PORGERA JOINT VENTURE

ENVIRONMENTAL MONITORING

2010 ANNUAL REPORT

JANUARY – DECEMBER 2010

Prepared by: PJV Environment Department
P.O. Box 484, Mt. Hagen WHP
Papua New Guinea

Date: June 2011
Report No.: PJV ENV – 1/11

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Cover Photo:

Land Rehabilitation Coordinator, Steven Tevo, and Rehabilitation Officer, Rowena Petueli examine the growth of *Nothofagus* tree species on Kogai stable dump. Rehabilitation and revegetation of stable dumps and long-term stockpiles are essential to minimize rapid erosion and loss of soil cover from high rainfall.

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CSIRO

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

16 December 2011

Dear Charlie,

Re: Porgera 2010 Annual Environmental Report

A CSIRO-led review team has reviewed a draft of the 2010 Porgera Annual Environmental Report and provided detailed comments for consideration. Overall, the report was found to be technically sound, however, as expected with a report of this size, a number of minor recommendations were made for improvement.

Porgera Joint Venture (PJV) responded positively to the review team's recommendations and the final report has been modified in the light of these comments. We commend your team on their considerable efforts in producing this comprehensive report.

Sincerely

S. Apte

Dr Simon Apte
Program Leader
Contaminant Chemistry and Ecotoxicology

Dr Graeme Batley
Chief Research Scientist

EXECUTIVE SUMARY

The 2010 Annual Environmental Report has been prepared by the Porgera Joint Venture (PJV) for the PNG Department of Environment and Conservation in accordance with PJV's Environmental Management Plan. The main highlights for 2010 are as follows:

Hydrology and Sediment Transport

Hydro-meteorological and sediment transport data collection continued during the year at stations within the mine site and on the downstream river system. Overall data recovery was 93%, which continues the good performance of the last couple of years.

Rainfall at the Anawe plant site was 14% below the long-term average, which was consistent with the pattern at other stations in the upper river system. An unusually dry spell mid-year (driest on record) resulted in extended periods of lost production, due to well below average reservoir levels. River flows for stations in the upper and middle regions were below long-term averages, which is a reversal of recent trends over the last couple of years.

Relatively few data pertaining to physical sedimentology in the mine vicinity were collected during the year due to law and order problems in areas where Hydrology staff were unable to operate, although monthly spot TSS data were collected by the Chemistry staff. The new profile cross-sections on the Kaiya River were however resurveyed to ascertain any aggradation due to sediment run-out from the Anjolek erodible dump and valley wall erosion. Additionally, the PF10 profile (downstream Tomu River) was re-surveyed adding valuable data to existing, long-term datasets.

A review of sediment data and landscape processes showed that while total waste inputs to the river system were close to long-term median annual values, the Anawe erodible dump received well over its median value and the Anjolek dump well under. Although no significant morphological changes to the dumps were noted, degradation of the dump surface in the upper tract, and erosion of the Kaiya Valley walls in the lower tract were observed. The toe of the Anjolek erodible dump had moved about 100 m downstream. The toe of the Anawe erodible dump was stable, but processes of overspill and erosion of the southern (Maiapam) flank were ongoing. Given the high rate of waste input to the Anawe dump in 2010, careful observation of the dump morphology should be undertaken in 2011.

New profile data for the Kaiya River showed that aggradation of between 0.5 and 2 m had occurred at selected locations. There was no evidence of significant morphological change to either the Lower Pongema River or the Upper Porgera River. Although new LiDar surveys of the dumps had been completed, at the time of writing, data are not yet ready for reporting and therefore estimates of sediment load for 2010 were made using historical data. A review of TSS data showed values close to long-term median annual values.

New analyses undertaken this year included a comparison of the rainfall record to Pacific Decadal Oscillation and ENSO indices, and results of a one-off survey of flow and sediment processes in the lower Strickland River using ADCP technology.

Reviews of the 2010 hydrological and sediment transport data and monitoring were carried out by consultants Chris Fink of CF Hydrometrics and Dr Andy Markham of Hydrobiology respectively.

Tailings Monitoring

The average daily discharge of tailings from the Process Plant during 2010 was 14,249 tonnes compared to the 2009 and 2008 average rates of 14,879 and 16,526 tonnes per day, respectively.

As in previous years, monitoring of the tailings discharge was conducted on a daily basis during 2010 to independently check the automatic control systems and determine whether the tailings neutralisation circuit was performing as designed. Tailings monitoring results for 2010 indicated that the neutralisation circuit had operated efficiently during the year in detoxifying residual cyanide in the Process Plant tailings discharge.

Dissolved and total concentrations for the various trace metals in tailings varied throughout 2010 and showed no distinct trends except for the dissolved silver results which were at or below the detection limit throughout the year.

Over the 10-year period from 2001-2010, the dissolved and total concentrations of all metals in tailings showed no distinct trends with the exception of total mercury and dissolved nickel, both of which tended downwards.

The concentrations of the various forms of cyanide in tailings, i.e. total, WAD, CAC and thiocyanate remained within acceptable limits during 2010. The most notable variations occurred in 2009 for total, WAD and CAC cyanide, and thiocyanate when concentrations decreased noticeably as a result of the Cyanide Destruction Plant (CDP) being commissioned in early 2009.

Tailings pH mean values remained for most of the time within the control limits (6.4 to 6.6) throughout 2010.

Compliance Monitoring at SG3

As in previous years, compliance monitoring was conducted during 2010 on the Upper Strickland River at Tumbudu, where the stream gauging station SG3 is located, to determine whether water quality compliance criteria set by the PNG Government were being met. Each month, 16 samples were taken, i.e. one sample every 6 hours over a 4-day period, and analysed for trace metals and other water quality parameters.

All compliance criteria during 2010, as determined by the mean concentrations of the water samples analysed each month for various trace metals and other water quality parameters, were met in accordance with PNG Government requirements.

Concentrations of all relevant parameters at SG3, especially dissolved metals, during 2010 and for the 10-year period from 2001-2010 were well below their respective compliance criteria.

Over the 10-year period, no dissolved or total trace metals showed any distinct trends with the exception of total mercury. Concentrations of total mercury have decreased noticeably over 10 years and historical records show that prior to 2001 mean annual total mercury concentrations were generally greater than 0.6 µg/L. This confirms the observations over time that there is less mercury within the ore body with increasing depth in the open pit.

Most concentrations of dissolved ammonia were at or near the detection limit during 2010. For 2001-2010, the detection limit for ammonia improved from 25 to 5 µg/L during 2009 due to analyses now being conducted at the NMI Laboratory in Sydney rather than the PJV Environmental Chemistry Laboratory at Porgera. Sulfate concentrations at SG3 showed no distinct trend during 2010 while the 10-year period from 2001-2010 showed a slight increase. The pH values showed little change during 2010 and limited variation over the 10-year period.

Ongoing maintenance problems with the sewage treatment plants continued during 2010 preventing a number of the faecal coliform and TSS values from achieving compliance. Further maintenance work is needed to improve these results. However, all BOD_5 results for the sewage treatment plants were in compliance. All faecal and total coliform results for the drinking water plants during 2010 were below detection limits..

Summary Table - Mean monthly trace metal concentrations at SG3 for 2010 (all units in µg/L)

Month	As-D	As-T	Cd-D	Cd-T	Cr-D	Cr-T	Cu-D	Cu-T	Fe-D	Fe-T	Pb-D	Pb-T	Hg-D	Hg-T	Ni-D	Ni-T	Ag-D	Ag-T	Zn-D	Zn-T
Jan	1.5	45	<0.2	1.9	<1	61	1.2	99	15	94940	<0.5	149	<0.1	0.1	<1	113	<0.2	0.8	6.1	510
Feb	1.7	48	<0.2	1.7	<1	55	1.0	74	5.5	68560	<0.5	122	<0.1	0.1	<1	88	<0.2	0.9	2.6	415
Mar	2.0	74	<0.2	2.1	<1	39	1.2	62	6.3	54630	<0.5	224	<0.1	0.2	<1	48	<0.2	1.7	4.5	510
Apr	1.7	47	<0.2	2.1	<1	54	<1	60	10	71940	0.6	119	<0.1	0.2	<1	71	<0.2	1.0	2.1	1060
May	1.8	42	<0.2	1.0	<1	35	<1	49	2.3	46940	<0.5	63	<0.1	0.1	<1	64	<0.2	0.7	2.7	310
Jun	1.9	39	<0.2	2.5	<1	15	1.2	45	5.0	16560	<0.5	151	<0.1	0.1	<1	25	<0.2	1.0	9.1	580
Jul	1.9	69	<0.2	4.3	<1	19	<1	53	5.0	17450	<0.5	248	<0.1	0.1	<1	17	<0.2	2.0	12	870
Aug	4.0	77	<0.2	1.8	<1	32	1.9	45	5.0	41330	<0.5	134	<0.1	0.1	<1	53	<0.2	1.6	6.4	420
Sep	1.8	75	<0.2	3.7	<1	13	1.9	54	7.3	17560	<0.5	168	<0.1	0.1	<1	18	<0.2	1.6	10	725
Oct	1.7	68	<0.2	2.2	<1	38	1.8	50	7.0	56810	<0.5	105	<0.1	0.1	<1	43	<0.2	1.3	6.6	500
Nov	1.7	104	<0.2	5.1	<1	48	<1	77	51	74690	<0.5	340	<0.1	0.3	<1	54	<0.2	3.1	12	1010
Dec	1.9	61	<0.2	3.0	<1	29	1.4	54	5.0	42000	<0.5	143	<0.1	0.1	<1	37	<0.2	1.5	5.9	465
Criterion	**50**		**1**		**10**		**10**		**NC**		**3**		**NC**		**50**		**4**		**50**	
Note: D = dissolved; T = total; NC = no criterion																				

Summary Table - Mean annual trace metals concentrations at SG3 since 2001 (all units in µg/L except pH)

Year	As-D	As-T	Cd-D	Cd-T	Cr-D	Cr-T	Cu-D	Cu-T	Fe-D	Fe-T	Pb-D	Pb-T	Hg-D	Hg-T	Ni-D	Ni-T	Ag-D	Ag-T	Zn-D	Zn-T	pH-L
2001	3.0	65	<0.2	2.0	0.8	32	2.0	42	167	48800	0.6	109	<0.1	0.6	<1	49	<0.2	2.0	7.0	450	8.2
2002	4.0	85	<0.2	2.0	<1	45	2.0	54	106	56700	0.6	151	<0.1	0.3	<1	67	<0.2	2.0	6.0	395	8.2
2003	3.0	77	<0.2	2.0	<1	39	1.0	53	28	49400	<0.5	139	<0.1	0.2	<1	58	<0.2	1.0	5.0	409	8.0
2004	4.0	83	<0.2	1.0	<1	33	1.0	41	40	42900	<0.5	118	<0.1	<0.1	<1	46	<0.2	2.0	3.0	270	7.8
2005	2.6	69	<0.2	1.4	<1	48	1.4	65	46	66810	<0.5	123	<0.1	<0.1	1.2	71	<0.2	1.2	3.0	353	8.1
2006	1.9	44	<0.2	2.0	<1	45	1.5	64	53	53050	<0.5	112	<0.1	<0.1	1.1	65	<0.2	0.9	4.4	444	8.1
2007	2.9	69	<0.2	1.4	<1	41	1.6	56	55	51800	<0.5	93	<0.1	<0.1	<1	59	<0.2	0.9	4.7	352	8.0
2008	1.2	50	<0.2	1.8	<1	49	1.4	63	32	64400	<0.5	98	<0.1	<0.1	<1	66	<0.2	1.1	4.4	438	8.0
2009	1.8	71	<0.2	2.1	<1	70	1.3	80	13	81800	<0.5	149	<0.1	0.2	<1	99	<0.2	1.3	3.9	546	8.1
2010	1.9	62	<0.2	2.6	<1	37	1.3	60	11	50330	<0.5	164	<0.1	0.1	<1	53	<0.2	1.4	6.6	630	8.1
Criterion	**50**		**1**		**10**		**10**		**NC**		**3**		**NC**		**50**		**4**		**50**		**6.0-9.0**
Note: D = dissolved; T = total; NC = no criterion; L = laboratory																					

River Monitoring

Water quality and bed sediment monitoring of the fate of trace metals from the Porgera operations was conducted during 2010 at a number of downstream locations from the mine site to Lake Murray comprising SG1, SG2, Wankipe, SG3, Bebelubi, SG4, SG5 and SG6 on the Herbert River. Off-river control sites on the Upper Lagaip River, Pori River, Ok Om, Kuru River, Baia River and Tomu River were included in the monitoring program.

For each monitoring location, water quality samples were analysed for dissolved and total trace metals, and physical parameters, to assess water quality conditions in the Porgera/ Lagaip/Strickland river system downstream of the mine. Bed sediment samples taken at the same locations along the river system were analysed for metals in the <63 micron (<63 μm) size fraction and for total metals. This determined whether the trace metals were present in either the finer or coarser fractions.

The mean dissolved concentrations of arsenic, chromium, copper, lead, nickel and silver for 2010 were below the respective SG3 compliance criteria at all monitoring stations downstream of the mine, including SG1. Cadmium and zinc were the exception with all values below the respective SG3 compliance criteria downstream of SG1. Total values of all trace metals decreased substantially from the SG1 monitoring station to the Lower Strickland region at SG5 due to dilution by natural suspended sediments from tributaries joining the main river.

The 2010 annual mean dissolved concentrations of all relevant trace metals at SG2 (i.e. arsenic, cadmium, chromium, copper, lead, nickel, silver and zinc) were lower than the respective compliance criteria set for SG3. This occurred, even though SG2 is about one quarter the down-river distance to SG3 (42 vs 165 km). The 2010 annual mean value for copper at SG2 in particular was 2.0 µg/L, which is much lower than values obtained in the years prior to 2009 and well below the SG3 compliance criterion of 10 µg/L. This change is due to commissioning the Cyanide Destruction Plant (CDP) within the Process Plant in early 2009. The CDP was installed to reduce WAD cyanide levels in tailings but it also had the additional effect of reducing some dissolved metals at SG2, especially copper.

For the 10-year period from 2001 to 2010, dissolved and total metal concentrations in the water column for all the potential metal contaminants, including arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver and zinc, have generally shown little change downstream of the mine.

For downstream bed sediments, trace metal concentrations in the <63 µm and total fractions showed considerable variability along the length of the river system from the Porgera mine to SG5 in the Lower Strickland region. The values generally have decreased as mine-derived sediments become diluted with the influx of natural sediments from tributaries along the river system. Sometimes this trend was difficult to see because of the relatively low number of samples taken during the year and the existence of background levels of metals in the natural sediments. For 2010, the dissolved and total concentrations for most metals decreased, as expected, with increasing distance downstream of the mine, however, chromium, nickel and selenium showed no distinct trends for either the finer or total fractions.

Concentrations of dissolved and total metals at most local sites for 2010 were, in general, similar to those obtained over the 10-year period from 2001-2010. Concentrations of dissolved and total metals including arsenic, copper, iron, lead and nickel at 28 Level, Yakatabari Creek and Yunarilama portal were relatively higher due to discharges from the open pit and underground workings. Other metals, including cadmium, chromium, mercury, silver and zinc only showed higher concentrations for total metals at these locations.

Dissolved cadmium and zinc concentrations sampled in drainage from the main stable dumps for 2010, when compared with the 10-year period from 2001-2010, show that metal leaching from minor sulfide oxidation within the dumps may have decreased. The respective 2010 median values for both dissolved cadmium and zinc in drainage from the Kogai and North Anawe stable dumps appear lower than the long-term values. This is certainly the case for cadmium, while zinc shows a marginal decrease. Kogai stable dump, sampled at Kogai toe, has been capped with soil since 2003 with follow-up revegetation and it seems that sulfide oxidation within this dump is becoming minimal. The Anawe North stable dump, sampled at Wendako Creek, is still being used for mining purposes, has yet to be capped and sulfide oxidation is still evident but it could be decreasing. The respective dissolved cadmium and zinc median concentrations for Starter Dump 'A' (monitored at SDA toe), which was the original trial stable dump, show low values and indicates that the sulfide oxidation is now far less active.

Dissolved metal concentrations in local creeks decrease rapidly downstream due to river dilution from tributaries and adsorption onto natural sediments. However, total metals (ie metal-bearing total suspended solids mainly) decrease by natural sediment dilution from landslides throughout the catchment and from sediment-laden tributaries of the Porgera/ Lagaip/Strickland river system.

Lake Murray

Some mine-derived, metal-bearing sediment from the Strickland River enters the southern end of Lake Murray via the Herbert River, and deposition can occur within the lake. This is caused by flow reversals in the Herbert River approximately 15% of the time (NSR, 1995), due to high water levels in the Strickland River from heavy rainfall in the mountains. In 2000, a significant natural breach of the western bank of the Strickland River occurred adjacent to the Mamboi River, which flows into Lake Murray. Sediment from the Strickland River, including some mine-derived sediment, has entered the southern end of Lake Murray via the Mamboi River since that time.

As a consequence of Strickland River sediment entering Lake Murray, PJV is required to monitor the lake for the duration of the Porgera mine life. PJV's monitoring activities are concerned to a large extent with the origin, movement and fate of arsenic and mercury, while other trace metals and water quality parameters are also examined.

Bed sediment results for arsenic concentrations in the finer <63 μm size fraction showed a higher concentration of arsenic in the southern and central regions of the lake with a downward progression heading north. This trend has resulted from arsenic-bearing fine particulates entering Lake Murray from the Strickland River during reverse flows in the Herbert River. In contrast to arsenic, bed sediment results for mercury concentrations for the <63 μm fraction were at or below the detection limit. Bed sediment results for other trace metals in the <63 μm fraction varied considerably although copper, lead, nickel, silver and zinc showed higher concentrations in the southern end of the lake similar to arsenic. Chromium and iron showed higher values in the north. Cadmium and selenium concentrations were all at or below their common detection limit of 0.5 mg/kg.

Bed sediments in the total size fraction showed higher concentrations of arsenic, copper, lead, nickel, silver and zinc in the southern end of the lake. Chromium, iron and selenium showed higher values in the northern end. Cadmium and mercury values were at or below their respective detection limits.

For water quality in Lake Murray, the concentrations of all dissolved metals except iron and zinc were at or below their respective detection levels. Neither iron nor zinc showed any distinct trend throughout the year. Similarly, total concentrations for all the relevant metals except iron and zinc were at or below their respective detection limits. Total zinc concentrations showed an upward trend from north to south while iron showed no distinct trend.

The analyses for sulfate and pH showed no distinct regional trends throughout the year, while with all results for pH showed the lake water to be slightly acidic. Dissolved chloride concentrations were at or below the detection limit throughout the lake during the year.

Biological Monitoring

The full report on biological monitoring, which summarises the biological data collected between 1 January and 31 December 2010, is presented as Appendix 3 of this report and a summarized version is presented as Section 7.

The aims of the biological programs are twofold. Firstly, they provide specimens for tissue trace metal and sorbitol dehydrogenase (SDH) analyses that are useful for biomonitoring and human metal intake studies via aquatic food consumption. Secondly, they generate data to assess changes in the species richness, abundance and condition (state of health) of fish, and some invertebrates, that may have resulted from mining activities.

SPECIES RICHNESS, ABUNDANCE AND CONDITION

In the upper catchment, there was no evidence to suggest any mine-related impacts to the species richness, diversity, abundance or biomass of fish or prawns between sites for the year 2010. Rank correlations did detect some significant decreases over time in number of species, abundance and biomass for prawns. At Wankipe, for the period 2000 to 2010, negative trends were observed for species richness, abundance and biomass of prawns that were not matched at the reference site at Tomu. And at Wasiba negative trends in prawn abundance and biomass were observed for the period 2000 to 2010 that were not matched at the reference site at Ok Om. Standardised sampling is not currently undertaken at the reference sites at Kuru River and Pori River due to the lack of suitable sandbank to perform seine netting. It is planned that during 2011 backpack electrofishing will be implemented at all upper catchment sites to increase the likelihood of achieving sample numbers for tissue collection and to give another standardised method to measure species richness, abundance, diversity and biomass.

At lower Strickland River sites standardised gill and seine netting did not suggest any mine-related impacts to the species richness, diversity, abundance or biomass of fish or prawns for the year 2010 when compared with reference sites. Negative trends were detected for species richness, biomass and abundance for fish caught at Tiumsinawam that were not matched at the reference site at Tomu over the 2000 to 2010 period.

Hydroacoustic sampling was undertaken at the Strickland River off river water bodies, Kukufionga, Avu, Levame and Zongamange in May 2010. Between site differences were detected for the fish density recorded at the off-river water bodies during 2010. Fish density was found to be significantly greater ($p<0.001$) at Kukufionga than that observed at all the other off river water bodies surveyed. This result indicates that the potentially impacted site upstream of the Herbert River confluence at Kukufionga showed significantly higher fish density indicating no likely mine derived effects.

Specimen condition in the upper catchment indicated a significant difference for the fish *N. equinus* at Wasiba when compared with fish collected at Kuru River, indicating a possible mine-related effect. This trend was not observed between Wasiba and the other reference sites, Ok Om or Pori River, but should be closely monitored throughout 2011. Spearman's rank correlations indicated that *N. equinus* condition was significantly decreasing at Wasiba which was not observed at any of the reference sites.
The condition of fish and prawns at lower Strickland River sites was not found to be significantly different between downstream-of-mine sites and reference sites during 2010. However, a significant decreasing trend in the condition of *P. macrorhynchus* collected at Tiumsinawam was detected over the time period 2000 to 2010 which was not matched at the reference site at Tomu.

Overall the catch and abundance recorded at downstream of mine sites during 2010 did not indicate any direct impact due to mining activities, but trends detected in the upper catchment data from 2000 to 2010 or where there were data available, indicated that prawn species richness, abundance and biomass may be decreasing. Unfortunately, standardised catch methods in the upper catchment can be somewhat compromised by environmental conditions at the time of sampling. This will hopefully be rectified by the use of electrofishing methods in 2011. At sites in the lower Strickland region, during 2010 there were no significant differences detected between sites indicating no mine related impact.

Fish condition investigations indicated that most of the species caught during 2010 were in good health. The exception to this was *N. equinus* collected at Wasiba when compared with fish caught the reference sites.

TISSUE METAL CONCENTRATIONS

Laboratory based quality assurance was acceptable for samples analysed in Quarters 1, 2, 3 and 4.

The consistent use of field blanks was a great improvement over recent years. A total of 46 field blanks were used in 2010, a major improvement on 2008, where only seven field blanks were used, and over 2009, where 31 field blanks were used. The level of field blanks used in 2010 should be maintained. The analysis of the field blanks indicated that some contamination of samples was occurring during sample processing and possibly during sample preparation at the analytical laboratory, as well as instrument variation. A continued effort to ensure that the laboratory is as clean a possible and dissection of samples is done using clean techniques is needed. The results of the field blank analysis indicated that a greater margin of error should be associated with the samples analysed in 2010 and the subsequent tissue metals analysis.

Temporal and Spatial Variation

Tissue sampling of target organisms was undertaken at all planned sites in 2010, except at Lake Murray where landowner intervention and unreasonable compensation demands prevented sampling for tissues from occurring. Prawns were sampled from a number of extra sites in the lower Strickland as part of the prawn bioaccumulation study. Samples were collected from sites Kukufionga, Strickland River at Oxbow 3 entrance, Strickland River above Everill Junction and Fly River at Ogwa.

The extent of mine-related (and in some cases anomalous) elevation of metal bioaccumulation is discussed in detail for each metal in Section 7.2, Tissue Metal Concentrations, of this report.

The elevated levels of metals in tissues from downstream-of-mine sites in the upper catchment and the lower Strickland region observed in previous years annual reports continued in 2010. Concentrations of cadmium and lead have continued to be detected at significantly elevated levels in prawn cephalothorax tissues collected from established downstream-of-mine sites as far down river as SG5. Overall, these results indicated that the pattern of bioaccumulation of metals at downstream-of-mine sites in the Lagaip River and the lower Strickland region has continued with small alterations to the difference seen in the uptake of some metals; for example, mercury was not detected at significantly elevated levels at downstream-of-mine sites compared with reference sites and was also seen to have decreased in some tissues over both long and short time periods. There was also some correlation with biological data that the cyanide destruct circuit is reducing the availability of some metals downstream of the mine.

While the presence of some metals at elevated levels has continued in 2010, quality control measures using field blanks indicated that contamination has continued to be a problem for some metals. Taking into account the error associated with the analysis of the tissues, the results of the tissue metals analysis during 2010 were very similar to those seen in past years' programs.

The results of the tissue metal concentrations for each tissue type and organism type were screened against the lowest observed concentration co-occurring with an effect (LOEC) from the effects database of Jarvinen and Ankley (1999). Sites where the ratio of results above:below the corresponding effects threshold for impact sites was found to be greater than for any of the corresponding reference sites were found at all impacted sites down to Bebelubi for cadmium in prawn cephalothorax and to Tiumsinawam for fish liver. Other sites where the ratio found the results above the corresponding effects threshold were Tiumsinawam for copper in fish flesh, Bebelubi for copper in fish liver, Tiumsinawam and Bebelubi for zinc in fish liver and Bebelubi for mercury in fish liver.

The collection of prawn samples for SDH analysis from the upper catchment continued in 2010 and was also expanded to sites in the lower Strickland region, with samples collected from Strickland River at Oxbow 3 entrance, SG5 and Fly River at Ogwa. Results for SDH analysis in 2010 indicated that prawns collected from Wankipe in the upper catchment had significantly elevated hepatic cell damage when compared with samples collected from the reference sites at Ok Om and Pori River. This result differed from that seen in analysis undertaken in 2006 and 2009, where Wasiba was seen to also have elevated levels of hepatic cell damage indicating that prawns at Wasiba during 2010 were under less stress than seen in previous surveys, which may be a result of the cyanide destruct circuit reducing the available metals downstream from the mine.

Results for samples collected at sites in the lower Strickland region indicated that prawns from site Oxbow 3 entrance had significantly elevated hepatic cell damage when compared with samples collected from SG5, while samples from Ogwa were statistically similar to samples collected from both Oxbow 3 entrance and SG5. As prawns were not collected from any reference sites in the lower Strickland region in 2010, it is not known whether the levels of hepatic cell damage observed are at levels of concern at the downstream-of-mine sites. This will hopefully be rectified during the 2011 program with the collection of prawns from an appropriate reference site. It is not known whether the amount of hepatic cell damage reflected by these increased levels of SDH is tolerable by the prawn species sampled. Investigations into the relationship between these levels of SDH in the prawn abdomen and organism health would allow for a better understanding of the state of the populations in the upper catchment and lower Strickland region.

A screening of the samples of fish and prawns collected in 2010 using appropriate human health standards and guidelines (see Appendix 2, Section 3.6) indicated that none of the samples collected had concentrations of metals above the standards and guidelines. It can be stated that there is a low likelihood of human health impacts from the consumption of the edible portion of the fish and prawns in the upper catchment and the lower Strickland region.

Rehabilitation

Significant changes in the areas of disturbance between 2009 and 2010 were an increase of 15 ha for the Anawe North stable dump, 38 ha for the Kogai stable dump and no change to the open pit. Total waste rock dumped was 9.4 million tonnes at Kogai stable dump and 7.5 million tonnes on the Anawe North stable dump. Total waste rock dumped to Anawe erodible dump was 6.6 million tonnes and 2.7 million tonnes to the Anjolek erodible dump.

Erosion and sediment control measures were installed at Anawe stable dump as black sediment and brown mudstone were dumped on the benches and slopes. Two benches on stage 5B were seeded with environment seed mix to control and minimise erosion above the stage 5B mining area.

A total of 43,420 tree seedlings, including *Nothofagus grandis* and *Nothofagus perri* were planted on Kogai stable dump. The edible plant Karuka (*Pandanus jiulianettii*) was also planted on the area.

A survey of soil cover on the Kogai stable dump showed an improvement in the fertility of the surface soil layers due to fertilization and the establishment of a groundcover. Total phosphorus concentrations in the soil were high with 406 mg/kg compared to 30 mg/kg as expected levels. Potassium soil levels were above the suggested value of 0.3 mg/kg while CEC levels were also high compared to the expected levels of >10 mg/kg. The mean pH of the soils was 7.8.

A plant species survey conducted on Kogai rehabilitation areas showed that weeds have become dominant. It was recommended that maintenance weeding be carried out in all rehabilitation areas. Natural colonization by local plant species was low.

A legume nodule survey conducted on the Kogai rehabilitated sites revealed that the legumes used in the rehabilitation program were well nodulated.

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1.0 INTRODUCTION

This report has been prepared as a requirement of the Environment Permit WD-L3(121) clause 42 and the Environment Permit WE-L3(91) clause 8, as agreed to between Porgera Joint Venture (PJV) and PNG Department of Environment and Conservation (DEC).

The report is in eight sections with three appendices and presents information pertaining to environmental management and monitoring at the Porgera gold mine and in the downstream river system during 2010.

Section 2 of this report provides 2010 hydro-meteorological and sediment transport monitoring data for the Porgera local region and downstream along the Strickland River system to Lake Murray. This information is critical in assessing other factors including river dilution rates and predictions of material movement and suspended sediment. It also influences the erosion rates of erodible dumps and the total contribution of mine-derived material, including tailings, to the river system. Rainfall also influences the frequency of landslips and non-mine derived sediment to the river system.

Section 3 presents 2010 monitoring data for tailings discharge which contributes both metal-bearing sediment and dissolved metals to the river system. The concentration of dissolved metals in tailings slurry and river dilution rates have considerable influence on the levels of dissolved metals, especially at the compliance point SG3, and in fish and prawns along the river system. The monitoring data also assess the potential effects downstream from Process Plant operational changes that can occur periodically.

Section 4 summarises the 2010 SG3 compliance monitoring results at Tumbudu on the Upper Strickland River which marks the end of the tailings mixing zone set by the PNG Government, and it is important for PJV to verify compliance with permit conditions at this location. In addition, SG3 marks the end of the tailings and erodible waste rock compensation zone for people living downstream of the mine.

Section 5 presents 2010 water quality and sediment results at various monitoring locations from the Porgera region along the Porgera/Lagaip/Strickland River system to upstream of the Fly River junction. Since mining operations began at Porgera in 1990, PJV has operated a comprehensive environmental monitoring program to assess riverine impacts caused by the disposal of tailings and incompetent waste rock from the mine.

Section 6 presents 2010 sediment and water quality monitoring data for Lake Murray. Flow reversals from the Strickland River into Lake Murray via the Herbert River enable some mine-derived, metal-bearing sediment to enter the southern end of Lake Murray where deposition can occur. Lake Murray has relatively-high, naturally-occurring levels of mercury within the lake and the purpose of PJV's monitoring was to assess whether the small amount of mercury released from the mine would exacerbate the existing problem. PJV monitoring has confirmed that the mine operations have had no effect on mercury levels within the lake over the past 20 years.

Section 7 is a summary report of the 2010 biological monitoring program downstream of the Porgera mine along the Strickland River system, including Lake Murray. The monitoring program provides specimens for tissue metal analysis for bio-monitoring and human metal intake studies via aquatic food consumption. The program also assesses potential changes in the species richness, abundance and condition of fish and invertebrates from the mining activities. The full biological report is presented as Appendix 3.

Section 8 addresses the progress of rehabilitation programs around the Porgera mine site during 2010. The programs include progressive landform rehabilitation during the operational phase, as well as progressive revegetation where required, especially on recently-disturbed ground.

2.0 HYDROLOGY AND SEDIMENT TRANSPORT

2.1 Introduction

Hydrological data are critical to the other riverine studies conducted by PJV because they enable assessment of dilution rates and predictions of material movement and suspended sediment. It also influences erosion rates of erodible dumps and the total contribution of mine derived material including tailings to the river system. Heavy rain also influences the frequency of landslips and non-mine derived sediment to the river system. The rate of river flow has a great impact on total suspended solids in both the upper and lower river.

This section overviews the hydrometeorological and sediment transport data collected during 2010 as part of PJV's environmental management and monitoring program and, at local stations for operational and mine closure purposes. Figure 2-1 shows the key sites along the Porgera-Lagaip-Strickland Rivers system as well as the Ok Om control station. Meteorological data was collected at Anawe (mine site) meteorology station while rainfall data continued to be collected at either stand-alone stations or in tandem with river flow data collection.

Sedimentation data collection during the year involved total suspended solids (TSS) as well as river profiling in the middle and low reaches only. Hydrology and sediment transport data collected during the year were reviewed by CF Hydrometrics (Canberra, Australia) and Hydrobiology Pty (Brisbane, Australia) consultants, respectively..

