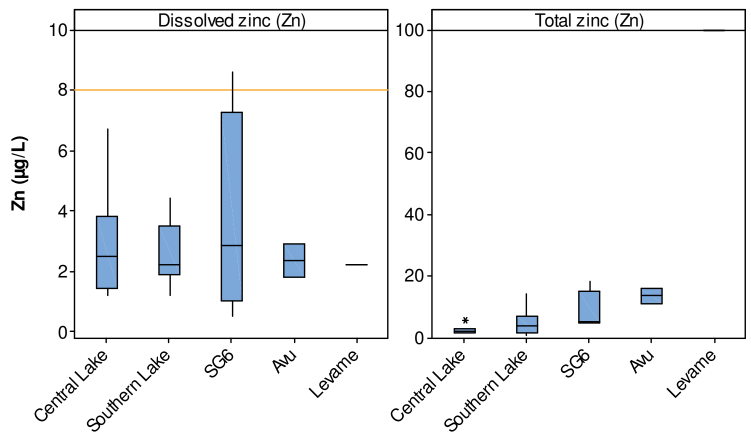



Figure D-43 Zinc in water Lake Murray and ORWBs test sites 2015

**Table D-19 Performance assessment – Based on the trend of the annual median of water 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.**

| Water Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend 2011 - 2015 |
|---|---|---|---|---|
| Central Lake (Trend of Annual Medians from 2011 - 2015) | pH | 0.310 | 0.123 | No change over time |
| | TSS | 0.570 | 0.006 | Increasing over time |
| | Ag-D | -0.735 | <0.001 | Reducing over time |
| | As-D | -0.078 | 0.707 | No change over time |
| | Cd-D | -0.735 | <0.001 | Reducing over time |
| | Cr-D | -0.934 | <0.001 | Reducing over time |
| | Cu-D | -0.121 | 0.556 | No change over time |
| | Fe-D | -0.897 | <0.001 | Reducing over time |
| | Hg-D | -0.632 | <0.001 | Reducing over time |
| | Ni-D | -0.354 | 0.076 | No change over time |
| | Pb-D | -0.735 | <0.001 | Reducing over time |
| | Se-D | -0.690 | <0.001 | Reducing over time |
| | Zn-D | 0.166 | 0.418 | No change over time |
| Southern Lake (Trend of Annual Medians from 2011 - 2015) | pH | -0.162 | 0.331 | No change over time |
| | TSS | 0.436 | 0.018 | Increasing over time |
| | Ag-D | -0.889 | <0.001 | Reducing over time |
| | As-D | -0.235 | 0.156 | No change over time |
| | Cd-D | -0.889 | <0.001 | Reducing over time |
| | Cr-D | -0.843 | <0.001 | Reducing over time |
| | Cu-D | -0.506 | <0.001 | Reducing over time |
| | Fe-D | -0.775 | <0.001 | Reducing over time |
| | Hg-D | -0.889 | <0.001 | Reducing over time |
| | Ni-D | -0.820 | <0.001 | Reducing over time |
| | Pb-D | -0.889 | <0.001 | Reducing over time |
| | Se-D | -0.850 | <0.001 | Reducing over time |
| | Zn-D | -0.123 | 0.462 | No change over time |
| SG6 (Trend of Annual Medians from 2011 - 2015) | pH | 0.379 | 0.163 | No change over time |
| | TSS | 0.353 | 0.216 | No change over time |
| | Ag-D | -0.746 | <0.001 | Reducing over time |
| | As-D | -0.067 | 0.799 | No change over time |
| | Cd-D | -0.746 | <0.001 | Reducing over time |
| | Cr-D | -0.431 | 0.084 | No change over time |
| | Cu-D | 0.006 | 0.981 | No change over time |
| | Fe-D | -0.887 | <0.001 | Reducing over time |
| | Hg-D | -0.419 | 0.094 | No change over time |
| | Ni-D | -0.536 | 0.027 | Reducing over time |
| | Pb-D | -0.746 | <0.001 | Reducing over time |
| | Se-D | -0.522 | 0.046 | Reducing over time |
| | Zn-D | -0.022 | 0.933 | No change over time |

| Water Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend 2011 - 2015 |
|---|---|---|---|---|
| Kukufionga<br><br>(Trend of Annual Medians from 2011 - 2015) | All | | | Spearman rho and p values only cover 2011-2014. Nil data collected in 2015 and to perform spearman will only result in introduction of bias. |
| Zongamange<br><br>(Trend of Annual Medians from 2011 - 2015) | All | | | |
| Avu<br><br>(Trend of Annual Medians from 2011 - 2015) | pH | 0.160 | 0.603 | No change over time |
| | TSS | 0.584 | 0.046 | Increasing over time |
| | Ag-D | -0.828 | <0.001 | Reducing over time |
| | As-D | -0.006 | 0.982 | No change over time |
| | Cd-D | -0.828 | <0.001 | Reducing over time |
| | Cr-D | -0.450 | 0.092 | No change over time |
| | Cu-D | -0.081 | 0.775 | No change over time |
| | Fe-D | -0.516 | 0.049 | Reducing over time |
| | Hg-D | -0.084 | 0.767 | No change over time |
| | Ni-D | -0.191 | 0.495 | No change over time |
| | Pb-D | -0.162 | 0.565 | No change over time |
| | Se-D | -0.628 | 0.022 | Reducing over time |
| | Zn-D | 0.036 | 0.897 | 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**

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

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

TSM = Test Site Median

ND = No determination

**Table E-2 Sediment quality upper river test sites - SG1 2015 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* | 6 | 6 | 0.50 | TSM < Upper TV | Step 1 | 1.0 | NA | LOW |
| As-WAE* | 6 | 6 | 5.5 | TSM < Upper TV | Step 1 | 20 | NA | LOW |
| Cd-WAE* | 6 | 6 | 0.82 | TSM < Upper TV | Step 1 | 1.5 | NA | LOW |
| Cr-WAE* | 6 | 6 | 3.8 | TSM < Upper TV | Step 1 | 80 | NA | LOW |
| Cu-WAE* | 6 | 6 | 6.3 | TSM < Upper TV | Step 1 | 65 | NA | LOW |
| Hg-WAE* | 6 | 6 | 0.01 | TSM < Upper TV | Step 1 | 0.15 | NA | LOW |
| Ni-WAE* | 6 | 6 | 5.1 | TSM < Upper TV | Step 1 | 27 | NA | LOW |
| Pb-WAE* | 6 | NA | 125 | TSM > Upper TV | Step 2 | 50 | NA | POTENTIAL |
| Se-WAE* | 6 | NA | 0.50 | TSM = Upper TV | Step 3 | 0.50 | NA | LOW |
| Zn-WAE* | 6 | 6 | 114 | TSM < Upper TV | Step 1 | 200 | NA | LOW |

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

**Table E-3 Sediment quality upper river test sites - SG2 2015 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 | 12 | 12 | 0.50 | TSM < Upper TV | Step 1 | 1.0 | <0.001 | LOW |
| As-WAE | 12 | 12 | 6.9 | TSM < Upper TV | Step 1 | 20 | 0.001 | LOW |
| Cd-WAE | 12 | 10 | 0.90 | TSM < Upper TV | Step 1 | 1.5 | 0.003 | LOW |
| Cr-WAE | 12 | 12 | 5.9 | TSM < Upper TV | Step 1 | 80 | 0.001 | LOW |
| Cu-WAE | 12 | 12 | 14 | TSM < Upper TV | Step 1 | 65 | 0.001 | LOW |
| Hg-WAE | 12 | 12 | 0.02 | TSM < Upper TV | Step 1 | 0.15 | 0.001 | LOW |
| Ni-WAE | 12 | 12 | 6.7 | TSM < Upper TV | Step 1 | 27 | 0.001 | LOW |
| Pb-WAE | 12 | NA | 71 | TSM > Upper TV | Step 2 | 50 | NA | POTENTIAL |
| Se-WAE | 12 | NA | 0.50 | TSM = Upper TV | Step 3 | 0.50 | NA | LOW |
| Zn-WAE | 12 | 10 | 130 | TSM < Upper TV | Step 1 | 200 | 0.010 | LOW |

**Table E-4 Sediment quality upper river test sites - Wasiba 2015 median (WAE whole sediment mg/kg)**

| Test Site | | | | Initial Assessment | | TV | Statistical Test Result (P=0.05) | Risk Assessment |
|---|---|---|---|---|---|---|---|---|
| Wankipe | N | N (Test) | Median | Result | Go to | | | |
| Ag-WAE | 15 | 15 | 0.50 | TSM < Upper TV | Step 1 | 1.0 | <0.001 | LOW |
| As-WAE | 15 | 15 | 6.3 | TSM < Upper TV | Step 1 | 20 | <0.001 | LOW |
| Cd-WAE | 15 | 14 | 0.71 | TSM < Upper TV | Step 1 | 1.5 | 0.001 | LOW |
| Cr-WAE | 15 | 15 | 4.0 | TSM < Upper TV | Step 1 | 80 | 0.001 | LOW |
| Cu-WAE | 15 | 15 | 10 | TSM < Upper TV | Step 1 | 65 | 0.001 | LOW |
| Hg-WAE | 15 | 15 | 0.01 | TSM < Upper TV | Step 1 | 0.15 | <0.001 | LOW |
| Ni-WAE | 15 | 15 | 12 | TSM < Upper TV | Step 1 | 27 | <0.001 | LOW |
| Pb-WAE | 15 | NA | 54 | TSM > Upper TV | Step 2 | 50 | NA | POTENTIAL |
| Se-WAE | 15 | NA | 0.50 | TSM = Upper TV | Step 3 | 0.5 | NA | LOW |
| Zn-WAE | 15 | 13 | 81 | TSM < Upper TV | Step 1 | 200 | 0.006 | LOW |

NA – Wilcoxon not run.

**Table E-5 Sediment quality upper river test sites - Wankipe 2015 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 | 15 | 15 | 0.50 | TSM < Upper TV | Step 1 | 1.0 | <0.001 | LOW |
| As-WAE | 15 | 15 | 6.0 | TSM < Upper TV | Step 1 | 20 | <0.001 | LOW |
| Cd-WAE | 15 | 15 | 0.59 | TSM < Upper TV | Step 1 | 1.5 | 0.001 | LOW |
| Cr-WAE | 15 | 15 | 3.8 | TSM < Upper TV | Step 1 | 80 | <0.001 | LOW |
| Cu-WAE | 15 | 15 | 10 | TSM < Upper TV | Step 1 | 65 | <0.001 | LOW |
| Hg-WAE | 15 | 15 | 0.01 | TSM < Upper TV | Step 1 | 0.15 | <0.001 | LOW |
| Ni-WAE | 15 | 15 | 8.4 | TSM < Upper TV | Step 1 | 27 | 0.001 | LOW |
| Pb-WAE | 15 | 15 | 44 | TSM < Upper TV | Step 1 | 50 | 0.213 | POTENTIAL |
| Se-WAE | 15 | NA | 0.50 | TSM = Upper TV | Step 3 | 0.5 | NA | LOW |
| Zn-WAE | 15 | 15 | 78 | TSM < Upper TV | Step 1 | 200 | 0.007 | LOW |

**Table E-6 Sediment quality upper river test sites - SG3 2015 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 | 61 | 61 | 0.50 | TSM < Upper TV | Step 1 | 1.0 | <0.001 | LOW |
| As-WAE | 61 | 61 | 4.8 | TSM < Upper TV | Step 1 | 20 | <0.001 | LOW |
| Cd-WAE | 61 | 60 | 0.58 | TSM < Upper TV | Step 1 | 1.5 | <0.001 | LOW |
| Cr-WAE | 61 | 61 | 3.2 | TSM < Upper TV | Step 1 | 80 | <0.001 | LOW |
| Cu-WAE | 61 | 61 | 9.6 | TSM < Upper TV | Step 1 | 65 | <0.001 | LOW |
| Hg-WAE | 61 | 61 | 0.01 | TSM < Upper TV | Step 1 | 0.15 | <0.001 | LOW |
| Ni-WAE | 61 | 60 | 9.5 | TSM < Upper TV | Step 1 | 27 | <0.001 | LOW |
| Pb-WAE | 61 | 61 | 28 | TSM < Upper TV | Step 1 | 50 | <0.001 | LOW |
| Se-WAE | 61 | NA | 0.50 | TSM = Upper TV | Step 3 | 0.5 | NA | LOW |
| Zn-WAE | 61 | 60 | 70 | TSM < Upper TV | Step 1 | 200 | <0.001 | LOW |

**Table E-7 Sediment quality lower river test sites - Bebelubi 2015 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 | 6 | 6 | 0.50 | TSM < Upper TV | Step 1 | 1.0 | NA | LOW* |
| As-WAE | 6 | 6 | 3.4 | TSM < Upper TV | Step 1 | 20 | NA | LOW* |
| Cd-WAE | 6 | 6 | 0.50 | TSM < Upper TV | Step 1 | 1.5 | NA | LOW* |
| Cr-WAE | 6 | 6 | 6.2 | TSM < Upper TV | Step 1 | 80 | NA | LOW* |
| Cu-WAE | 6 | 6 | 6.5 | TSM < Upper TV | Step 1 | 65 | NA | LOW* |
| Hg-WAE | 6 | 6 | 0.01 | TSM < Upper TV | Step 1 | 0.2 | NA | LOW* |
| Ni-WAE | 6 | 6 | 18 | TSM < Upper TV | Step 1 | 21 | NA | LOW* |
| Pb-WAE | 6 | 6 | 13 | TSM < Upper TV | Step 1 | 50 | NA | LOW* |
| Se-WAE | 6 | NA | 0.50 | TSM = Upper TV | Step 3 | 0.5 | NA | LOW* |
| Zn-WAE | 6 | 6 | 44 | TSM < Upper TV | Step 1 | 200 | NA | LOW* |

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

**Table E-8 Sediment quality lower river test sites - SG4/Tiumsinawam 2015 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 | 8 | 8 | 0.50 | TSM < Upper TV | Step 1 | 1.0 | 0.007 | LOW |
| As-WAE | 8 | 8 | 2.3 | TSM < Upper TV | Step 1 | 20 | 0.008 | LOW |
| Cd-WAE | 8 | 8 | 0.50 | TSM < Upper TV | Step 1 | 1.5 | 0.007 | LOW |
| Cr-WAE | 8 | 8 | 3.8 | TSM < Upper TV | Step 1 | 80 | 0.007 | LOW |
| Cu-WAE | 8 | 8 | 6.4 | TSM < Upper TV | Step 1 | 65 | 0.007 | LOW |
| Hg-WAE | 8 | 8 | 0.01 | TSM < Upper TV | Step 1 | 0.2 | 0.007 | LOW |
| Ni-WAE | 8 | 8 | 9.0 | TSM < Upper TV | Step 1 | 21 | 0.007 | LOW |
| Pb-WAE | 8 | 8 | 9.4 | TSM < Upper TV | Step 1 | 50 | 0.007 | LOW |
| Se-WAE | 8 | NA | 0.50 | TSM = Upper TV | Step 3 | 0.50 | NA | LOW |
| Zn-WAE | 8 | 8 | 34 | TSM < Upper TV | Step 1 | 200 | 0.007 | LOW |

**Table E-9 Sediment quality lower river test sites - SG5 2015 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 | 8 | 8 | 0.50 | TSM < Upper TV | Step 1 | 1.0 | 0.007 | LOW |
| As-WAE | 8 | 8 | 4.2 | TSM < Upper TV | Step 1 | 20 | 0.007 | LOW |
| Cd-WAE | 8 | 8 | 0.50 | TSM < Upper TV | Step 1 | 1.5 | 0.007 | LOW |
| Cr-WAE | 8 | 8 | 21 | TSM < Upper TV | Step 1 | 80 | 0.007 | LOW |
| Cu-WAE | 8 | 8 | 13 | TSM < Upper TV | Step 1 | 65 | 0.007 | LOW |
| Hg-WAE | 8 | 8 | 0.01 | TSM < Upper TV | Step 1 | 0.2 | 0.007 | LOW |
| Ni-WAE | 8 | NA | 38 | TSM > Upper TV | Step 2 | 21 | NA | POTENTIAL |
| Pb-WAE | 8 | 8 | 19 | TSM < Upper TV | Step 1 | 50 | 0.007 | LOW |
| Se-WAE | 8 | NA | 0.50 | TSM = Upper TV | Step 3 | 0.5 | NA | LOW |
| Zn-WAE | 8 | 8 | 120 | TSM < Upper TV | Step 1 | 200 | 0.007 | LOW |