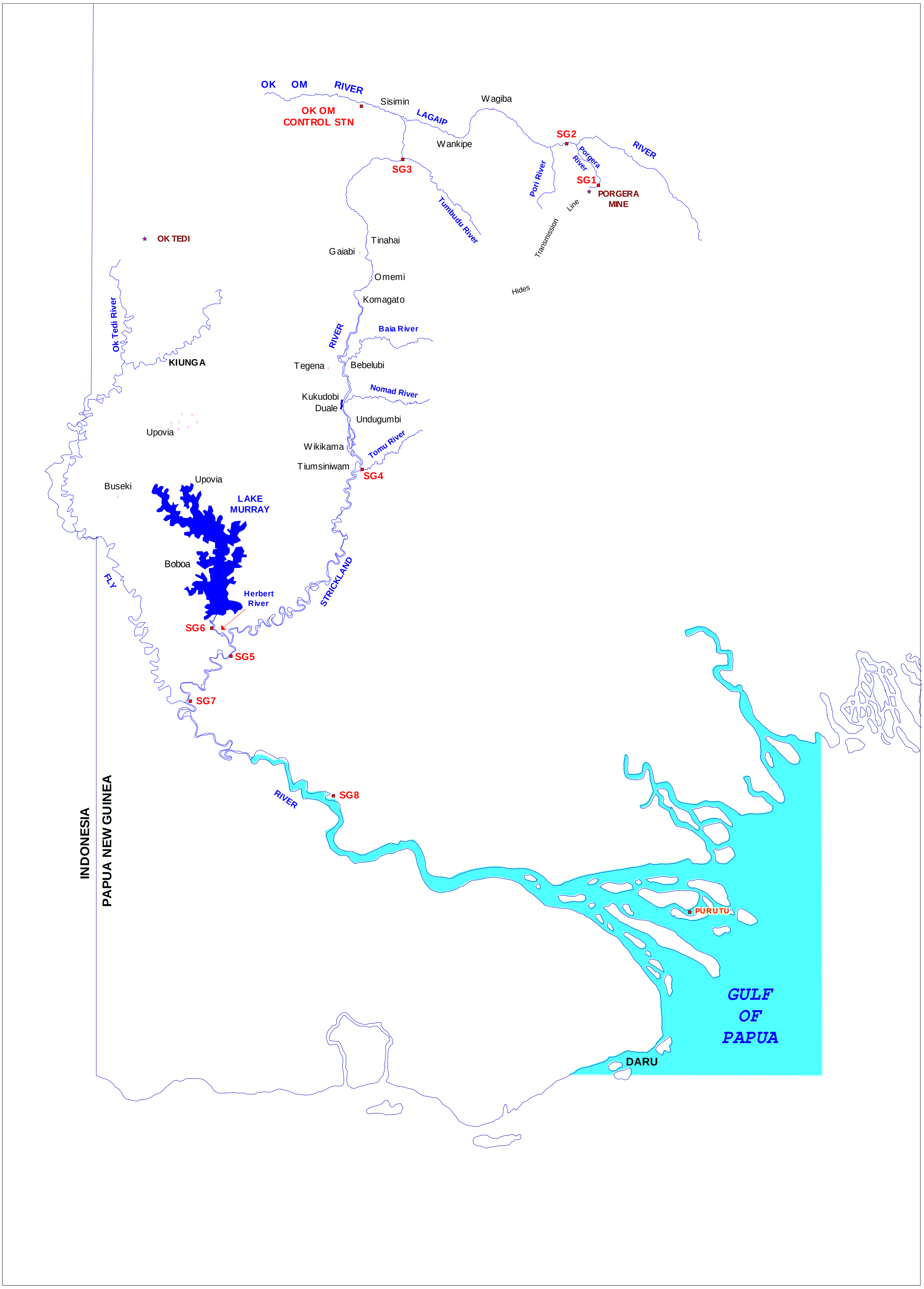


Figure 2-1 Location of environmental monitoring stations

2.2 Major Tasks Undertaken during Year

Law and order problems and tribal conflicts prevented many activities outside those required for compliance and licensing requirements. Some EMP activities (i.e. cross-section profiling along the Porgera River) were not possible due to personal safety concerns.

2.2.1 Rating Curves

Rating curves for key stations have been maintained throughout the year, with most sites receiving sufficient calibration checks (gaugings) to validate ratings.

The 'base flow' range of the SG2 rating was refined using additional low flow gaugings that were obtained during the dry period mid-year. All other sites currently appear to be relatively stable, indicating that sediment and bed loads are balanced and little or no aggradation or deposition occurred during the year.

2.2.2 Data Recovery

Continuously recording stations operating at or downstream of the mine are listed in Table 2-1. The overall data recovery rate of 93% during the year was a good result, and above the notional target of 92% (refer Figure 2-2 and Table 2-1 over). Generally, good data recovery was achieved at the main riverine stations with the majority of data loss attributable to ongoing vandalism, major flood damage at Ok Om early in the year (exceeded approximately 7m gauge height on 20th March) and exposure of sensors during the extended dry spell mid year.

Rainfall data recovery was excellent, with no loss across the entire network.

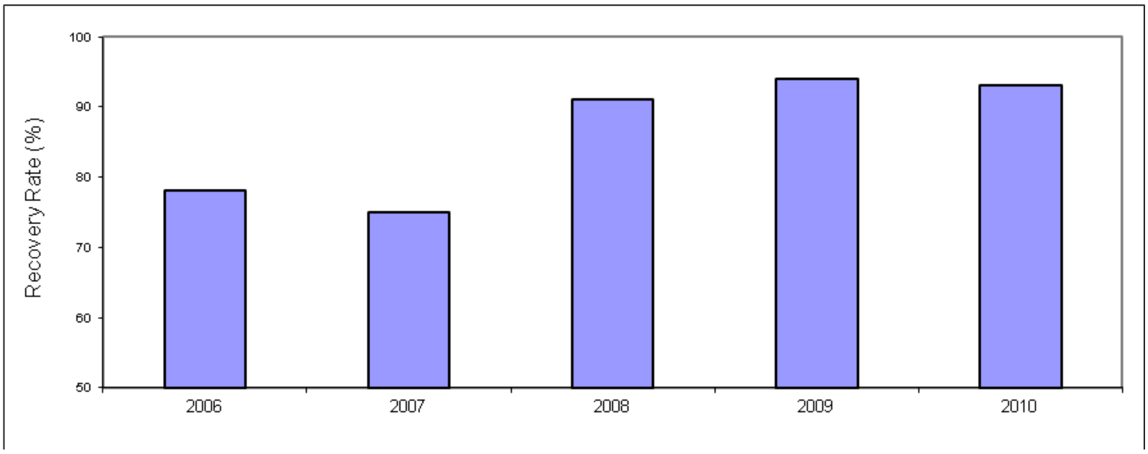


Figure 2-2 Overall data recovery at monitoring stations (previous 5 years)

Table 2-1 Data recovery (%) from continuously recording stations for previous 5 years

Station	Variable	2006	2007	2008	2009	2010	Comments (2010 data)
Open Pit	Rainfall	84	89	100	100	100	
Waile Creek	Rainfall	100	100	100	100	100	
Adit weir	Water level	76	92	95	100	#	Poor quality due to siltation
Kogai–SAG Mill	Water level	87	51	98	100	95	Instrument malfunction
Yunarilama	Water level	32	75	86	99	91	Instrument malfunction
Kogai-Culvert	Water level	89	55	75	85	96	Instrument malfunction
Pongema	Rainfall Water level	100 96	100 75	89 94	100 85	100 99	 Instrument malfunction
SG2	Rainfall Water level	51 50	100 75	92 91	95 100	100 94	 Below instrument - dry period
Ok Om	Rainfall Water level	100 92	100 100	100 94	100 85	100 46	 Flood damage
SG3	Rainfall Water level	100 90	75 88	100 88	100 100	100 82	 Orifice damaged by bushfire
SG4	Rainfall Water level	75 25	38 37	100 85	88 78	100 71	 Vandalised
SG5	Rainfall Water level	91 40	73 18	53 100	100 82	100 100	
Anawe	All climatic variables	96	94	94	99	100	
Overall		**78**	**75**	**91**	**94**	**93**	

Note: # - insufficient data

2.3 Hydrometeorological Data

Meteorological data continued to be collected during the year at stations around the mine site and along the river system.

2.3.1 Meteorology at Porgera

Meteorological data collection at Anawe plant site is a combination of time-based (daily read) data and continuous logger data (rainfall, temperature, humidity and wind vectors, barometric pressure and solar radiation). The parameters monitored include rainfall, temperature (maximum, minimum, dry and wet bulb), evaporation, wind speed and direction, wind run and sunshine duration.

Table 2-2 and Figure 2-3 give a summary of the meteorology data collected during the year. From Table 2-2, daily maximum temperature range was 15°C to 30°C, while the daily minimum range was 8.3°C to 27°C with a daily mean of 16°C. Minimal seasonal variability occurs throughout the year at Porgera.

Table 2-2 Summary of meteorological data for 2010 at Anawe Plant site

Parameter	Yearly total (2010)	Daily high	Daily low	Daily mean (2010)	Long-term daily mean
Max Temp (°C)	-	30.0	15.0	23.5	20.2
Min Temp (°C)	-	27.0	8.3	13.1	12.2
Mean Daily (°C)	-	-	-	15.9	16.1
Sunshine (hr)	1,534	11.1	0.0	4.4	3.9
Evaporation (mm)	1,031	12.2	0.0	2.9	2.8
Wind Run (km)	14,840	120	0	41.2	47

Cloud cover is heavy over the Porgera valley and is mainly influenced by orographic effects. Sunshine hours for the year ranged from 0 to 11 hours with the daily average being 4.4 hours against long-term daily mean of only 3.7 hours.

Evaporation at Porgera is relatively low compared to other parts of the highlands. The total evaporation of 1,031 mm during the year was approximately ⅓ of the total rainfall (3,199 mm). The long-term annual average evaporation is 994 mm. As a contrast, evaporation in the lowlands of PNG is in the order of 2,300 to 2,400 mm per annum (McAlpine *et al.*, 1983).

Winds are low in the shelter of the Porgera valley and generally prevail from an easterly direction. There is minimal seasonal variation in wind direction, which is mainly katabatic (drainage flow) in nature. Total wind run during 2010 was equal to 14,840 km (an average of 0.5 m/s). Daily wind run (maximum 120 km) and wind speeds (maximum gust of 3.9 m/s) recorded in the Porgera valley are highly variable and attributed to orographic (related to increasing topography) influence.

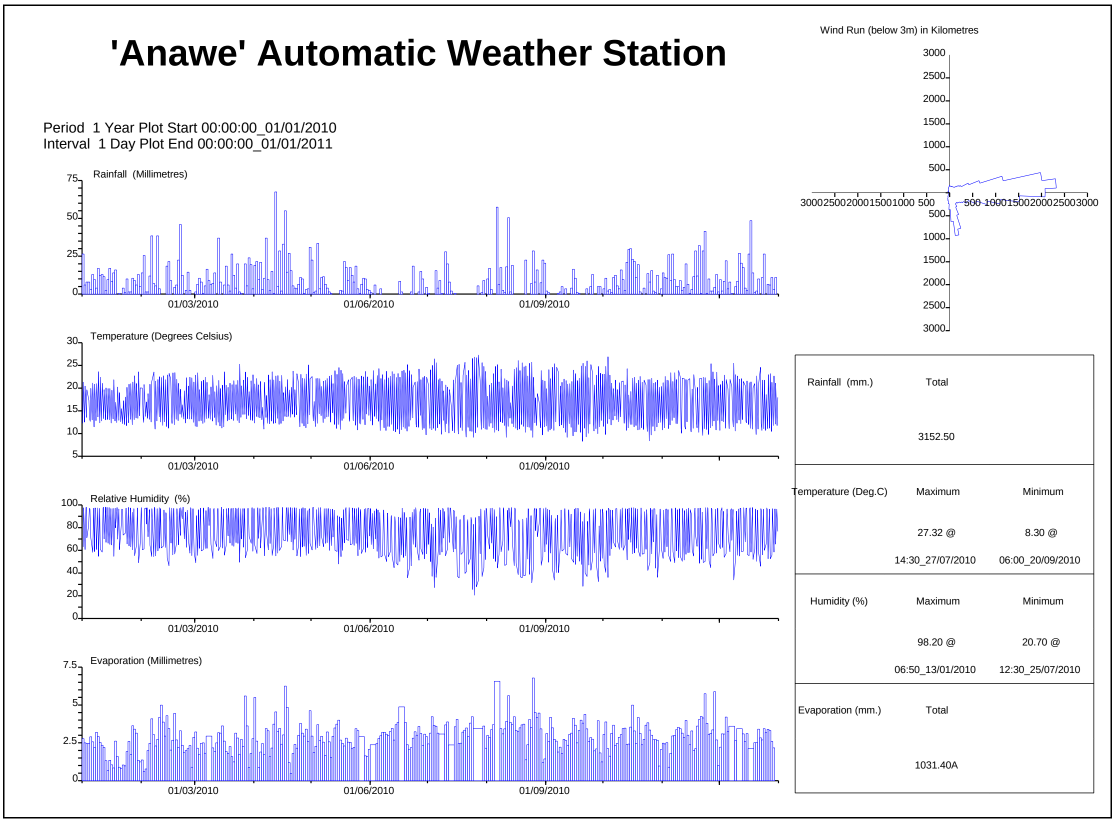


Figure 2-3 Summary of Anawe Plant site (Pandadaka) weather station data

Note variation between Anawe daily read rainfall and the automatic station is due to resolution differences (0.2mm versus 0.5mm respectively). To maintain consistency with historic data, the daily read rainfall data is utilized for all analysis (except short term intensities).

2.3.2 Rainfall

Rainfall stations are either stand-alone or water-level combined data loggers with secondary logger backup. Additional data backup is provided by the telemetry system at equipped sites.

Anawe Plant Site

The historical rainfall at Anawe is shown in Figure 2-4 and Table 2-3 over. From Figure 2-4, there is a median variability of about 30% between the years with 1997, 1982 and 1990 being the driest, and 1977, 1983 and 2006 being the wettest years on record. The highest annual rainfall recorded at Anawe is 4,413 mm in 1977, with a maximum daily rainfall of 89 mm being recorded in August 1990 (an ARI of 1:10). 2010 was the fourth driest year on record, with June, July and September being the driest of those months on record. The maximum daily rainfall for 2010 was 66.6 mm on 18th December, a maximum intensity of 9.0mm in 6 minute occurred on 25th December, while the highest hourly intensity was 38.5mm on 7th August.

Figure 2-5 shows rainfall at Anawe during the year against long-term monthly averages. Total rainfall of 3,199 mm on 281 wet days was 14% below the long-term annual average rainfall of 3,717 mm. From the long-term pattern, January to April and October are generally the wettest months at Porgera.

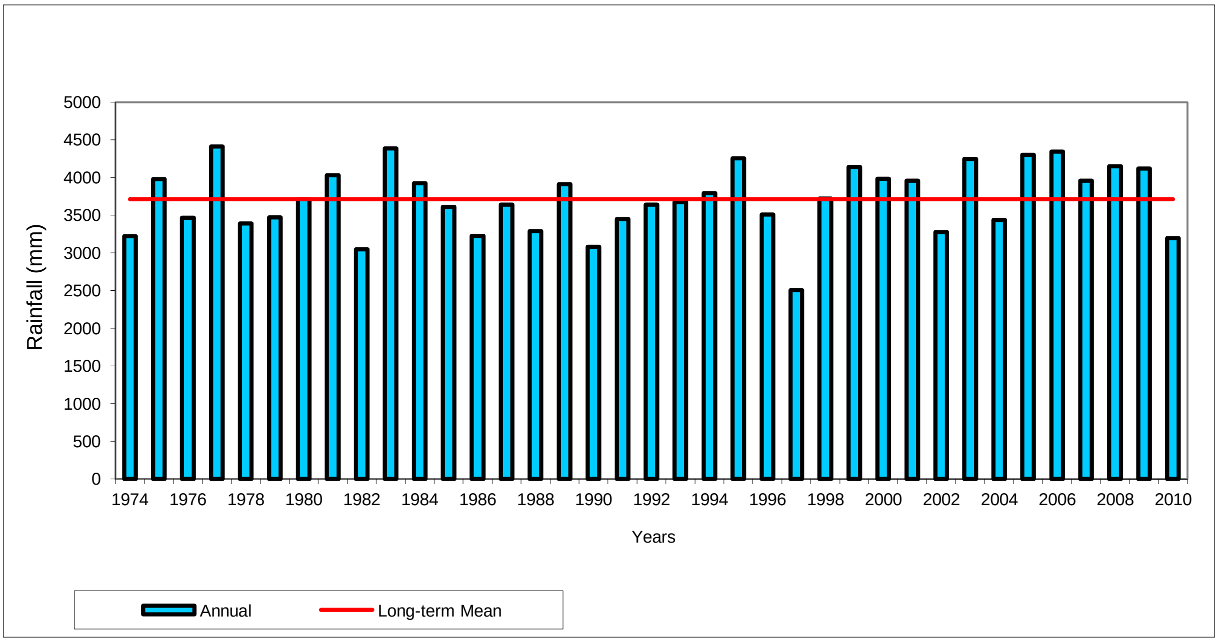


Figure 2-4 Annual rainfall at Anawe plant site since 1974

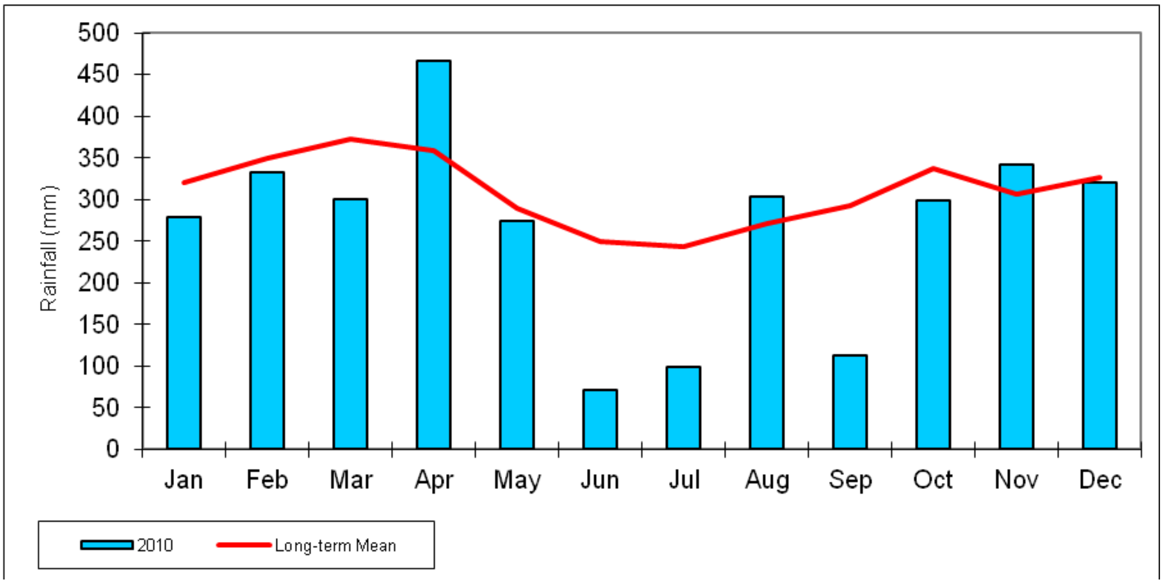


Figure 2-5 Rainfall at Anawe plant site during 2010 against long term monthly means

Table 2-3 9AM Anawe rainfall summary since 1974 (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Monthly	Annual Total	Year Max.	Year
1974	301.5	424.3	264.6	319.4	155.3	222.1	242.4	150.1	193.6	424.8	203.0	320.0	268.4	3221.1	424.8	**1974**
1975	332.1	539.6	475.4	472.0	405.1	291.4	220.1	242.8	193.0	197.5	247.0	367.0	331.9	3983.0	539.6	**1975**
1976	287.0	233.0	252.5	284.5	294.0	213.0	348.5	184.5	180.5	468.0	301.5	422.0	289.1	3469.0	468.0	**1976**
1977	399.5	494.5	314.5	367.0	295.5	335.5	343.5	512.0	405.0	465.5	228.5	252.0	367.8	4413.0	512.0	**1977**
1978	217.0	251.5	381.5	299.0	264.0	132.0	182.0	259.0	387.0	319.0	321.0	377.0	282.5	3390.0	387.0	**1978**
1979	84.0	343.0	593.0	390.0	284.0	212.0	226.5	178.5	289.0	312.0	248.0	314.0	289.5	3474.0	593.0	**1979**
1980	387.5	235.5	348.0	296.5	385.0	230.0	259.5	372.0	263.0	306.0	252.0	377.0	309.3	3712.0	387.5	**1980**
1981	463.0	280.0	285.6	334.0	301.5	326.5	282.0	312.0	341.0	402.0	328.0	376.2	336.0	4031.8	463.0	**1981**
1982	344.0	333.0	338.0	220.0	302.5	311.5	123.0	243.5	205.5	250.0	119.0	259.0	254.1	3049.0	344.0	**1982**
1983	401.0	346.5	451.5	342.5	388.0	267.5	268.0	332.5	327.0	417.0	433.0	415.0	365.8	4389.5	451.5	**1983**
1984	319.0	457.1	348.5	296.5	394.0	290.5	222.5	285.0	304.0	340.0	267.0	401.5	327.1	3925.6	457.1	**1984**
1985	275.0	452.0	191.0	322.0	175.0	343.0	177.0	270.0	415.0	348.5	327.0	317.0	301.0	3612.5	452.0	**1985**
1986	321.0	334.0	475.0	305.0	139.5	331.0	178.0	157.5	185.5	351.0	313.0	138.0	269.0	3228.5	475.0	**1986**
1987	490.0	152.0	329.0	398.5	268.0	359.0	184.0	294.5	260.0	323.0	355.8	229.3	303.6	3643.1	490.0	**1987**
1988	223.1	329.9	456.1	274.9	223.3	237.7	189.7	164.2	276.9	341.1	279.1	293.9	274.2	3289.9	456.1	**1988**
1989	254.8	348.7	448.4	387.9	357.9	202.0	223.1	376.8	328.4	387.3	351.8	247.1	326.2	3914.2	448.4	**1989**
1990	294.6	183.0	149.4	343.1	236.0	245.4	142.0	395.9	276.9	309.7	245.4	263.2	257.1	3084.6	395.9	**1990**
1991	294.5	377.4	255.7	357.4	236.5	223.6	285.4	399.4	129.1	358.4	236.9	297.5	287.7	3451.8	399.4	**1991**
1992	155.4	380.4	399.0	398.1	312.4	351.9	182.0	242.8	221.6	476.6	222.6	300.5	303.6	3643.3	476.6	**1992**
1993	417.8	103.4	241.1	303.0	218.4	381.9	471.0	207.8	261.1	274.0	325.4	469.3	306.2	3674.2	471.0	**1993**
1994	370.0	285.7	376.0	369.8	362.6	277.6	358.1	390.6	242.9	239.7	247.2	275.0	316.3	3795.2	390.6	**1994**
1995	447.3	439.2	371.0	457.6	359.8	295.2	164.1	231.6	314.4	328.6	437.0	412.3	354.8	4258.1	457.6	**1995**
1996	342.4	395.6	261.2	375.5	400.0	252.4	153.4	152.2	254.6	313.9	367.6	239.9	292.4	3508.7	400.0	**1996**
1997	297.5	437.3	52.4	275.0	145.1	84.7	318.7	107.5	144.2	88.2	228.2	327.0	208.8	2505.8	437.3	**1997**
1998	223.5	396.0	330.0	432.0	287.7	228.0	158.9	185.9	285.8	333.8	447.8	414.8	310.4	3724.2	447.8	**1998**
1999	437.6	371.0	516.0	382.4	213.3	195.4	236.6	395.0	264.6	388.1	409.9	333.0	345.2	4142.9	516.0	**1999**
2000	284.3	289.4	491.7	295.4	364.5	257.2	292.2	342.1	257.1	559.0	306.9	243.8	332.0	3983.6	559.0	**2000**
2001	222.7	430.4	451.0	471.7	333.6	262.0	302.5	199.8	293.0	252.8	441.1	300.6	330.1	3961.2	471.7	**2001**
2002	379.8	295.3	488.3	402.6	153.9	189.4	181.2	200.9	236.4	264.2	195.0	291.1	273.2	3278.1	488.3	**2002**
2003	323.4	361.4	474.2	451.2	316.8	110.6	450.6	345.0	328.2	394.8	213.6	477.1	353.9	4246.9	477.1	**2003**
2004	246.3	478.1	368.4	199.9	340.8	229.8	185.8	292.2	333.8	258.1	259.1	247.4	286.6	3439.7	478.1	**2004**
2005	303.2	189.6	460.4	425.4	345.2	265.6	310.4	376.8	452.8	356.0	415.7	402.0	358.6	4303.1	460.4	**2005**
2006	436.1	334.8	565.2	518.4	279.3	345.5	281.6	237.3	569.3	238.9	354.6	183.4	362.0	4344.4	569.3	**2006**
2007	400.5	320.8	461.6	274.8	312.9	143.2	242.2	251.0	505.6	402.7	240.7	402.2	329.9	3958.2	505.6	**2007**
2008	265.2	504.6	370.0	396.2	257.4	290.6	164.0	136.2	436.2	391.6	510.6	430.0	346.1	4152.6	510.6	**2008**
2009	341.4	478.2	457.1	328.0	314.0	263.3	373.5	303.8	321.8	274.6	348.6	314.7	343.3	4119.0	478.2	**2009**
2010	277.8	332.6	300.6	466.9	273.7	71.5	99.0	303.0	111.8	299.2	342.3	320.8	266.6	3199.2	466.9	**2010**
Mean	**320.6**	**349.7**	**372.8**	**357.7**	**289.1**	**250.5**	**243.9**	**271.1**	**291.8**	**336.6**	**307.3**	**325.7**	**309.7**	**3716.8**	**465.0**	**Mean**
Max	490.0	539.6	593.0	518.4	405.1	381.9	471.0	512.0	569.3	559.0	510.6	477.1	**367.8**	**4413.0**	**593.0**	**Max**
Min	84.0	103.4	52.4	199.9	139.5	71.5	99.0	107.5	111.8	88.2	119.0	138.0	**208.8**	**2505.8**	**344.0**	**Min**
% Dev.	-13.3	-4.9	-19.4	30.5	-5.3	-71.5	-59.4	11.8	-61.7	-11.1	11.4	-1.5	**-13.9**	**-13.9**	**0.4**	
Long Term Monthly Average:				**309.7**		**Wettest Year:**		**4413 mm in 1977**								
Long Term Annual Average:				**3716.8**		**Dryest Year:**		**2505 mm in 1997**								

Open Pit Rainfall

Rainfall data collection at this station commenced in 1988. Figure 2-6 shows the historical data since 1988 with the 3 wettest years being 2005, 1995, and 1989, and the driest years being 1997, 1990 and 1992. The annual long-term average of 3,790 mm at the Open Pit gauge compares well with the Anawe plant site value of 3,717 mm, the two stations being in close proximity, though quite different elevation and exposure conditions.

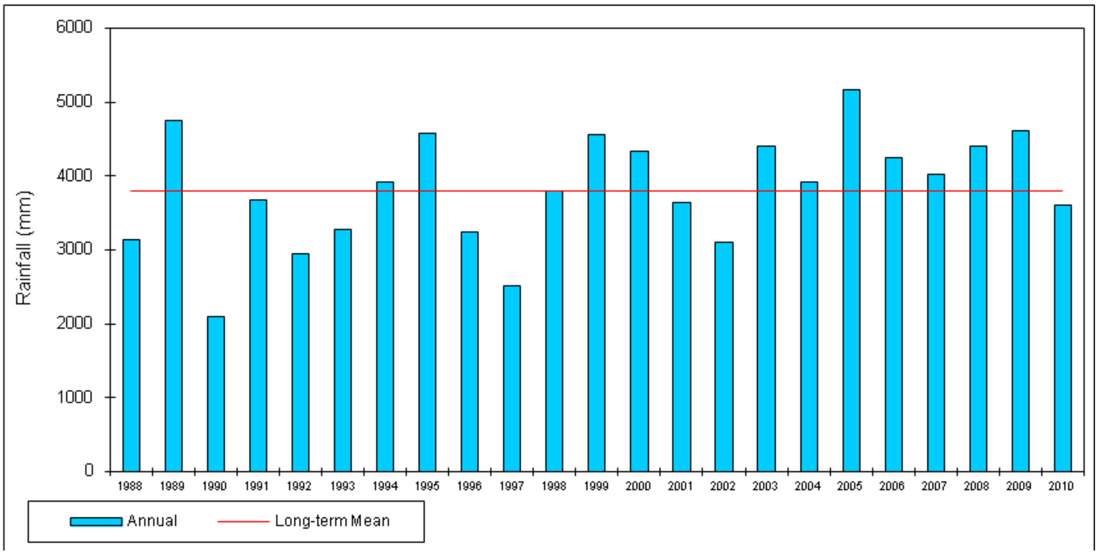


Figure 2-6 Annual rainfall at Open Pit since 1988

Rainfall at the Open Pit during 2010 compared to long-term monthly averages is shown in Figure 2-7. Total rainfall of 3,600 mm (288 wet days) for the year was close to the annual average of 3,790mm. The April monthly rainfall of 464 mm was the highest for the year. The maximum daily rainfall was 74 mm on 13th April, while the highest intensity storm of 14.5 mm in 6 minutes occurred on the 13th October. The highest hourly intensity was 36 mm on 7th February.

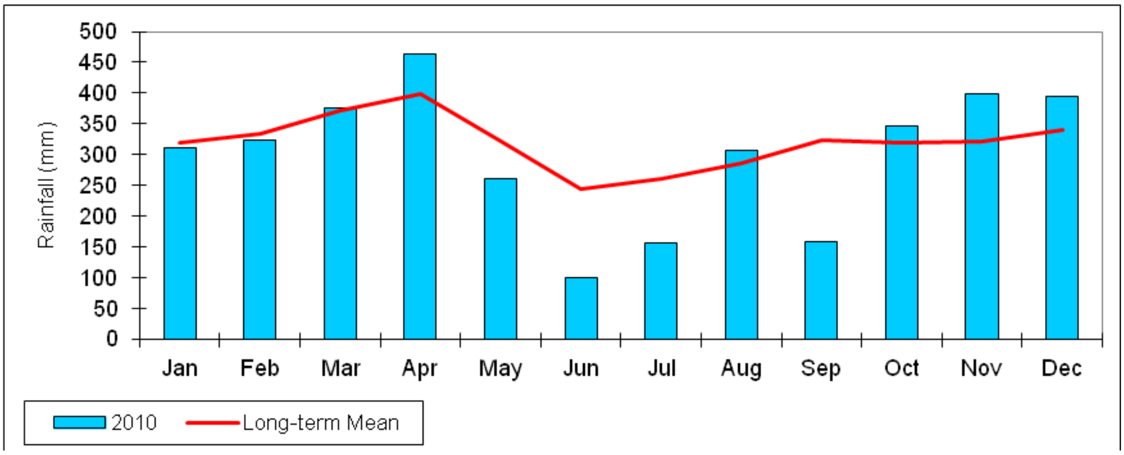


Figure 2-7 Rainfall at Open Pit during 2010 against long term monthly means

Waile Creek Rainfall and Reservoir Level

Figure 2-8 shows monthly rainfall and the average reservoir water levels at the Waile Creek dam during the year. Total annual rainfall of 2,920 mm (288 wet days) during the year was slightly above the annual average of 2,835 mm. The November monthly rainfall of 343mm was the highest for the year while June recorded the lowest monthly rainfall of only 74mm. The maximum daily rainfall was 41mm on 22nd February, with both the highest intensity of 7mm in 6 minutes and the highest hourly intensity of 20.5 mm occurring on 10th December.

Reservoir exceeded only 33% full (253 ML) for 90% of the time. Maximum level in March was 1.88m above spillway which is equivalent to 758 ML (98% full), and in July and August the level dropped to -5.2m which is equivalent to only 88 ML or 11% of capacity, which resulted in extended 'shut down s' due to insufficient water for operations.

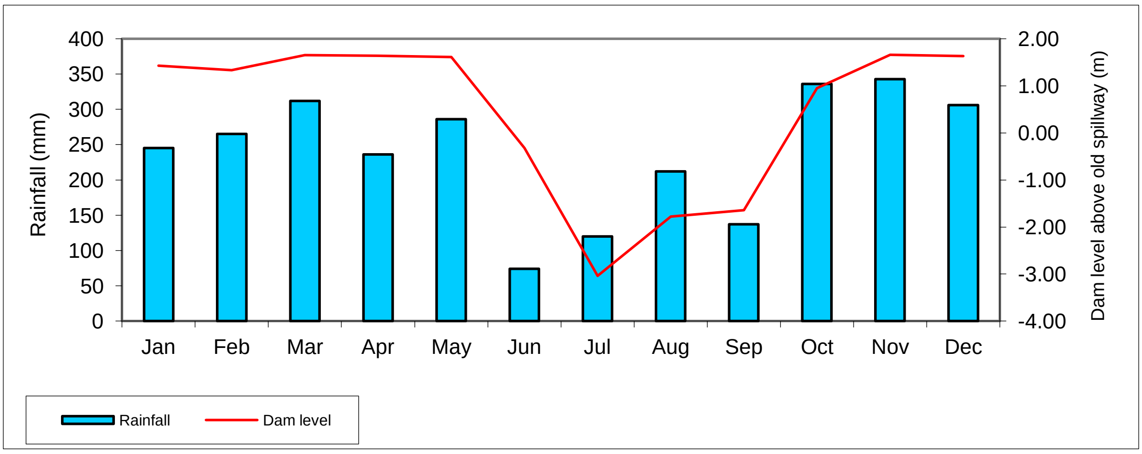


Figure 2-8 Rainfall (mm) and average dam level (m) at Waile Creek Dam during 2010

Pongema River Rainfall

Figure 2-9 shows Pongema (Suyan) rainfall during 2010 against long-term monthly averages. Total annual rainfall of 2,930 mm (275 wet days) during the year is slightly below the long term annual average of 2,965 mm. The April monthly rainfall of 401 mm was the highest for the year. The maximum daily rainfall was 62 mm on 13th April, with the highest intensity storm being 12.5 mm in 6 minutes on 31st July. The highest hourly intensity was 32 mm on the 16th September.

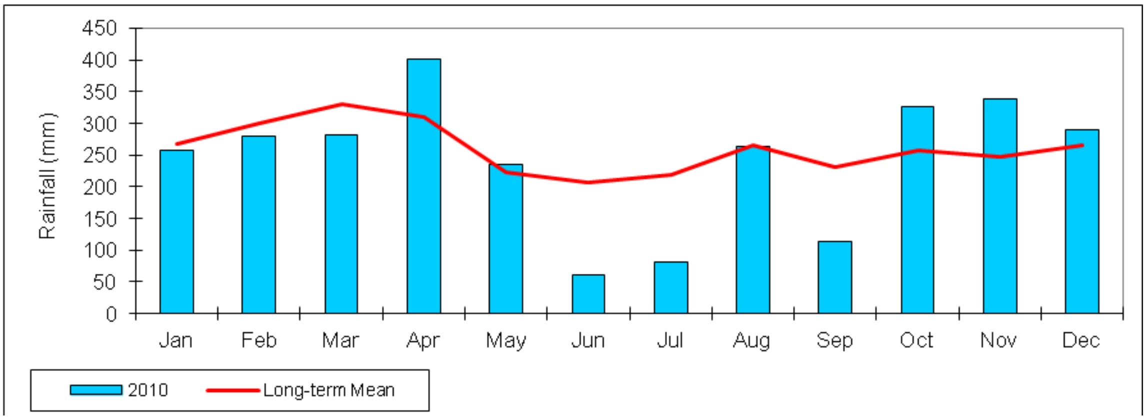


Figure 2-9 Rainfall at Pongema during 2010 against long-term monthly means

Lagaip River at SG2 Rainfall

Figure 2-10 shows monthly rainfall at SG2 during the year against long-term monthly averages. Total annual rainfall of 2,240 mm (252 wet days) during the year is 17% higher than the annual average of 1,912 mm. The May monthly rainfall of 330 mm was the highest for the year. The maximum daily rainfall was 61mm on 19th April, the highest intensity storm of 10.5 mm in 6 minutes occurred on 29th November while the highest hourly intensity of 41 mm fell on 19th May.

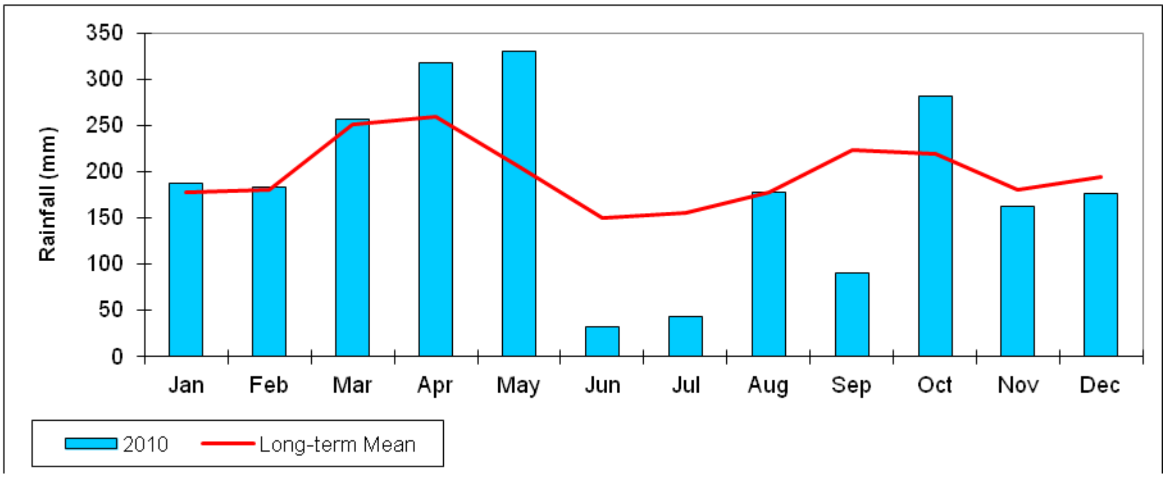


Figure 2-10 Rainfall at SG2 during 2010 against long-term monthly means

Ok Om 'Control Station' Rainfall

Figure 2-11 shows monthly rainfall at Ok Om during the year. The total annual rainfall of 1,820 mm (240 wet days) during the year is 13% lower than the annual average of 2,114 mm. The January and April monthly rainfalls of 242mm were the highest for the year while July recorded the lowest rainfall of 55 mm. The maximum daily rainfall was 58 mm on 6th December, with the highest intensity storm of 10 mm in 6 minutes occurring on the 3rd October and the highest hourly intensity of 45.5 mm on the 6th December.

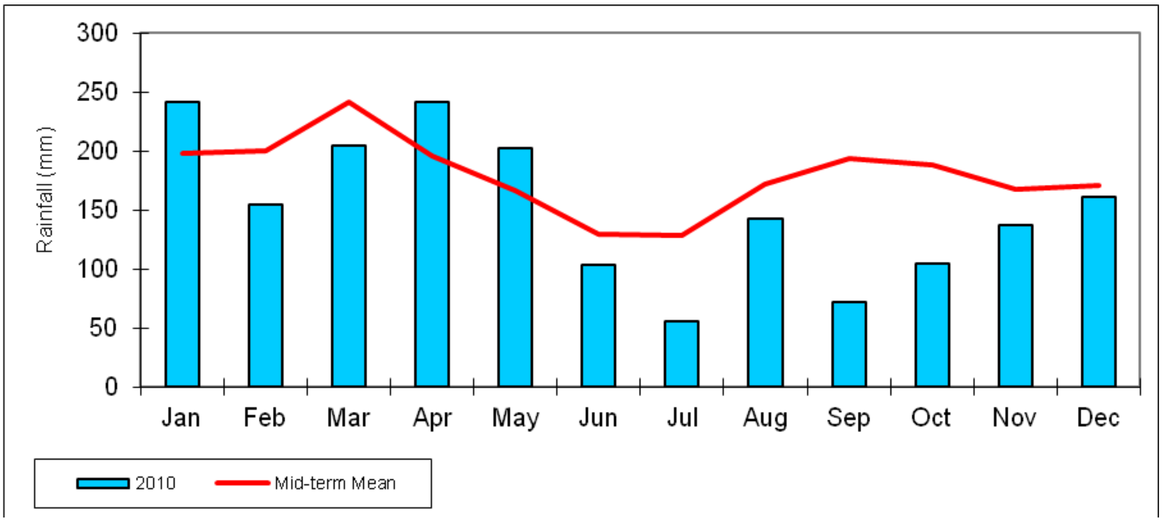


Figure 2-11 Rainfall at Ok Om during 2010 against long-term monthly means

Strickland River at SG3 Rainfall

Figure 2-12 shows monthly rainfall at SG3 during the year against long-term monthly averages. Total annual rainfall of 2,080 mm (256 wet days) during the year was 12% above the annual average of 1,870 mm. The August monthly rainfall of 243 mm was the highest for the year, with a maximum daily rainfall of 57 mm on 1st January, while the highest 6 minute intensity of 9.5 mm fell on the 14th September and the highest hourly intensity of 43 mm on 30th September.

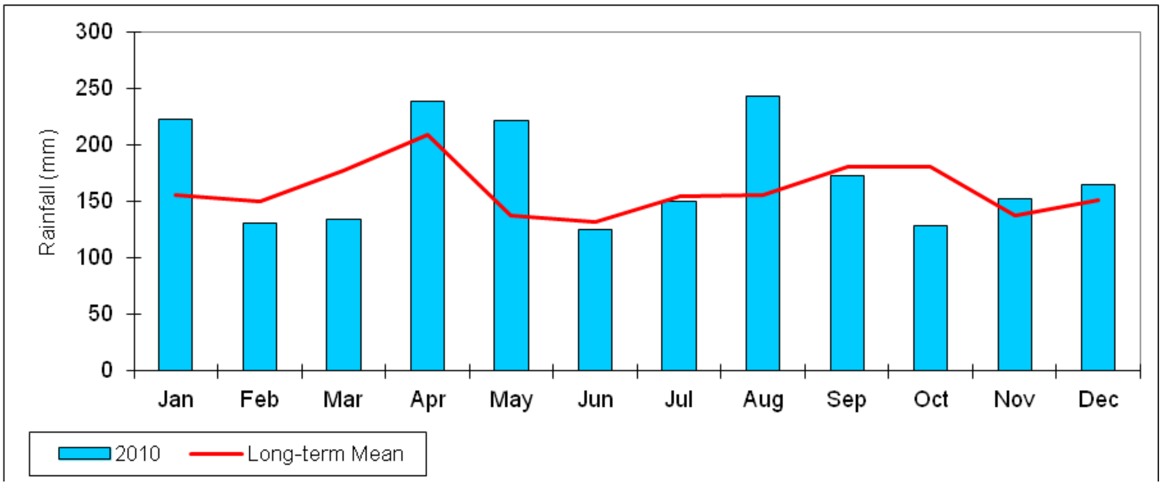


Figure 2-12 Rainfall at SG3 during 2010 against long-term monthly means

Strickland River at SG4 (Tomu)

Figure 2-13 shows annual rainfall during the year and the long term average since station establishment. Total rainfall recorded during the year at SG4 was 5,860 mm (323 wet days) compared to an annual average of 3,870 mm. The September rainfall of 945 mm was the highest monthly recorded for the year. The maximum daily recorded rainfall was 235 mm on 21st February. The hourly intensity of 80 mm on 8th September and 14mm in 6 minutes on 20th March were the highest.

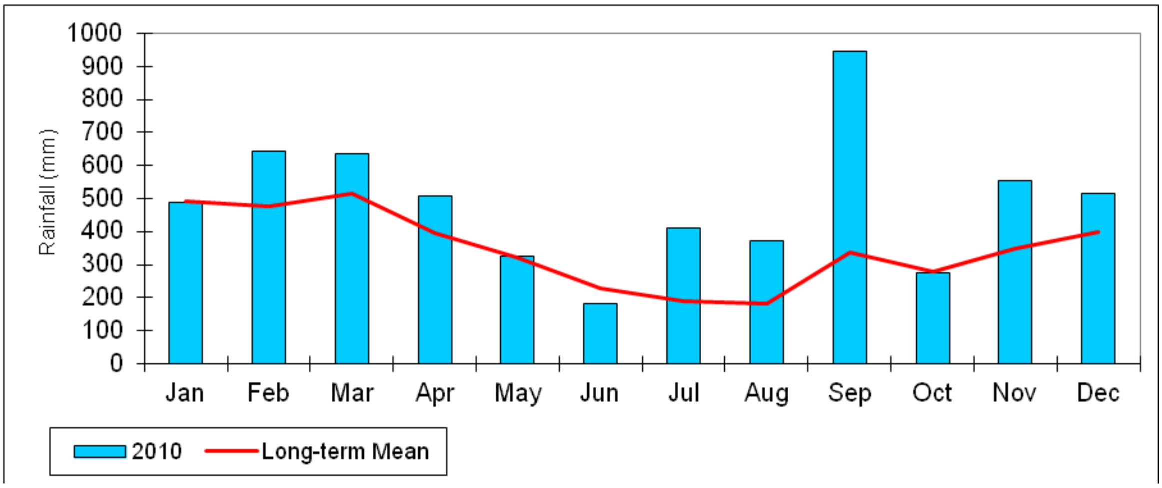


Figure 2-13 Rainfall at SG4 during 2010 against long-term monthly means

Strickland River at SG5 (d/s Lake Murray)

Figure 2-14 shows annual rainfall during the year for this station which was established in 2004. Total rainfall recorded during the year at SG5 was 3,135 mm (272 wet days) while the '6 year' annual mean is 2,205 mm. The March rainfall of 485mm was the highest for the year. The maximum daily rainfall was 110 mm on 24th March, as did a storm with an intensity of 67.5 mm in 1 hour. The highest recorded 6 minute intensity was 13.5 mm on 27th November.

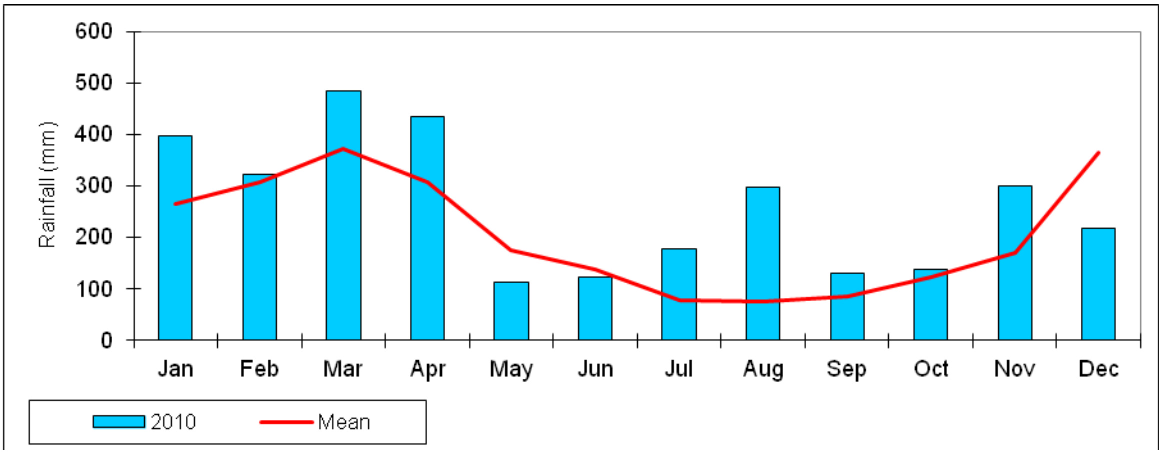


Figure 2-14 Rainfall at SG5 during 2010 against the long-term monthly mean

2.3.3 Summary of Stations in Strickland Catchment

Figure 2-15 shows annual rainfall at stations in the upper, middle and lower Strickland and demonstrates that rainfall at the middle catchment stations (SG2, Ok Om and SG3) is lower than both the upper and lower catchment stations. The main reason is that these riverine stations are located in the shelter of steep ridges creating rain shadow effects, as well as orographic uplift affecting the upper stations. Conversely, rainfall in the Strickland lowlands tends to be considerably higher than in the upper Lagaip catchment and is probably caused by the orographic barrier of the Muller Range and Mt. Bosavi.

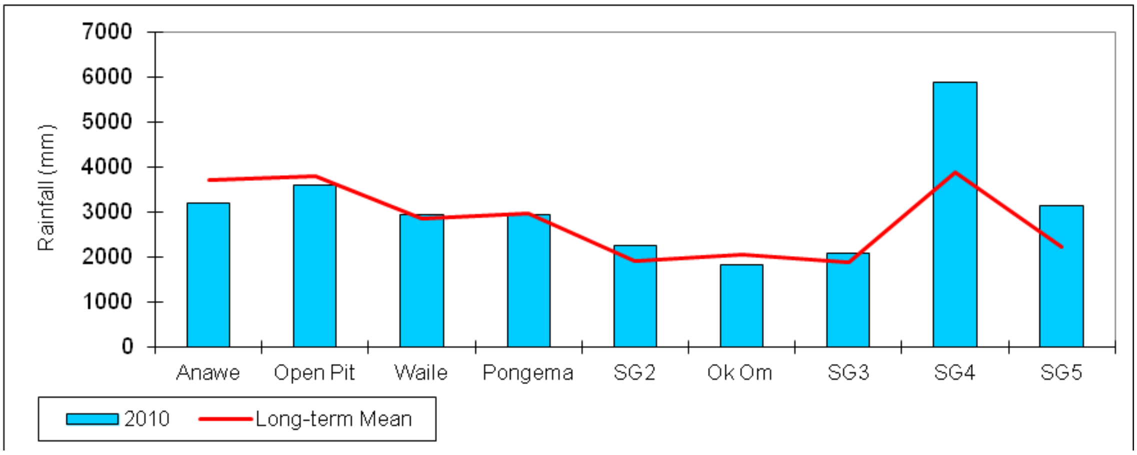


Figure 2-15 Comparison of long-term annual rainfall at sites in the Strickland catchment

2.3.4 River Flows

The river systems directly impacted by the mine are primarily the Porgera, Lagaip and Strickland rivers. These can broadly be grouped into 3 regions of interest, these being; upper catchment (Porgera valley), middle catchment (SG2 to SG3) and lower catchment (SG3 to lowlands/floodplain).

Continuous river flow data were collected at the key stations along the river system and, at local sites within and in the vicinity of the mine site during the year. In general, flows were below average in the upper and middle regions, which is commensurate with rainfall being near or below average. Whereas, flows on the lowlands are above average, as was the rainfall.

A summary of river flow data collected at the operational stations during the year is given in Table 2-4*,* while plots of the main stations are presented in Figures 2-16 to 2-20*.*

Table 2-4 Summary of mean daily flows for riverine stations during 2010

Station	Days lost	Max. Daily Mean (cumecs)	Min. Daily Mean (cumecs)	Daily Mean (cumecs)	Long-term Daily Mean
Kogai @ SAG Mill	18	3.3	0.25	0.93	1.18
Kogai @ Culvert	17	4.4	0.05	0.94	1.89
Portal @ Yunarilama	35	0.84	0.005	0.16	0.24
Pongema	4	23	1.6	6.6	5.7
Lagaip @ SG2	0	535	35	158	206
Ok Om	200	348	27	#	125
Strickland @ SG3	64	2755	165	568	740
Strickland @ SG4	107	8340	1115	2790	2510
Strickland @ SG5	0	4925	2325	3800	3275

 # - insufficient data

The Local Stations (upper catchment)

Monitoring of flow data at the 28 Level Adit and the Portal (Yunarilama Creek) are operational requirements for the pit and underground operations, while data from the Kogai stations are used for the Kogai stable waste dump water handling strategies and stability for closure scenarios. Pongema, as a main tributary of the Porgera River downstream of the Tailings outlet is monitored for its dilutory capacity and as a prospective hydro electric site. Mean daily flows during the year for the SAG Mill (Kogai Dump Toe) and Pongema sites of 81 ML and 570 ML respectively were below long-term averages.

Figure 2-16 over presents a comparison of flows at SAG Mill (upstream extraction point), Kogai Ck. (Alipis access road bridge) and Pongema for the year.

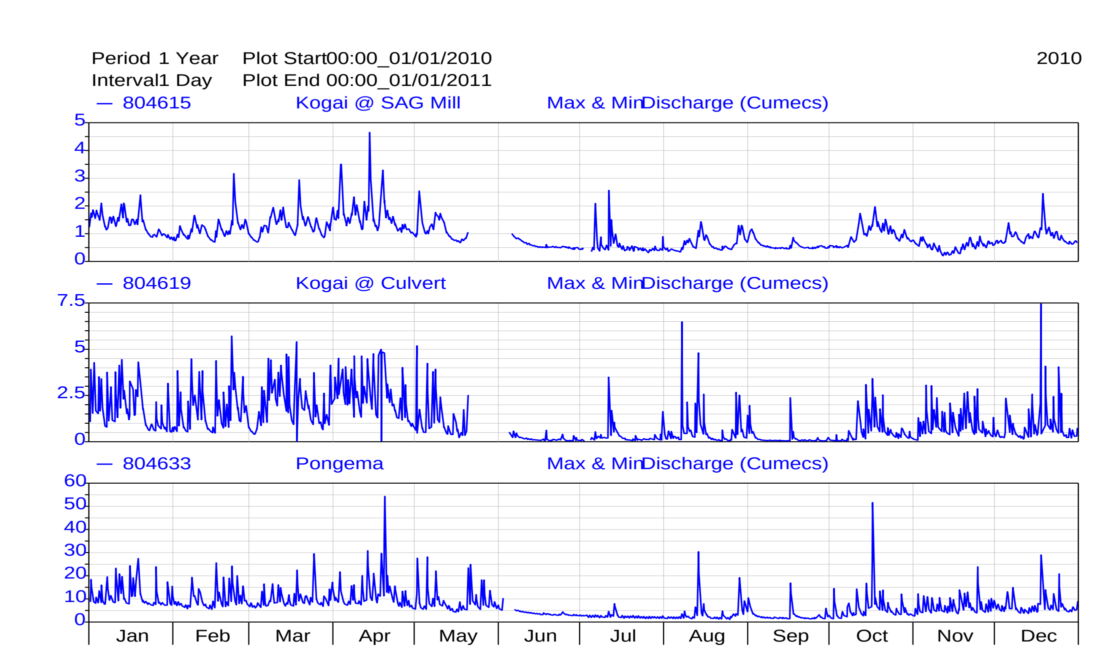


Figure 2-16 Instantaneous flows (daily) at SAG Mill, Culvert and Pongema for 2010

Key Downstream River Stations (middle catchment)

The combined flow of SG2 and Ok Om (28% and 17% respectively) contribute approximately 45% of the total flow at SG3. The remaining 55% is contributed by intermediate catchments, primarily the Pori and Tumbudu rivers. Figure 2-17 shows a comparison of the mean flows at SG2, Ok Om and SG3 during the year. At SG2, the mean daily flow was 158 cumecs compared to a long term mean of 206 cumecs, while at Ok Om (control site) mean daily flow was 103 cumecs compared to a mid term mean of 124 cumecs. At SG3, the mean daily flow for the year was 568 cumecs (49 GL per day) compared to a long-term value of 740 cumecs (60 GL per day).

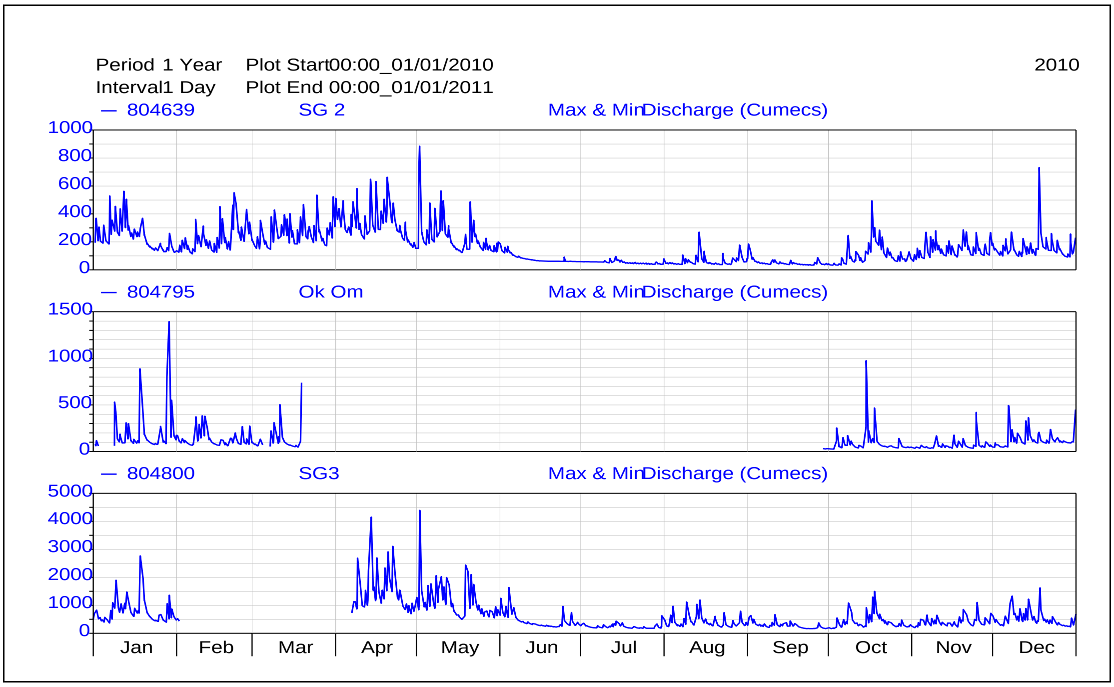


Figure 2-17 Instantaneous flows (daily) at SG2, Ok Om and SG3 for 2010

SG3 (compliance site)

The total flow for the year at SG3 of 18,600 GL (prorated for 64 days missing record) was approximately 20% below the long-term average of 21,950 GL. April with 2,940 GL had the highest recorded monthly flow while July with 633 GL had the least. Figure 2-18 shows the daily total flows for the year at SG3 while Figure 2-19 shows total monthly flows against long-term monthly averages.

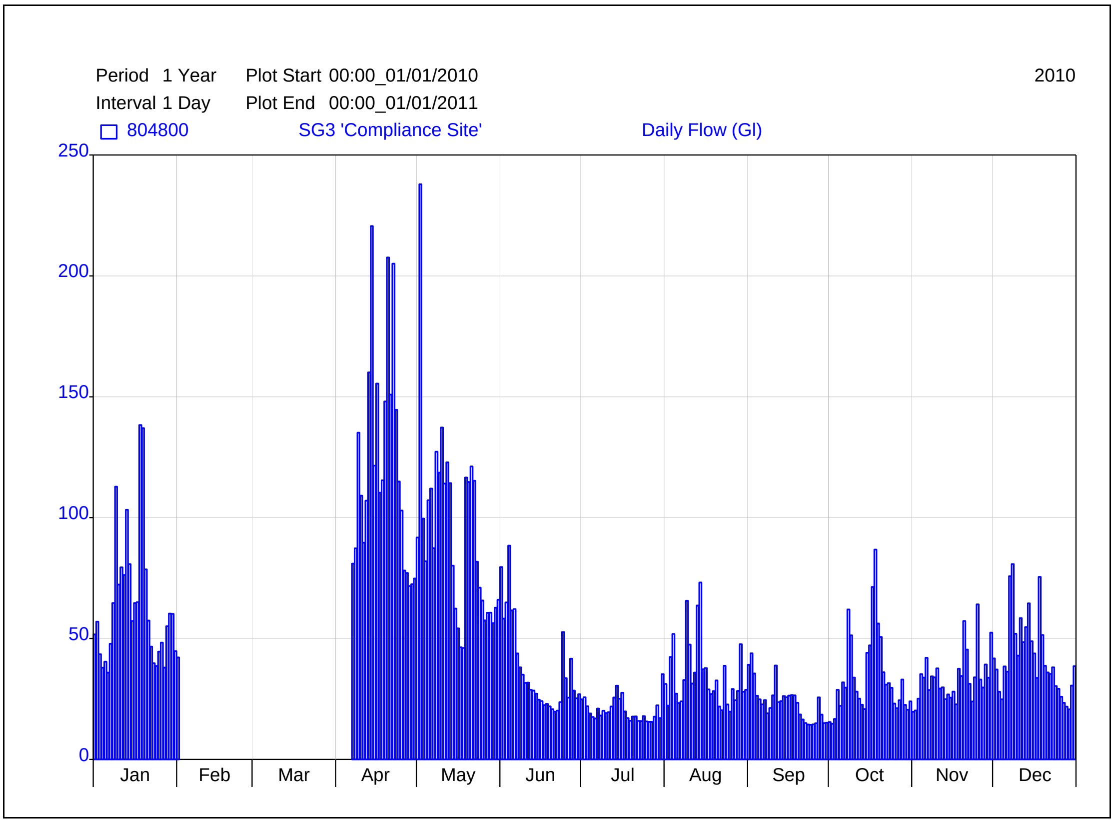


Figure 2-18 Daily total flows at the SG3 compliance site for 2010 (gigalitres)

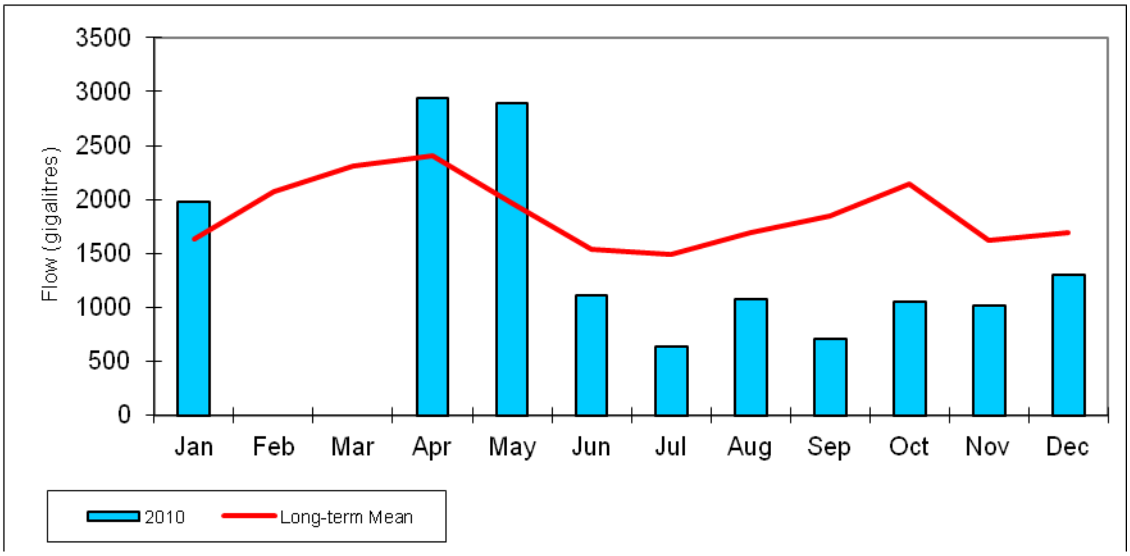


Figure 2-19 Flow at SG3 during 2010 against long term monthly means

Downstream River Stations (lower catchment)

SG4 and SG5 are monitored primarily for flow determination as applicable to the estimation of sediment and metals yields.

SG4 data show higher flow values and higher rainfall than stations in the upper and middle catchments, which is in accord with the PNG Flood Estimation Manual (Model) for the area. Specific yield (i.e. the runoff per unit area) for the catchment area contributing to SG4 is also higher than for all upstream gauging stations. In fact the catchment to the compliance point at SG3 only contributes approximately 25% of total flows passing SG4. Figure 2-20 shows the daily flow comparison between SG4 and SG3.

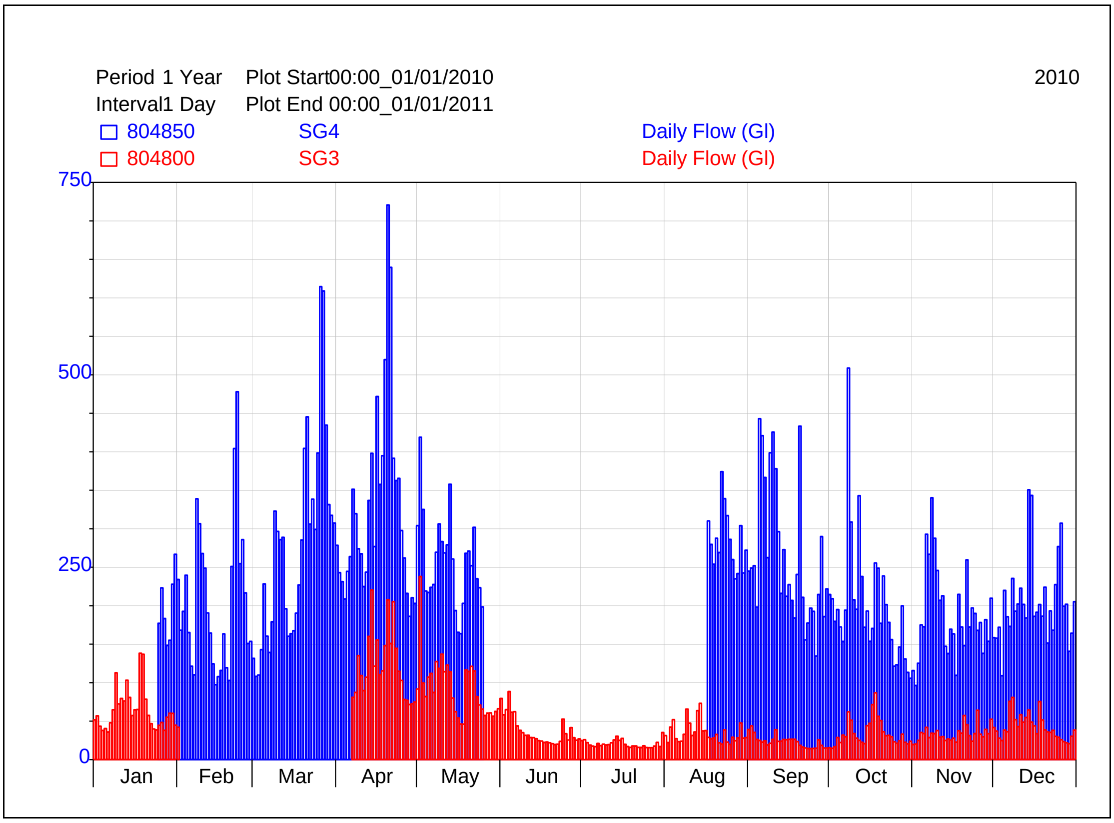


Figure 2-20 Daily flow comparison (gigalitres) between SG3 and SG4 for 2010

There is however, a relatively small increase in flow between SG4 and SG5. Primary reasons for this being minimal tributary inflow (Tomu, Aiema and Herbert Rivers) to the Strickland between the two gauging stations, and considerable floodplain storage that would tend to attenuate flood flows, plus occasional reverse flow into Lake Murray.