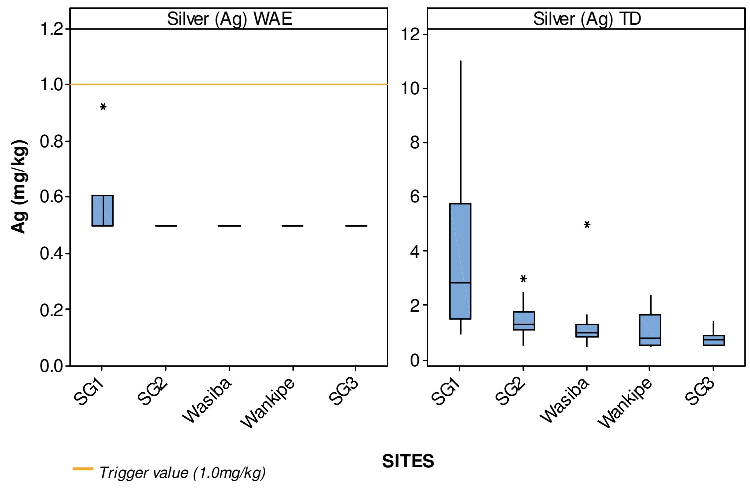



**Figure E-1 Silver in sediment upper river test sites 2015**

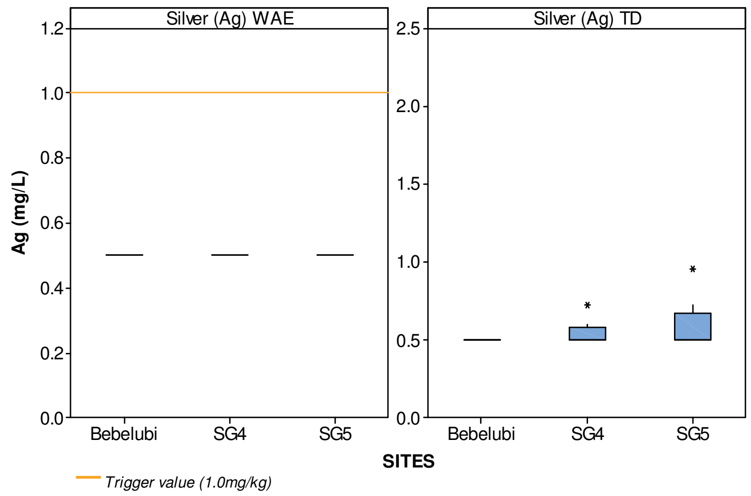



**Figure E-2 Silver in sediment lower river test sites 2015**

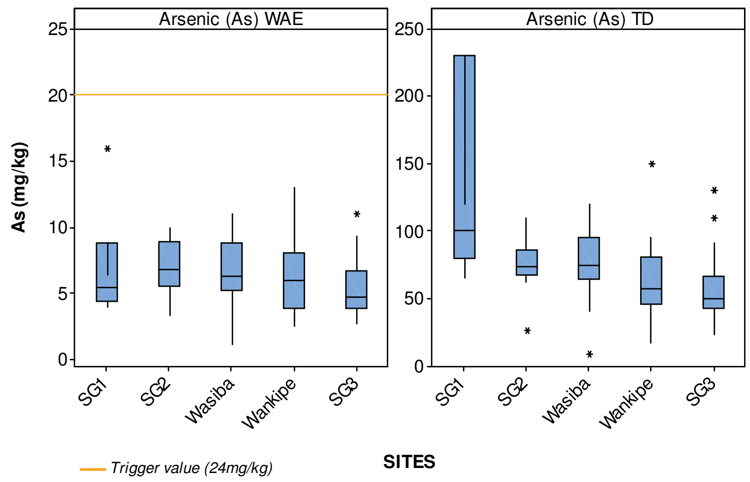



**Figure E-3 Arsenic in sediment upper river test sites 2015**

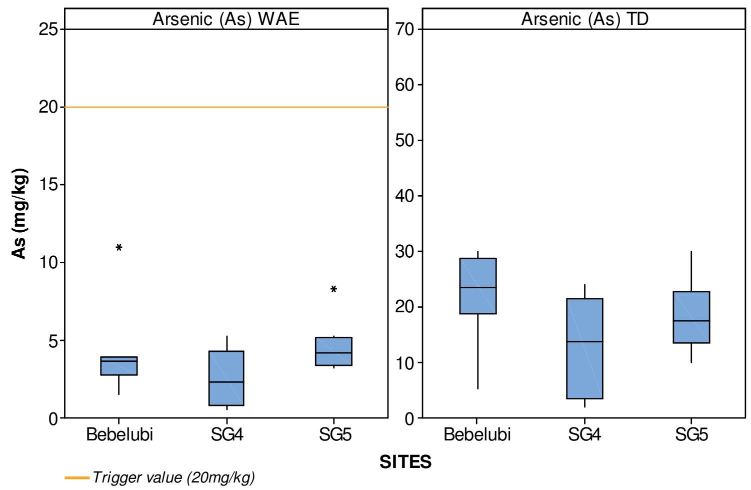



**Figure E-4 Arsenic in sediment lower river test sites 2015**

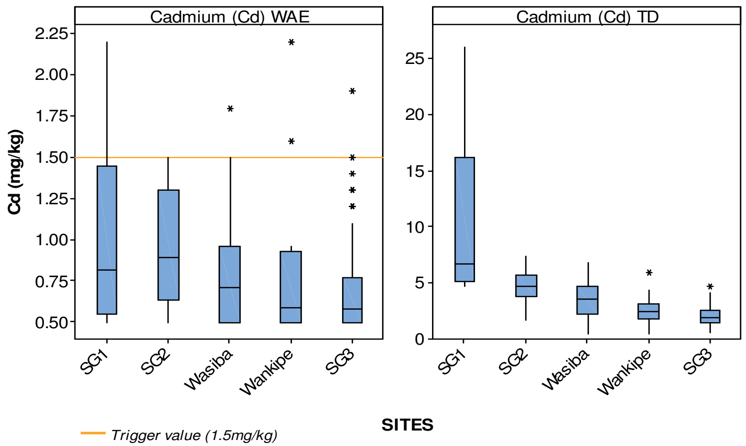



**Figure E-5 Cadmium in sediment upper river test sites 2015**

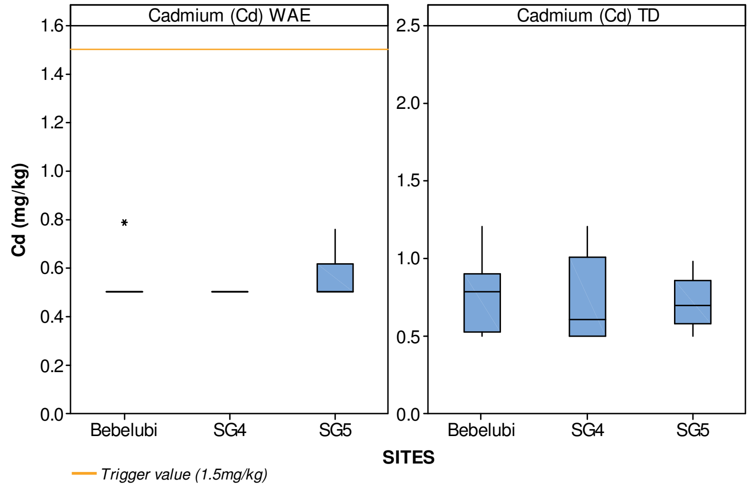



**Figure E-6 Cadmium in sediment lower river test sites 2015**

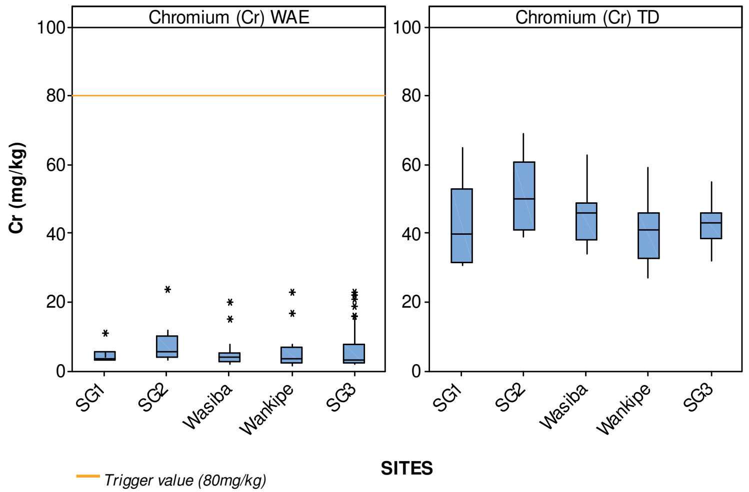



**Figure E-7 Chromium in sediment upper river test sites 2015**

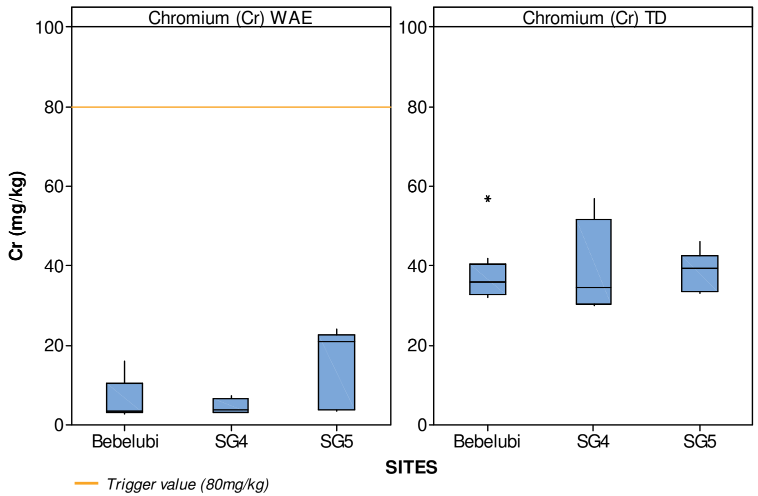



**Figure E-8 Chromium in sediment lower river test sites 2015**

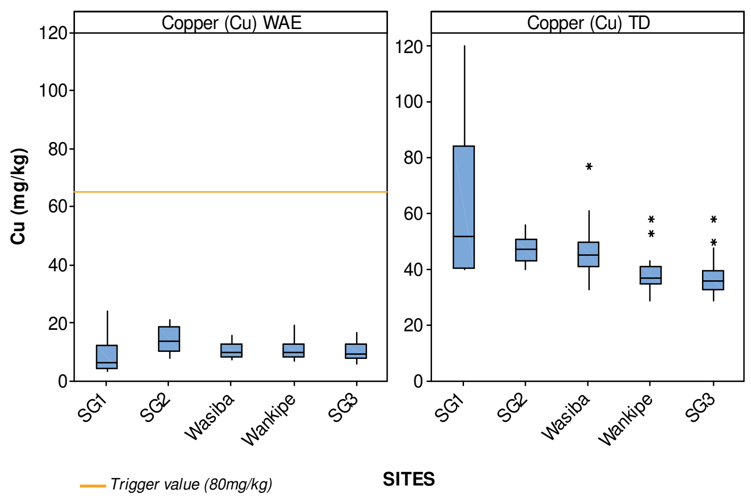



**Figure E-9 Copper in sediment upper river test sites 2015**

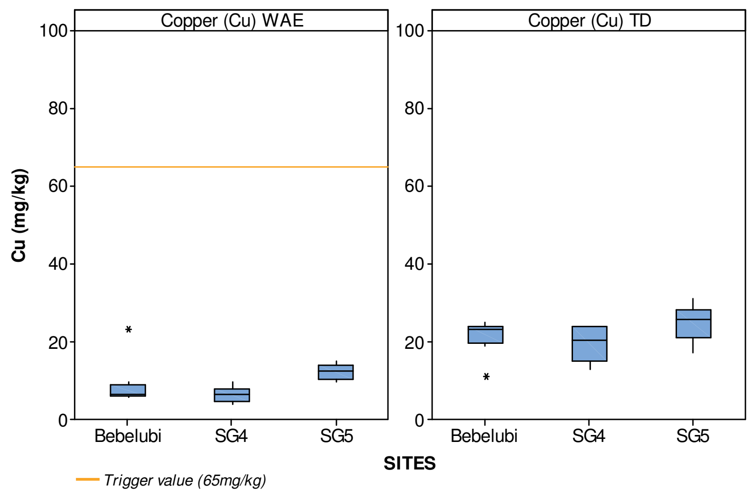



**Figure E-10 Copper in sediment lower river test sites 2015**

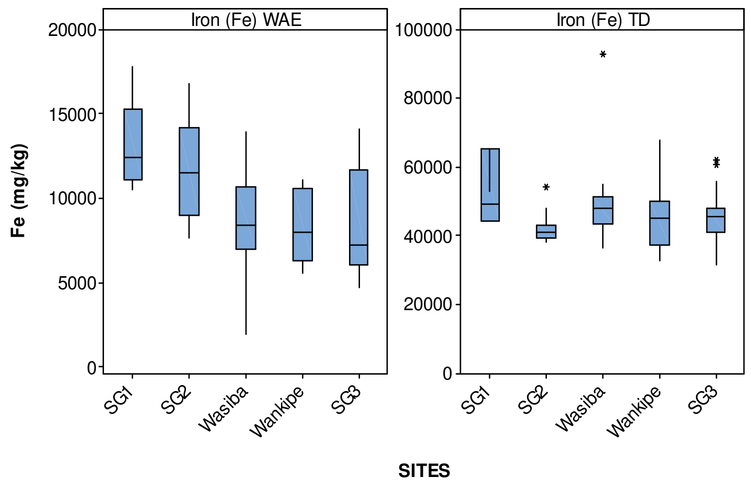



**Figure E-11 Iron in sediment upper river test sites 2015**

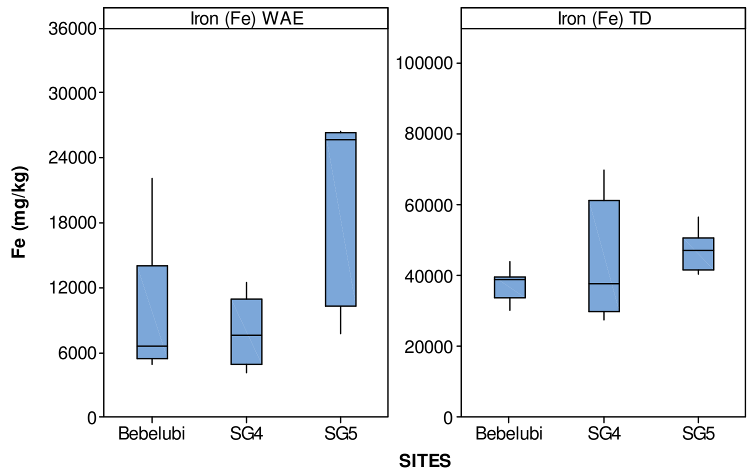



**Figure E-12 Iron in sediment lower river test sites 2015**

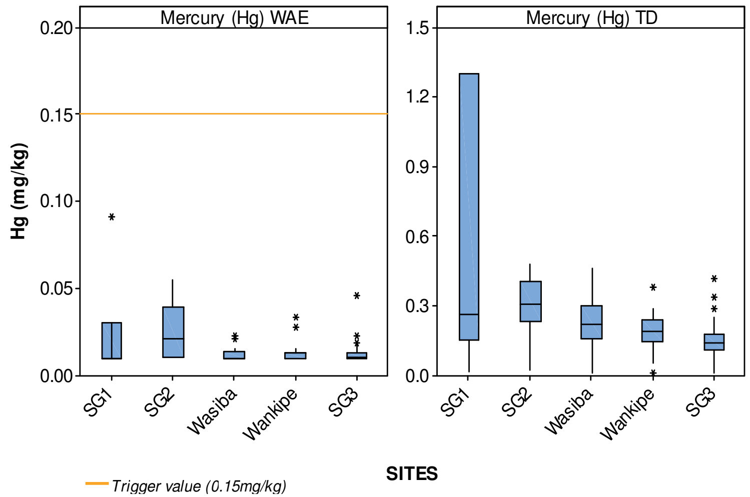



**Figure E-13 Mercury in sediment upper river test sites 2015**

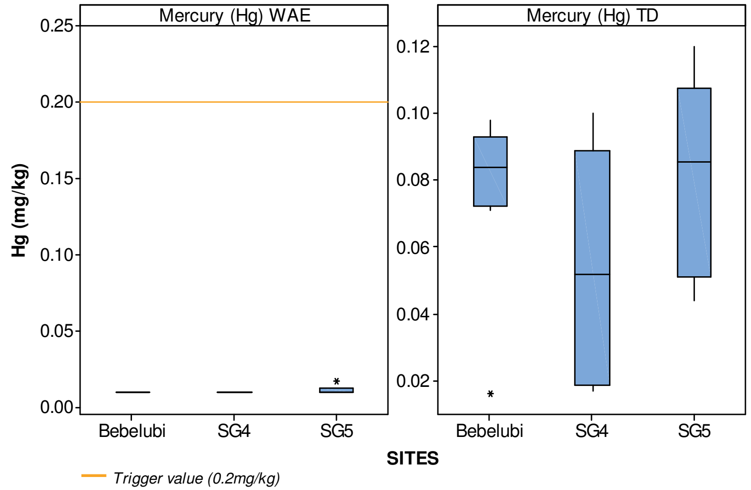



**Figure E-14 Mercury in sediment lower river test sites 2015**

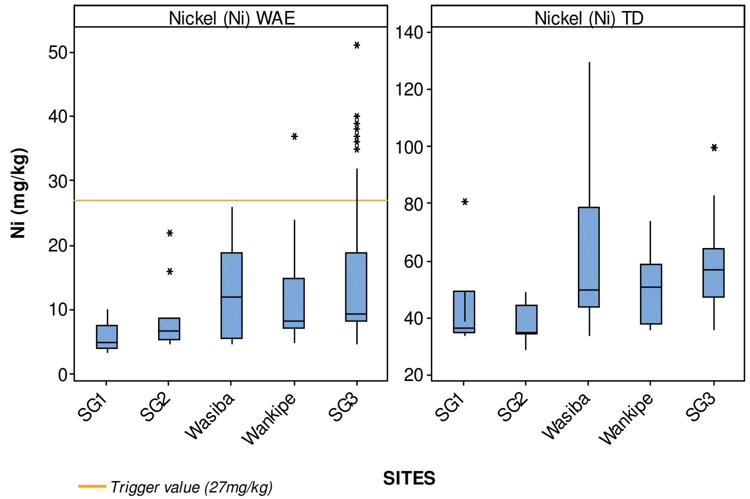



**Figure E-15 Nickel in sediment upper river test sites 2015**

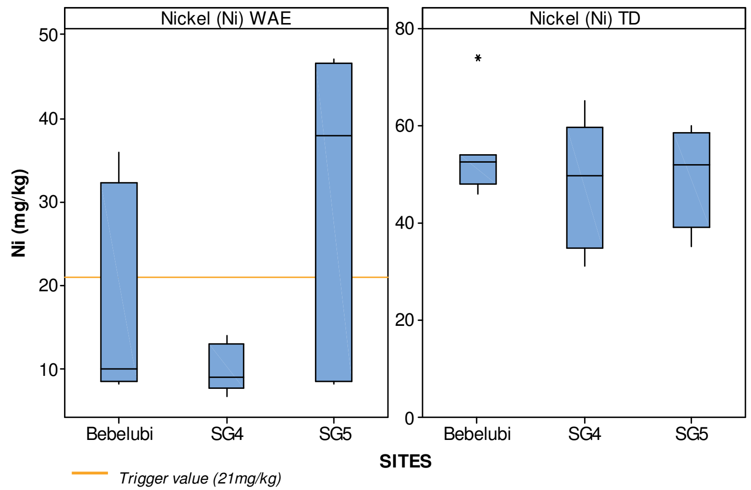



**Figure E-16 Nickel in sediment lower river test sites 2015**

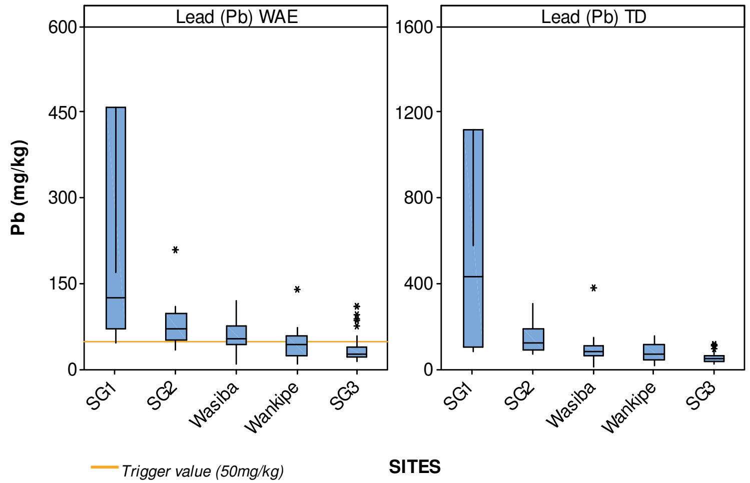



Figure E-17 Lead in sediment upper river test sites 2015

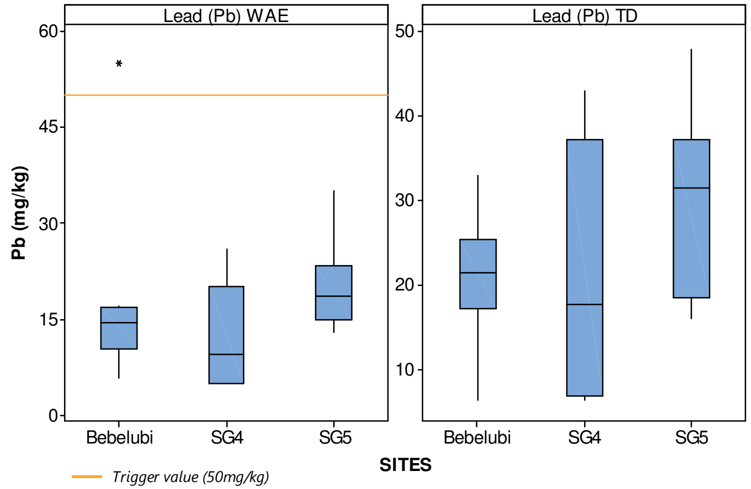



Figure E-18 Lead in sediment lower river test sites 2015

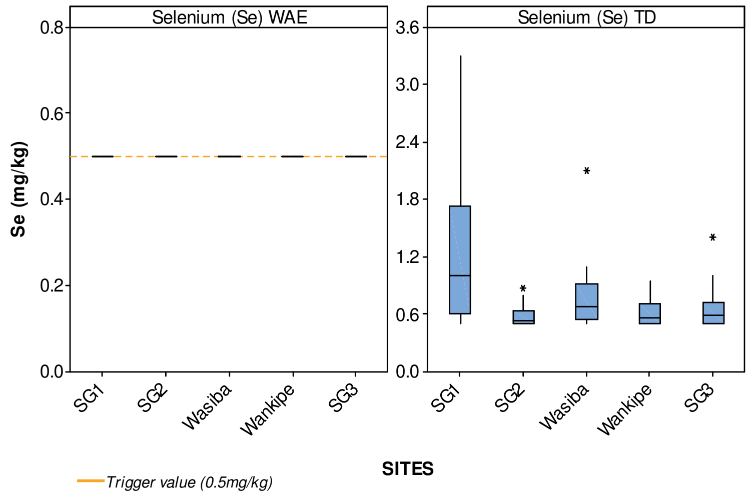



Figure E-19 Selenium in sediment upper river test sites 2015

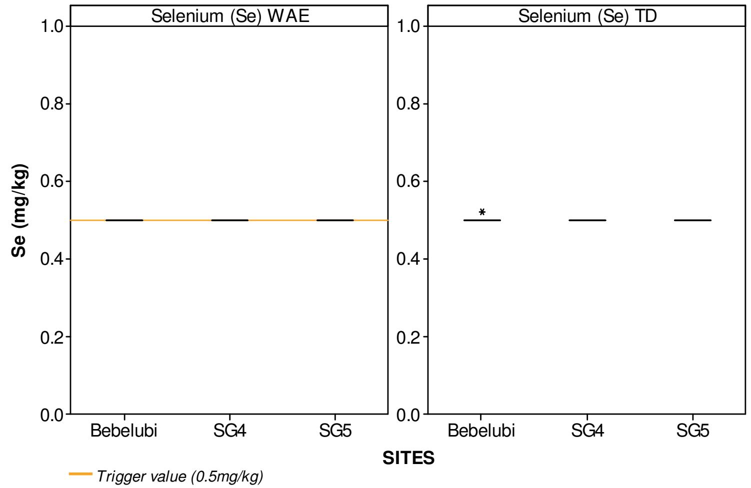



Figure E-20 Selenium in sediment lower river test sites 2015

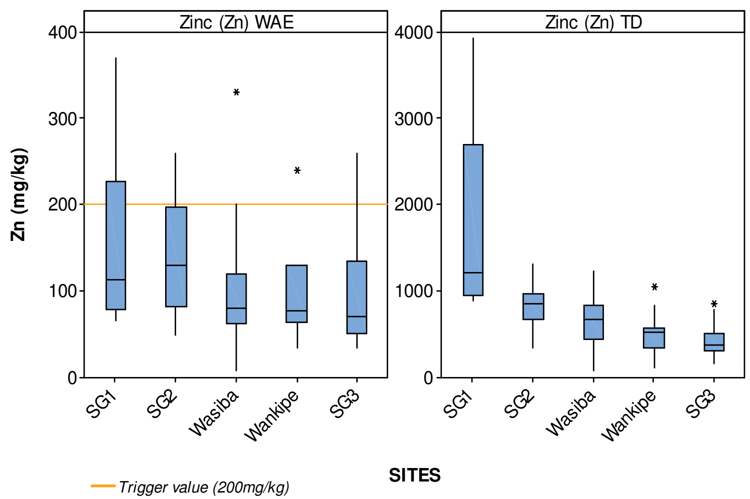



**Figure E-21 Zinc in sediment upper river test sites 2015**

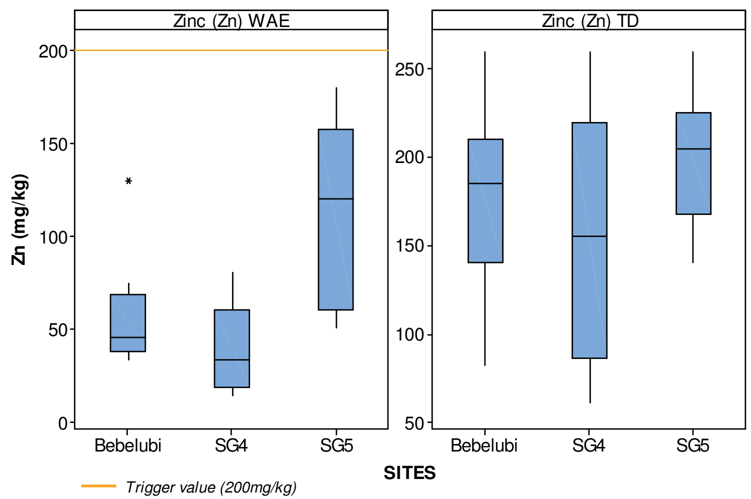



**Figure E-22 Zinc in sediment lower river test sites 2015**

**Table E-10 Performance assessment – Based on the trend of the annual median of sediment quality indicators at upper river test sites relative to the trend of the annual median of water quality indicators at upper river 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 2011 - 2015 |
|---|---|---|---|---|
| SG1 (Trend of Annual Medians 2011 - 2015) | Ag-WAE | 0.299 | 0.176 | No change over time |
| | As-WAE | 0.278 | 0.201 | No change over time |
| | Cd-WAE | 0.227 | 0.309 | No change over time |
| | Cr-WAE | 0.520 | 0.012 | Increased over time |
| | Cu-WAE | 0.330 | 0.134 | No change over time |
| | Hg-WAE | -0.564 | 0.009 | Reduced over time |
| | Ni-WAE | 0.491 | 0.020 | Increased over time |
| | Pb-WAE | 0.076 | 0.737 | No change over time |
| | Se-WAE | <LOR | <LOR | No change over time |
| | Zn-WAE | 0.252 | 0.259 | No change over time |
| SG2 (Trend of Annual Medians 2011 - 2015) | Ag-WAE | <LOR | <LOR | No change over time |
| | As-WAE | 0.447 | 0.017 | Increased over time |
| | Cd-WAE | 0.332 | 0.085 | No change over time |
| | Cr-WAE | 0.669 | 0.000 | Increased over time |
| | Cu-WAE | 0.368 | 0.054 | No change over time |
| | Hg-WAE | -0.116 | 0.558 | No change over time |
| | Ni-WAE | 0.461 | 0.014 | Increased over time |
| | Pb-WAE | 0.002 | 0.990 | No change over time |
| | Se-WAE | <LOR | <LOR | No change over time |
| | Zn-WAE | 0.361 | 0.059 | No change over time |
| Wasiba (Trend of Annual Medians 2011 - 2015) | Ag-WAE | <LOR | <LOR | No change over time |
| | As-WAE | 0.398 | 0.054 | No change over time |
| | Cd-WAE | 0.405 | 0.049 | Increased over time |
| | Cr-WAE | 0.181 | 0.399 | No change over time |
| | Cu-WAE | 0.318 | 0.130 | No change over time |
| | Hg-WAE | 0.237 | 0.265 | No change over time |
| | Ni-WAE | 0.087 | 0.686 | No change over time |
| | Pb-WAE | 0.056 | 0.795 | No change over time |
| | Se-WAE | <LOR | <LOR | No change over time |
| | Zn-WAE | 0.261 | 0.217 | No change over time |
| Wankipe (Trend of Annual Medians 2011 - 2015) | Ag-WAE | <LOR | <LOR | No change over time |
| | As-WAE | 0.567 | 0.001 | Increased over time |
| | Cd-WAE | 0.438 | 0.011 | Increased over time |
| | Cr-WAE | 0.539 | 0.001 | Increased over time |
| | Cu-WAE | 0.652 | 0.000 | Increased over time |
| | Hg-WAE | -0.090 | 0.619 | No change over time |
| | Ni-WAE | 0.161 | 0.370 | No change over time |
| | Pb-WAE | 0.304 | 0.086 | No change over time |
| | Se-WAE | <LOR | <LOR | No change over time |
| | Zn-WAE | 0.454 | 0.008 | Increased over time |

| Sediment Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend 2011 - 2015 |
|---|---|---|---|---|
| SG3<br><br>(Trend of Annual Medians 2011 - 2015) | Ag-WAE | <LOR | <LOR | No change over time |
| | As-WAE | 0.757 | 0.000 | Increased over time |
| | Cd-WAE | 0.545 | 0.000 | Increased over time |
| | Cr-WAE | 0.696 | 0.000 | Increased over time |
| | Cu-WAE | 0.780 | 0.000 | Increased over time |
| | Hg-WAE | -0.108 | 0.188 | No change over time |
| | Ni-WAE | 0.139 | 0.089 | No change over time |
| | Pb-WAE | 0.546 | 0.000 | Increased over time |
| | Se-WAE | <LOR | <LOR | No change over time |
| | Zn-WAE | 0.659 | 0.000 | 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 the annual median of sediment quality indicators at lower river test sites relative to the trend of the annual median of water quality indicators at lower river 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 2013 - 2015 |
|---|---|---|---|---|
| Bebelubi (Trend of Annual Medians 2013 - 2015) | Ag-WAE | <LOR | <LOR | No change over time |
| | As-WAE | 0.223 | 0.444 | No change over time |
| | Cd-WAE | 0.232 | 0.425 | No change over time |
| | Cr-WAE | 0.743 | 0.002 | Increased over time |
| | Cu-WAE | 0.282 | 0.328 | No change over time |
| | Hg-WAE | -0.464 | 0.095 | No change over time |
| | Ni-WAE | 0.260 | 0.369 | No change over time |
| | Pb-WAE | -0.334 | 0.243 | No change over time |
| | Se-WAE | <LOR | <LOR | No change over time |
| | Zn-WAE | 0.401 | 0.156 | No change over time |
| Tiumsinawam (Trend of Annual Medians 2013 - 2015) | Ag-WAE | <LOR | <LOR | No change over time |
| | As-WAE | 0.030 | 0.920 | No change over time |
| | Cd-WAE | <LOR | <LOR | No change over time |
| | Cr-WAE | 0.534 | 0.049 | Increased over time |
| | Cu-WAE | 0.284 | 0.326 | No change over time |
| | Hg-WAE | -0.523 | 0.055 | No change over time |
| | Ni-WAE | -0.134 | 0.647 | No change over time |
| | Pb-WAE | 0.060 | 0.840 | No change over time |
| | Se-WAE | <LOR | <LOR | No change over time |
| | Zn-WAE | 0.334 | 0.243 | No change over time |
| SG5 (Trend of Annual Medians 2013 - 2015) | Ag-WAE | <LOR | <LOR | No change over time |
| | As-WAE | 0.412 | 0.113 | No change over time |
| | Cd-WAE | 0.465 | 0.070 | No change over time |
| | Cr-WAE | 0.372 | 0.156 | No change over time |
| | Cu-WAE | 0.688 | 0.003 | Increased over time |
| | Hg-WAE | 0.081 | 0.765 | No change over time |
| | Ni-WAE | 0.372 | 0.155 | No change over time |
| | Pb-WAE | 0.543 | 0.030 | Increased over time |
| | Se-WAE | <LOR | <LOR | No change over time |
| | Zn-WAE | 0.415 | 0.110 | 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 2015 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 | 11 | 11 | 0.50 | TSM < TV | Step 1 | 1.0 | 0.002 | LOW |
| As-WAE | 11 | 11 | 1.6 | TSM < TV | Step 1 | 20 | 0.002 | LOW |
| Cd-WAE | 11 | 11 | 0.50 | TSM < TV | Step 1 | 1.5 | 0.002 | LOW |
| Cr-WAE | 11 | 11 | 20 | TSM < TV | Step 1 | 80 | 0.002 | LOW |
| Cu-WAE | 11 | 11 | 17 | TSM < TV | Step 1 | 65 | 0.002 | LOW |
| Hg-WAE | 11 | 11 | 0.08 | TSM < TV | Step 1 | 0.15 | 0.002 | LOW |
| Ni-WAE | 11 | NA | 24 | TSM > TV | Step 2 | 21 | NA | POTENTIAL |
| Pb-WAE | 11 | 11 | 15 | TSM < TV | Step 1 | 50 | 0.002 | LOW |
| Se-WAE* | 11 | 0 | 0.50 | TSM = TV | Step 3 | 0.5 | NA | LOW |
| Zn-WAE | 11 | 11 | 86 | TSM < TV | Step 1 | 200 | 0.002 | LOW |