Data recovery and quality continue to be a problem at both sites, with bank instability and vandalism accounting for the majority of losses at these insolated locations.

The total flow for the year at SG5 was 120,000 GL with a mean daily flow of 328 GL. Too much data were lost at SG4 to allow the determination of accurate flow statistics.

2.3.5 River Profiling

A component of the monitoring program to assess the impacts of the mine on locations downstream of the erodible dumps, etc., is the surveying of profiles (cross section) that are obtained at designated locations to evaluate changes in stream bed levels. Unfortunately over the last few years, it has not been possible to undertake surveys at historical sites along the Porgera River due to civil unrest issues. Profiles were however undertaken at the new Kaiya River profiles and the lower riverine site of Profile10 on the Strickland River. Comparisons of these recent surveys with those from past surveys indicate no discernable aggradation (deposition) at this site.

The following figure illustrates changes at Profile 10 (approx. 40 km downstream from Tomu / Strickland confluence).

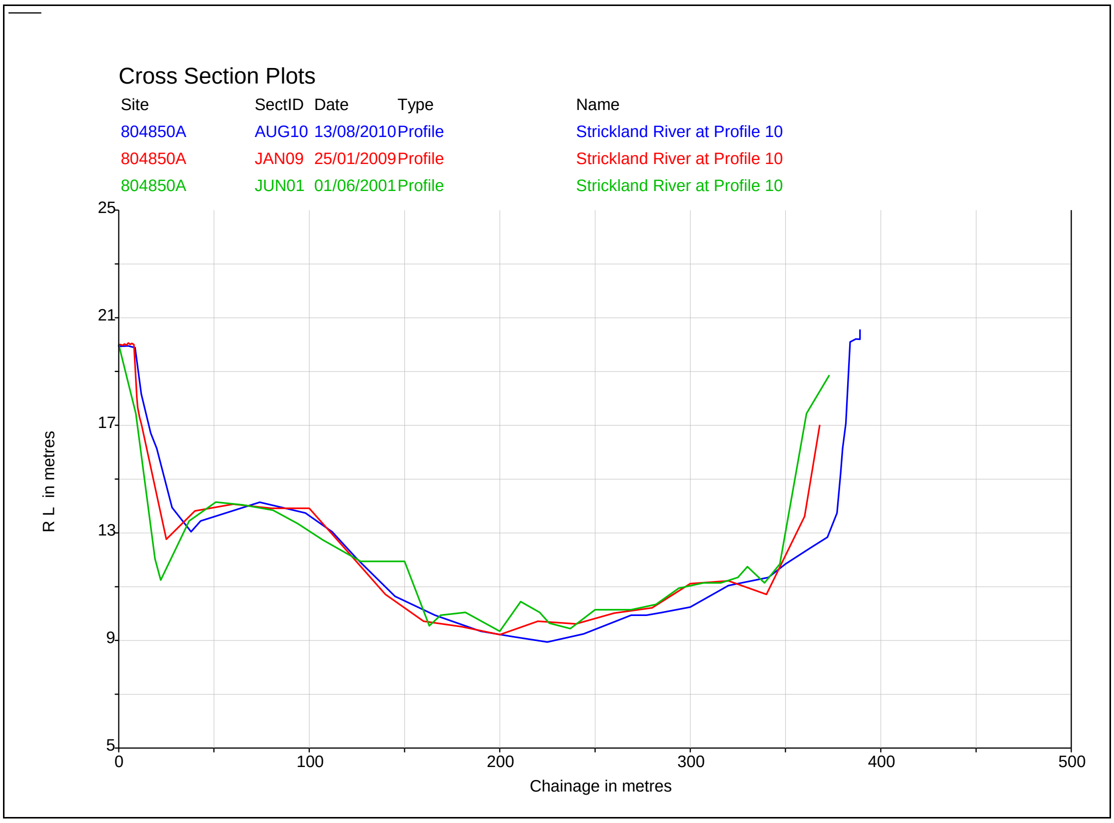


Figure 2-21 Profile comparison (2000–2009) at Profile 10

Following observed changes in the Kaiya River below the Anjolek erodible waste dump, 4 new profiles were established in 2009. Figures 2-22 to 2-24 below illustrate the current situation within the valley which will be compared to future surveys.

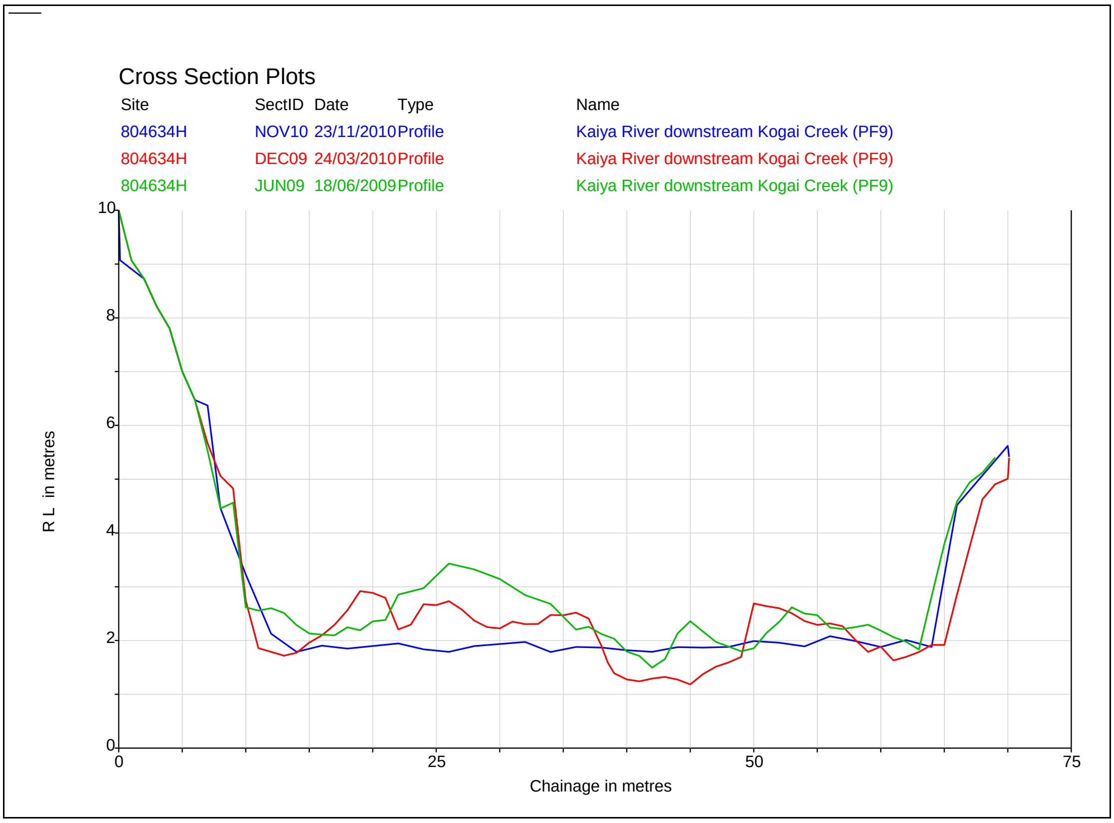


Figure 2-22 Profile comparisons for Kaiya River downstream of Kogai confluence

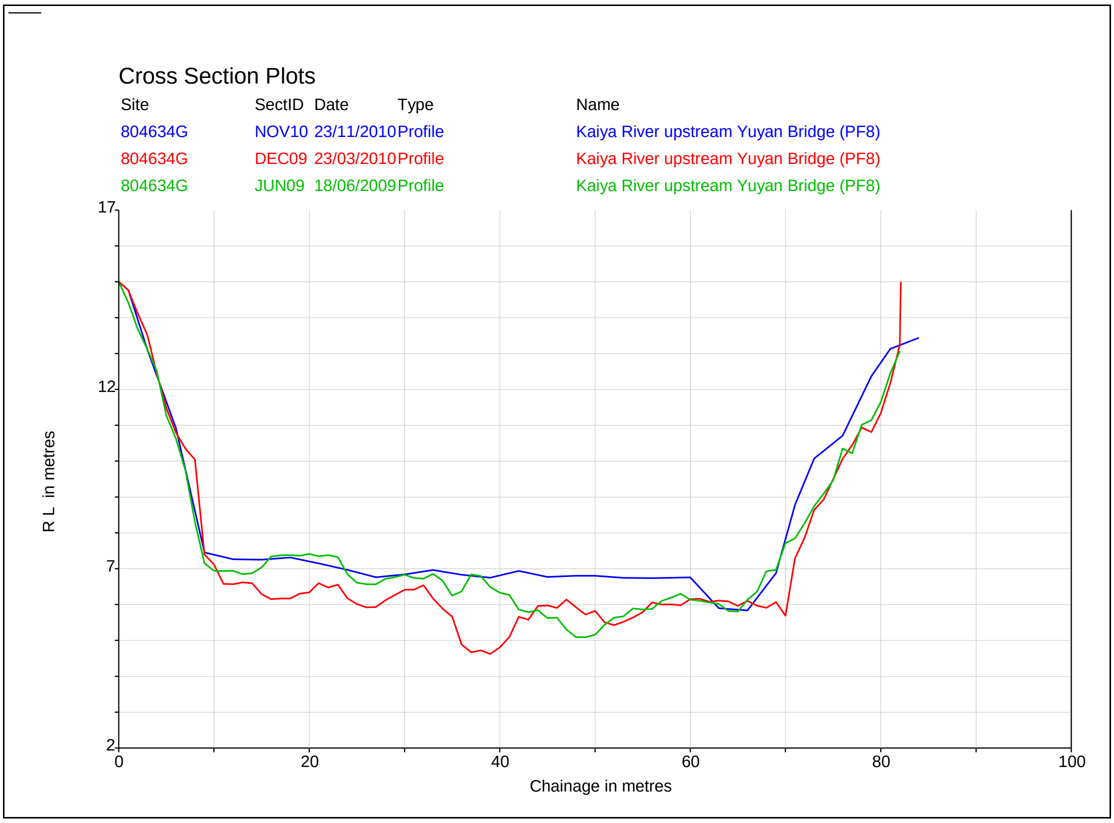


Figure 2-23 Profile comparisons for Kaiya River upstream of Yuyan Bridge

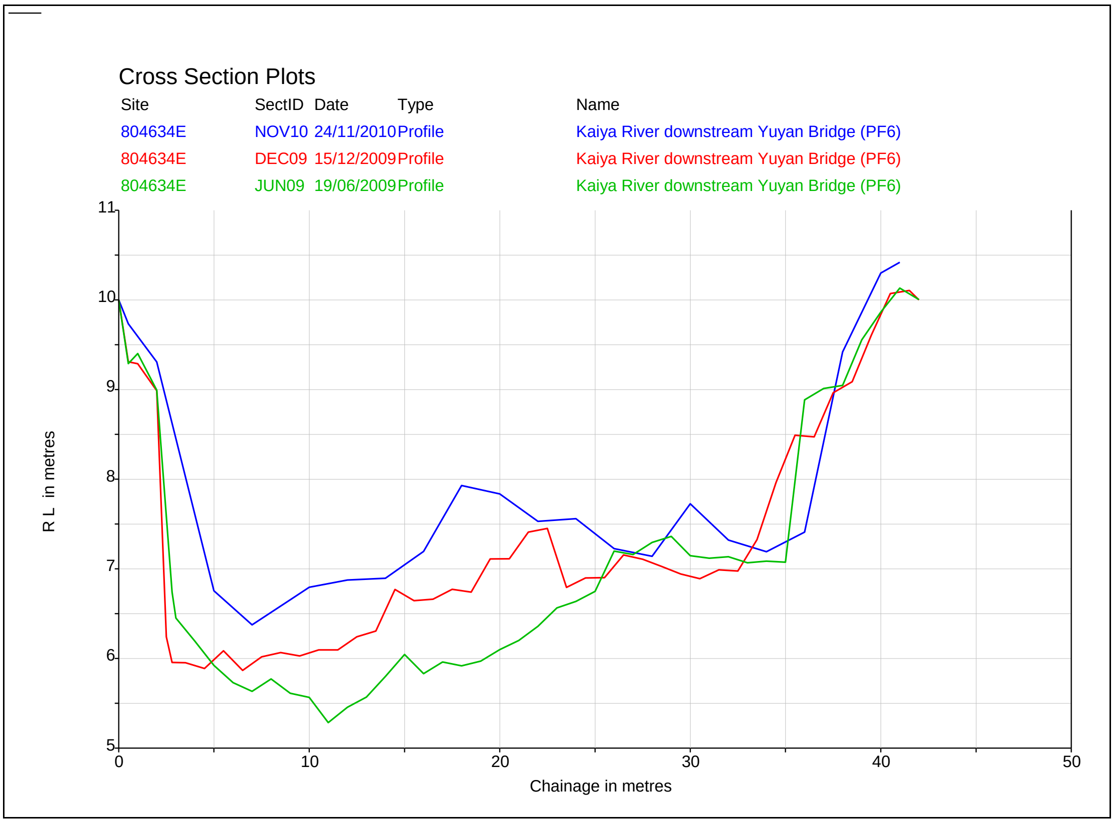


Figure 2-24 Profile comparisons for Kaiya River downstream of Yuyan Bridge

2.4 Sediment Transport Issues and Fate of Sediment

The the inputs, transport, storage and fate of mine-derived sediment in the river system have been assessed using routine monitoring of sediment processes and visual observations. Routine monitoring included total suspended solids (TSS) data collection and cross-section surveys at key locations along the river system.

Relatively few data pertaining to physical sedimentology were collected during the year, although monthly spot TSS data were collected by the Chemistry Section. However, (as previously discussed), four new profile cross sections were established in the Kaiya River for the purposes of monitoring aggradation due to sediment run-out from Anjolek Dump and valley wall erosion. In addition, an existing profile at PF10 (downstream from SG4) was re-surveyed adding valuable data to existing, long-term datasets.

Therefore, reporting for 2010 relied largely on historical trends and inferences from a limited dataset supported by visual observations. Data on the monthly dumping in the erodible dumps, which were compiled by the Mine Department, and the total tailings discharge for the year, are also presented.

The 2009 AER was the subject of a review by the CSIRO. The suggestions and constructive criticism emanating from that review were considered during the writing of this section of the 2010 AER.

2.4.1 Hydrological Context

As previously discussed in the Hydrology section, 2010 rainfall at Anawe and surrounds was lower than that recorded in recent years due to a mid-year dry spell. However, stations in the mid-catchment and lower catchment areas (i.e. SG2 to SG5) showed above average annual rainfall.

The rainfall pattern of recent years is also demonstrated in Figure 2-25 which shows a residual mass plot of annual rainfall at Anawe (the station with the longest period of record). The plotted lines represent the cumulative deviation of each year’s rainfall total 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.

Also plotted on Figure 2-26 is the Pacific Decadal Oscillation (PDO) index expressed as a residual mass in order to assess trends more clearly. The Pacific Decadal Oscillation is a pattern of Pacific climate variability that shifts phases on at least inter-decadal time scale, usually about 20 to 30 years. The PDO is detected as warm or cool surface waters in the Pacific Ocean, north of 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 (ENSO) episodes but operating over much longer timescales. Although ENSO events are strongly correlated to rainfall trends in parts of PNG, the Porgera rainfall also appears correlated with the PDO on a decadal scale although both indices are correlated well 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 variability (at least at Anawe) varies over both long and short-term timescales.

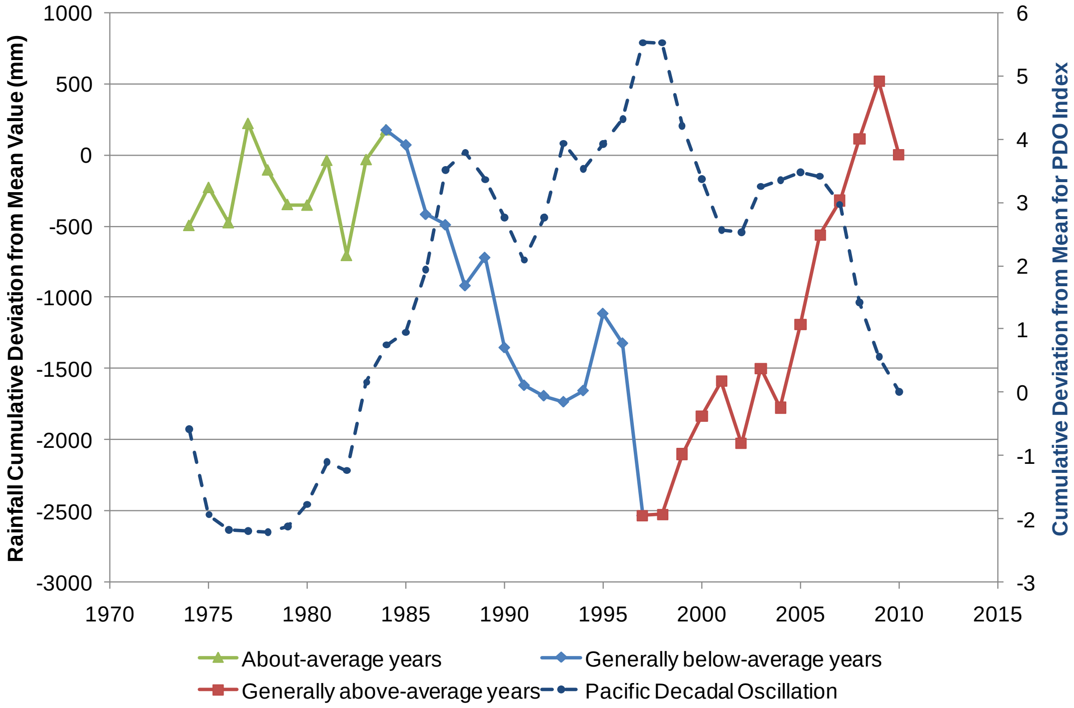


Figure 2-25 Residual mass plot of rainfall totals at Anawe rainfall Station

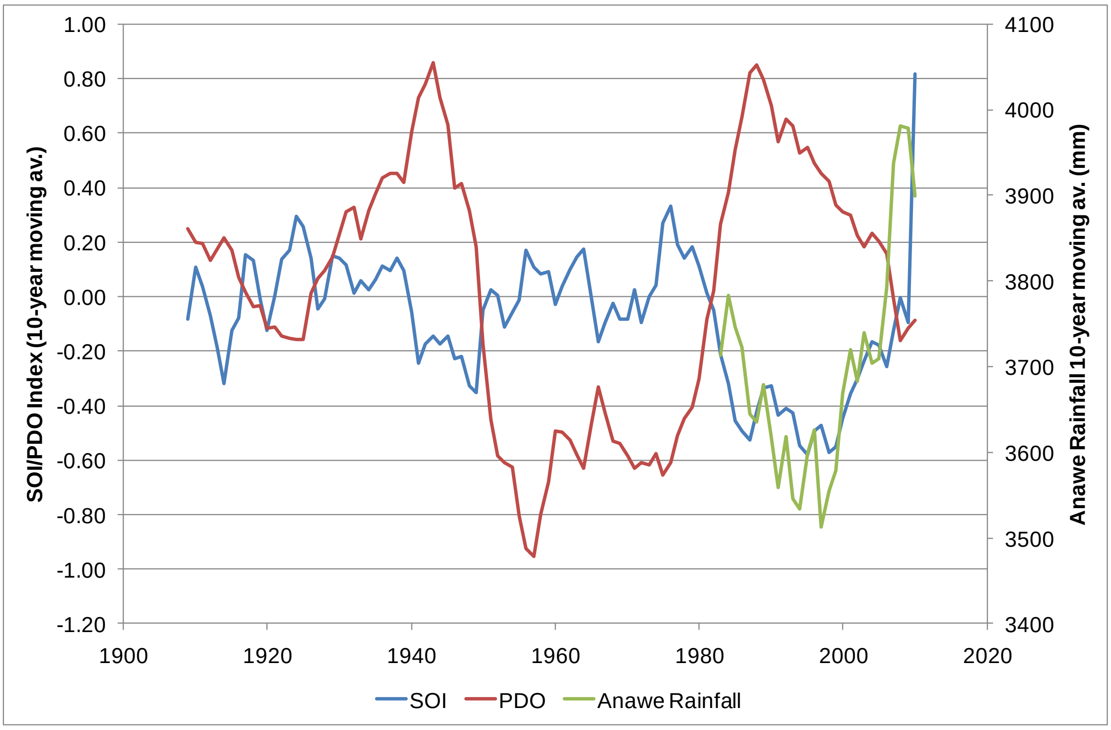


Figure 2-26 Anawe Rainfall, SOI and PDO indices on a 10-year moving average

The trend for recent years for flow discharge at key gauging stations is presented in Figure 2-27, which illustrates that flows were relatively low for the upstream stations and relatively high for the downstream stations (in the context of recorded historical data). Data from SG5 station are also presented on Figure 2-27 and show that the most significant downstream increase in discharge generally occurs between SG3 and SG4 (refer following section).

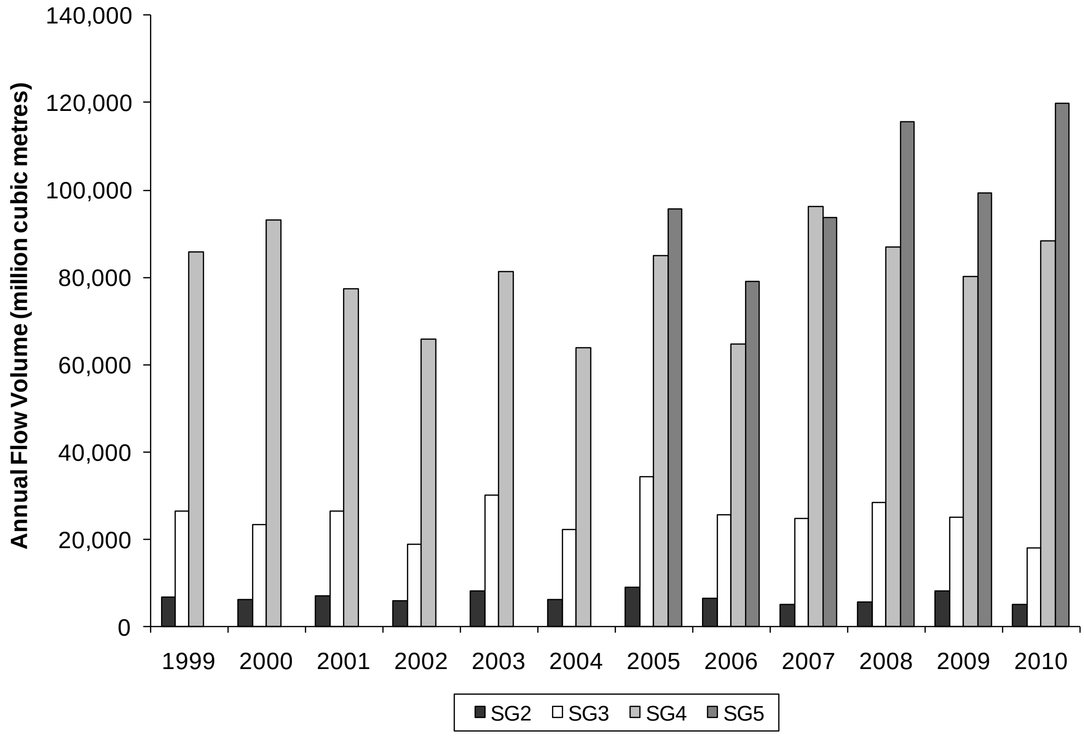


Figure 2-27 Comparison of annual flow volumes for main river gauging stations.

The mean annual (estimated) specific yield for the main river gauging station is presented in Figure 2-28. Specific yield is defined as runoff per unit area of contributing catchment. This is calculated separately for each gauging station so, for example, the specific yield for SG3 refers to the amount of water delivered to the river system from the catchment areas between SG2 and SG3, not the entire catchment area upstream from SG3. As described in previous Annual Reports, the specific yield for the contributing catchment between SG3 and SG4 is the highest recorded in the monitoring network. This means that more water per unit area is delivered to the river network between SG3 and SG4. This reflects high rainfall values in this area.

Historical data indicate that flow between SG4 and SG5 increases by a relatively small amount. Presumably this is partly due to the fact that there is minimal additional inflow to the Strickland between the two gauging stations, apart from the Tomu River which is relatively small compared to the mainstream flow. However, there are considerable floodplain storage and transfer processes between SG4 and SG5 which would affect the annual water balance between SG4 and SG5 to a large degree.

In terms of sediment transport processes, Figures 2-27 and 2-28 infer that there is a notable increase in the capacity of the river to transport sediment between SG2 and SG4 and, given that there has been no observed aggradation of the river bed downstream of SG1, then aggradation between SG1 and SG4 appears unlikely (although it is possible that the characteristics of the bed material size may be changing due to mine inputs). However, downstream of SG4 where discharge increases only by a small amount and the slope of the river flattens, deposition of sands and silts may be more likely.

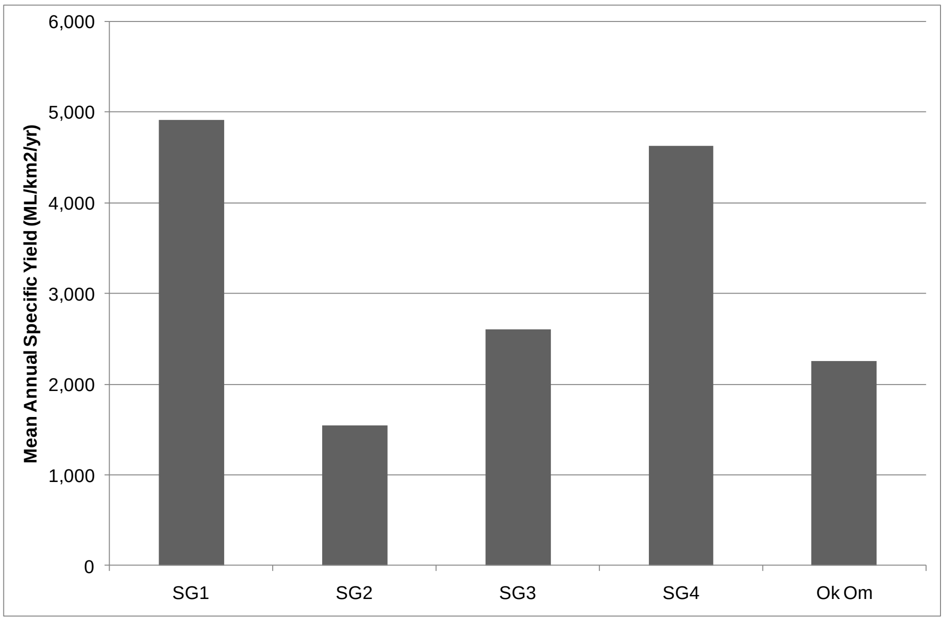


Figure 2-28. Mean annual specific yield for the main river gauging stations

2.4.2 Sources of Sediment (Inputs)

As discussed in previous Annual Reports, sediment in the Porgera-Lagaip and Strickland Rivers system is either natural or mine-derived. Natural sediment enters the river through landslides, rock avalanches and other mass failures from the steep terrain, and bank erosion, while mine-derived sediment enters the river system via the tailings and the erodible waste dumps. While input of mine derived sediments can be estimated from the known tailings discharge rate and an annual mass balance of the erodible waste dumps, input from natural sources is likely highly variable in terms of size characteristic, quantity and timing and can only be crudely estimated with available data.

The Porgera area is characterised by high rainfall rates, high rates of tectonic uplift, and high rates of weathering due to rock and soil types. The majority of sediment is likely delivered to the river systems from mass movements (landslides and the like) rather than by stream bank erosion or by fluvial processes. Saturated colluvium from such mass failures accumulates in channels where it remains mobile, initially moving as earth and mud flows. Ultimately, this material is entrained and transported downstream as sediment load (Davies *et al.* 2002).

Waste Rock and Tailings Inputs

A proportion of the mine's waste rock (nominally the incompetent or erodible fraction) is discharged to the Anawe and Anjolek erodible waste dumps (EWDs). Tailings are also discharged directly to the head of Anawe where they flow over the upper tract of the dump, the combine with natural flows along the southern flank. There have been a number of technical reviews of the EWDs over the last decade. Historically, key concerns with dump performance have been associated with uncertainty and disagreement over key geomechanical processes based on the perceived lack of analogies or case history. As time has passed, the opportunity to forecast future dump behaviour based on observed historical behaviour has obviously increased meaning that there is now less reliance on numerical or conceptual models, but more reliance on past observations and measurements. The remainder of this section provides a brief overview of the EWDs' histories based largely on the work of Davies *et al.* (2002) and Davies and Markham (2005).

The Anawe erodible dump is situated in a valley that slopes at approximately 8°. Local slopes around the dump head are as great as 25º. Between 1989 and 1991, just over 20 Mt of weathered mudstone was placed into the Anawe Valley just above Maiapam Creek. A combination of minor fluvial transport and mass movement of valley colluvium and the dumped material created a slow moving material transport system. This original dumping of material created few apparent issues at the time. There were no rapid movements and no downstream physical impacts of note. In 1992, when the Open Pit was starting to develop, a trial placement of incompetent stripping from rim development into Anjolek Creek, was carried out. Several hundred thousand tonnes of material were placed during the trial period and it was found that, while some material certainly did erode, much of the material simply flowed slowly as a mass movement not unlike the colluvial landslide movements throughout the region.

From 1992 to the end of 1996, the Anawe dump was primarily used for colluvium disposal stripped for the preparation of the Kogai stable dump foundations and other infrastructure and mine developments. In January 1997, the valley was re-opened as an erodible dump for waste rock that included black sediments, brown mudstone, colluvium, and oxidized pit rim material. The Anawe erodible dump has also been the riverine disposal site for mine tailings since mine start up.

The Anjolek dump is situated in the Anjolek and Mungarenk Valleys. As with Anawe, the original foundations comprised very thick deposits of clay colluvium overlying mudstone. Landslides also characterized the morphology in this area, including the Mungarenk Landslide Complex. The Mungarenk Valley was originally assessed as the preferred location for a stable waste dump in the 1980s, but was evaluated as an erodible dump in 1992 based on the performance of Anawe during mine construction. Placement of mine waste in Anjolek Creek commenced in August 1992. Use of the Mungarenk landslide area commenced in 1993.

While dumping rates to both dumps has been variable over the years, the cessation of dumping at Anjolek in 2003 for one year allowed for an insight into how the dump may behave post-closure.

2010 Data

Dumping occurred to both erodible dumps during the reporting period. From the Mine Dept haul truck dispatch tonnages, the total for Anjolek was 2,659,545 tonnes (well below the long term median annual value) while Anawe received 14,189,275 tonnes, well above the long term annual median.

Total tailing discharged to the Anawe Dump for 2009 was 5,200,752 tonnes dry solids, equivalent to a mean daily value of approximately 14,249 tonnes. This was similar to the 2009 figure but above the long term median value. Overall the combined amount of waste rock and tailings discharge to the river system was 22,049,572 tonnes, just below the long-term annual median value of 23,864,019 tonnes. Summaries of waste discharges are shown in Table 2-5, and in Figures 2-29 to 2-31.