**Table E-13 Sediment quality Lake Murray and ORWBs test sites South Lake 2015 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 | 10 | 10 | 0.50 | TSM < TV | Step 1 | 1.0 | 0.003 | LOW |
| As-WAE | 10 | 10 | 4.7 | TSM < TV | Step 1 | 20 | 0.003 | LOW |
| Cd-WAE | 10 | 10 | 0.50 | TSM < TV | Step 1 | 1.5 | 0.003 | LOW |
| Cr-WAE | 10 | 10 | 22 | TSM < TV | Step 1 | 80 | 0.003 | LOW |
| Cu-WAE | 10 | 10 | 22 | TSM < TV | Step 1 | 65 | 0.003 | LOW |
| Hg-WAE | 10 | 10 | 0.06 | TSM < TV | Step 1 | 0.15 | 0.003 | LOW |
| Ni-WAE | 10 | NA | 30 | TSM > TV | Step 2 | 21 | NA | POTENTIAL |
| Pb-WAE | 10 | 10 | 30 | TSM < TV | Step 1 | 50 | 0.026 | LOW |
| Se-WAE | 10 | NA | 0.50 | TSM = TV | Step 3 | 0.50 | NA | LOW |
| Zn-WAE | 10 | 10 | 110 | TSM < TV | Step 1 | 200 | 0.003 | LOW |

**Table E-14 Sediment quality Lake Murray and ORWBs test sites SG6 2015 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 | 4 | 4 | 0.50 | TSM < TV | Step 1 | 1.0 | 0.050 | LOW |
| As-WAE | 4 | 4 | 8.8 | TSM < TV | Step 1 | 20 | 0.050 | LOW |
| Cd-WAE | 4 | 4 | 0.50 | TSM < TV | Step 1 | 1.5 | 0.050 | LOW |
| Cr-WAE | 4 | 4 | 21 | TSM < TV | Step 1 | 80 | 0.050 | LOW |
| Cu-WAE | 4 | 4 | 22 | TSM < TV | Step 1 | 65 | 0.050 | LOW |
| Hg-WAE | 4 | 4 | 0.02 | TSM < TV | Step 1 | 0.15 | 0.050 | LOW |
| Ni-WAE | 4 | NA | 32 | TSM > TV | Step 2 | 21 | NA | POTENTIAL |
| Pb-WAE | 4 | 4 | 33 | TSM < TV | Step 1 | 50 | 0.050 | LOW |
| Se-WAE | 4 | 0 | 0.50 | TSM = TV | Step 3 | 0.50 | NA | LOW |
| Zn-WAE | 4 | 4 | 120 | TSM < TV | Step 1 | 200 | 0.050 | LOW |

**Table E-15 Sediment quality Lake Murray and ORWBs test sites Kukufionga 2015 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 | 0 | | | | | | | No data collected in 2015 therefore Wilcoxon for risk assessment not performed |
| As-WAE | 0 | | | | | | | |
| Cd-WAE | 0 | | | | | | | |
| Cr-WAE | 0 | | | | | | | |
| Cu-WAE | 0 | | | | | | | |
| Hg-WAE | 0 | | | | | | | |
| Ni-WAE | 0 | | | | | | | |
| Pb-WAE | 0 | | | | | | | |
| Se-WAE | 0 | | | | | | | |
| Zn-WAE | 0 | | | | | | | |

**Table E-16 Sediment quality Lake Murray and ORWBs test sites Zongamange 2015 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 | 0 | | | | | | | No data collected in 2015 therefore Wilcoxon for risk assessment not performed |
| As-WAE | 0 | | | | | | | |
| Cd-WAE | 0 | | | | | | | |
| Cr-WAE | 0 | | | | | | | |
| Cu-WAE | 0 | | | | | | | |
| Hg-WAE | 0 | | | | | | | |
| Ni-WAE | 0 | | | | | | | |
| Pb-WAE | 0 | | | | | | | |
| Se-WAE | 0 | | | | | | | |
| Zn-WAE | 0 | | | | | | | |

**Table E-17 Sediment quality Lake Murray and ORWBs test sites Avu 2015 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 | 2 | 2 | 0.50 | TSM < TV | Step 1 | 1.0 | 0.186 | LOW |
| As-WAE | 2 | 2 | 9.7 | TSM < TV | Step 1 | 20 | 0.187 | LOW |
| Cd-WAE | 2 | 2 | 0.62 | TSM < TV | Step 1 | 1.5 | 0.186 | LOW |
| Cr-WAE | 2 | 2 | 21 | TSM < TV | Step 1 | 80 | 0.186 | LOW |
| Cu-WAE | 2 | 2 | 24 | TSM < TV | Step 1 | 65 | 0.186 | LOW |
| Hg-WAE | 2 | 2 | 0.02 | TSM < TV | Step 1 | 0.15 | 0.186 | LOW |
| Ni-WAE | 2 | NA | 34 | TSM > TV | Step 2 | 21 | NA | POTENTIAL |
| Pb-WAE | 2 | NA | 62 | TSM > TV | Step 2 | 50 | NA | POTENTIAL |
| Se-WAE* | 2 | 0 | 0.5 | TSM = TV | Step 3 | 0.5 | NA | LOW |
| Zn-WAE | 2 | 2 | 170 | TSM < TV | Step 1 | 200 | 0.186 | LOW |

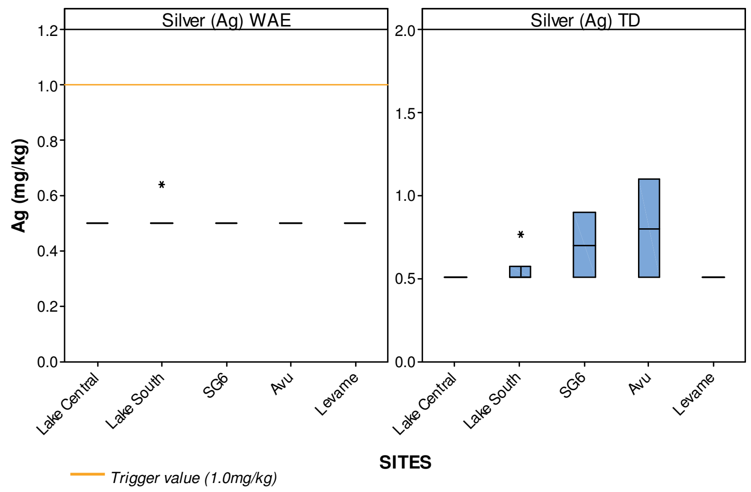



**Figure E-23 Silver in sediment LMY and ORWB test sites 2015**

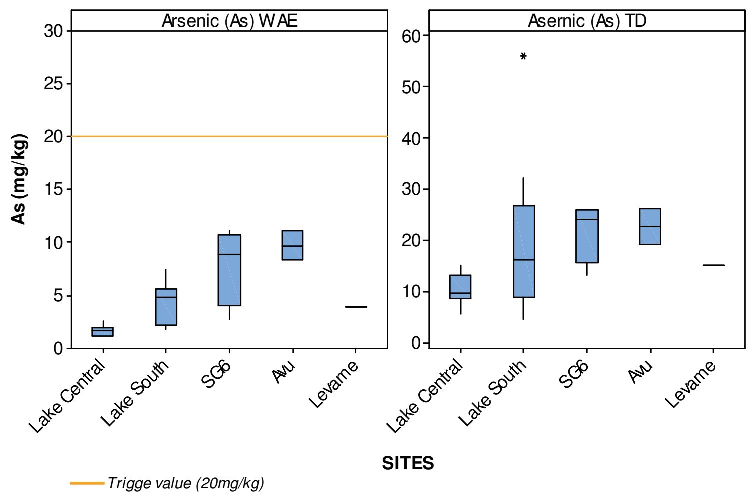



**Figure E-24 Arsenic in sediment LMY and ORWB test sites 2015**

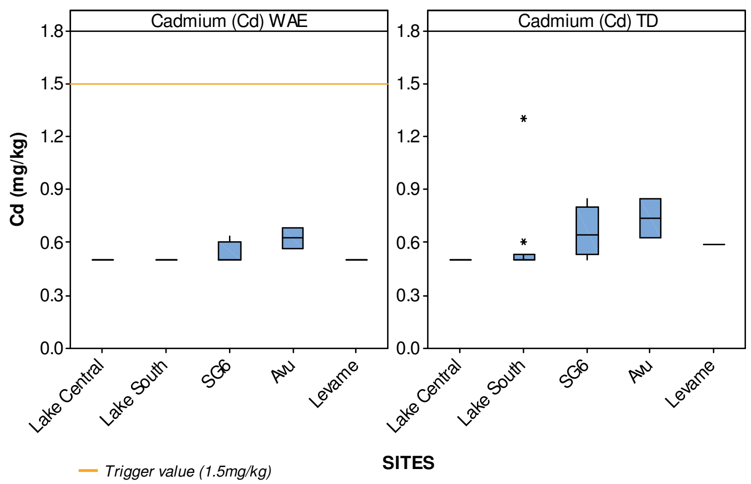



**Figure E-25 Cadmium in sediment LMY and ORWB test sites 2015**

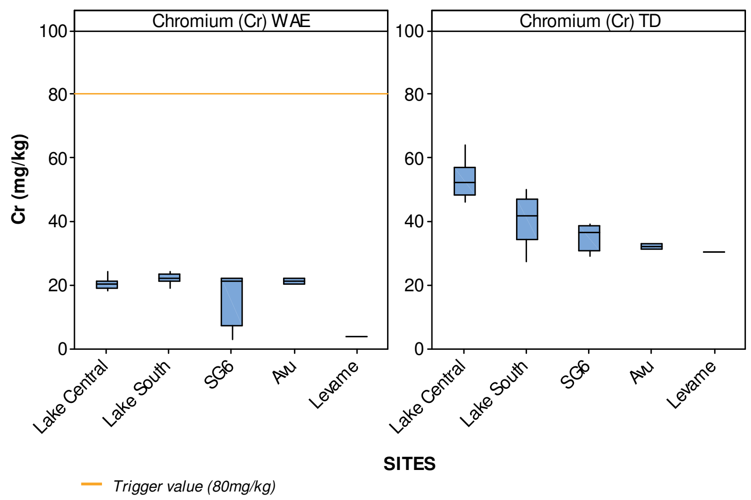



**Figure E-26 Chromium in sediment LMY and ORWB test sites 2015**

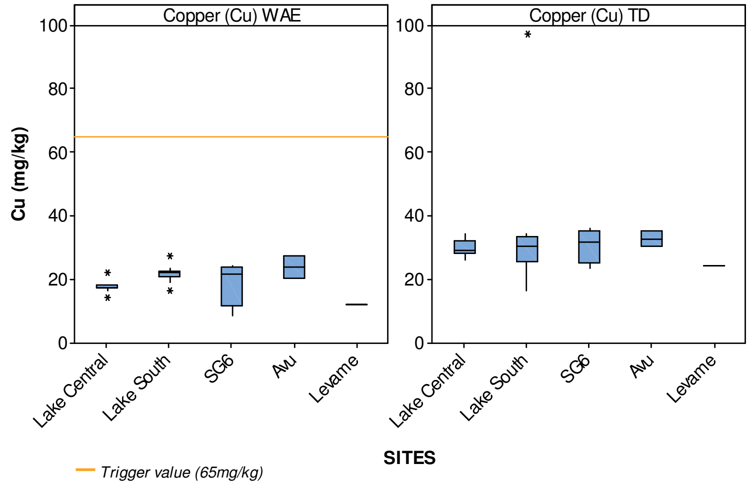



**Figure E-27 Copper in sediment LMY and ORWB test sites 2015**

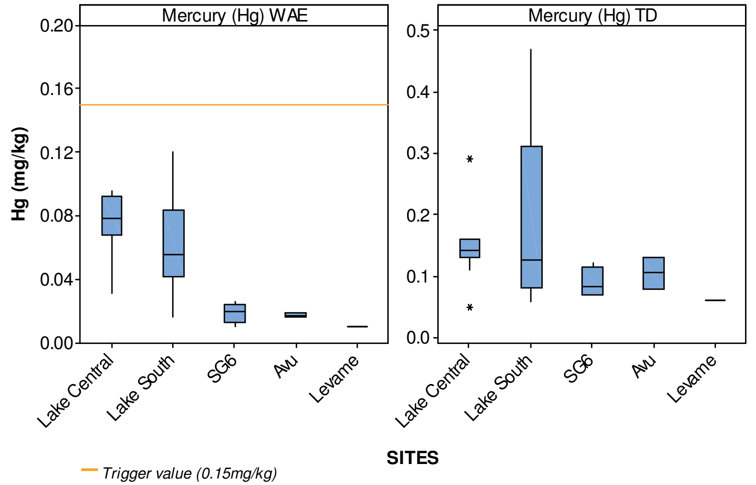



**Figure E-28 Mercury in sediment LMY and ORWB test sites 2015**

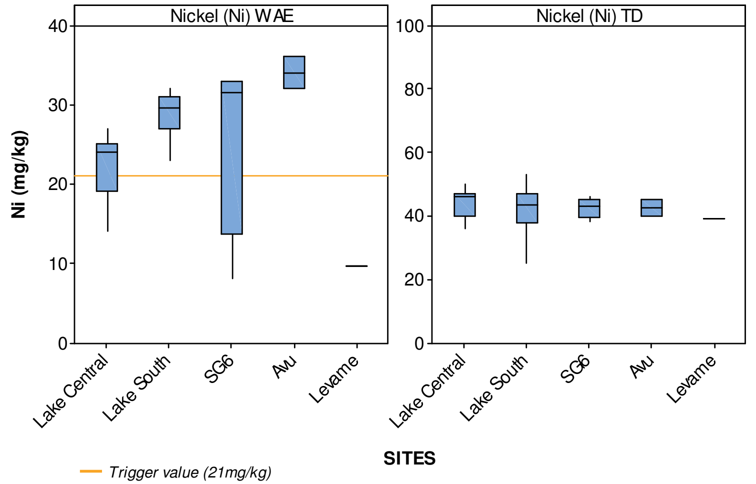



**Figure E-29 Nickel in sediment LMY and ORWB test sites 2015**

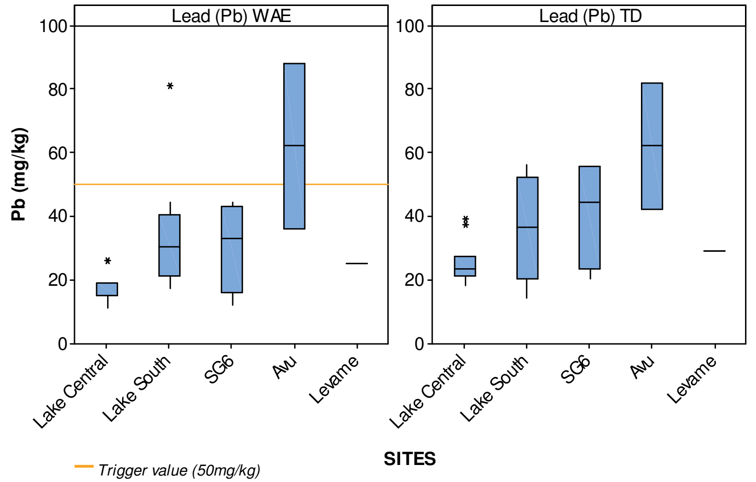



**Figure E-30 Lead in sediment LMY and ORWB test sites 2015**

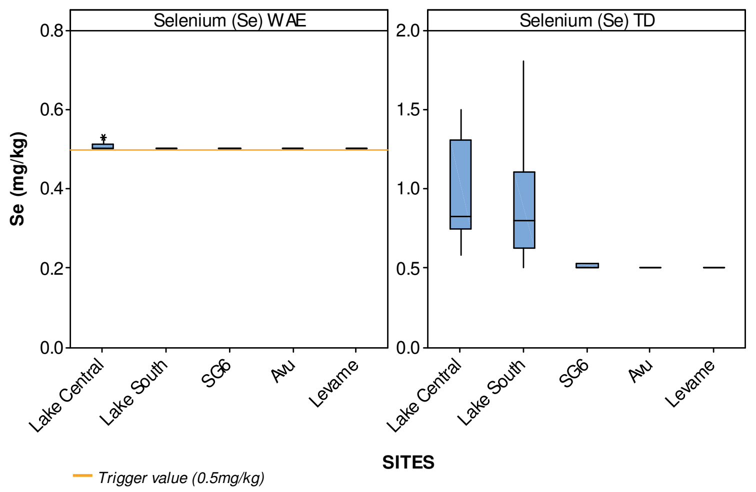



**Figure E-31 Selenium in sediment LMY and ORWB test sites 2015**

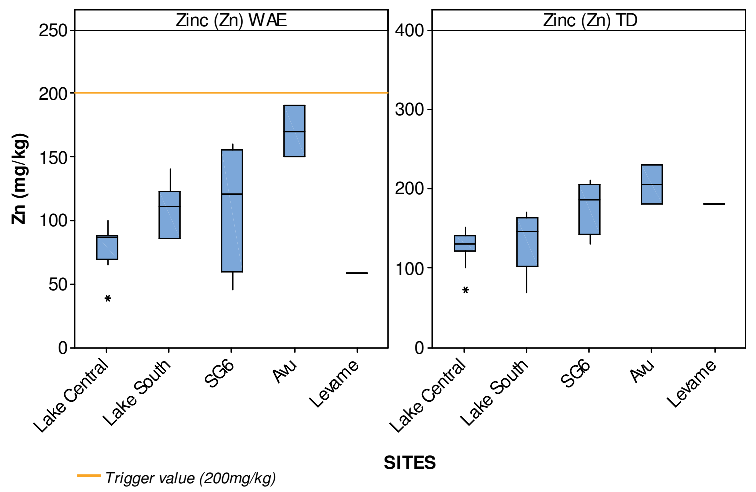



**Figure E-32 Zinc in sediment LMY and ORWB test sites 2015**

**Table E-18 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 2013 – 2014/2015 |
|---|---|---|---|---|
| Central Lake (Trend of Annual Medians 2013 - 2015) | Ag-WAE | <LOR | <LOR | No change over time |
| | As-WAE | 0.465 | 0.022 | Increased over time |
| | Cd-WAE | <LOR | <LOR | No change over time |
| | Cr-WAE | 0.913 | 0.000 | Increased over time |
| | Cu-WAE | 0.914 | 0.000 | Increased over time |
| | Hg-WAE | 0.130 | 0.543 | No change over time |
| | Ni-WAE | 0.918 | 0.000 | Increased over time |
| | Pb-WAE | 0.829 | 0.000 | Increased over time |
| | Se-WAE | 0.388 | 0.061 | No change over time |
| | Zn-WAE | 0.795 | 0.000 | Increased over time |
| Southern Lake (Trend of Annual Medians 2013 - 2015) | Ag-WAE | 0.226 | 0.235 | No change over time |
| | As-WAE | 0.556 | 0.002 | Increased over time |
| | Cd-WAE | <LOR | <LOR | No change over time |
| | Cr-WAE | 0.944 | 0.000 | Increased over time |
| | Cu-WAE | 0.894 | 0.000 | Increased over time |
| | Hg-WAE | -0.470 | 0.010 | Reduced over time |
| | Ni-WAE | 0.939 | 0.000 | Increased over time |
| | Pb-WAE | 0.353 | 0.061 | No change over time |
| | Se-WAE | <LOR | <LOR | No change over time |
| | Zn-WAE | 0.856 | 0.000 | Increased over time |
| SG6 (Trend of Annual Medians 2013 - 2015) | Ag-WAE | <LOR | <LOR | No change over time |
| | As-WAE | 0.266 | 0.338 | No change over time |
| | Cd-WAE | 0.410 | 0.129 | No change over time |
| | Cr-WAE | 0.529 | 0.043 | Increased over time |
| | Cu-WAE | 0.400 | 0.140 | No change over time |
| | Hg-WAE | 0.115 | 0.684 | No change over time |
| | Ni-WAE | 0.531 | 0.042 | Increased over time |
| | Pb-WAE | 0.135 | 0.631 | No change over time |
| | Se-WAE | <LOR | <LOR | No change over time |
| | Zn-WAE | 0.494 | 0.061 | No change over time |
| Kukufionga (Trend of Annual Medians 2013 - 2014) | Ag-WAE | <LOR | <LOR | No change over time |
| | As-WAE | 0.375 | 0.094 | No change over time |
| | Cd-WAE | <LOR | <LOR | No change over time |
| | Cr-WAE | 0.370 | 0.098 | No change over time |
| | Cu-WAE | 0.377 | 0.092 | No change over time |
| | Hg-WAE | -1.00 | * | No change over time |
| | Ni-WAE | 0.380 | 0.090 | No change over time |
| | Pb-WAE | 0.370 | 0.098 | No change over time |
| | Se-WAE | <LOR | <LOR | No change over time |
| | Zn-WAE | 0.375 | 0.094 | No change over time |

| Sediment Quality Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend 2013 – 2014/2015 |
|---|---|---|---|---|
| Zongamange (Trend of Annual Medians 2013 - 2014) | Ag-WAE | <LOR | <LOR | No change over time |
| | As-WAE | 0.436 | 0.104 | No change over time |
| | Cd-WAE | <LOR | <LOR | No change over time |
| | Cr-WAE | 0.436 | 0.104 | No change over time |
| | Cu-WAE | 0.456 | 0.088 | No change over time |
| | Hg-WAE | -0.452 | 0.090 | No change over time |
| | Ni-WAE | 0.449 | 0.093 | No change over time |
| | Pb-WAE | 0.452 | 0.090 | No change over time |
| | Se-WAE | <LOR | <LOR | No change over time |
| | Zn-WAE | 0.446 | 0.096 | No change over time |
| Avu (Trend of Annual Medians 2013 - 2014) | Ag-WAE | <LOR | <LOR | No change over time |
| | As-WAE | 0.520 | 0.032 | Increased over time |
| | Cd-WAE | 0.684 | 0.002 | Increased over time |
| | Cr-WAE | 0.674 | 0.003 | Increased over time |
| | Cu-WAE | 0.405 | 0.107 | No change over time |
| | Hg-WAE | -0.285 | 0.267 | No change over time |
| | Ni-WAE | 0.707 | 0.002 | Increased over time |
| | Pb-WAE | 0.430 | 0.085 | No change over time |
| | Se-WAE | <LOR | <LOR | No change over time |
| | Zn-WAE | 0.667 | 0.003 | 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**

<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 $\geq$ TV and TV, TSM and full TSM data set are $\nleq$ LOR</td><td>Step 2</td></tr>
<tr><td colspan="5">TSM = TV and TV, TSM and full TSM data set $\leq$ 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 $\geq$ TV and TV, TSM and full TSM data set are $\nleq$ LOR</td><td>POTENTIAL</td></tr>
<tr><td>3</td><td colspan="4">TSM = TV and TV, TSM and full TSM data set are $\leq$ LOR</td><td>LOW</td></tr>
</table>

TSM = Test Site Median

ND = No determination

**Table F-2 Tissue metal fish flesh upper river test sites 2015 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 | 22 | 22 | 0.03 | < | Step 1 | 0.20 | <0.001 | LOW |
| Cd | 22 | 22 | 0.003 | < | Step 1 | 0.02 | <0.001 | LOW |
| Cr | 22 | 20 | 0.01 | < | Step 1 | 0.02 | 0.041 | LOW |
| Cu | 22 | 22 | 0.15 | < | Step 1 | 0.48 | <0.001 | LOW |
| Hg | 22 | 21 | 0.08 | < | Step 1 | 0.09 | 0.049 | LOW |
| Ni | 22 | 22 | 0.01 | < | Step 1 | 0.10 | <0.001 | LOW |
| Pb | 22 | 22 | 0.01 | < | Step 1 | 0.17 | <0.001 | LOW |
| Se | 22 | 22 | 0.32 | < | Step 1 | 2.26 | <0.001 | LOW |
| Zn | 22 | 22 | 4.2 | < | Step 1 | 6.9 | <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 | 20 | 20 | 0.02 | < | Step 1 | 0.20 | <0.001 | LOW |
| Cd | 20 | 20 | 0.003 | < | Step 1 | 0.02 | <0.001 | LOW |
| Cr | 20 | 18 | 0.01 | < | Step 1 | 0.02 | 0.035 | LOW |
| Cu | 20 | 20 | 0.15 | < | Step 1 | 0.48 | <0.001 | LOW |
| Hg | 20 | 18 | 0.06 | < | Step 1 | 0.09 | <0.001 | LOW |
| Ni | 20 | 20 | 0.01 | < | Step 1 | 0.10 | <0.001 | LOW |
| Pb | 20 | 20 | 0.01 | < | Step 1 | 0.17 | <0.001 | LOW |
| Se | 20 | 20 | 0.27 | < | Step 1 | 2.26 | <0.001 | LOW |
| Zn | 20 | 20 | 3.65 | < | Step 1 | 6.9 | <0.001 | LOW |

**Table F-3 Tissue metal prawn abdomen upper river test sites 2015 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 | 26 | 26 | 0.04 | < | Step 1 | 0.06 | <0.001 | LOW |
| Cd | 26 | 25 | 0.05 | > | Step 2 | 0.01 | <0.001 | POTENTIAL |
| Cr | 26 | 26 | 0.02 | < | Step 1 | 0.11 | <0.001 | LOW |
| Cu | 26 | 26 | 6.7 | < | Step 1 | 9.82 | <0.001 | LOW |
| Hg* | 26 | 1 | 0.01 | = | Step 3 | 0.01 | 1.000 | LOW |
| Ni | 26 | 19 | 0.01 | < | Step 1 | 0.02 | 0.014 | LOW |
| Pb | 26 | 16 | 0.02 | > | Step 2 | 0.01 | 0.029 | POTENTIAL |
| Se | 26 | 26 | 0.57 | > | Step 2 | 0.43 | 1.000 | POTENTIAL |
| Zn | 26 | 23 | 15.5 | < | Step 1 | 16 | 0.210 | POTENTIAL |
| Test Site | | | | Initial Assessment | | TV | Statistical Test Result (P=0.05) | Risk Assessment |
| Wankipe | N | N (Test) | Median | Result | Go to | | | |
| As | 26 | 23 | 0.04 | < | Step 1 | 0.06 | 0.015 | LOW |
| Cd | 26 | 26 | 0.01 | = | Step 3 | 0.01 | 0.374 | POTENTIAL |
| Cr | 26 | 26 | 0.02 | < | Step 1 | 0.11 | <0.001 | LOW |
| Cu | 26 | 26 | 5.6 | < | Step 1 | 9.82 | <0.001 | LOW |
| Hg* | 26 | 0 | 0.01 | = | Step 3 | 0.01 | - | LOW |
| Ni | 26 | 18 | 0.02 | = | Step 3 | 0.02 | 0.486 | POTENTIAL |
| Pb | 26 | 9 | 0.01 | = | Step 3 | 0.01 | 0.009 | POTENTIAL |
| Se | 26 | 25 | 0.38 | < | Step 1 | 0.43 | 0.002 | LOW |
| Zn | 26 | 24 | 13 | < | Step 1 | 16 | <0.001 | LOW |

* Wilcoxon's test returns an error when all test and reference data are equal, which usually occurs when all results are < the analytical limit of reporting. So although the result is not statistically significant the TSM is considered = TV.

**Table F-4 Tissue metal fish flesh lower river test sites 2015 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 | 0 | | | | | 0.07 | | |
| Cd | 0 | | | | | 0.01 | | |
| Cr | 0 | | | | | 0.03 | | |
| Cu | 0 | | | | | 0.17 | | |
| Hg | 0 | | | | | 0.12 | | |
| Ni | 0 | | | | | 0.17 | | |
| Pb | 0 | | | | | 0.03 | | |
| Se | 0 | | | | | 2.36 | | |
| Zn | 0 | | | | | 4.78 | | |
| **Test Site** | | | | **Initial Assessment** | | **TV** | **Statistical Test Result (P=0.05)** | **Risk Assessment** |
| **Tiumsinawam** | **N** | **N (Test)** | **Median** | **Result** | **Go to** | | | |
| As | 18 | 18 | 0.01 | < | Step 1 | 0.07 | <0.001 | LOW |
| Cd | 18 | 18 | 0.003 | < | Step1 | 0.01 | 0.003 | LOW |
| Cr | 18 | 18 | 0.01 | < | Step1 | 0.03 | 0.019 | LOW |
| Cu | 18 | 17 | 0.09 | < | Step1 | 0.17 | <0.001 | LOW |
| Hg | 18 | 18 | 0.09 | < | Step1 | 0.12 | 0.021 | LOW |
| Ni | 18 | 18 | 0.01 | < | Step1 | 0.03 | <0.001 | LOW |
| Pb | 18 | 18 | 0.01 | < | Step1 | 0.17 | <0.001 | LOW |
| Se | 18 | 18 | 0.16 | < | Step1 | 2.26 | <0.001 | LOW |
| Zn | 18 | 18 | 3.55 | < | Step1 | 4.78 | 0.007 | 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. So although the result is not statistically significant the TSM is considered = TV.

**Table F-5 Bioaccumulation prawn abdomen lower river test sites 2015 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 | 16 | 15 | 0.12 | > | Step 2 | 0.10 | 0.005 | POTENTIAL |
| Cd | 16 | 16 | 0.01 | = | Step 3 | 0.01 | 0.003 | POTENTIAL |
| Cr | 16 | 16 | 0.02 | < | Step 1 | 0.06 | <0.001 | LOW |
| Cu | 16 | 16 | 8.5 | < | Step 1 | 11.6 | <0.001 | LOW |
| Hg* | 16 | 0 | 0.01 | = | Step 3 | 0.01 | - | LOW |
| Ni | 16 | 7 | 0.01 | = | Step 3 | 0.01 | 0.022 | POTENTIAL |
| Pb | 16 | 0 | 0.01 | = | Step 3 | 0.01 | - | LOW |
| Se | 16 | 16 | 0.33 | > | Step 2 | 0.31 | 0.211 | POTENTIAL |
| Zn | 16 | 11 | 16 | = | Step 1 | 16 | 0.038 | POTENTIAL |
| **Test Site** | | | | **Initial Assessment** | | **TV** | **Statistical Test Result (P=0.05)** | **Risk Assessment** |
| **Tiumsinawam** | **N** | **N (Test)** | **Median** | **Result** | **Go to** | | | |
| As | 26 | 23 | 0.07 | < | Step 1 | 0.10 | 0.001 | LOW |
| Cd | 26 | 22 | 0.01 | = | Step 3 | 0.01 | 0.770 | POTENTIAL |
| Cr | 26 | 26 | 0.02 | < | Step 1 | 0.06 | <0.001 | LOW |
| Cu | 26 | 26 | 6.85 | < | Step 1 | 11.6 | <0.001 | LOW |
| Hg* | 26 | 1 | 0.01 | = | Step 3 | 0.01 | 1.000 | LOW |
| Ni | 26 | 13 | 0.02 | > | Step 2 | 0.01 | 0.001 | POTENTIAL |
| Pb | 26 | 2 | 0.01 | = | Step 3 | 0.01 | 0.371 | POTENTIAL |
| Se | 26 | 23 | 0.29 | < | Step 1 | 0.31 | 0.001 | LOW |
| Zn | 26 | 25 | 12 | < | Step 1 | 16 | <0.001 | LOW |

* Wilcoxon's test returns an error when all test and reference data are equal, which usually occurs when all results are < the analytical limit of reporting. So although the result is not statistically significant the TSM is considered = TV.