Table 2-5 Summary of mine inputs to the river system during 2009

	Total for 2010 (tonnes)	Total To Date (tonnes)
Anawe	14,189,275	209,931,785
Anjolek	2,659,545	224,303,468
Tailings	5,200,752	89,801,802

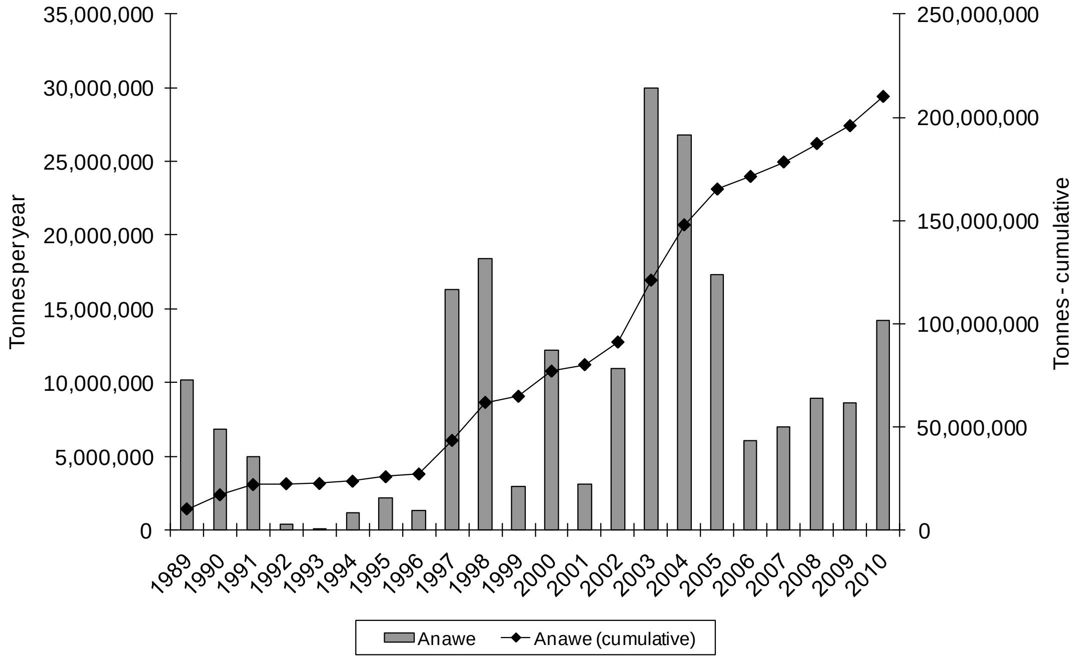


Figure 2-29 Yearly spoil placed at Anawe since July 1989 (values in tonnes)

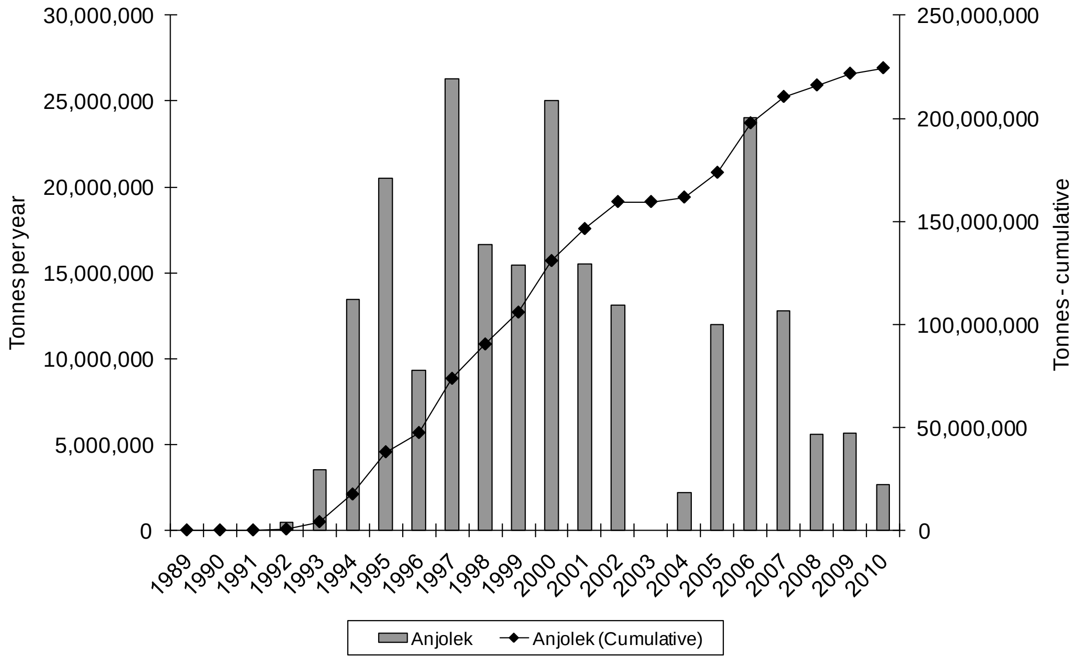


Figure 2-30 Yearly spoil placed at Anjolek since July 1992 (values in tonnes)

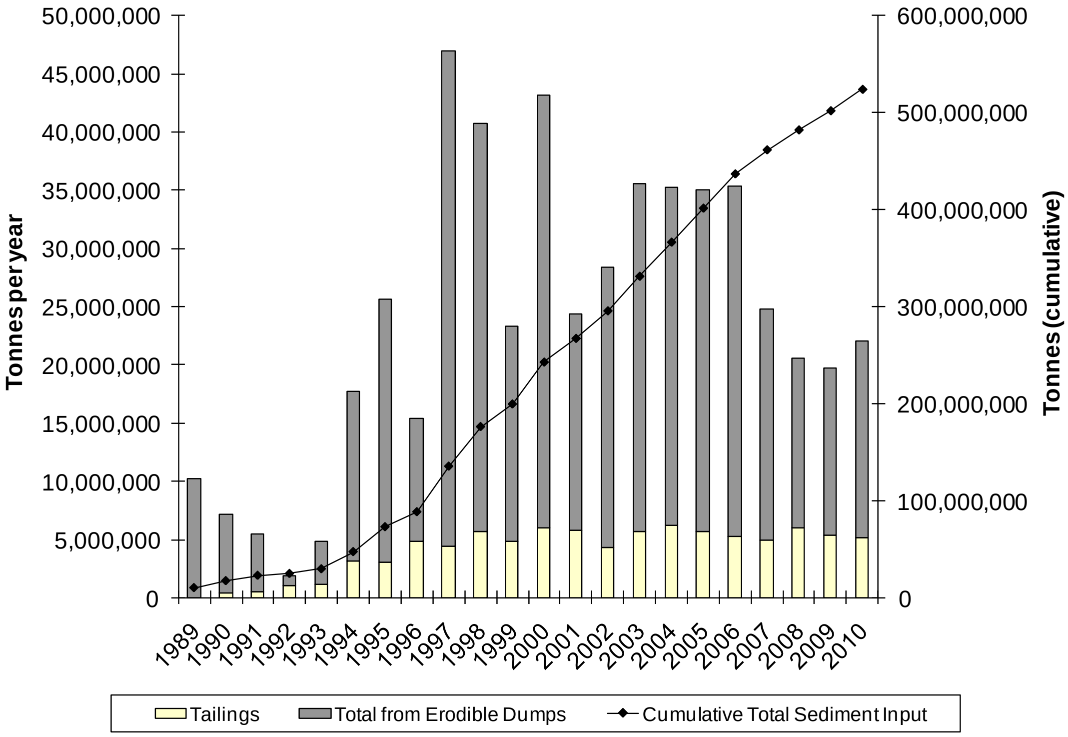


Figure 2-31 Total and cumulative (tailings and rock waste) sediment inputs to date

The material placed at Anawe during the reporting period represents the fifth highest annual total since 1989 while the Anjolek total was the fourth lowest since 1992. The combined waste rock total for both dumps was the 10th highest in 22 years.

The continued trend of low dump rates at Anjolek (compared to historical values) suggested that little significant change to the dump morphology might have been expected although widening at the toe area and ongoing sediment runout is occurring in the toe area and Kogai River (discussed in later sections). Increased dumping at Anawe suggested a greater level of morphological change may occur during 2011 (also discussed later). Historical survey data suggest that the dump (particularly the lower tract) is thought to respond more rapidly to upstream loading than Anawe.

The relation between rainfall and dump erosion is complex is not understood with any certainty other than to say that obviously erosion and sediment discharge is likely to be higher in wetter years although the sensitivity of erosion variability to rainfall variability, and the effect of numerous other complicating factors are unknown. The degree saturation of the dumps also affects their rheology, morphology and movement, and processes of erosion. However, based on the assumption that the removal of material from the dumps is largely controlled by the sediment transport capacity of the flanking stream networks, then the rate of sediment discharged downstream from the dumps is thought be relatively consistent from year to year. Unfortunately, due to the difficulties of monitoring flows and sediment loads downstream of the toes (due to both logistic and landowner reasons), there are little recent data available to support this hypothesis.

Figure 2-32 presents a comparison of the rainfall at Anawe and the amount of waste placed in the erodible dumps.

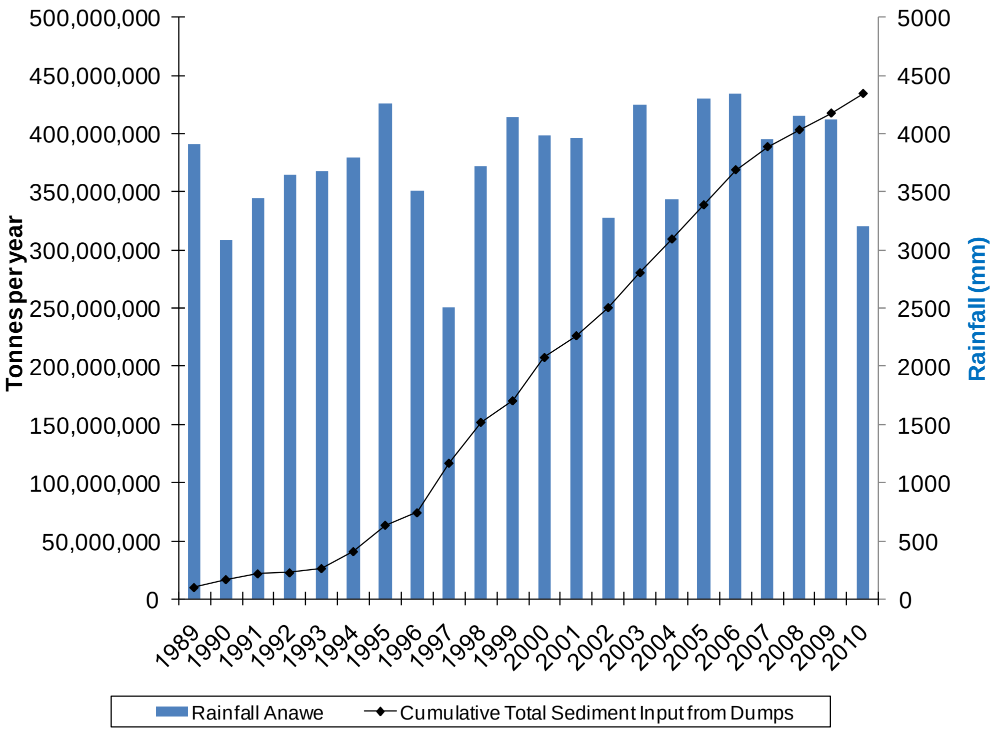


Figure 2-32 Comparison of rainfall totals and erodible dump placement rates

2.4.3 Status of the Erodible Dumps

An aerial inspection of the Anawe dump in February 2011 did not reveal significant morphological change despite the large amount of material dumped in 2010. Some build-up of material near the tiphead was reported by Environment staff and was confirmed during the aerial survey. The upper part of the dump tract appeared more mobile with dumped material flowing over the existing surface to a point approximately adjacent to the confluence with the Pongema River. At about the Pongema Confluence, the slope of the dump changes and processes of uplifting and thrusting occur. Downstream from that, the lower tract of the dump (between the Pongema River and the toe) was well vegetated and appeared stable (refer Plate 2-1). Further elevated levels of dumping in 2011 may see the runout extend of the lower tract of the dump, and potentially flow laterally towards the flanks. Assessment work undertaken during the Stage 6 Feasibility Study indicated (based on historic observations alone) that consistent dumping rates in excess of 1Mt/month or thereabouts could result in unpredictable and undesirable dump behavour (for both dumps). Overspill to the lower Pongema River is a possibility under sustained elevated dumping rates.

There was no notable change to the rate of morphological processes along the southern flank of the dump. Overspill to Maiapam Creek was still occurring and erosion of the toe of the Maiapam slide mass by combined tailings and Maiapam flows was observed. Erosion of the colluvial slopes of the Paiam slide mass was not considered significant and appeared similar to last year. The toe of the dump was in a similar position to that observed last year and, if anything, some erosion may have occurred (refer Plate 2-2).

Plate 2-1 Runout from Anawe Tiphead (arrow denotes extent)

Plate 2-2 Location of toe of Anawe Dump

At Anjolek, more significant morphological changes continued to occur despite the relatively low amount of waste dumped during 2010. The upper tract of the dump appeared to have eroded downwards somewhat while there was no evidence of overspill at the Aiyoko Saddle that has been a cause for concern for several years.

Erosion along the northern flank of the dump between the Kaiya River fan and the toe was ongoing with a major failure scar evident at Lepalama. Build up of material was evident in the lower part of the dump tract. The toe area has continued to widen and the toe itself had moved approximately 100 m downstream (Plate 2-3).

Over the past few years the transition between the dump toe and the Kaiya River has become less marked, with the toe flattening, widening and extending into the Kaiya River.

Plate 2-3 Changes to the toe of Anjolek Dump 2009 to 2010.

Long profiles of the dumps based on historical survey data are presented in Figures 2-33 and 2-34.

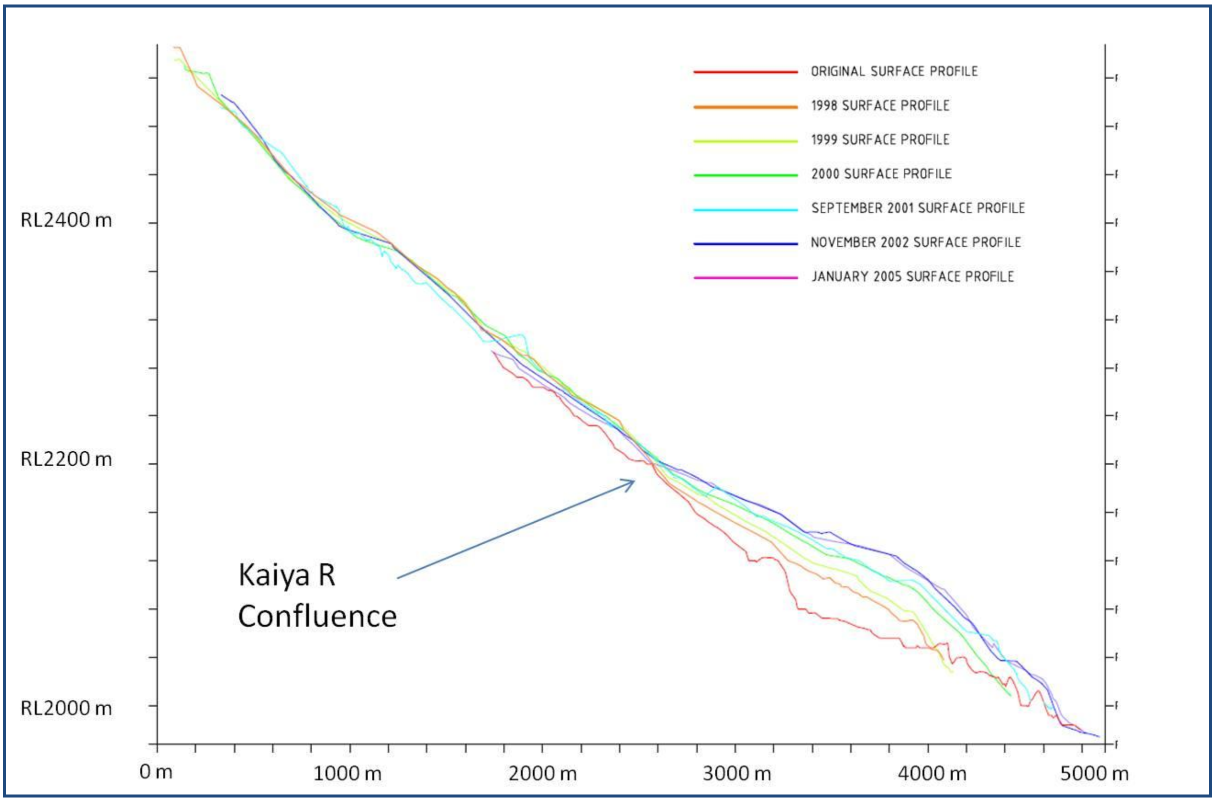


Figure 2-33 Long profiles of Anjolek Dump

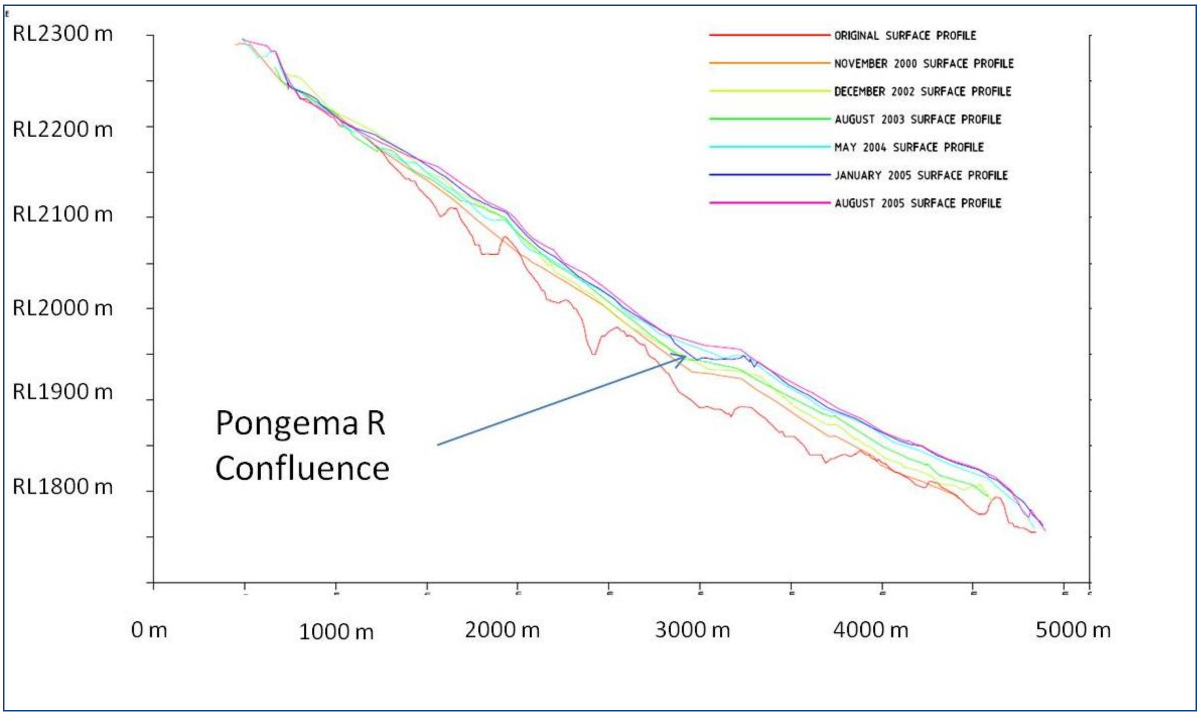


Figure 2-34 Long profiles of Anawe Dump

2.4.4 River Bed Aggradation

Once sediment is exported from the toes of the dumps, it is transported downstream by the flow. Coarser particles may settle out on the bed, on bars or on the floodplain from time to time along the river valley.

Changes in riverbed level due to sediment deposition are monitored through cross section profiles, which are located along the Kaiya, Pongema and Porgera Rivers and at the main gauging stations. The cross sections along the Kaiya River and Porgera River are particularly important as these are potential sediment 'runout' zones from the dump toes and significant changes to river morphology may be expected if dump movements occur. In the lower river, a single cross section (PF10) is located 60 km downstream from SG4.

Unfortunately, the more extensive historic network of cross sections between the Mine and the Lagaip River has been significantly reduced over the years due largely to inadequate maintenance, land access issues and loss of critical benchmarks due to bank collapse or river aggradation. At the time of writing, profiles in the Porgera River are not being undertaken due to land access issues. However, as previously discussed, four new cross sections were established in 2009 along the Kaiya River, and a survey at PF10 (Strickland River downstream of the Tomu River) was completed.

Kaiya River between Anjolek Toe and Porgera River

This reach of the Kaiya River has been subject to variable but persistent aggradation and valley widening. Since 2007, the rapid changes to the toe of Anjolek Dump (described above) have resulted increased rates of sediment delivery, aggradation and widening in the downstream reaches of the Kaiya River. Figure 2-35 shows that aggradation has occurred at all four new cross section locations.

Although cross-section plots (refer section 2.3.5) show high variability in the morphology of the river bed, the minimum RL of the bed at all four sections has increased since 2009 although between 2009 and early 2010 there appeared to be temporary degradation near Kogai Junction and at Yuyan Bridge which agrees well with the interpretation of visual observations made in the 2009 AER. However, since early 2010, aggradation has clearly occurred. This adds weight to the hypothesis that sediment moves along the reach in pulses and, while some erosion occurs from time to time (a process known as 'cut-and-fill') there is, overall, net aggradation along the reach of the Kaiya River between the toe of Anjolek and the Pongema River.

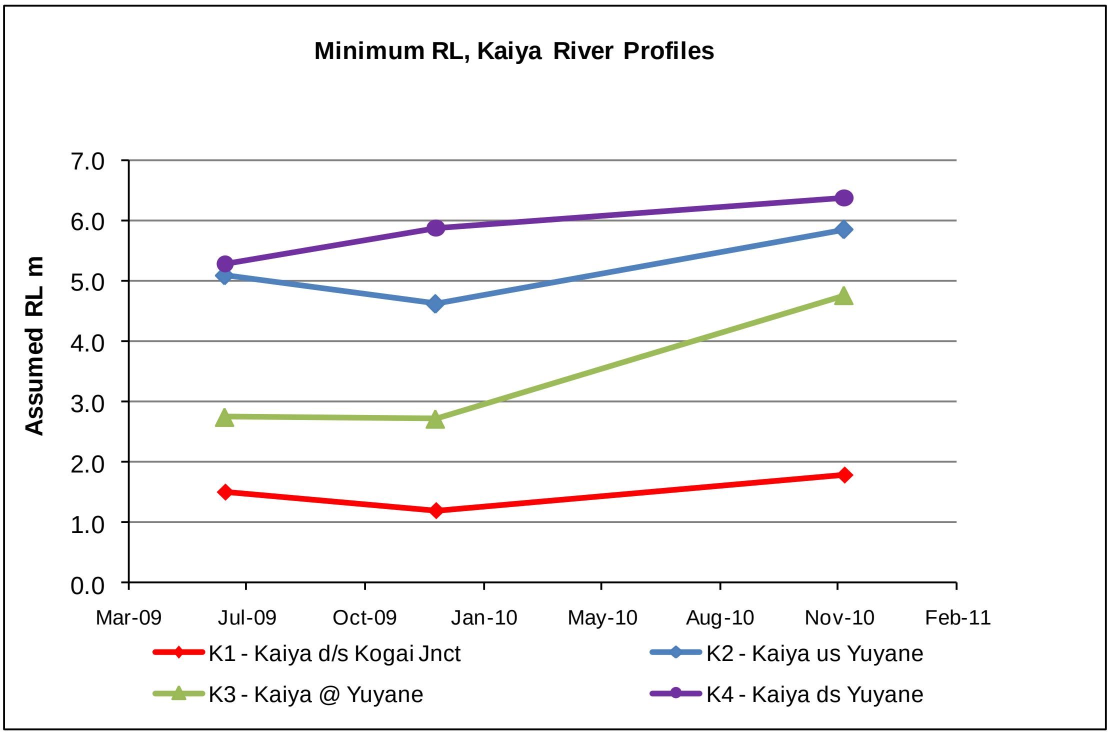


Figure 2-35 Aggradation along the Kaiya River

Plate 2-4 shows comparative aerial photographs of the junction of the Kogai River and Kaiya River taken in 2009 and 2010 respectively. This site was chosen as a representative site along the Kaiya River between the toe of Anjolek and the Pongema River confluence due to the long history of photographs at that location. Data from section K1 (Figures 2-22 and 2-35) show a highly variable cross section form which changes with time as the flow path shifts across the valley floor but data suggest that there has been about 0.5m of aggradation here since late 2009.

Plate 2-4 Confluence of the Kogai and Kaiya Rivers.

Significant and accelerated widening and aggradation has occurred at Yuyan Bridge since 1997 as runout from the toe of Anjolek dump has migrated along the Kaiya River (e.g. Plate 2-5). Although no surveys were conducted at this location up to 2009, the rate of aggradation was estimated by eye by reference to the dimensions of the Bailey Bridge deck panels, which are approximately 1.6 m deep, and by assuming that the average bed level of the channel is 0.5 m below the water surface. In late 2008, the bridge was raised by an unknown amount and the reference was lost.

In June 2009 a cross section was established at Yuyan Bridge and results of the surveys are shown in Figures 2-23 and 2-35. The results of the survey were combined with the visual observations of bed level change (using professional judgement to establish a join between the datasets) with the result presented in Figure 2-36.

Plate 2-5 Bed aggradation at Yuyan Bridge, Kaiya River.

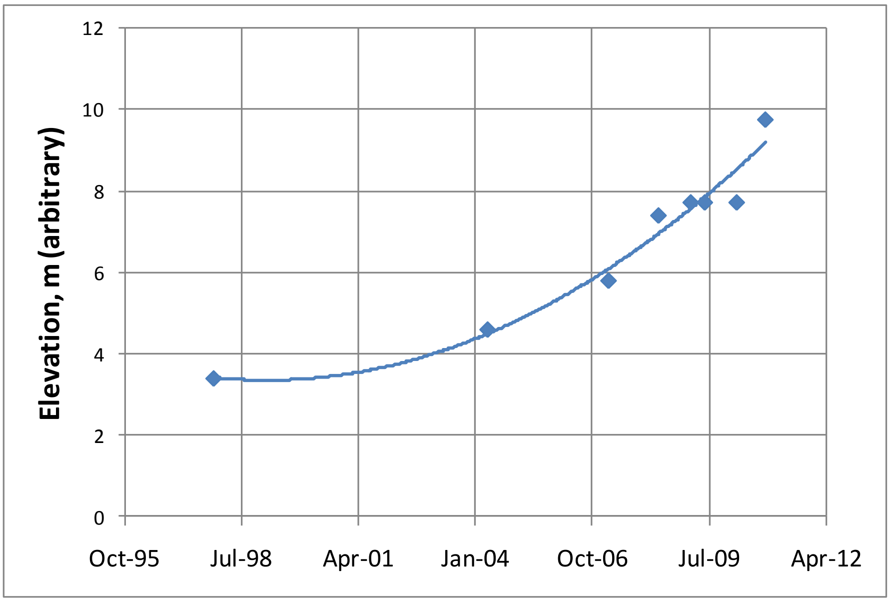


Figure 2-36 Estimated rate of bed build-up at Yuyan Bridge using historic photographs and recent survey data

Further downstream, the confluence of the Kaiya River and Pongema River has also changed quite significantly in recent years due to runout from the dumps, leading to cross sections PF4 and PF5 becoming inundated with sediment. Despite the lack of data and the high variability of the bed morphology, the best estimate is that at least 3-5 m of aggradation has occurred in this area. Figure 2-35 suggests that approximately 1 m of aggradation has occurred in the Lower Kaiya River since June 2009.

Pongema River between Anawe Toe and Porgera River

There were no significant changes noted along this reach compared with the results of the 2010 helicopter inspection.

SG1 to SG2

There were no significant changes noted along the upper Porgera River compared with the results of the 2010 helicopter inspection. Historic daily mean gauge data showed that the bed of the Porgera River at SG1 increased by approximately 2 m following initial dumping, and then a notable increase and decrease between 1998 and 1999 following a period of high dumping (Figure 2-37).

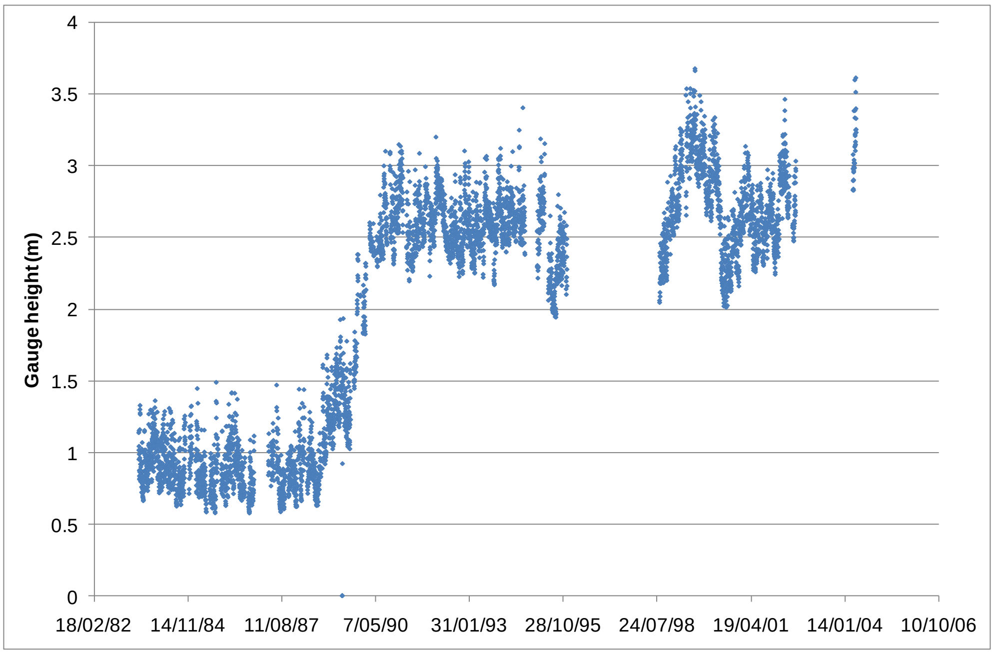


Figure 2-37 Estimated rate of historic bed level change at SG1 based on mean daily water level.

SG2 to SG4

No cross sections were measured at SG2 during 2010. However time-series profile data supported by specific gauge data (i.e. rating curve shifts) indicated a notable downcutting of the bed (about 1.5m since late 1980s). The reason for this downcutting is not known, but it is presumed that the river is incising (or rejuvenating) towards an equilibrium profile, possibly in response to localized uplift. Although no surveys were undertaken in the Porgera River during 2010, historic data showed a similar trend at profile PF6 (Porgera River near the Tilia River Junction) but not at PF3 (located between SG2 and PF6). Overall these results continue to suggest that no net build-up of mine-derived sediment is occurring in the lower Porgera River and the upper Lagaip River. A time-series of the minimum bed elevation for each survey for SG2 and the specific gauge plot (rating curve shift) is shown in Figure 2-38 and 2-39.

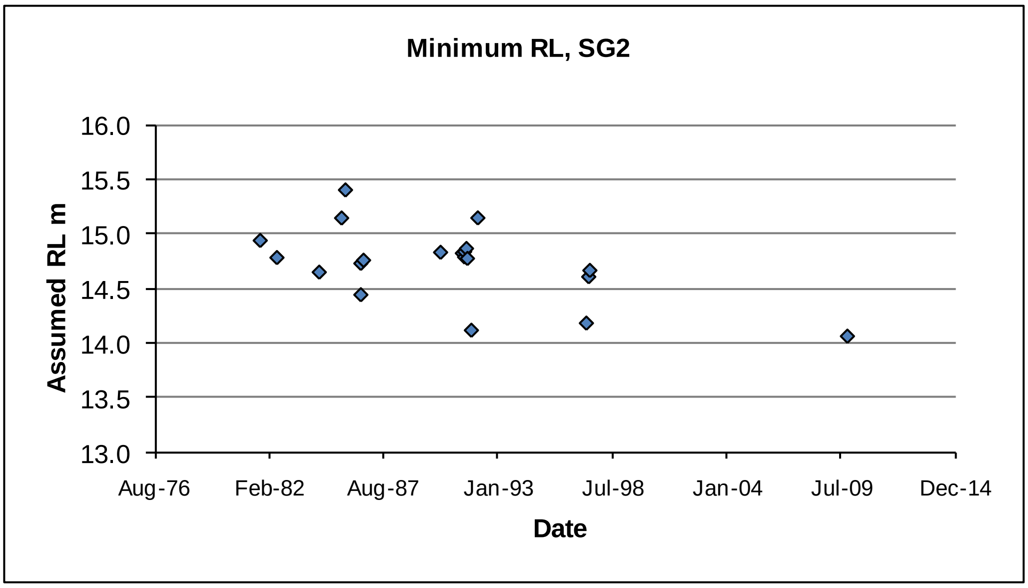


Figure 2-38 Time series of minimum measured bed elevation at SG2

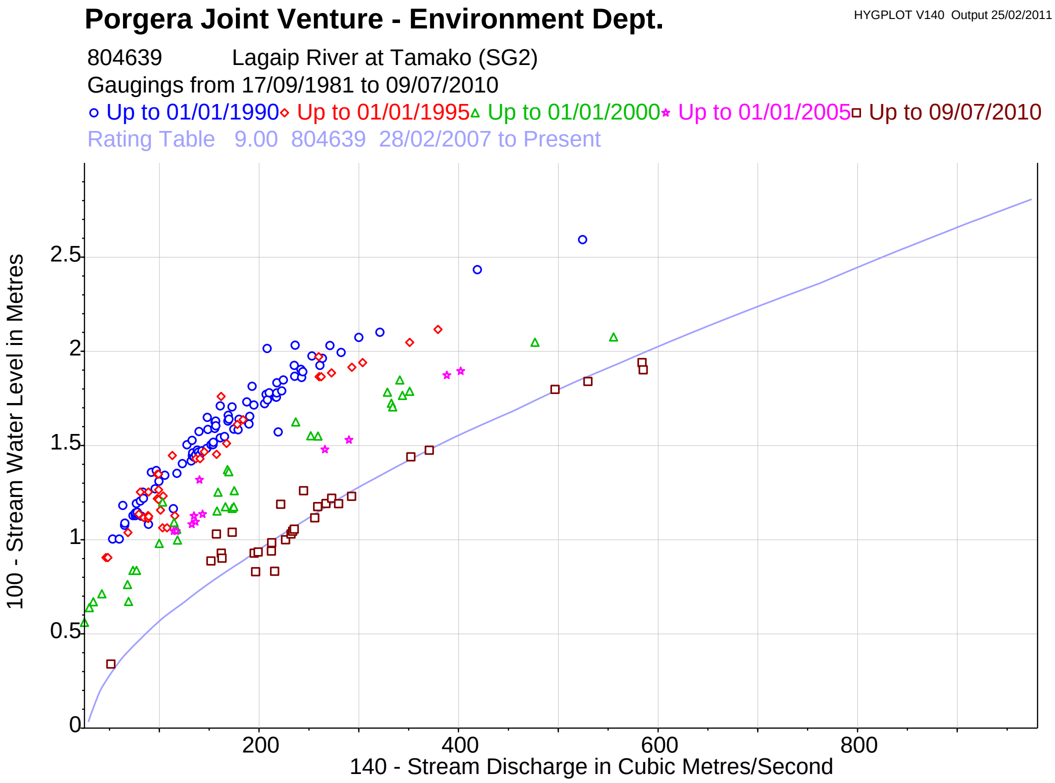


Figure 2-39 Rating curve shifts for SG2

No net aggradation is expected to occur between SG2 and SG4 which includes the Lagaip River, and the Strickland River through the Strickland Gorge and the upper section of the Strickland River lowlands. The river through these reaches is fast flowing and subject to sediment inputs from many natural landslides. Apart from the gauging cross section at SG3, no cross sections are established between SG2 and SG4.