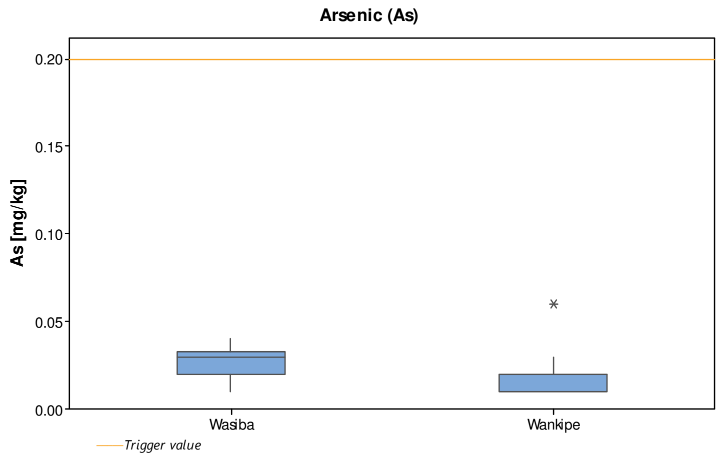



Figure F-1 Arsenic in fish flesh upper river test sites 2015

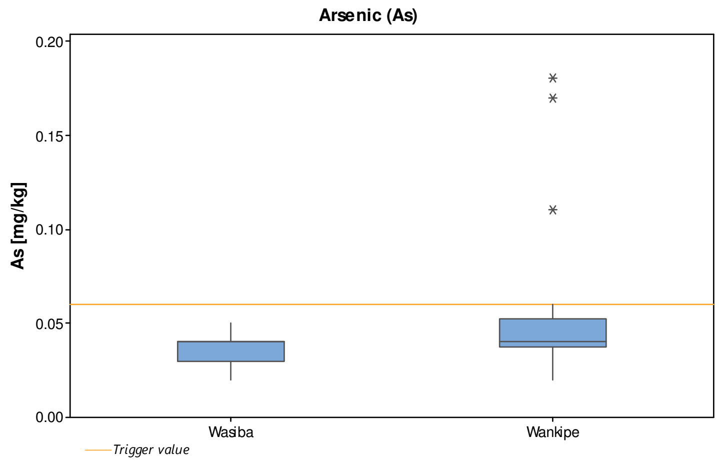



Figure F-2 Arsenic in prawn abdomen upper river test sites 2015

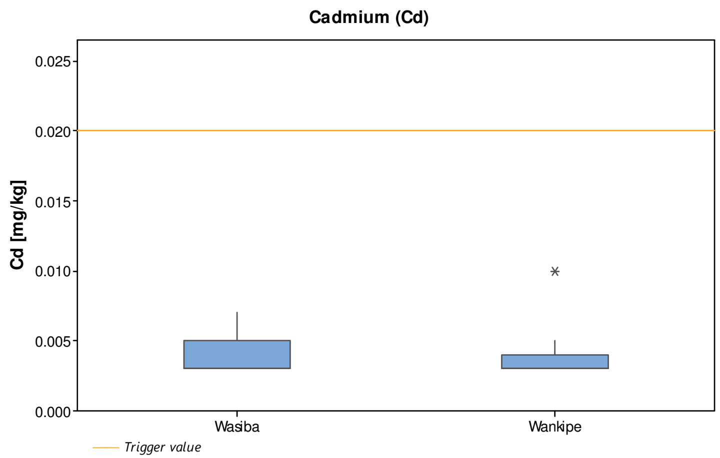



Figure F-3 Cadmium in fish flesh upper river test sites 2015

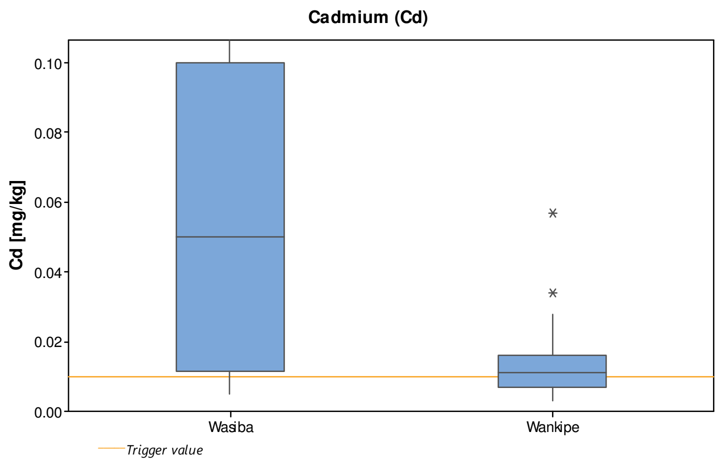



Figure F-4 Cadmium in prawn abdomen upper river test sites 2015

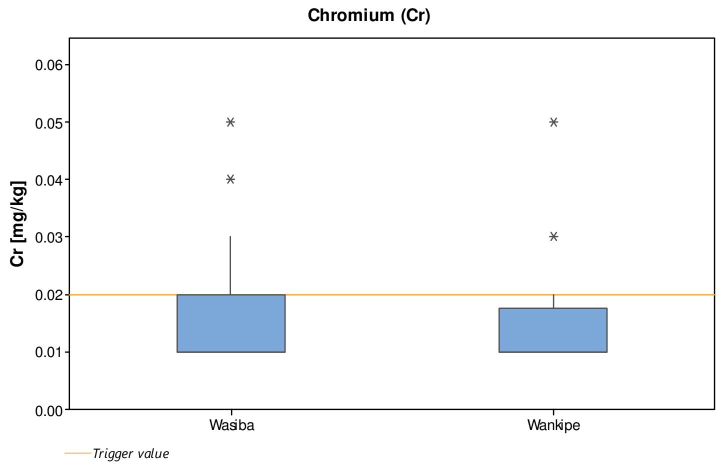



**Figure F-5 Chromium in fish flesh upper river test sites 2015**

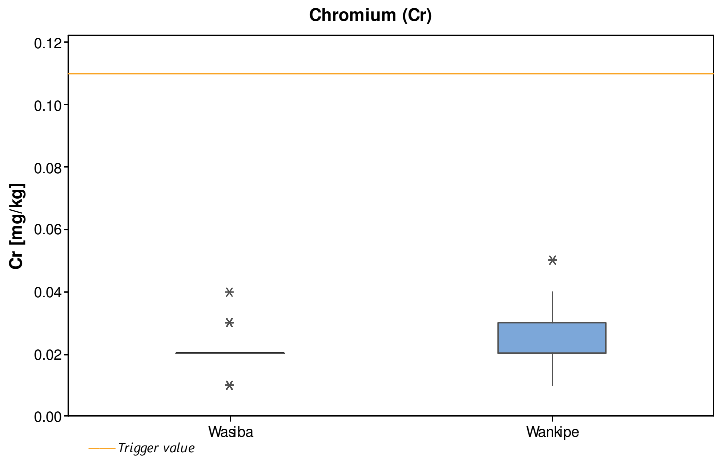



**Figure F-6 Chromium in prawn abdomen Upper River test sites 2015**

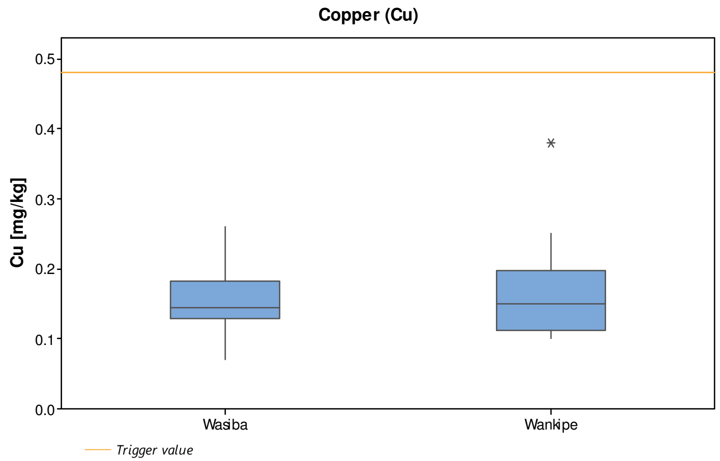



**Figure F-7 Copper in fish flesh upper river test sites 2015**

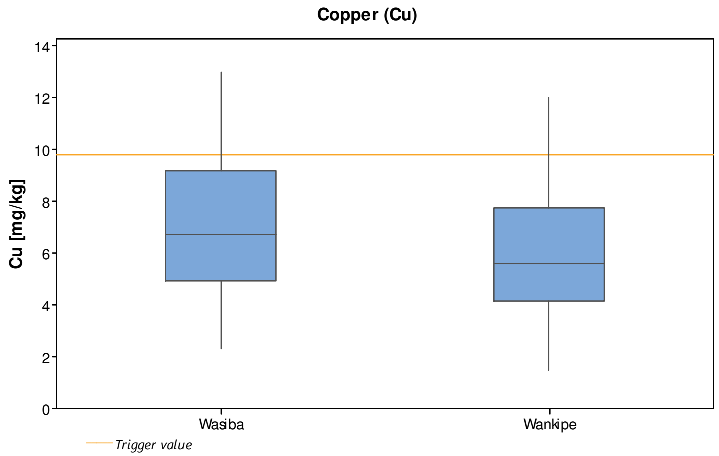



**Figure F-8 Copper in prawn abdomen upper river test sites 2015**

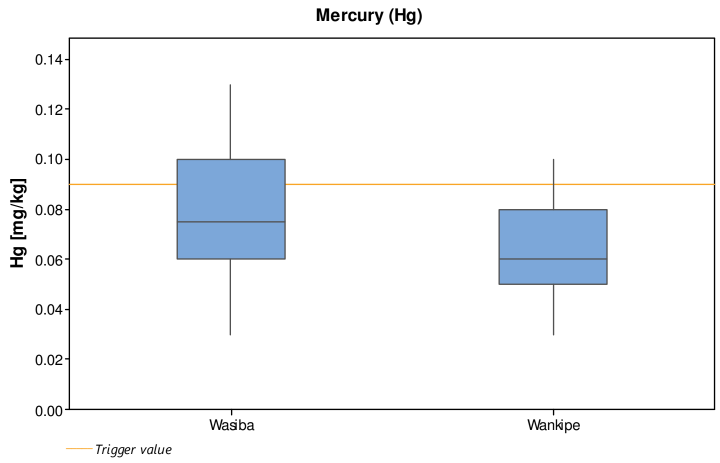



**Figure F-9 Mercury in fish flesh upper river test sites 2015**

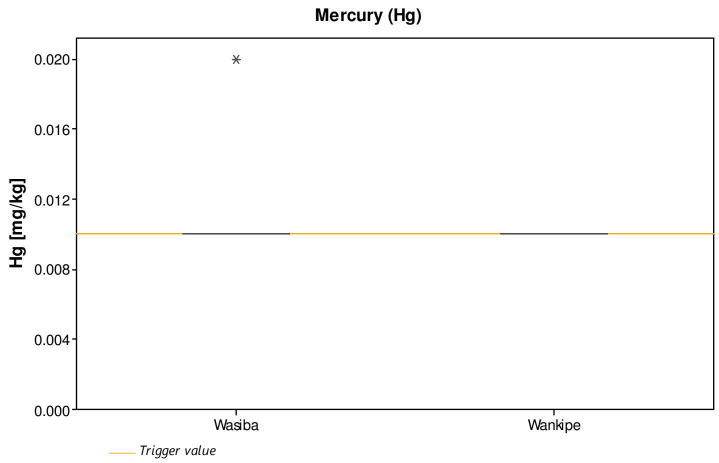



**Figure F-10 Mercury in prawn abdomen upper river test sites 2015**

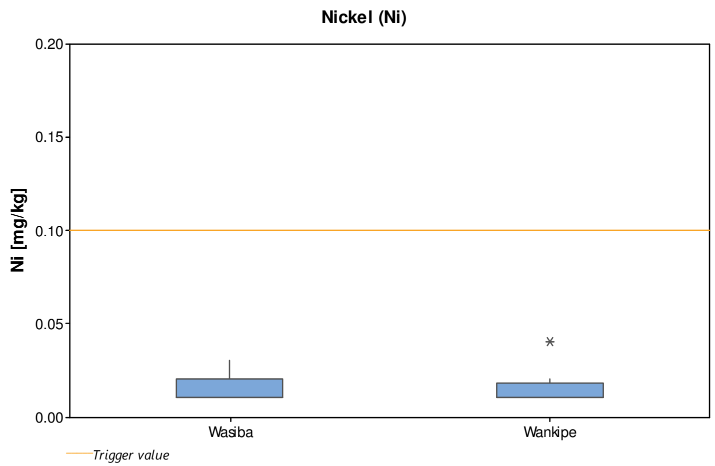



**Figure F-11 Nickel in fish flesh upper river test sites 2015**

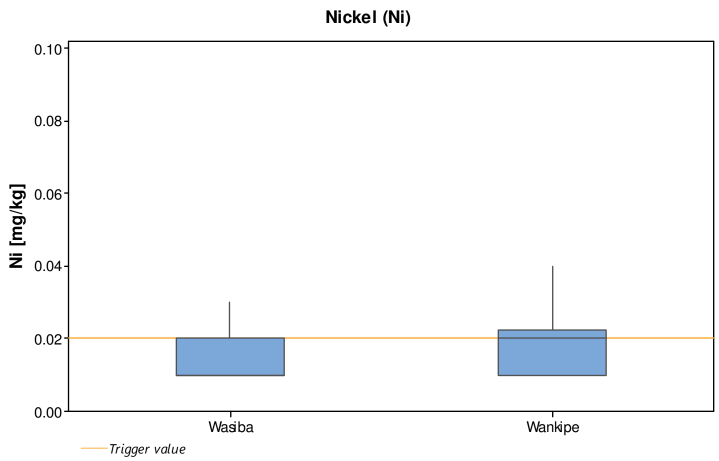



**Figure F-12 Nickel in prawn abdomen upper river test sites 2015**

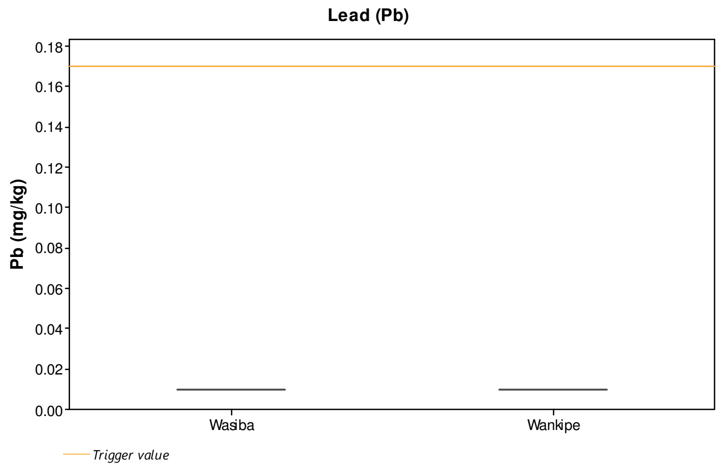



**Figure F-13 Lead in fish flesh upper river test sites 2015**

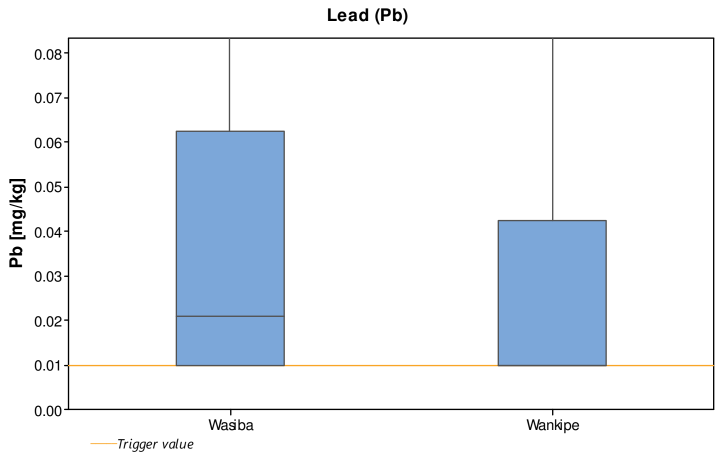



**Figure F-14 Lead in prawn abdomen upper river test sites 2015**

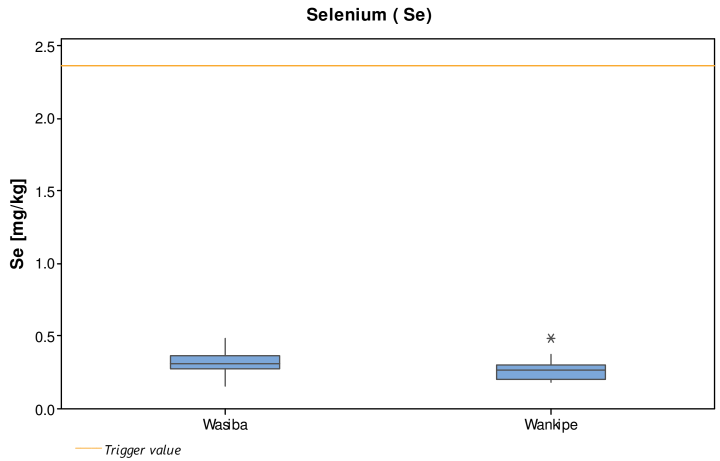



**Figure F-15 Selenium in fish flesh upper river test sites 2015**

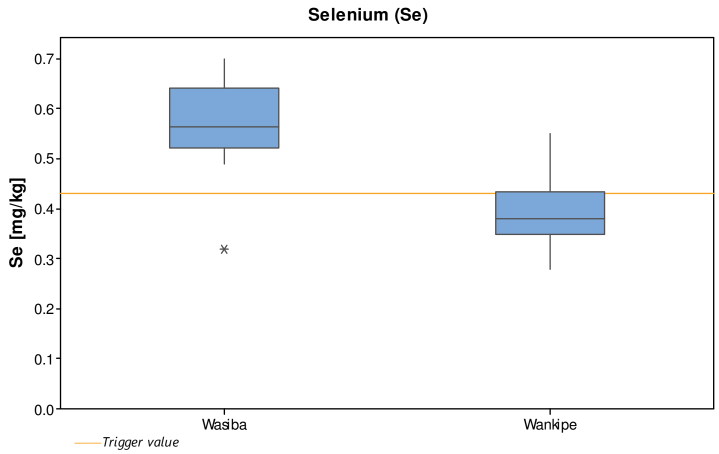
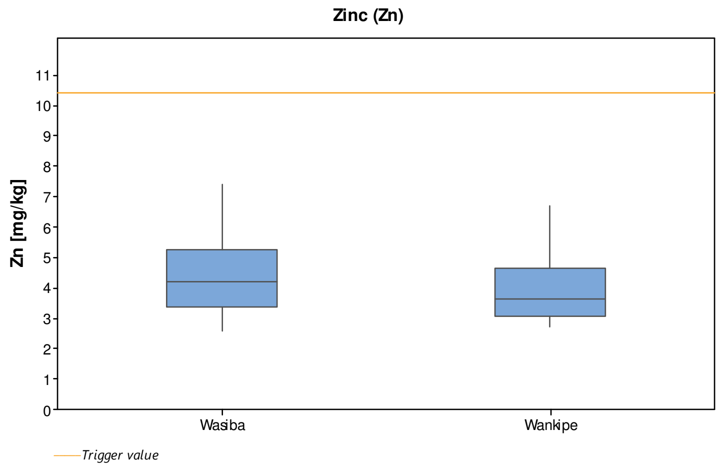



**Figure F-16 Selenium in prawn abdomen upper river test sites 2015**



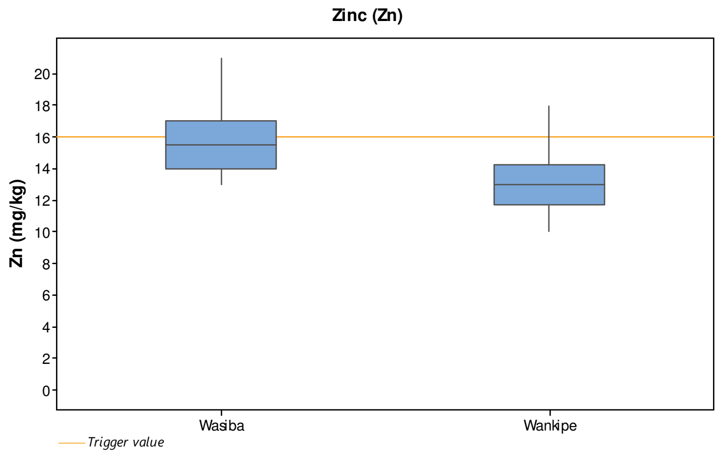
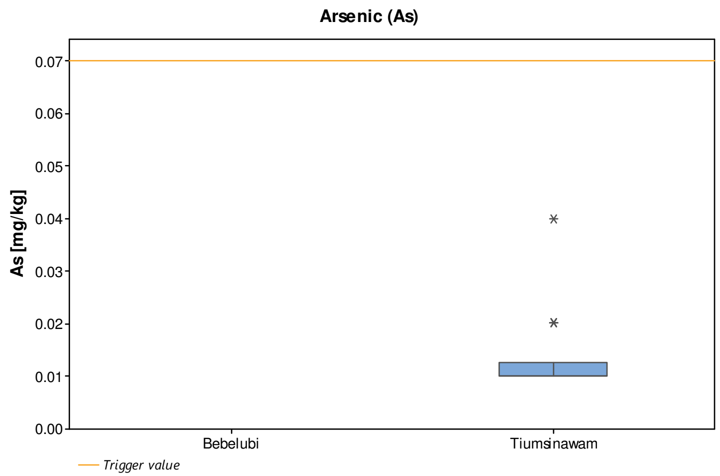




**Figure F-17 Zinc in fish flesh upper river test sites 2015**

**Figure F-18 Zinc in prawn abdomen upper river test sites 2015**



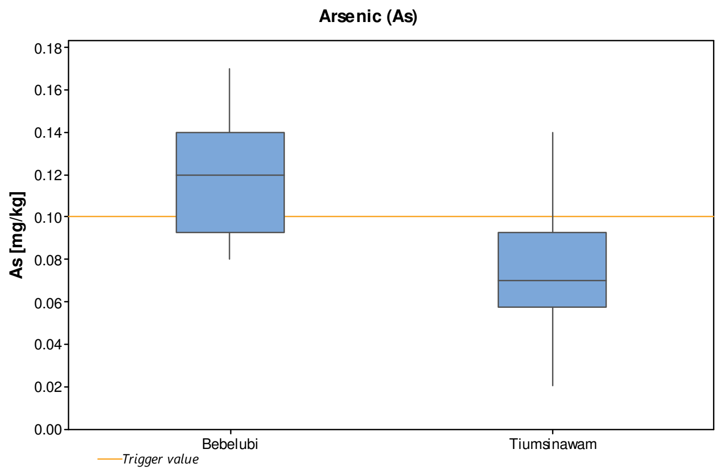




**Figure F-19 Arsenics in fish flesh lower river test sites 2015**

**Figure F-20 Arsenic in prawn abdomen lower river test sites 2015**

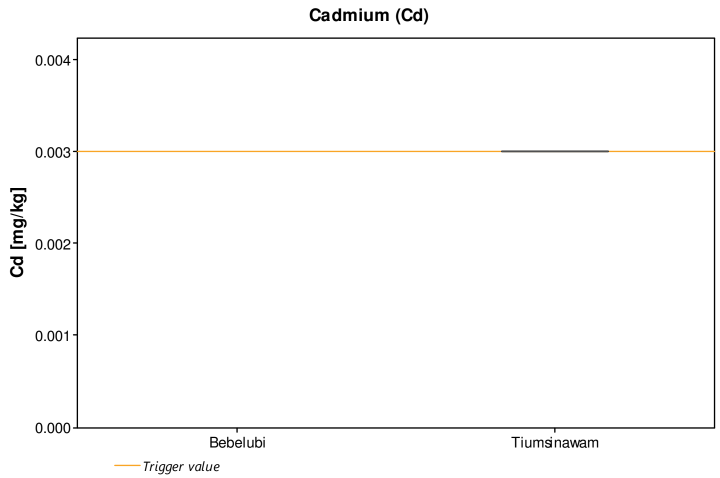



**Figure F-21 Cadmium in fish flesh lower river test sites 2015**

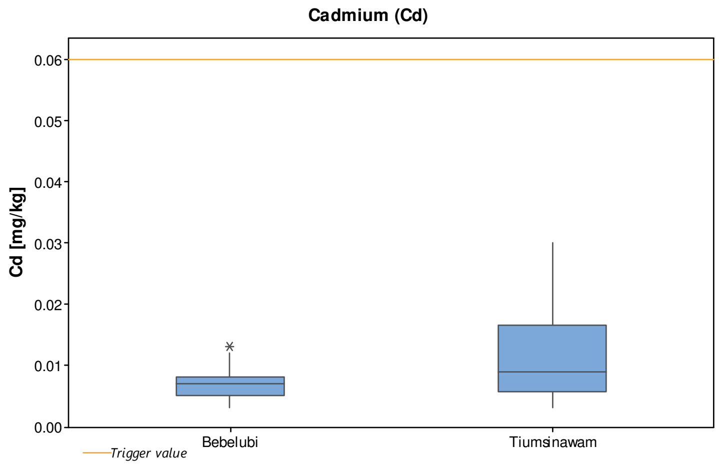



**Figure F-22 Cadmium in prawn abdomen lower river test sites 2015**

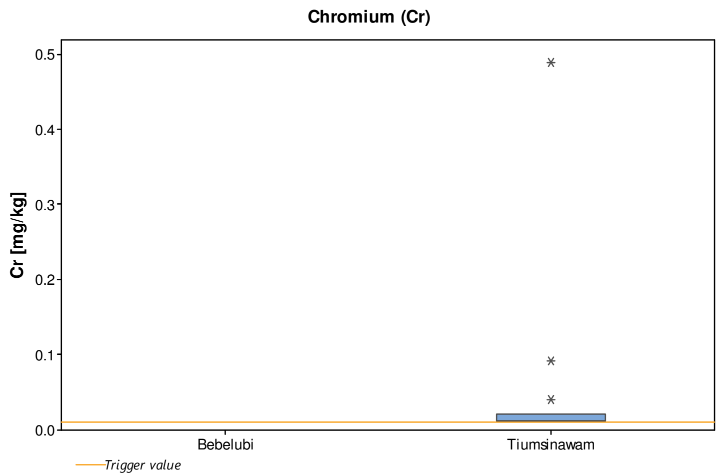



**Figure F-23 Chromium in fish flesh lower river test sites 2015**

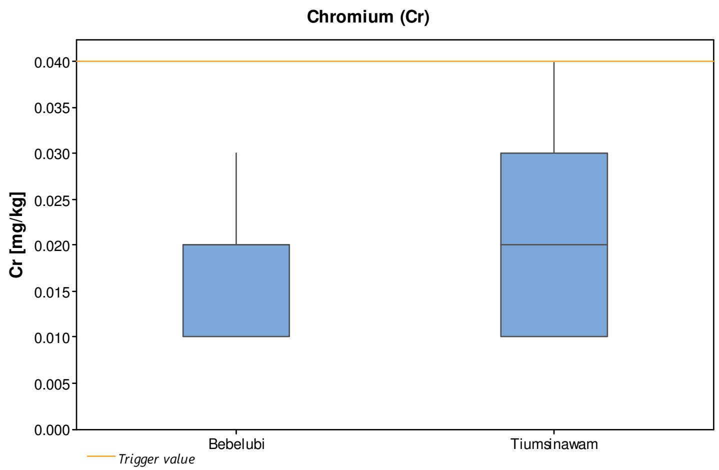



**Figure F-24 Chromium in prawn abdomen lower river test sites 2015**

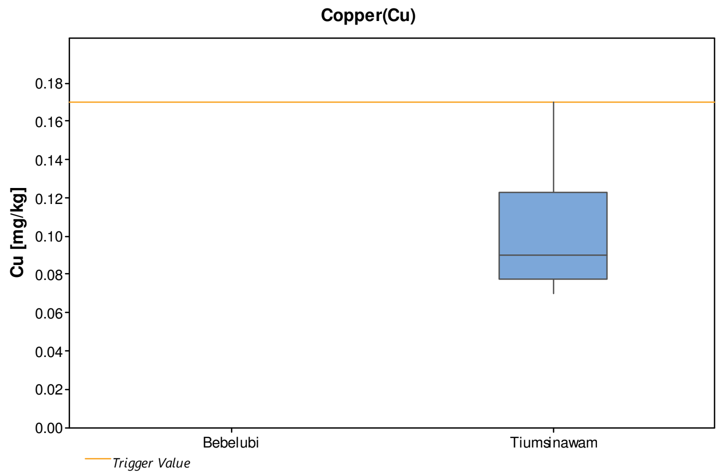



Figure F-25 Copper in fish flesh lower river test sites 2015

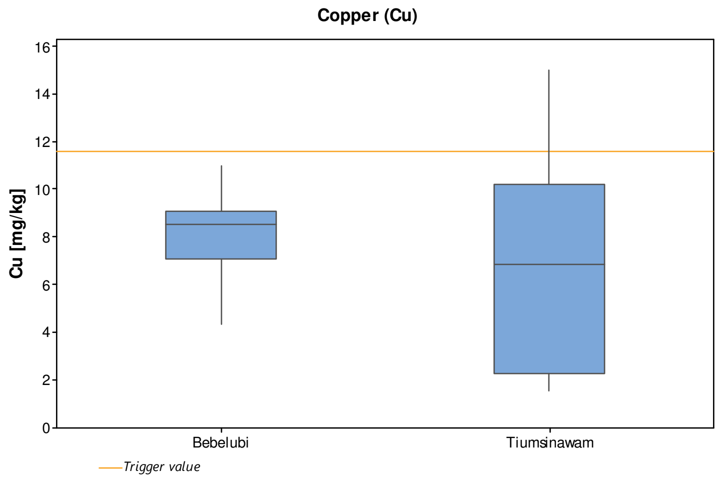



Figure F-26 Copper in prawn abdomen lower river test sites 2015

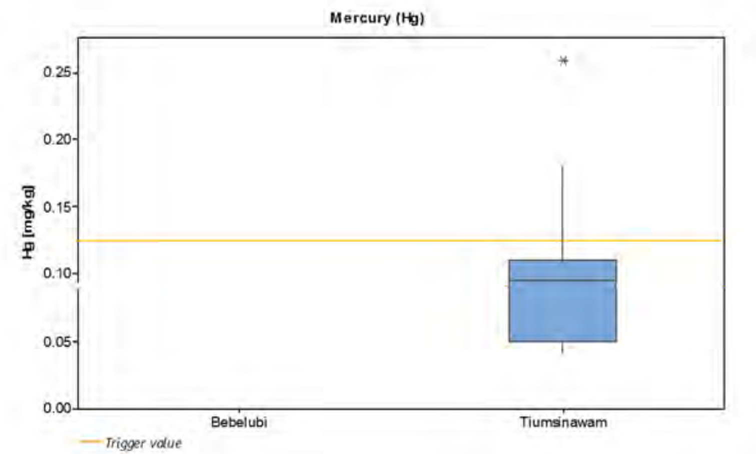



Figure F-27 Mercury in fish flesh lower river test sites 2015

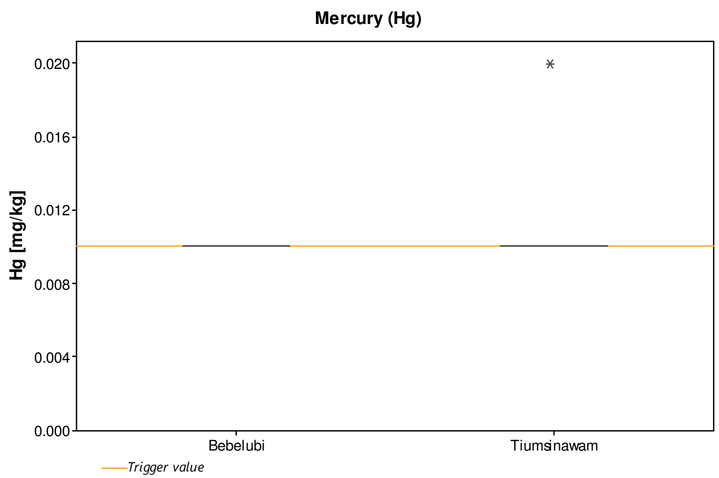



Figure F-28 Mercury in prawn abdomen lower river test sites 2015

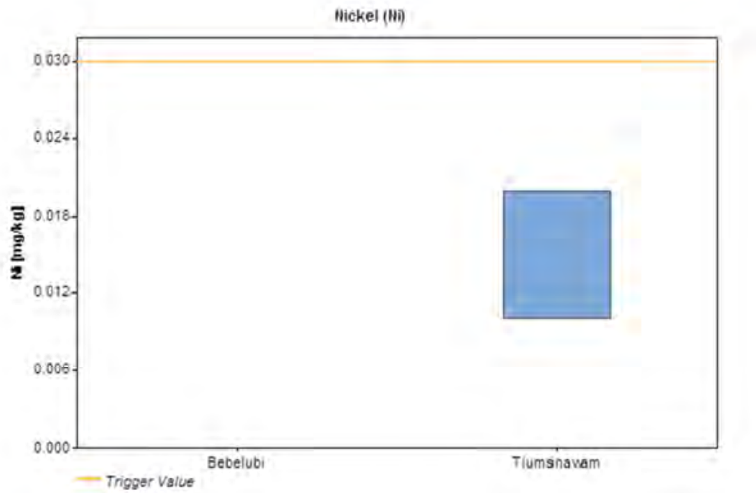



**Figure F-29 Nickel in fish flesh lower river test sites 2015**

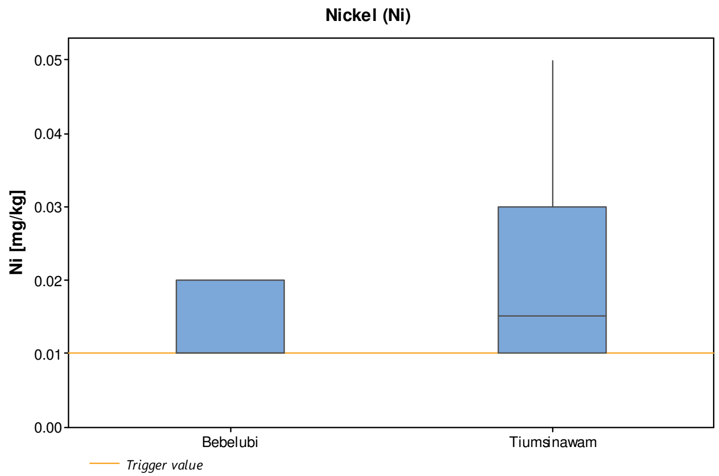



**Figure F-30 Nickel in prawn abdomen lower river test sites 2015**

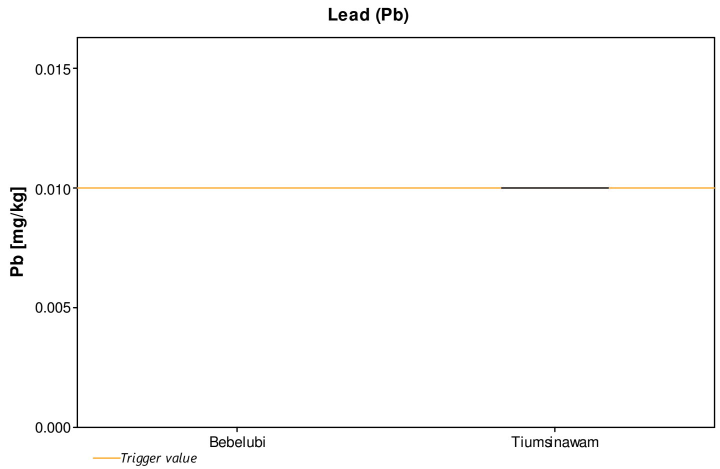



**Figure F-31 Lead in fish flesh lower river test sites 2015**

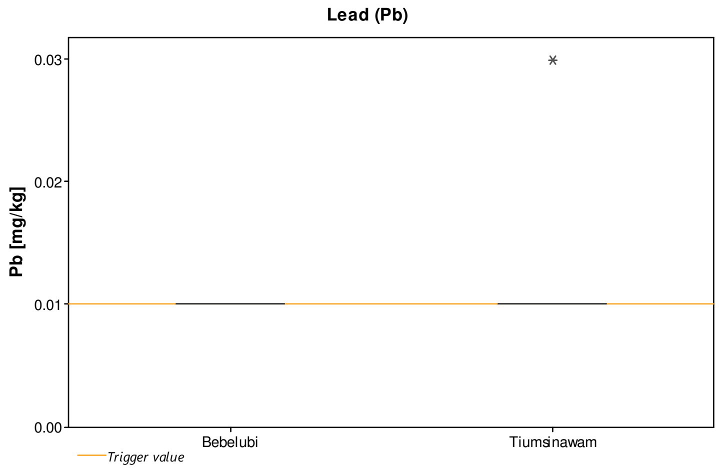



**Figure F-32 Lead in prawn abdomen lower river test site 2015**

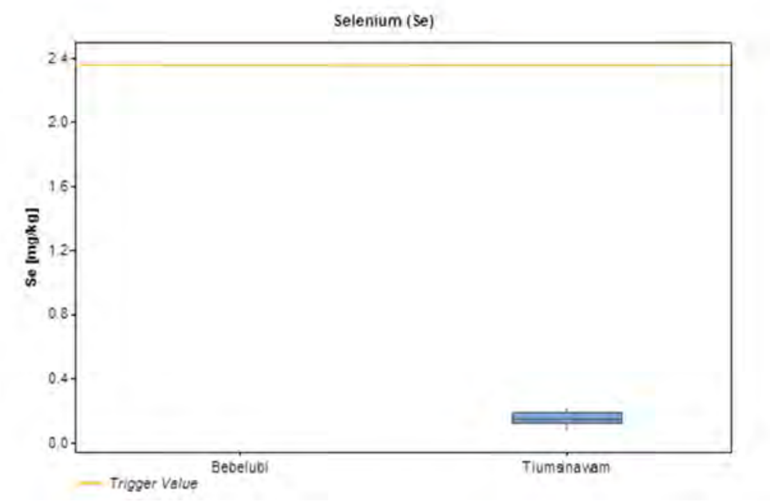



Figure F-33 Selenium in fish flesh lower river test sites 2015

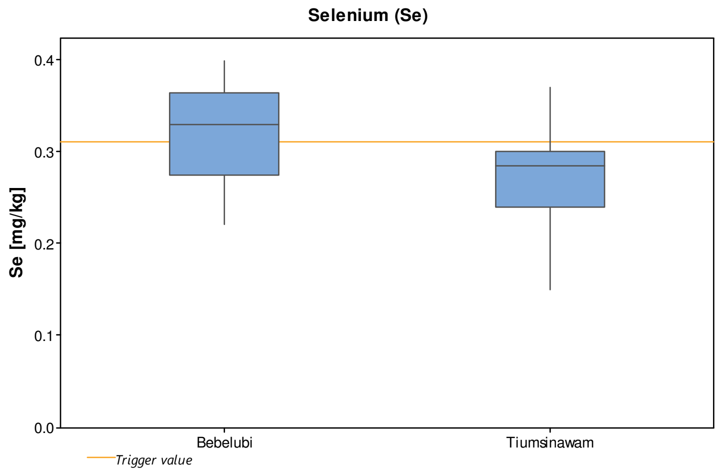



Figure F-34 Selenium in prawn abdomen lower river test sites 2015

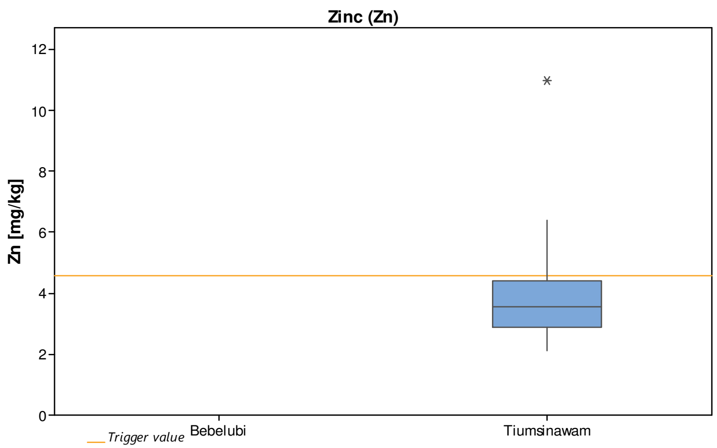



Figure F-35 Zinc in fish flesh lower river test sites 2015

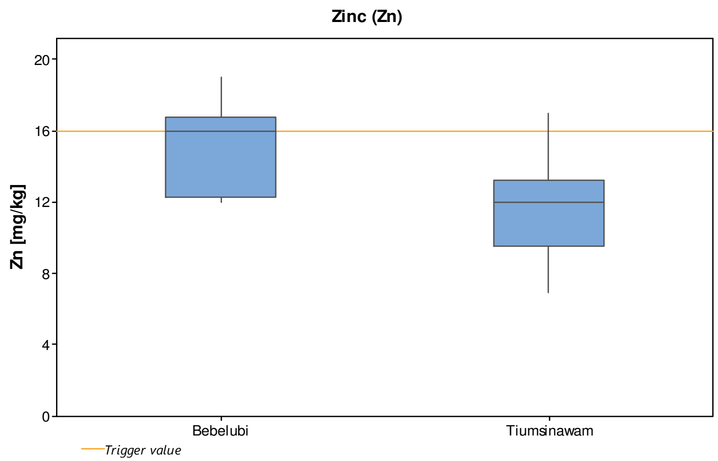



Figure F-36 Zinc in prawn abdomen lower river test sites 2015

**Table F-6 Performance assessment – Based on the trend of the annual median of tissue metals in fish flesh at upper river test sites relative to the trend of the annual median of tissue metals in fish flesh at upper river reference sites from 2011-2015 using Spearman Rank Test.**

| Fish Flesh Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend 2011 - 2015 |
|---|---|---|---|---|
| Wasiba (Trend of Annual Median 2011 - 2015) | As | 0.866 | 0.058 | No change over time |
| | Cd | -0.707 | 0.182 | No change over time |
| | Cr | <LOR | <LOR | No change over time |
| | Cu | -0.700 | 0.188 | No change over time |
| | Hg | 0.667 | 0.219 | No change over time |
| | Ni | -0.354 | 0.559 | No change over time |
| | Pb | <LOR | <LOR | No change over time |
| | Se | -0.400 | 0.505 | No change over time |
| | Zn | -0.900 | 0.037 | Decreasing over time |
| Wankipe (Trend of Annual Median 2011 - 2015) | As | <LOR | <LOR | No change over time |
| | Cd | -0.707 | 0.182 | No change over time |
| | Cr | <LOR | <LOR | No change over time |
| | Cu | -0.700 | 0.188 | No change over time |
| | Hg | 0.224 | 0.718 | No change over time |
| | Ni | <LOR | <LOR | No change over time |
| | Pb | <LOR | <LOR | No change over time |
| | Se | -0.400 | 0.505 | No change over time |
| | Zn | -0.700 | 0.188 | No change over time |

LOR = Analytical Limit of Reporting. <LOR – All results within the data set are <LOR, in which case the Spearman Rank test returns an error result, however the results indicate no change over time.

**Table F-7 Performance assessment – Based on the trend of the annual median of tissue metals in prawn abdomen at upper river test sites relative to the trend of the annual median of tissue metals in prawn abdomen at upper river reference sites from 2011 -2015 using Spearman Rank Test.**

| Prawn Abdomen Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend 2011 - 2015 |
|---|---|---|---|---|
| Wasiba (Trend of Annual Median 2011 - 2015) | As | 0.000 | 1.000 | No change over time |
| | Cd | -0.600 | 0.285 | No change over time |