SG4 to Everill's Junction (Fly River)

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. A number of cross sections exist in this reach, including PF10 at SG4 (60km downstream from the Tomu River Junction).

A single profile was measured at PF10 in August 2010. A comparison of the minimum bed elevations (RLs) for all surveys showed a variable temporal pattern, but no clear evidence of ongoing aggradation or degradation (Figure 2-40).

The results of Swanson *et al*, 2008 indicated that there is approximately a 13% long-term loss of total sediment load to the floodplain below this zone (of the order of 10Mt per year based on estimates of sediment load in this zone).

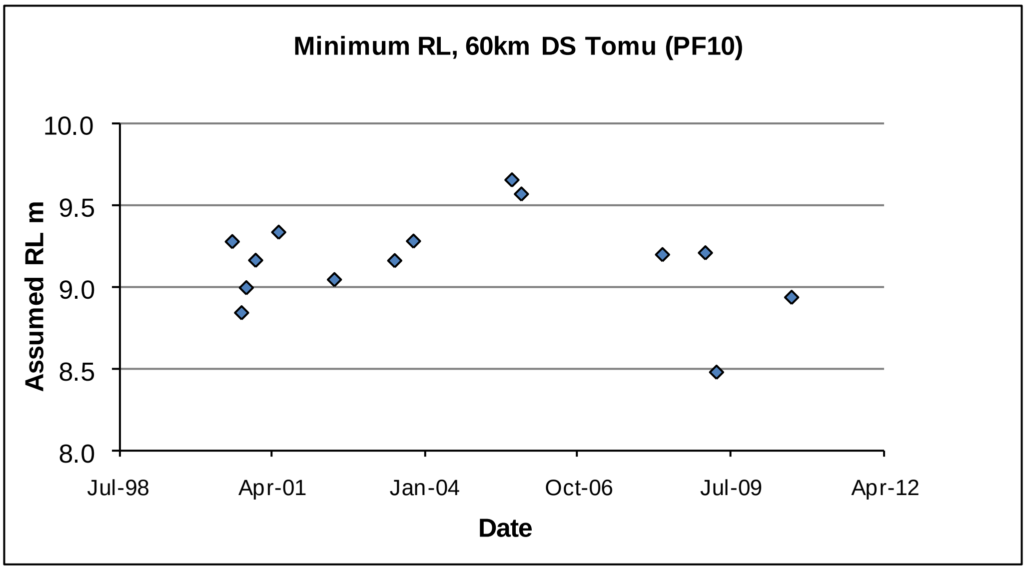


Figure 2-40 Time series of minimum measured bed elevation at PF10.

2.4.5 Sediment Transport

Export of Sediment from Tailings and Erodible Dumps

Attempts have been made to estimate the amount of sediment discharged by the mine to the receiving environment. It is stressed that year-to-year estimates are based on limited data and a large number of assumptions. Various lines of evidence are brought together to present a best estimate of the annual sediment load at SG3. Future reports will contain an estimate of uncertainty associated with load estimates based on statistical analysis.

It is assumed that most of the tailings is discharged across Anawe Dump and to the river system. From visual observations, it is known that some tailings are stored in Anawe Dump but the amount is not known. For the purposes of this report, 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 bed storage.

It is also known that sediment inputs to the dump tracts also occur from bank erosion and eroded valley walls (in addition to the dump tracts, this effect extends along the Kaiya River to the start of the Porgera River). The exact quantities are unknown.

In order to estimate the discharge of silt, sand and gravel from the dumps, it is necessary to estimate the particle size distribution for material at the toe of the dump. A number of estimates of this parameter have been made in previous studies and there is considerable variability in the results. This is due to the difficulty of assigning a single grain size distribution to the very large range of particle sizes, and their spatial variability, at the dump toe. A summary of the various estimates of particle size distribution for the combined dump toes is presented in Table 2-6, which also shows the adopted size distribution used for the purposes of sediment transport calculations.

Table 2-6 Previous estimates of particle size distribution of dump-toe material

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

NB: 1997 Anawe toe sample result considered to be inconsistent with other results (likely due to sampling methods) and was excluded from the calculation of the mean values.

Although previous survey data and mass-balance calculations for the dumps indicated that approximately 50-60% of material input was lost downstream as a long-term average, more recent survey data suggested that this figure was about 20-30% over recent years (Davies *et al.* 2008). This is less than previously calculated based on older survey data but there remains considerable uncertainty over these estimates. Table 2-7 shows the adopted values for the long term proportion of dump mass that is transported downstream, and the long term sediment transport rates for each dump. Although variable from year to year, historic survey data suggest that the long term mean value for loss of mass (i.e. export of sediment) from the erodible dumps (combined) is about 12 Mt/y (refer Table 2-7). This appears a reasonable estimate as the estimated suspended load at SG1 (based on historic measured data) is approximately 10 Mt/y.

Regular surveys and on-going volume-difference calculations represent a more reliable way to estimate sediment lost downstream from the dumps. Topographic (LiDAR) surveys of both dumps commenced during 2009. At the time of writing, two surveys had been undertaken (June 2008 and March 2001 for Anawe and November 2008 and July 2010 for Anjolek) although the second Anjolek survey was only partly completed. Data are currently being analysed and corrected and preliminary results for Anawe suggest the amount of sediment exported during the reporting period may have been somewhat lower than the assumed long term value. Further data analysis and surveys will enable a more accurate future estimate.

Table 2-7 Summary of long-term dump mass balance from survey data

	Approximate % of Total Dumped Material Released based on Survey Data	Long term mean downstream transport rate (Mt/yr). (Total mass exported downstream from survey data divided by number of years between survey)
Anjolek	57	6.95
Anawe	52	5.03

For 2010, the total estimated mine-derived export of sediment from the dumps was computed as 95% of the tailings exporting the dump added to an estimate of the material exported from the erodible dumps for that year. Table 2-8 presents an estimate of the suspended sediment component of the mine-derived sediment load that was discharged to the river system during 2010. Suspended sediment is that part of the total sediment load that travels in suspension in the water column but maintains occasional contact with the bed.

Table 2-8 Estimate of mine derived suspended sediment for 2010

Source	Total Sediment Discharged (Mt/yr)	Suspended Sediment Component (Mt/yr)	Comments
Tailings (mill data)	4.9 (5.2 x 0.95)	4.7 (4.9 x 0.95)	Assumes 95% of tailings is transported as suspended load and 5% remains stored in the Anawe Dump
Erodible Dumps (long-term mean value used)	12.0	7.1	Assumes 59% (silt fraction) travels as suspended load
Total	16.9	11.8	

Based on the above information, a year-by-year breakdown of sediment exported from the erodible dumps was made by using annual dumping and tailings discharge data and applying an annual weighting factor for rainfall variability to each year. It should be noted that this breakdown is a very crude estimate based on assumed annual variability of long-term parameters and supported by very few data. The results are shown in Figure 2-41.

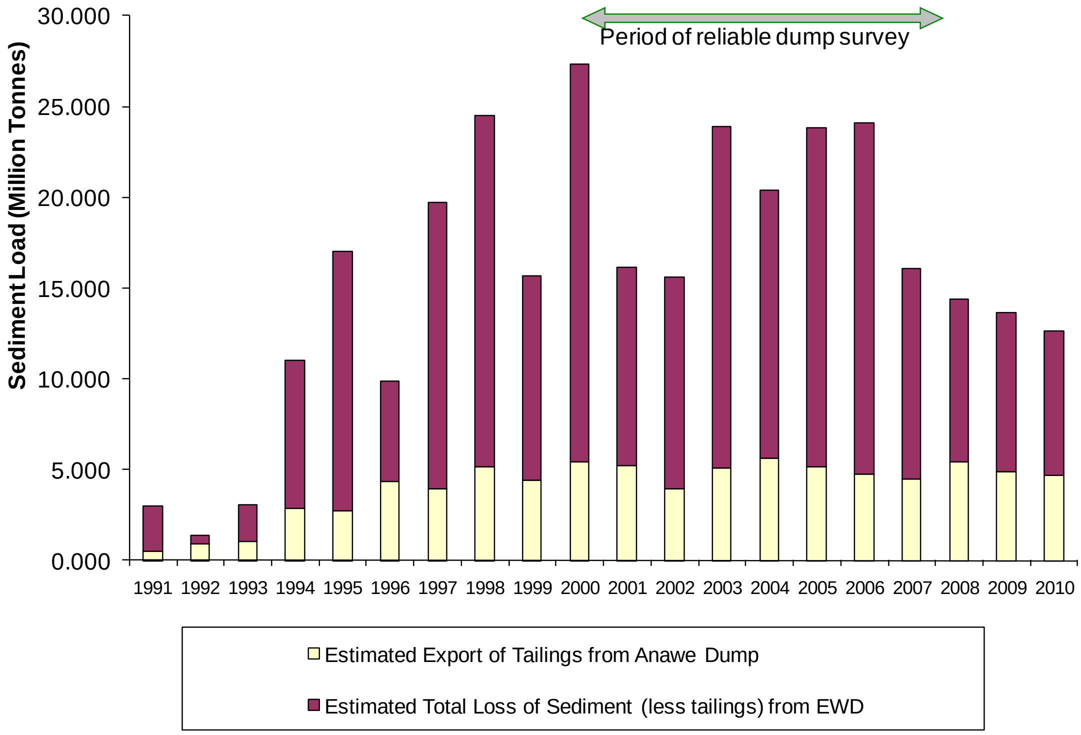


Figure 2-41 Estimate of downstream tailings and waste rock export from Erodible Dumps.

Transport of Sediment along the River System

Sediment that is not deposited within the channel or overbank is transported downstream by the flow. Most of the mine-derived sediment that is transported along the river is referred to as suspended load which is that part of the total load that remains suspended in the flow most of the time. Total suspended solids (TSS) data were collected by the Chemistry Section at key sites throughout the reporting period for the purposes of estimating annual suspended sediment loads at different points in the river system.

Over the past few years, correlations between TSS (gulp method) and TSS (depth-integrated method) have been established for SG3, Ok Om and SG4 which enable gulp samples taken from the side of the river to be adjusted to be more representative of the true cross section mean TSS value. These correlations are now well established and the only requirement for further depth-integrated samples at these stations will be to verify the existing relations. The established correlations are shown on Figure 2-42.

For 2010, SG3 provided the best overall flow and TSS dataset enabling the annual suspended sediment load to be calculated for that particular location (albeit with considerable uncertainty). Annual loads at other stations could not be estimated due to insufficient sample numbers. However, the likely range of sediment load values has been estimated for all stations as a result of ongoing sampling over a number of years, although year-to-year analyses are not possible on these limited datasets.

Apart from the main river gauging stations, TSS samples were also taken from a number of local stations, mostly for the purposes of specific project work or mine layout changes. Summary statistics for TSS data are presented in Section 5.

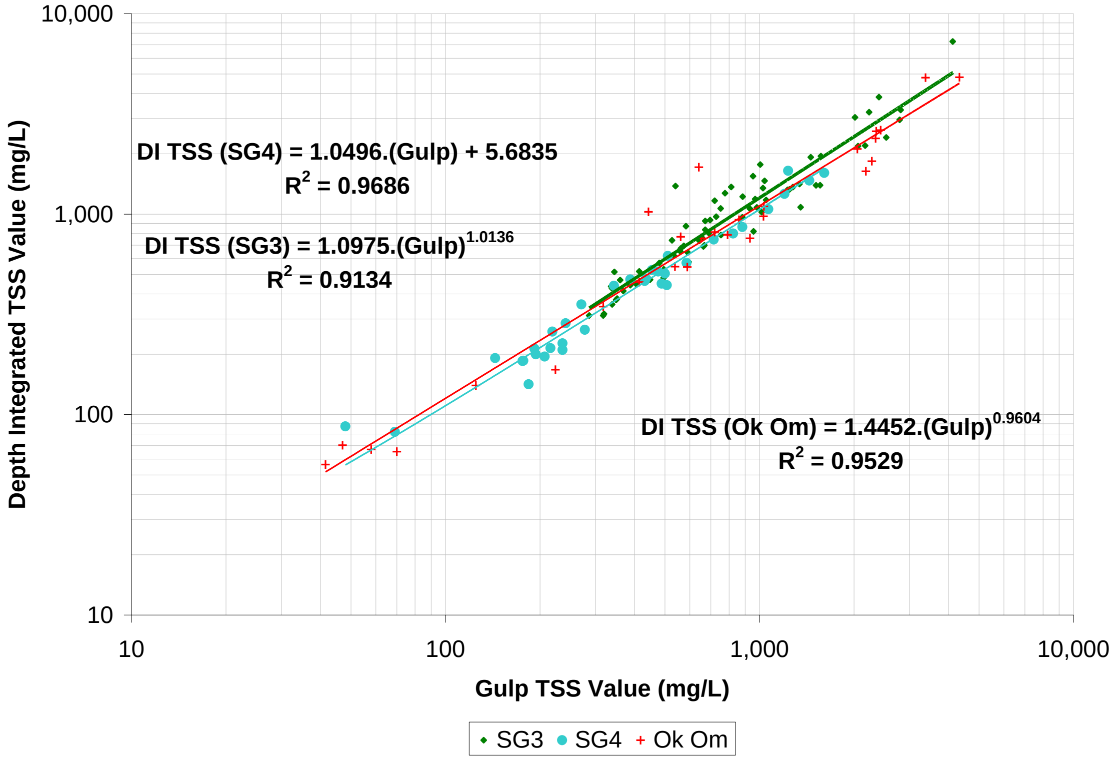


Figure 2-42 Relationship between depth-integrated and gulp TSS at SG3, SG4 and Ok Om

There is no clear relation between TSS concentrations and flow rate at any of the gauging stations. This is partly because the discharge of tailings remains relatively constant regardless of flow, and also that the processes of natural sediment delivery to the stream network are complex and not necessarily related to flow. Therefore it is not possible to estimate suspended sediment concentrations based on flow alone. Figure 2-43 and 2-44 compare mean daily flow with mean daily TSS values at SG2 and SG3 for the reporting period illustrating the complexity of the relation between flow and TSS.

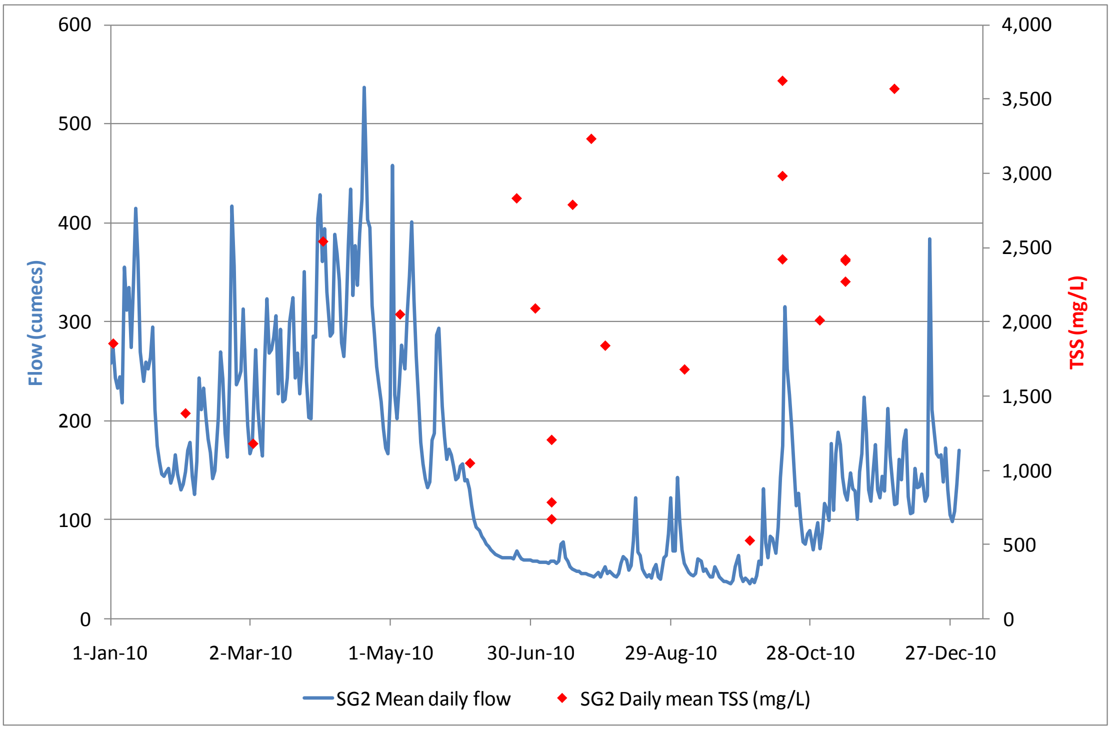


Figure 2-43 Flow hydrograph and TSS spot samples at SG2

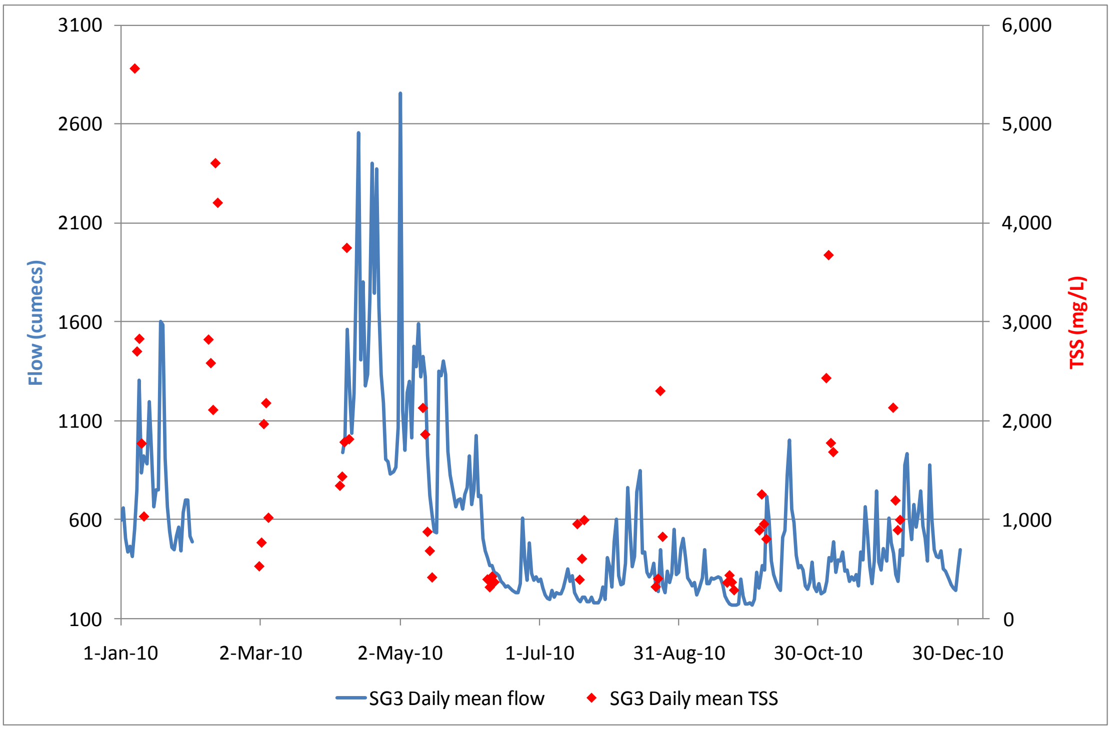


Figure 2-44 Flow hydrograph and TSS spot samples at SG3

Figure 2-45 shows the medians of the daily TSS concentration for different flow percentiles at each of the main downriver gauging stations. The period of record for each station varied but overlapped to a large degree covering several years. For the stations closest to the mine, data show that TSS decreases with flow with the exception of the very highest flows when TSS is again high above a certain threshold. This indicates that for the very highest flows, much greater rates of sediment transport occur due to high rates of river bank and hillslope erosion, and the transport of this and coarser sands and finer gravels in suspension in the upper catchment. For the lower river gauging stations, where flood peaks are more gradual and rates of hillslope erosion lower due to the flatter terrain, such extreme and episodic sediment transport processes do not appear to occur. Rather, TSS values generally decrease with flow rate due to dilution.

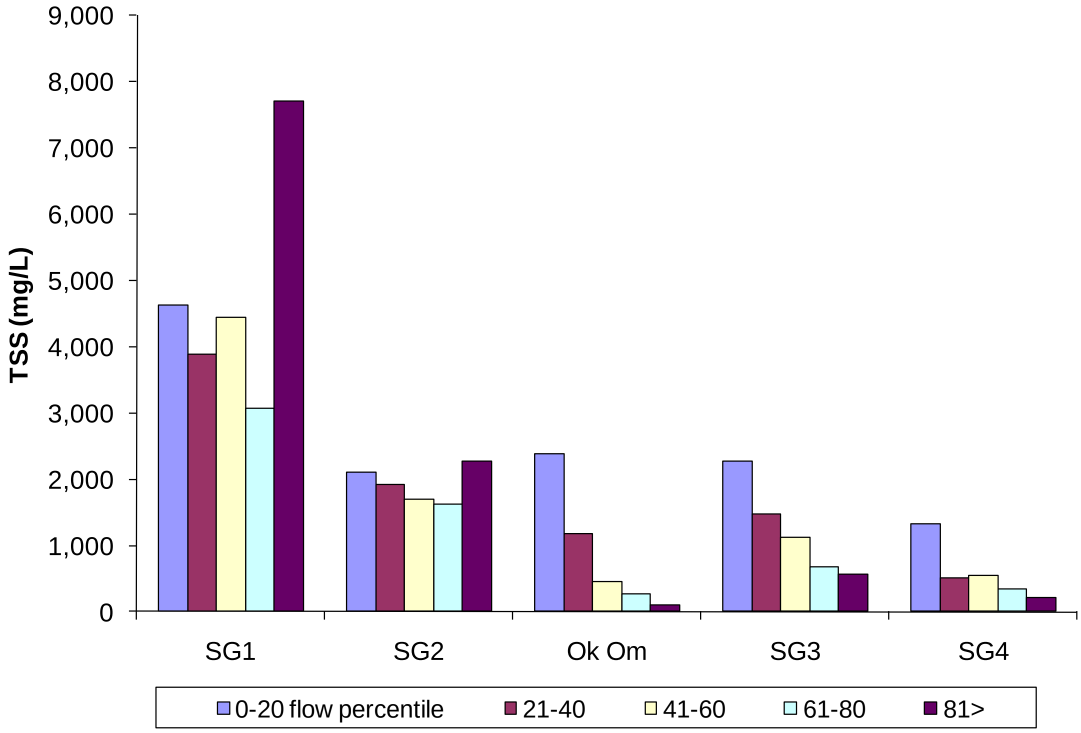


Figure 2-45 Variation of TSS for different flow rates (full period of record)

Spot Measurements of Suspended Load using ADCP Technology

In March 2010, five days were spent at Lake Murray for the purpose of conducting flow and sediment measurements using and ADCP (Acoustic Doppler Current Profiler). ADCP technology offers a number of significant advantages over conventional current meter gauging. Significantly, a gauging can be done (e.g. at SG5) in a few minutes (as opposed to an hour or more), and the acoustic backscatter data can be used to estimate suspended sediment loads.

Plate 2-6 ADCP setup on the dinghy

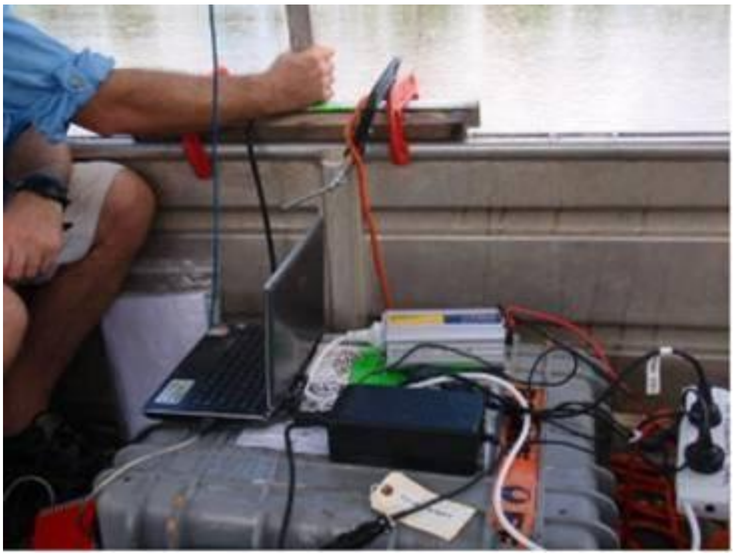


Plate 2-7 ADCP and differential GPS communications setup

In addition to flow measurements, suspended sediment samples were taken using an 'Alpha' point sampling bottle in order to undertake a one-off calibration of the ADCP backscatter data for the purposes of using those backscatter data to estimate suspended sediment concentration. At each section, nine TSS samples were taken and averaged to provide a mean value for the section.

ADCP gaugings were undertaken on the Herbert River, the Strickland River (above the Herbert), SG5 and the Strickland River at Levame. Three to five repeat transects were taken at each site during each sampling event. A summary of results is shown in Table 2-9 below. Note that each flow reading represents the mean of several repeat transects, while each mean TSS value is a section-average value estimated from nine individual samples. Results proved highly accurate with the sum of the Herbert River flow and the Strickland Upstream flow agreeing with the SG5 flow to within a few tens of cumecs.

Table 2-9 Summary of ADCP results

Date	Strickland u/s Herbert R		Herbert R u/s Strickland R		Strickland R at SG5		Strickland R at Levame		Gauge Ht SG5
	Flow (cumecs)	Mean TSS (mg/L)	Flow (cumecs)	Mean TSS (mg/L)	Flow (cumecs)	Mean TSS (mg/L)	Flow (cumecs)	Mean TSS (mg/L)	
14/3/10	2,512	67	968		3,631	328			8.313
15/3/10			1,174	637	3,530		3,624	780	8.388
16/3/10	2,146		1,233		3,404	646			8.283

Although flow measurements were accurate and consistent, there was some variability in the TSS values. Particularly surprising was the fact that TSS values for the Herbert River were higher than those measured for the Strickland River. This meant that there was considerable variability and uncertainty associated with suspended sediment load during the survey. However, the best estimate of the suspended sediment load during the period of survey (obtained by averaging sediment loads for SG5 and Levame) was 65 Mt/yr.

Figure 2-46 and 2-47 below show example ADCP output for flow (top) and acoustic backscatter (bottom) at SG5. Acoustic backscatter is a surrogate measure of particle concentration in the water.

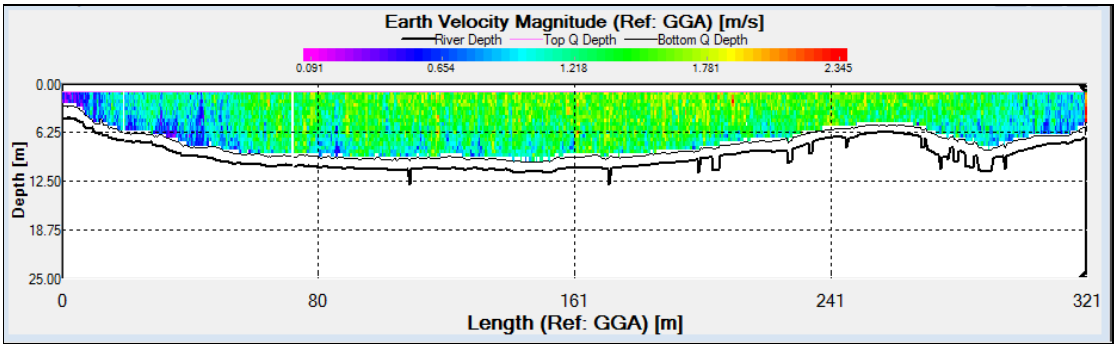


Figure 2-46 Velocity profile at SG5 (total discharge 3,545,cumecs)

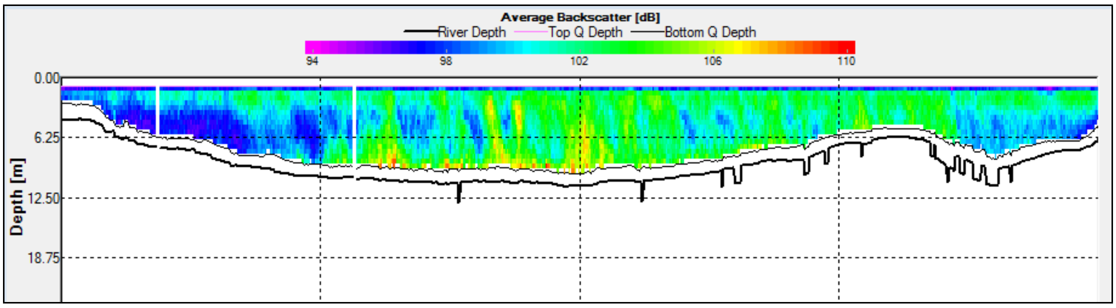


Figure 2-47 Backscatter profile at SG5
NB Backscatter is a crude approximation of TSS. Green, yellow and red in infer higher TSS.

Next, the SediView computer program was used to estimate TSS concentration from the ADCP backscatter data and collected TSS samples. Figures 2-48 and 2-49 show examples of outputs of flow, TSS concentrations, and TSS contours for the Strickland River at Levame. The results indicate that higher flow rates and TSS concentrations occurred across the point bar (shallower part of the cross section). Therefore most of the sediment load was moving across the point bar in this example.

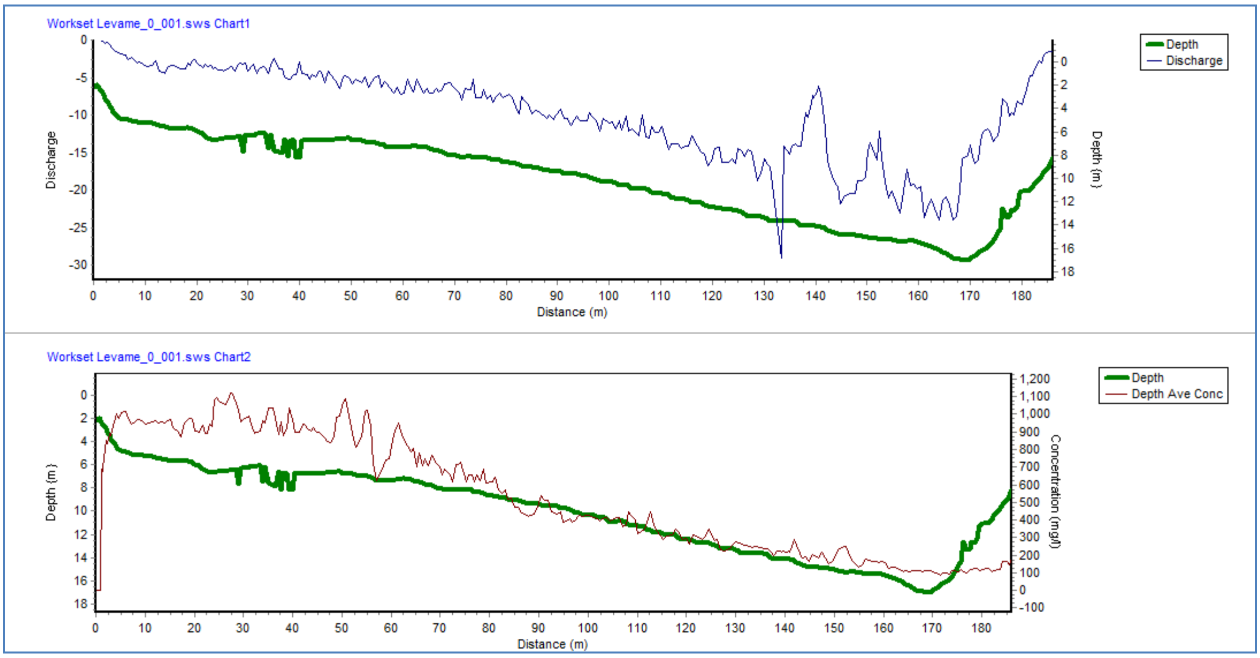


Figure 2-48 Discharge and TSS estimates for Strickland River at Levame

Profile plots of discharge (top) and depth average TSS concentration (bottom) for the Strickland River at Levame, as estimated by the computer program SediView.