| | Cr | 0.577 | 0.308 | No change over time |
| | Cu | 0.564 | 0.322 | No change over time |
| | Hg | <LOR | <LOR | No change over time |
| | Ni | -0.354 | 0.559 | No change over time |
| | Pb | 0.707 | 0.182 | No change over time |
| | Se | 0.300 | 0.624 | No change over time |
| | Zn | 0.051 | 0.935 | No change over time |
| Wankipe (Trend of Annual Median 2011 - 2015) | As | -0.255 | 0.424 | No change over time |
| | Cd | 0.248 | 0.437 | No change over time |
| | Cr | -0.226 | 0.480 | No change over time |
| | Cu | 0.063 | 0.846 | No change over time |
| | Hg | <LOR | <LOR | No change over time |
| | Ni | 0.686 | 0.014 | Increasing over time |
| | Pb | <LOR | <LOR | No change over time |
| | Se | 0.284 | 0.372 | No change over time |
| | Zn | -0.233 | 0.467 | No change over time |

LOR = Analytical Limit of Reporting. <LOR – All results within the data set are <LOR, in which case the Spearman Rank test returns an error result, however the results indicate no change over time.

**Table F-8 Performance assessment – Based on the trend of the annual median of tissue metals in fish flesh at lower river test sites relative to the trend of the annual median of tissue metals in fish flesh at lower river reference sites from 2011-2015 of the operation using Spearman Rank Test.**

| Fish flesh Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend 2011 - 2015 |
|---|---|---|---|---|
| Bebelubi (Trend of Annual Median 2011 - 2015) | As | <LOR | <LOR | No change over time |
| | Cd | <LOR | <LOR | No change over time |
| | Cr | 0.775 | 0.225 | No change over time |
| | Cu | 0.600 | 0.400 | No change over time |
| | Hg | 0.400 | 0.600 | No change over time |
| | Ni | -0.258 | 0.742 | No change over time |
| | Pb | <LOR | <LOR | No change over time |
| | Se | <LOR | <LOR | No change over time |
| | Zn | 0.000 | 1.000 | No change over time |
| Tiumsinawam (Trend of Annual Median 2011 - 2015) | As | <LOR | <LOR | No change over time |
| | Cd | -0.707 | 0.182 | No change over time |
| | Cr | <LOR | <LOR | No change over time |
| | Cu | -0.667 | 0.219 | No change over time |
| | Hg | 0.700 | 0.188 | No change over time |
| | Ni | <LOR | <LOR | No change over time |
| | Pb | <LOR | <LOR | No change over time |
| | Se | 0.738 | 0.155 | No change over time |
| | Zn | 0.616 | 0.269 | No change over time |

LOR = Analytical Limit of Reporting. <LOR – All results within the data set are <LOR, in which case the Spearman Rank test returns an error result, however the results indicate no change over time.

**Table F-9 Performance assessment – Based on the trend of the annual median of tissue metals in prawn abdomen at lower river test sites relative to the trend of the annual median of tissue metals in prawn abdomen at lower river reference sites from 2011- 2015 of the operation using Spearman Rank Test.**

| Prawn Abdomen Site | Parameter | Spearman's rho | P-Value (P=0.05) | Trend 2011 - 2015 |
|---|---|---|---|---|
| Bebelubi (Trend of Annual Median 2011 - 2015) | As | 0.400 | 0.505 | No change over time |
| | Cd | -0.707 | 0.182 | No change over time |
| | Cr | 0.354 | 0.559 | No change over time |
| | Cu | 0.800 | 0.104 | No change over time |
| | Hg | <LOR | <LOR | No change over time |
| | Ni | 0.354 | 0.559 | No change over time |
| | Pb | <LOR | <LOR | No change over time |
| | Se | 0.700 | 0.188 | No change over time |
| | Zn | 0.821 | 0.089 | No change over time |
| Tiumsinawam (Trend of Annual Median 2011 - 2015) | As | -0.316 | 0.604 | No change over time |
| | Cd | -0.707 | 0.182 | No change over time |
| | Cr | 0.000 | 1.000 | No change over time |
| | Cu | 0.500 | 0.391 | No change over time |
| | Hg | <LOR | <LOR | No change over time |
| | Ni | 0.707 | 0.182 | No change over time |
| | Pb | <LOR | <LOR | No change over time |
| | Se | 0.051 | 0.935 | No change over time |
| | Zn | 0.410 | 0.493 | No change over time |

LOR = Analytical Limit of Reporting. <LOR – All results within the data set are <LOR, in which case the Spearman Rank test returns an error result, however the results indicate no change over time