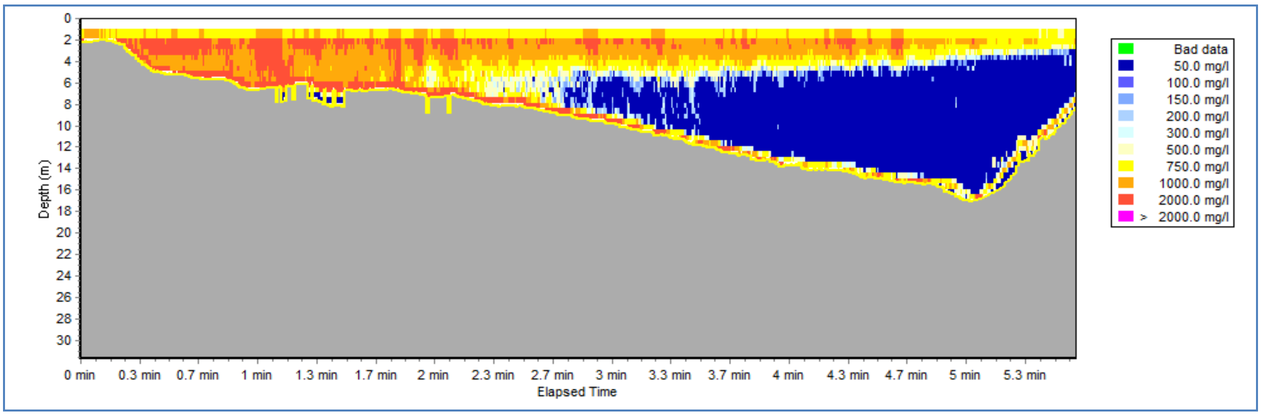


Figure 2-49 Contour plot of estimated TSS concentration, Strickland at Levame

Finally, a long-section was undertaken across the Strickland River and up along the centreline of the Herbert River for a distance of approximately 2km. The purpose of this was to show how acoustic backscatter data can be used to determine turbidity (and TSS). A contour plot showing acoustic backscatter output is presented in Figure 2-50, and clearly shows the areas of higher backscatter (TSS concentration).

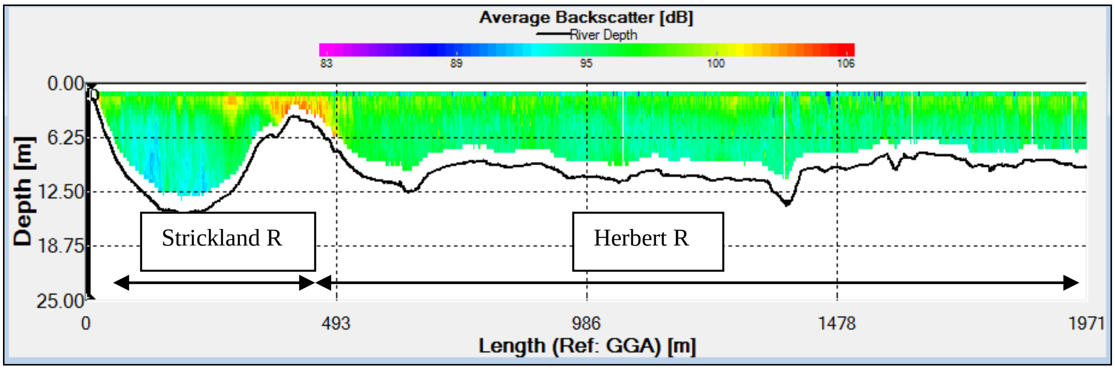


Figure 2-50 Transect across the Strickland River and up along the Herbert River
Red and yellow infer high turbidity zones. Light blue infers lower turbidity.

Estimation of Sediment Load for SG3 using Measured Data

Annual suspended sediment transport at SG3 was also estimated using actual TSS and flow data and the usual analysis procedure adopted for annual reporting. The method involved calculating daily loads for those days of the year where both TSS and flow data were available. The sum of the total daily loads for these days was then factored up according to the total flow volume for the year as recorded by data loggers, i.e.:

Total Annual Suspended Sediment = MDL x (LDF/MDF)

where MDL = Measured Daily Load (i.e. the sum of the daily loads measured on sampling days), LDF = Total flow volume from logger for the whole year and MDF = measured daily flow volume (i.e. total of gauged flows on sampling days).

A second method was then used which involved a statistical analysis to correct the results for discrepancies arising from irregularly sampled record and continuous record of flow (refer CSIRO (1996) for details of this methodology). This method was derived specifically for PJV during the CSIRO 1996 review. These two methods generally give very similar results.

Using the above methods, the estimated total suspended sediment load for SG3 was 37 million tonnes for the reporting period. However, it should be noted that there is considerable uncertainty over this figure and the year to year variations in the estimated load are likely well within the uncertainty associated with the input data and calculation method. However, on a long term basis, the approximate values of the annual sediment load and the proportion of that which is mine-derived are presented with more certainty.

Using this value, the proportion of total suspended sediment load that was mine-derived during the reporting period (2009) at SG3 was estimated to be approximately 25% which compares to a long term mean value of approximately 32%. This (latter) figure agrees very well with the results of geochemical analyses on sediments conducted as part of the NSF (US National Science Foundation) sponsored Margins Source to Sink Research Program which reported 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).

Insufficient data were collected at other stations for the purposes of computing the total annual suspended sediment loads. As discussed in previous reports, the suspended sediment load is expected to be similar between SG4 and SG5 although flow and sediment transport is complicated in this region due to floodplain storage and transfers. It is estimated that 13% of the river suspended sediment load discharges to the floodplain and in off-river water bodies (Swanson et al 2008).

TSS data for 2010 show that values were generally close to long term median values (Figure 2-51).

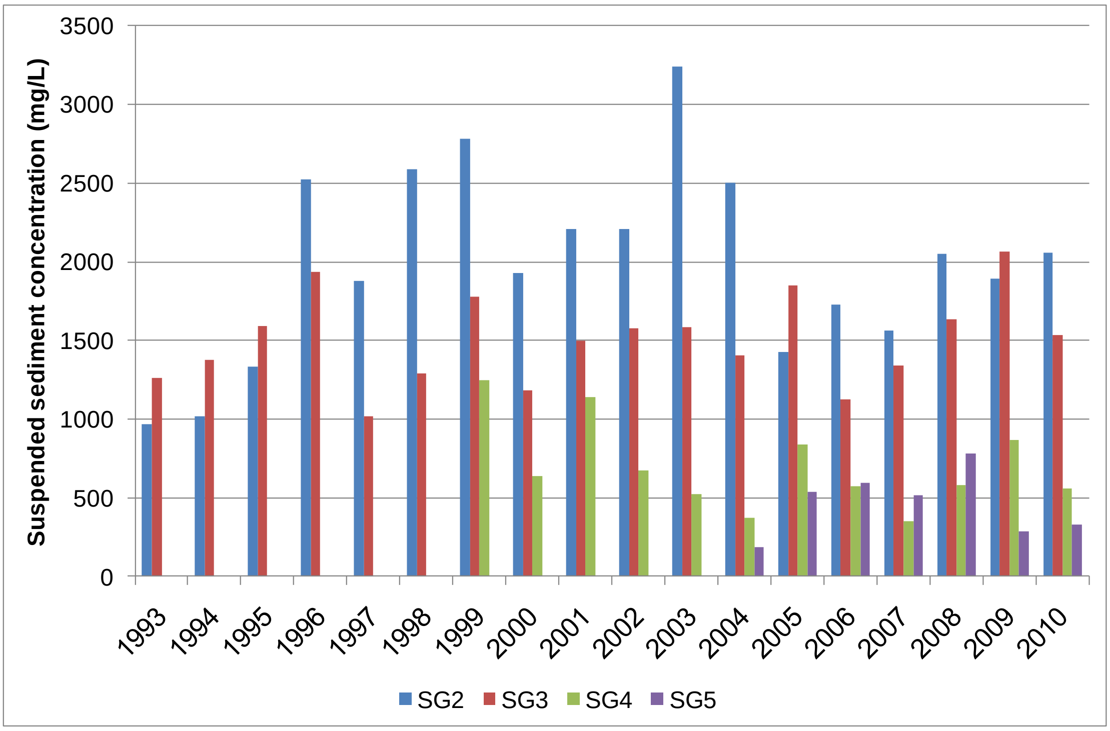


Figure 2-51 Mean annual TSS values at key stations

Overall Summary

Figure 2-52 shows the estimated breakdown of the total suspended sediment load at SG3 since 1991. Figure 2-53 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.

Erodible dump discharge is estimated by multiplying the annual truck dump figure by the long-term rate (approximately 0.55 from the dump survey), then multiplied by the estimated fines fraction (0.59). A weighting is also applied to the computed dump export figures to account for above or below average rainfall.

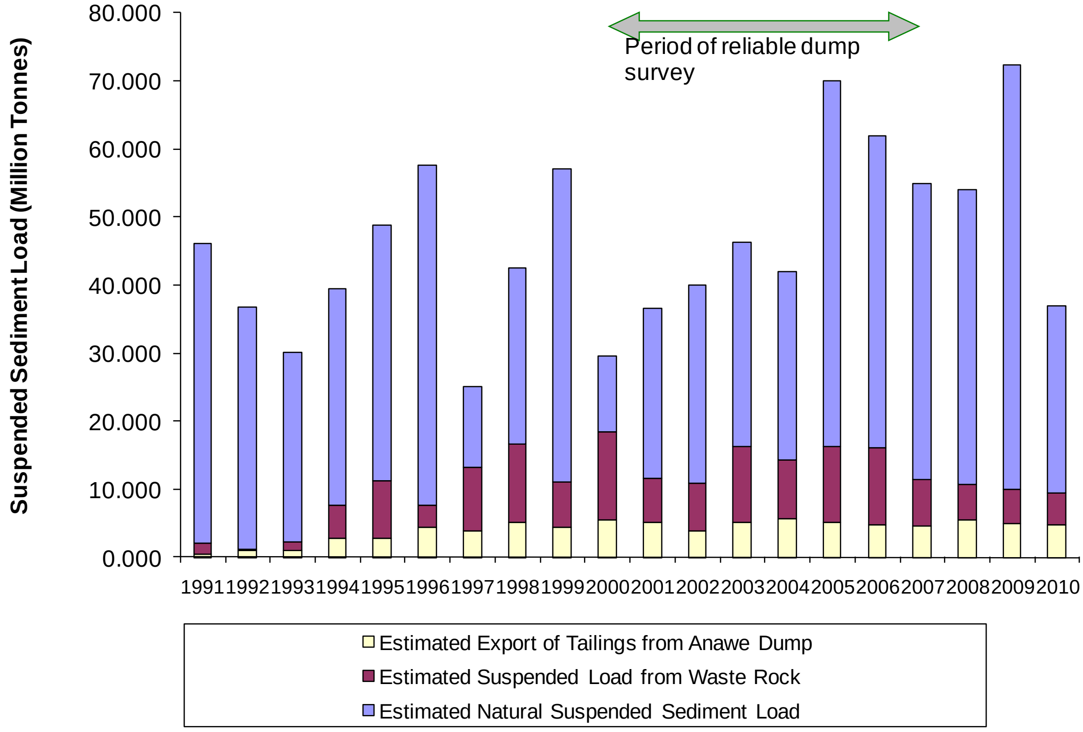


Figure 2-52 Estimated suspended sediment budget at SG3 since 1991

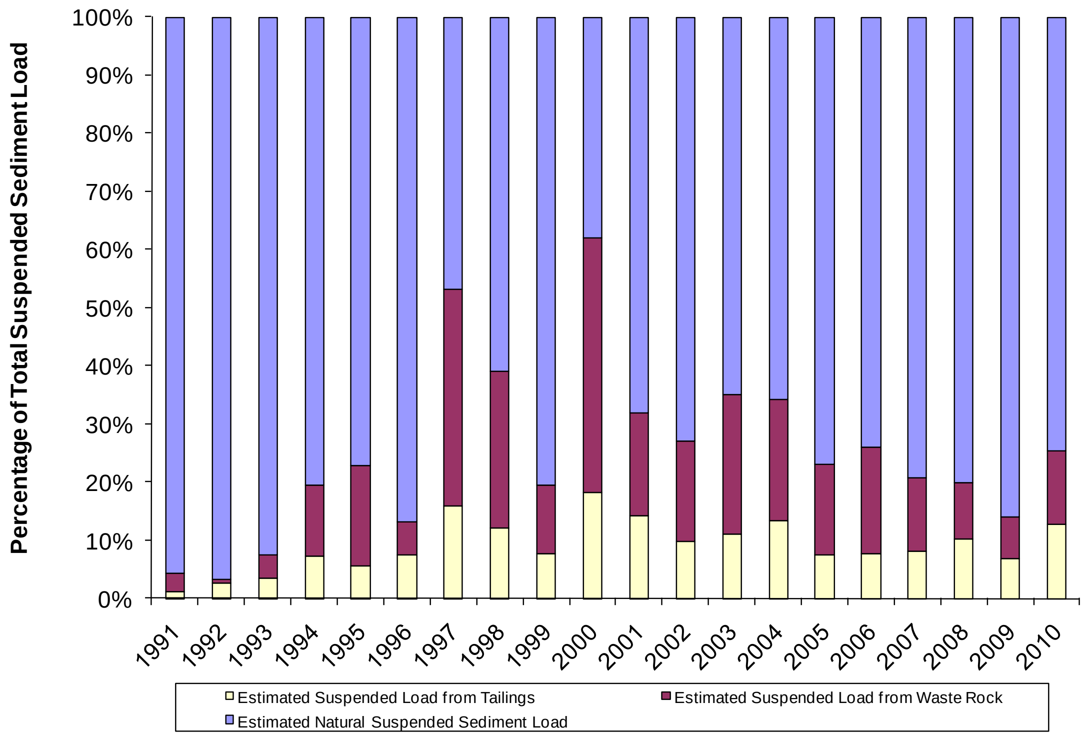


Figure 2-53 Estimated suspended sediment budget at SG3 expressed as %

Bed Material Load

The preceding discussion presents an annual budget for suspended sediment only (fine sands, silts and clays). Bed material load (coarse sands and gravels that are transported along the bed of the river) comprises the remaining 41% of the material eroded from the dumps every year. It is difficult to verify the bed material load budget from field measurements as sampling is extremely difficult and can be hazardous. Estimates are complicated by the fact that some of the bed material load becomes washload during high flow events (because higher flows can transport larger particles).

Furthermore, abrasion of larger particles occurs during sediment transport along the river meaning that some of the gravels and boulders eroded from the dump are broken down into finer fractions by physical impacts with other particles. Generic rules of thumb derived from the literature suggest that about 10-15% of a river's total load may be comprised of bed material load. Based on this, the bed material input to the river from the erodible dumps would have been approximately 5.0 Mt per year (~12.0 Mt x 0.41).

References

CSIRO, 1996. *Review of riverine impacts*. Prepared for PJV by CSIRO, December 1996.

Davies, M,, Parker, G, and Savigny, W. 2002. *Porgera Mine Erodible Dumps Review Panel Final Report*, consultants' report to the PJV.

Davies, M. and Markham, A., 2005. Porgera Mine Erodible Dumps, Technical Review of Performance, consultants' report to the PJV.

Davies, M., Mules, G., Markham, A. and Blong R., 2008. *Porgera Joint Venture Porgera Mine Erodible Dumps, Technical Review of Performance Relative to Planned Stage 6 Expansion*, review panel report to the PJV.

Klohn Crippen, 1999*, Erodible Dump Performance Model, Phase III: February 1999 Calibration*, draft consultant report to the PJV.

McAlpine, J.F. and Keig, G. with Falls, R., (1983), *Climate of Papua New Guinea.* CSIRO in association with ANU Press, Canberra.

Swanson, K.M., Watson., E., Aalto, R., Wesley Lauer, J., Bera, M.T., Marshall, A., Taylor, M.P., Apte, S.C. and Dietrich, W., 2008. *Sediment Load and Floodplain Deposition Rates: Comparison of the Fly and Strickland Rivers, Papua New Guinea*, Journal of Geophysical Research, 113, F01S03.

Parker, G., 1993. *Site visit, June, 1993.* Consultant's report to the PJV, June 9' 1993.

3.0 TAILINGS MONITORING

3.1 Introduction

The riverine disposal of Porgera mine tailings contributes both metal-bearing sediment and dissolved metals to the river system. Tailings are discharged onto the Anawe erodible dump where a portion of the tailings previously trapped in the dump is also released into the river system each year as the dump erodes. The geochemistry of the tailings, the concentration of dissolved metals in the tailings liquor, and dilution rates along the river system have a great influence on the levels of dissolved metals in the water column, notably at the SG3 compliance point at the end of the mixing zone, and in metal levels in fish and prawns along the river system. These dissolved metal concentrations are tempered largely by adsorption onto natural riverine suspended sediments and to a lesser extent by complexation with dissolved organic matter within the turbid river system.

The treatment of tailings in the Process Plant, and, in particular, lime dosing to maintain the pH above 6.5, ensures that dissolved metal concentrations in the discharge are acceptable. This enables compliance to be achieved at SG3 and that metal concentrations in fish and prawns, which are present in the river system downstream of SG2, remain acceptable and within international food standard limits.

The mean daily Process Plant treated tailings output in 2010 was 14,249 tonnes per day compared to the 2009 and 2008 averages of 14,879 and 16,526 tonnes per day, respectively. These values were obtained from regular pulp density measurements taken throughout each day (on a weight/weight basis) on ore pulp entering the Process Plant. Since only gold is extracted in the process (a tiny fraction compared with the total quantity of ore throughput), the solid tailings released is taken as the same as the ore quantity input. Using ore pulp densities (% w/w) and a solid tailings SG of 2.7 t/m^3, the total volume of tailings slurry released in cubic metres per day can also be calculated.

Tailings monitoring was conducted during 2010 on discharge pipe samples to determine whether the tailings neutralization circuit was operating as efficiently as designed by effectively detoxifying the Process Plant tailings before discharge.

3.2 Methods

During 2010, the tailings neutralisation circuit was monitored for performance on a continuous basis. Online monitoring of pH was recorded in the Process Plant control room, with low level set points programmed to sound an alarm if the pH dropped below 6.3 for the initial alarm. Procedures are in place for senior Environmental and Process Plant personnel to be notified if the alarm is raised.

Under normal operations, should the pH fall further below 6.0, the tailings neutralisation circuit is temporarily shut down and tailings discharge ceases until the problem is rectified. The problem, if it occurs, is normally short-term and involves either difficulties with lime addition for pH control, or temporary plant shutdown for maintenance.

During 2010, hourly grab samples of tailings were collected and measured for pH and free cyanide by the Process Plant operators. PJV environmental staff collected two snap samples of tailings each day, morning and afternoon. To obtain dissolved metal samples, a portion of each grab sample was passed through acid-washed polycarbonate filtration apparatus containing cellulous nitrate polycarbonate filter membranes (0.45µm). Each of these samples was made into a weekly composite to be analysed for dissolved metals (defined as <0.45µm filter size), and each composite sample was then preserved by acidifying with ultra-pure grade nitric acid and packed in coolers containing 'dry ice'. A separate weekly composite to be analysed for total trace metals was made from the daily grab samples but was not preserved with acid. Both the dissolved and total weekly composite sampleswere sent to the National Measurement Institute (NMI) laboratory in Sydney (formerly Australian Government Analytical Laboratory, AGAL) for analysis.

Analyses that were conducted in-house in the PJV Environmental Chemistry Laboratory on individual grab samples included pH, weak acid dissociable cyanide (WAD CN), cyanide amenable to chlorination (CAC), thiocyanate, conductivity, total suspended solids and temperature. Results from the two daily grab samples were then averaged for reporting purposes.

Daily composites were prepared for sulfate, and total and weak acid dissociable cyanide from the two snap samples and analysed inhouse.

The results for dissolved and total trace metals as well as cyanide, pH and total suspended solids for 2010 are presented in Tables 3-1A to 3-13A. Summary statistical results for the metals and the other parameters mostly from 2001 to 2010 are presented in Tables 3-1B to 3-13B.

3.3 Results and Discussion

The dissolved and total concentrations of tailings for the various trace metals varied throughout 2010. Details are provided in the following sub-sections. In summary, the 2010 values for dissolved and total metals showed no distinct trends. Dissolved silver concentrations were at or below the detection limit throughout the year.

Over the 10-year period from 2001-2010, the dissolved and total concentrations of all metals in tailings showed no distinct trends with the exception of total mercury and dissolved nickel, both of which showed downward trends.

The concentrations of the various forms of cyanide in tailings, i.e. total, WAD, CAC and thiocyanate remained within acceptable limits during 2010. The most notable variations occurred in 2009 for total, WAD and CAC cyanide, and thiocyanate when concentrations decreased noticeably due to the Cyanide Destruction Plant (CDP) being commissioned in early 2009. The ongoing purpose of this plant is to reduce WAD cyanide in the tailings discharged to the environment to less than 0.5 mg/L in accordance with the International Cyanide Management Code.

Tailings pH mean values remained for most of the time within the control limits (6.4 to 6.6) throughout 2010.

3.3.1 Arsenic

Figure 3-1A shows the boxplots for dissolved and total arsenic concentrations for 2010. The results for both dissolved and total arsenic were low throughout the year except for the elevated dissolved result in December which was checked and found to be correct. The reason is unclear since there was no corresponding increase in total arsenic. The 2010 mean monthly concentrations for arsenic are shown in Table 3-1A.

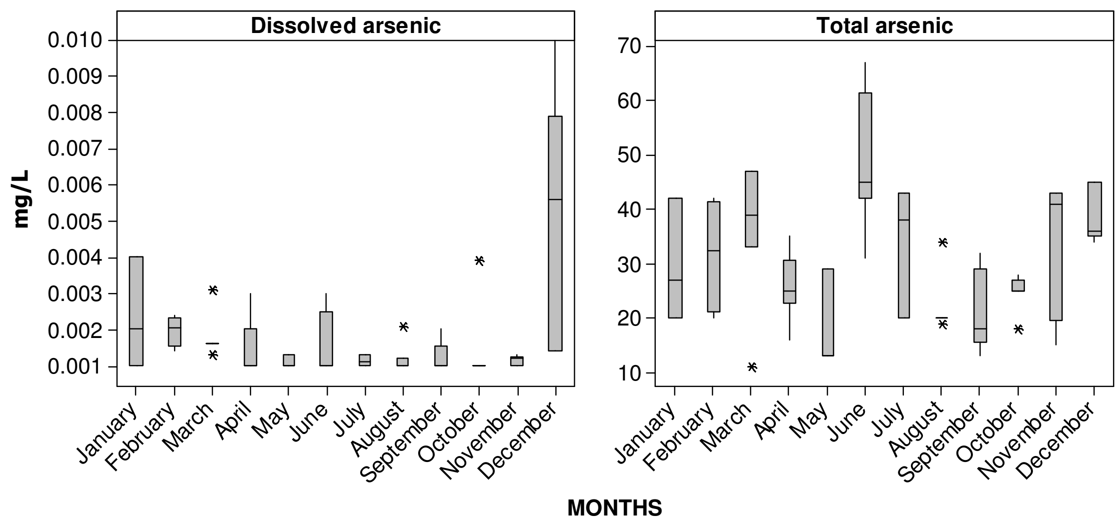


Figure 3-1A Box plots of dissolved and total arsenic in tailings for 2010

Table 3-1A Mean monthly concentrations (mg/L) for dissolved and total arsenic for 2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
As-D	0.002	0.002	0.002	0.002	0.001	0.002	0.001	0.001	0.001	0.002	0.001	0.007
As-T	29	32	34	26	19	47	33	22	22	25	31	38

Figure 3-1B presents the boxplots for dissolved and total arsenic in tailings from 2001 to 2010. Dissolved arsenic concentrations prior to 2006 were considerably higher than the much lower results obtained since then. The reason for this step-down change is uncertain since the total concentrations were relatively steady during the same period.

Table 3-1B gives a statistical summary of arsenic annual concentrations in tailings for both the dissolved and total fractions from 2001 to 2010.

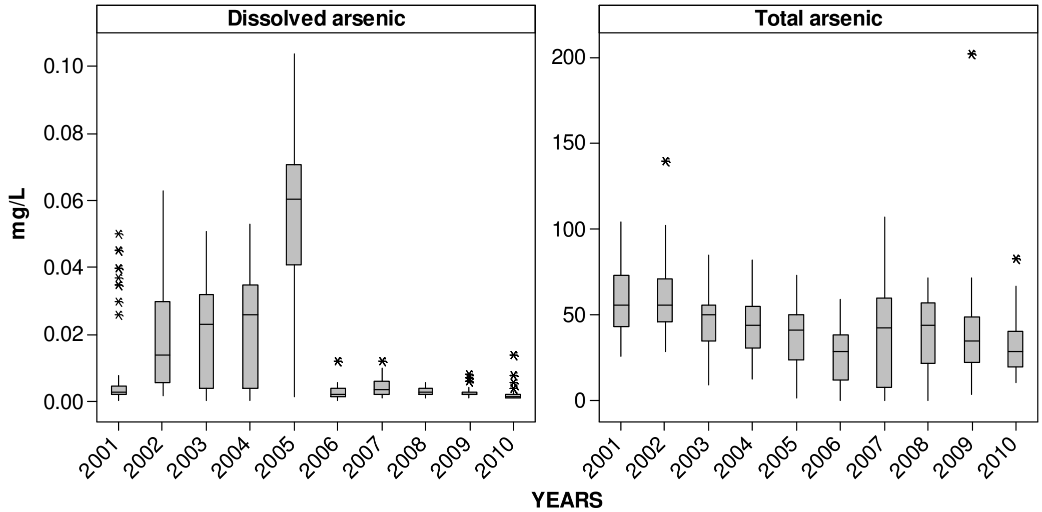


Figure 3-1B Box plots of dissolved and total arsenic in tailings from 2001-2010

Table 3-1B Summary statistics for dissolved and total arsenic concentrations in tailings since 2001 (results in mg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved arsenic									
2001	As-D	48	0.006	0.003	0.009	0.0002	0.045	0.002	0.005
2002	As-D	35	0.033	0.016	0.041	0.0030	0.2	0.007	0.043
2003	As-D	48	0.020	0.024	0.016	0.0003	0.051	0.004	0.031
2004	As-D	48	0.022	0.026	0.018	0.0004	0.053	0.004	0.036
2005	As-D	48	0.055	0.060	0.026	0.001	0.1	0.041	0.071
2006	As-D	45	0.003	0.002	0.002	0.0003	0.012	0.002	0.004
2007	As-D	45	0.004	0.004	0.003	0.001	0.012	0.002	0.006
2008	As-D	52	0.003	0.003	0.001	0.001	0.006	0.002	0.004
2009	As-D	49	0.003	0.002	0.001	0.001	0.008	0.002	0.003
2010	As-D	48	0.002	0.001	0.002	0.001	0.014	0.001	0.002
Total arsenic									
2001	As-T	48	59	57	20	26	104	44	74
2002	As-T	35	61	57	21	29	140	48	71
2003	As-T	48	47	51	15	9.6	85	42	56
2004	As-T	48	44	44	17	13	82	31	55
2005	As-T	48	39	41	15	12	73	24	50
2006	As-T	45	27	28	15	1.7	59	12	38
2007	As-T	45	37	41	28	0.01	107	6.9	57
2008	As-T	52	39	44	20	0.2	72	22	57
2009	As-D	49	38	35	29	3.9	202	23	49
2010	As-D	48	31	29	14	11	83	20	41

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved arsenic, T=Total arsenic, N=Number of analyses per year, Stdev=Standard Deviation.

3.3.2 Cadmium

Figure 3-2A shows the boxplots for dissolved and total cadmium concentrations in tailings for 2010. The dissolved and total values varied noticeably throughout the year. The 2010 mean monthly concentrations for cadmium are shown in Table 3-2A.

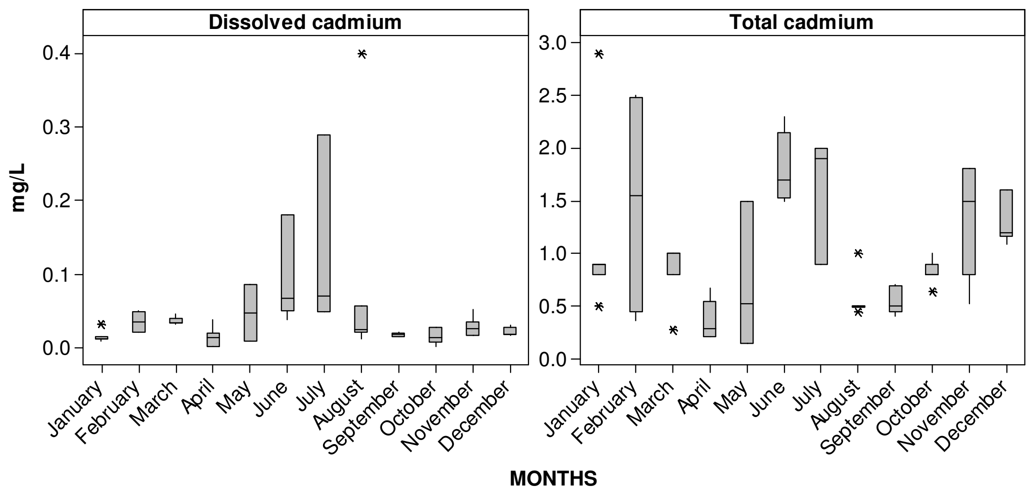


Figure 3-2A Box plots of dissolved and total cadmium in tailings for 2010

Table 3-2A Mean monthly concentrations (mg/L) for dissolved and total cadmium for 2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Cd-D	0.017	0.036	0.038	0.016	0.049	0.094	0.10	0.095	0.018	0.014	0.030	0.023
Cd-T	1.2	1.5	0.8	0.4	0.8	1.8	1.5	0.6	0.6	0.8	1.2	1.3

Figure 3-2B shows the dissolved and total cadmium concentrations in tailings for the period 2001 to 2010.

Table 3-2B gives a statistical summary of cadmium annual concentrations in tailings for both dissolved and total fractions from 2001-2010. Mean dissolved cadmium concentrations rose noticeably from 2001 to 2003 due to a pH optimisation trial at the mill but have since reduced to lower levels. The pH optimisation trials are described in detail in previous Annual Environmental Reports.

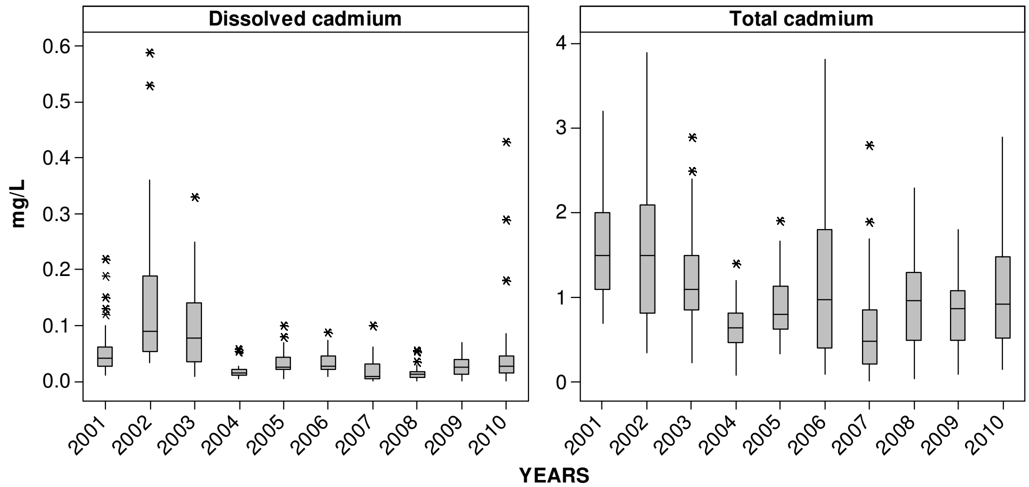


Figure 3-2B Box plots of dissolved and total cadmium in tailings from 2001-2010

Table 3-2B Summary statistics for dissolved and total cadmium concentrations in tailings since 2001 (results in mg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved cadmium									
2001	Cd-D	48	0.052	0.043	0.038	0.012	0.22	0.027	0.061
2002	Cd-D	35	0.140	0.096	0.130	0.034	0.59	0.060	0.2
2003	Cd-D	48	0.090	0.073	0.069	0.0084	0.33	0.036	0.1
2004	Cd-D	48	0.018	0.016	0.009	0.005	0.057	0.011	0.022
2005	Cd-D	48	0.033	0.026	0.019	0.006	0.10	0.021	0.043
2006	Cd-D	45	0.033	0.028	0.018	0.009	0.088	0.021	0.045
2007	Cd-D	45	0.020	0.010	0.021	0.0002	0.10	0.006	0.031
2008	Cd-D	52	0.020	0.014	0.011	0.001	0.055	0.008	0.018
2009	Cd-D	49	0.027	0.026	0.016	0.001	0.069	0.013	0.040
2010	Cd-D	48	0.044	0.027	0.064	0.001	0.40	0.015	0.046
Total cadmium									
2001	Cd-T	48	1.6	1.5	0.6	0.7	3.2	1.1	2.0
2002	Cd-T	35	1.6	1.6	0.8	0.4	3.9	1.0	2.1
2003	Cd-T	48	1.2	1.1	0.5	0.2	2.9	0.8	1.5
2004	Cd-T	48	0.7	0.6	0.3	0.08	1.4	0.5	0.8
2005	Cd-T	48	0.9	0.8	0.4	0.3	1.9	0.6	1.1
2006	Cd-T	45	1.2	1.0	0.9	0.1	3.8	0.4	1.8
2007	Cd-T	45	0.6	0.5	0.6	0.01	2.8	0.2	0.9
2008	Cd-T	52	0.9	1.0	0.6	0.04	2.3	0.5	1.3
2009	Cd-T	49	0.8	0.9	0.4	0.1	1.8	0.5	1.1
2010	Cd-T	48	1.0	0.9	0.6	0.2	2.9	0.5	1.5

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved cadmium, T=Total cadmium, N=Number of analyses per year, Stdev=Standard Deviation.

3.3.3 Chromium

Figure 3-3A shows the boxplots for both dissolved and total chromium concentrations for 2010. All values for dissolved chromium were at or near the detection limit throughout the year with the exception of October. The elevated values have been checked as correct but the reason for the rise is unknown since the total values for October are not unusually high. Total concentrations were varied during the same period. The 2010 mean monthly concentrations for chromium are shown in Table 3-3A.

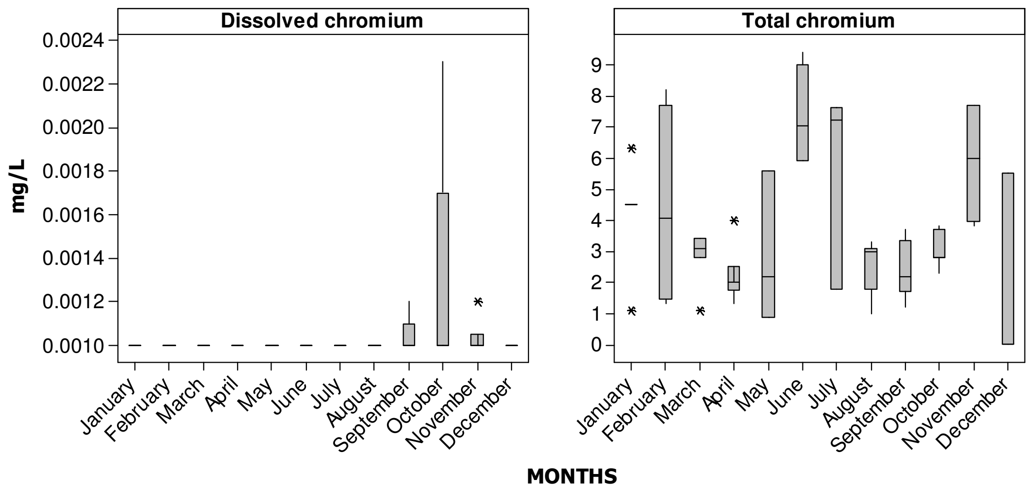


Figure 3-3A Box plots of dissolved and total chromium in tailings for 2010

Table 3-3A Mean monthly concentrations (mg/L) for dissolved and total chromium for 2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Cr-D	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Cr-T	4.1	4.4	2.7	2.3	3.0	7.3	5.3	2.5	2.5	3.1	5.5	1.8

Figure 3-3B shows box plots of dissolved and total chromium in tailings from 2001 to 2010. Both dissolved and total chromium concentrations showed varied results over the 10-year period.

Table 3-3B gives a statistical summary of chromium annual concentrations in tailings for both dissolved and total fractions from 2001-2010.

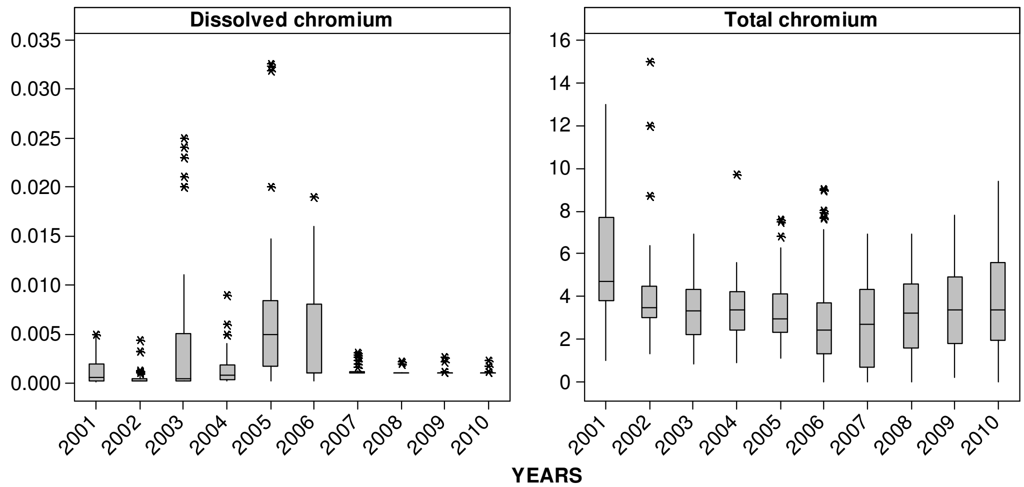


Figure 3-3B Box plots of dissolved & total chromium in tailings from 2001-2010

Table3-3B Summary statistics for dissolved and total chromium concentrations in tailings since 2001 (results in mg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved chromium									
2001	Cr-D	48	0.002	0.001	0.003	0.0001	0.011	0.0002	0.003
2002	Cr-D	35	0.050	0.0004	0.128	0.0002	0.52	0.0002	0.0011
2003	Cr-D	48	0.013	0.0006	0.031	0.0002	0.17	0.0002	0.0093
2004	Cr-D	48	0.002	0.0007	0.002	0.0002	0.009	0.0003	0.0018
2005	Cr-D	48	0.007	0.005	0.008	0.0002	0.033	0.002	0.008
2006	Cr-D	45	0.004	0.001	0.005	0.0002	0.019	0.001	0.008
2007	Cr-D	45	0.001	0.001	0.0005	0.001	0.003	0.001	0.001
2008	Cr-D	52	0.001	0.001	0.000	0.001	0.001	0.001	0.001
2009	Cr-D	49	0.001	0.001	0.0003	0.001	0.003	0.001	0.001
2010	Cr-D	48	0.001	0.001	0.0002	0.001	0.002	0.001	0.001
Total chromium									
2001	Cr-T	48	5.6	4.8	2.9	1.0	13	3.7	7.8
2002	Cr-T	35	4.5	3.7	2.8	1.3	15	3.1	4.6
2003	Cr-T	48	3.4	3.4	1.5	0.86	6.9	2.2	4.4
2004	Cr-T	48	3.4	3.4	1.5	0.87	9.7	2.1	4.3
2005	Cr-T	48	3.3	3.0	1.6	1.1	7.6	2.3	4.1
2006	Cr-T	45	3.2	2.4	2.6	0.006	9.0	1.3	3.7
2007	Cr-T	45	3.2	2.6	3.8	0.002	25	0.7	4.3
2008	Cr-T	52	3.1	3.2	1.8	0.008	6.9	1.6	4.6
2009	Cr-T	49	3.3	3.5	1.9	0.20	7.8	1.8	4.8
2010	Cr-T	48	3.7	3.4	2.3	0.001	9.4	2.0	5.6

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved chromium, Total chromium, N=Number of analyses per year, Stdev=Standard Deviation

3.3.4 Copper

Figure 3-4A shows the box plots during 2010 for concentrations of both dissolved and total copper. Dissolved copper values showed a sharp rise during April which probably reflected operating difficulties with the Cyanide Destruction Plant during that month before returning to normal. Total concentrations varied noticeably over the same period. The 2010 mean monthly concentrations for copper are shown in Table 3-4A.

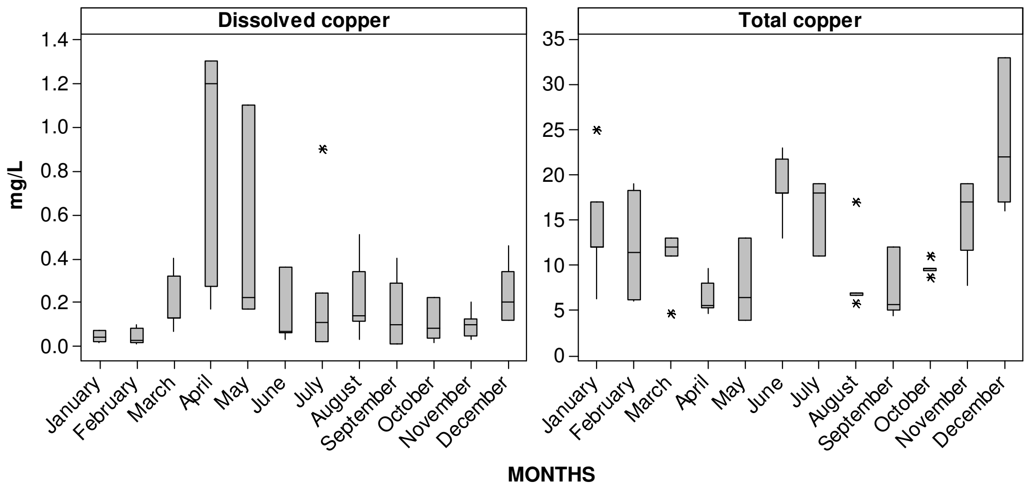


Figure 3-4A Box plots of dissolved and total copper in tailings for 2010

Table 3-4A Mean monthly concentrations (mg/L) for dissolved and total copper for 2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Cu-D	0.04	0.04	0.2	0.8	0.5	0.2	0.3	0.2	0.2	0.1	0.1	0.3
Cu-T	15	12	10	6.7	8.0	18	15	8.5	8.4	9.7	15	23

Figure 3-4B shows box plots of dissolved and total copper in tailings from 2001 to 2010. Dissolved and total copper concentrations varied over the 10-year period, and the low values for dissolved copper for 2009 and 2010 demonstrate the positive effect of the CDP in reducing the copper levels.

Table 3-4B gives a statistical summary of copper annual concentrations in tailings for both dissolved and total fractions from 2001-2010. As mentioned above, the mean dissolved copper concentration decreased sharply in 2009 and 2010 following the commissioning of the CDP.

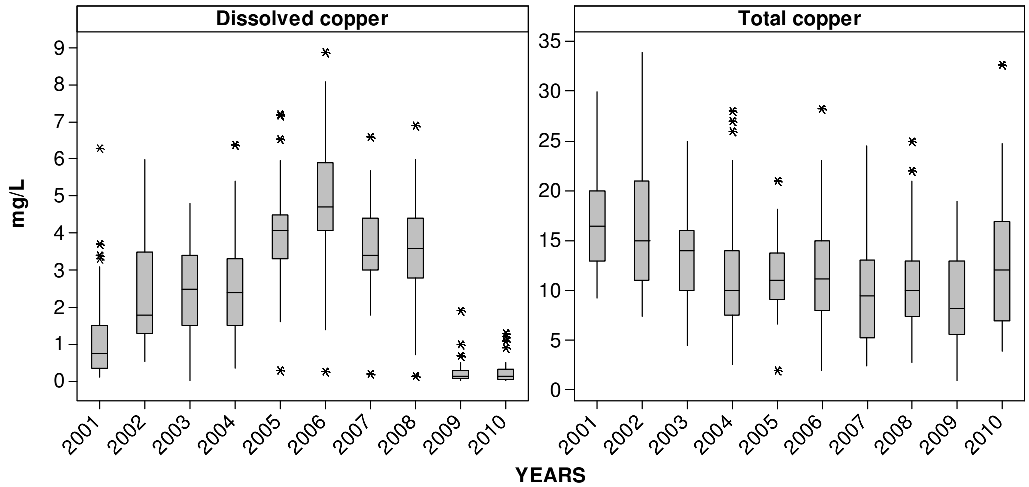


Figure 3-4B Box plots of dissolved and total copper in tailings from 2001-2010

Table 3-4B Summary statistics for dissolved and total copper concentrations in tailings since 2001 (results in mg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved copper									
2001	Cu-D	48	1.0	0.8	0.9	0.11	3.7	0.35	1.5
2002	Cu-D	35	2.5	2.0	1.5	0.54	5.8	1.3	3.5
2003	Cu-D	48	2.5	2.6	1.2	0.01	4.8	1.5	3.3
2004	Cu-D	48	2.6	2.4	1.3	0.36	6.4	1.5	3.3
2005	Cu-D	48	4.1	4.1	1.3	0.3	7.2	3.3	4.5
2006	Cu-D	45	4.9	4.7	1.8	0.3	8.9	4.1	5.9
2007	Cu-D	45	3.6	3.4	1.1	0.2	6.6	3.0	4.4
2008	Cu-D	52	3.5	3.6	1.5	0.1	6.9	2.8	4.4
2009	Cu-D	49	0.3	0.1	0.4	0.01	1.9	0.08	0.3
2010	Cu-D	48	0.2	0.1	0.3	0.01	1.3	0.04	0.3
Total copper									
2001	Cu-T	48	17	17	5.0	9.2	30	13	21
2002	Cu-T	35	17	16	6.2	7.4	34	12	21
2003	Cu-T	48	14	14	4.2	4.9	25	10	16
2004	Cu-T	48	11	10	6.0	2.5	28	7.0	14
2005	Cu-T	48	12	11	3.3	6.6	21	9.2	14
2006	Cu-T	45	12	11	5.5	1.9	28	8.0	15
2007	Cu-T	45	11	9.4	15	2.4	114	5.2	13
2008	Cu-T	52	11	10	5.2	2.7	25	7.4	14
2009	Cu-T	49	9.3	8.2	4.7	0.9	19	5.7	13
2010	Cu-T	48	13	12	6.4	3.9	33	6.9	17

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved copper, T=Total copper, N=Number of analyses per year, Stedv=Standard deviation.

3.3.5 Iron

Figure 3-5A shows the box plots during 2010 for both dissolved and total concentrations of iron. Both dissolved and total iron results varied noticeably throughout the year. The 2010 mean monthly concentrations for iron are shown in Table 3-5A.

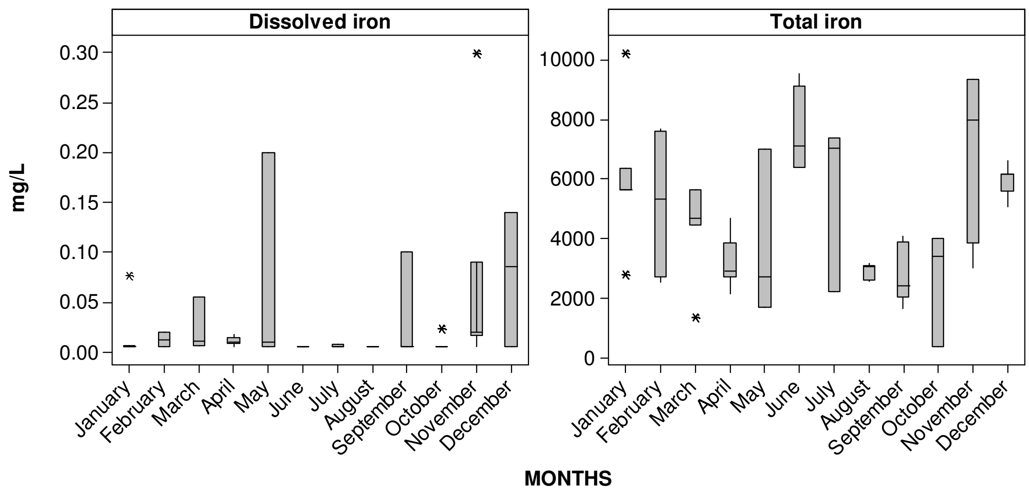


Figure 3-5A Box plots of dissolved and total iron in tailings for 2010

Table 3-5A Mean monthly concentrations (mg/L) for dissolved and total iron for 2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Fe-D	0.008	0.013	0.028	0.011	0.069	0.005	0.005	0.005	0.031	0.009	0.082	0.068
Fe-T	6200	5230	4200	3320	3960	7540	5560	2960	2960	2230	6340	5890

Figure 3-5B shows box plots of dissolved and total iron in tailings from 2001 to 2010. Dissolved iron concentrations have decreased over the 10-year period from higher values of the early 2000s during the pH trial to the current low levels. Total concentrations have decreased slightly over the same period.

Table 3-5B gives a statistical summary of iron annual concentrations in tailings for both dissolved and total fractions from 2001 to 2010.

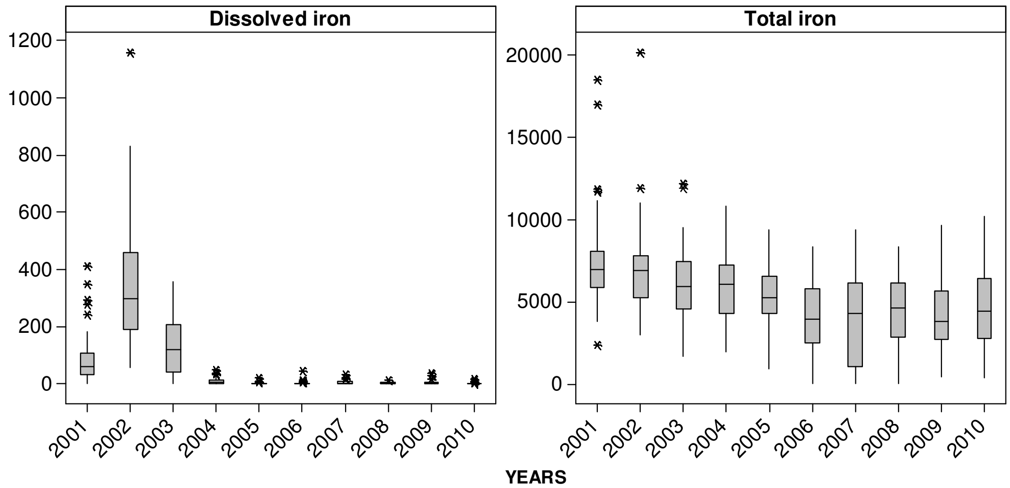


Figure 3-5B Box plots of dissolved and total iron in tailings from 2001-2010

Table 3-5B Summary statistics for dissolved and total iron concentrations in tailings since 2001 (results in mg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved iron									
2001	Fe-D	48	95	61	102	0.48	411	34	106
2002	Fe-D	35	347	307	232	55	1160	190	393
2003	Fe-D	48	126	119	96	0.50	357	44	205
2004	Fe-D	48	9.3	7.3	10	0.033	47	1.5	13
2005	Fe-D	48	1.9	0.5	3.4	0.003	20	0.09	2.8
2006	Fe-D	45	2.5	0.4	6.5	0.005	43	0.1	2.0
2007	Fe-D	45	5.1	1.8	7.1	0.005	32	0.09	7.5
2008	Fe-D	52	3.5	2.8	3.2	0.009	13	1.0	5.3
2009	Fe-D	49	4.5	0.8	7.7	0.005	38	0.01	6.0
2010	Fe-D	48	0.8	0.01	3.1	0.005	18	0.003	0.020
Total iron									
2001	Fe-T	48	7494	6955	2938	2340	18500	5706	8090
2002	Fe-T	35	7231	7060	2924	3015	20200	5560	7835
2003	Fe-T	48	6119	6030	2240	1700	12200	4877	7490
2004	Fe-T	48	5703	6070	2049	1953	10850	4228	7375
2005	Fe-T	48	5220	5240	1770	1820	9400	4280	6550
2006	Fe-T	45	4140	3970	2210	212	8380	2480	5790
2007	Fe-T	45	3980	4040	2740	6.4	9400	935	6180
2008	Fe-T	52	4353	4605	2193	12	8320	2822	5960
2009	Fe-T	49	4465	3825	2417	470	9690	2877	5735
2010	Fe-T	48	4732	4464	2398	366	10240	2815	6415

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved iron, T=Total iron, N=Number of analyses per year, Stdev=Standard deviation.

3.3.6 Lead

Figure 3-6A shows the box plots during 2010 for both dissolved and total concentrations of lead. Most dissolved lead values were at or near the detection level throughout the year while total lead concentrations varied noticeably over the same period. The 2010 mean monthly concentrations for lead are shown in Table 3-6A.

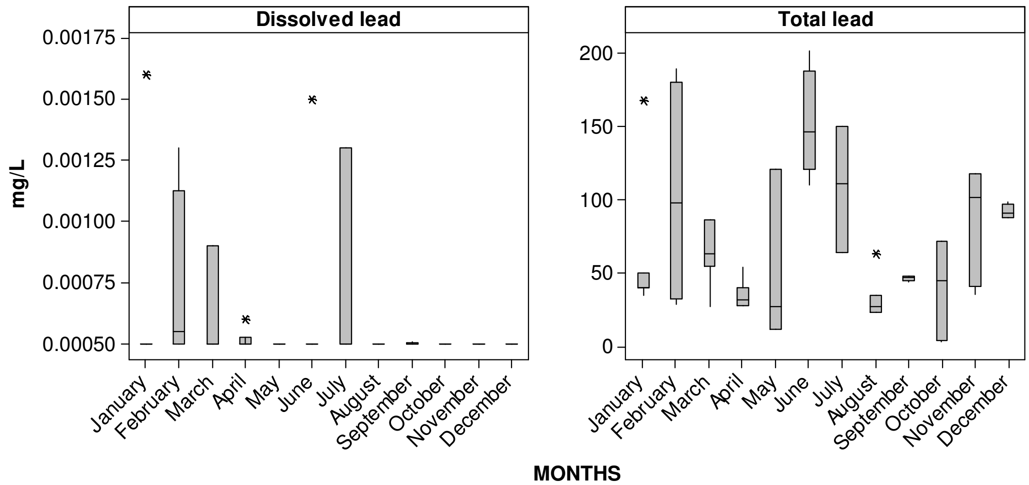


Figure 3-6A Box plots of dissolved and total lead in tailings for 2010

Table 3-6A Mean monthly concentrations (mg/L) for dissolved and total lead for 2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Pb-D	0.0008	0.0007	0.0007	0.0005	0.0005	0.0007	0.0007	0.0005	0.0005	0.0005	0.0005	0.0005
Pb-T	70	104	60	37	56	147	107	33	46	35	78	93

Figure 3-6B shows box plots of dissolved and total lead in tailings from 2001 to 2010. Dissolved lead values were elevated during the pH trial in the early 2000s.

Table 3-6B gives a statistical summary of lead annual concentrations in tailings for both dissolved and total lead over the 10-year period. The rise in dissolved lead in the early 2000s resulting from the pH optimsation trial at the mill can be seen in the table.

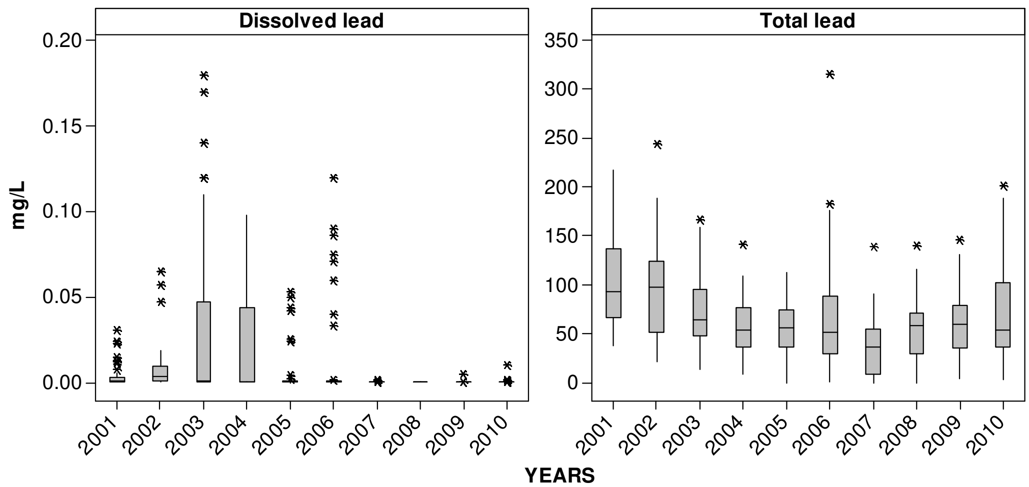


Figure 3-6B Box plots of dissolved and total lead in tailings from 2001-2010

Table 3-6B Summary statistics for dissolved and total lead concentration in tailings since 2001 (results in mg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved lead									
2001	Pb-D	48	0.004	0.0009	0.0068	0.0002	0.03	0.0003	0.003
2002	Pb-D	35	0.005	0.0026	0.0051	0.0002	0.02	0.0013	0.006
2003	Pb-D	48	0.031	0.0012	0.052	0.0002	0.18	0.0002	0.047
2004	Pb-D	48	0.021	0.0007	0.028	0.0001	0.098	0.0002	0.044
2005	Pb-D	48	0.006	0.0002	0.014	0.0002	0.053	0.0002	0.0009
2006	Pb-D	45	0.013	0.0005	0.030	0.0002	0.1	0.0002	0.0008
2007	Pb-D	45	0.001	0.0005	0.0002	0.0005	0.002	0.0005	0.0005
2008	Pb-D	52	0.0005	0.0005	0.0000	0.0005	0.0005	0.0005	0.0005
2009	Pb-D	49	0.0007	0.0005	0.0009	0.0005	0.005	0.0005	0.0005
2010	Pb-D	48	0.0008	0.0005	0.0001	0.0005	0.010	0.0005	0.0005
Total lead									
2001	Pb-T	48	101	93	42	38	218	69	138
2002	Pb-T	35	104	102	52	31	244	62	130
2003	Pb-T	48	71	64	37	13	167	48	95
2004	Pb-T	48	56	53	27	8.3	141	36	77
2005	Pb-T	48	56	57	26	0.002	113	36	75
2006	Pb-T	45	70	54	60	5.9	315	31	89
2007	Pb-T	45	35	36	27	0.002	139	7.4	53
2008	Pb-T	52	55	59	30	0.1	140	29	71
2009	Pb-T	49	60	60	32	3.8	146	35	78
2010	Pb-T	48	72	54	49	3.0	202	36	102

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved lead, T=Total lead, N=Number of analyses per year, Stdev=Standard deviation.

3.3.7 Mercury

Figure 3-7A shows the boxplots during 2010 for both dissolved and total concentrations of mercury. Both dissolved and total mercury varied throughout the year but values were very low. The 2010 mean monthly concentrations for mercury are shown in Table 3-1A.

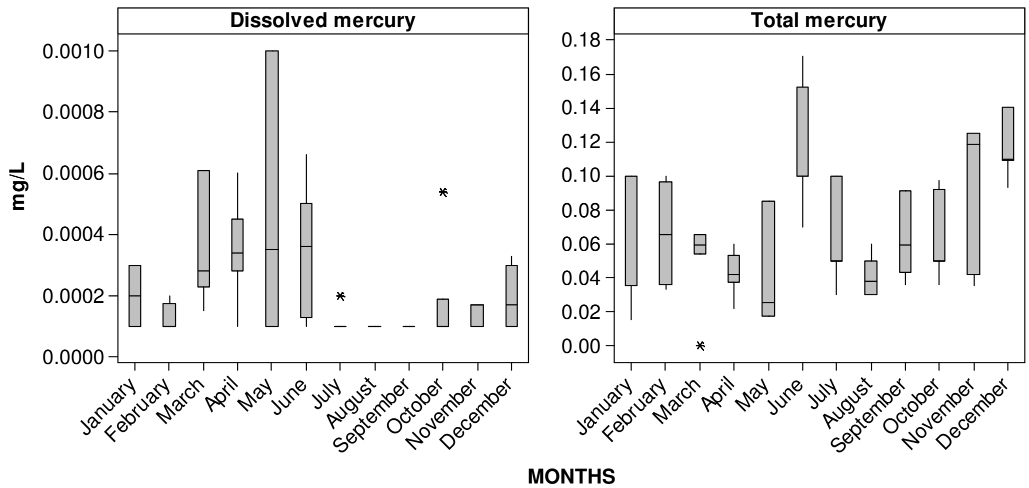


Figure 3-7A Box plots of dissolved and total mercury in tailings for 2010

Table 3-7A Mean monthly concentrations (mg/L) for dissolved and total mercury for 2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Hg-D	0.0002	0.0001	0.0003	0.0004	0.0005	0.0004	0.0001	0.0001	0.0001	0.0002	0.0001	0.0002
Hg-T	0.060	0.066	0.047	0.044	0.044	0.10	0.060	0.040	0.060	0.067	0.083	0.10

Figure 3-7B shows box plots of dissolved and total mercury concentrations in tailings from 2001 to 2010. The dissolved mercury values have remained reasonably consistent since 2001 while total mercury shows a gradual decline which corresponds with geological observations with increasing depth within the open pit.

Table 3-7B gives a statistical summary of mercury annual concentrations in tailings for both dissolved and total fractions from 2001 to 2010.

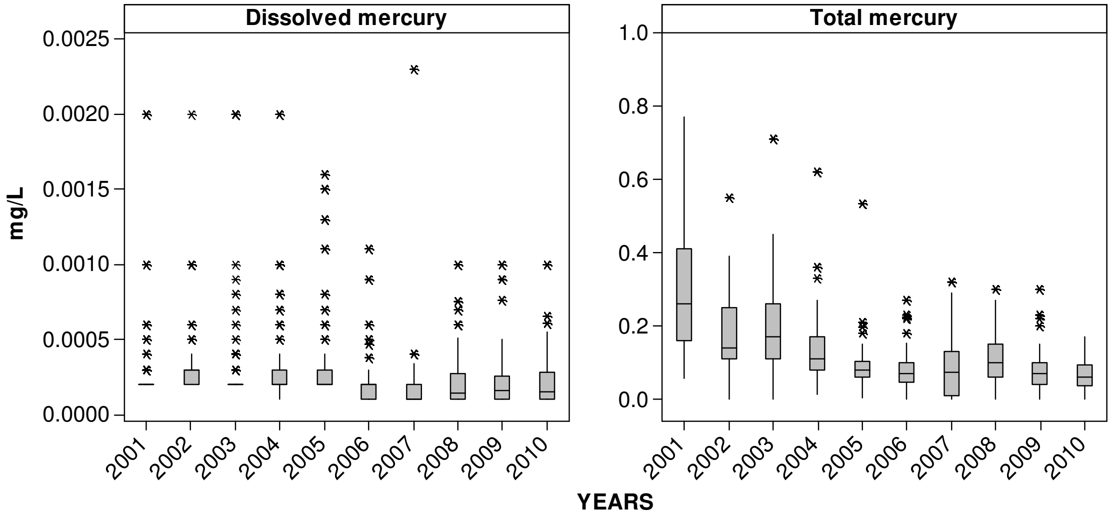


Figure 3-7B Boxplots of dissolved and total mercury in tailings from 2001-2010

Table 3-7B Summary statistics for dissolved and total mercury concentrations in tailings since 2001 (results in mg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved mercury									
2001	Hg-D	48	0.0003	0.0002	0.0003	0.0002	0.002	0.0002	0.0002
2002	Hg-D	35	0.0006	0.0003	0.0014	0.0002	0.008	0.0002	0.0003
2003	Hg-D	48	0.0003	0.0002	0.0004	0.0002	0.002	0.0002	0.0002
2004	Hg-D	48	0.0004	0.0002	0.0003	0.0001	0.002	0.0002	0.0004
2005	Hg-D	48	0.0003	0.0002	0.0003	0.0002	0.002	0.0002	0.0003
2006	Hg-D	45	0.0003	0.0002	0.0004	0.0001	0.003	0.0001	0.0002
2007	Hg-D	45	0.0002	0.0001	0.0003	0.0001	0.002	0.0001	0.0002
2008	Hg-D	52	0.0002	0.0001	0.0002	0.0001	0.001	0.0001	0.0003
2009	Hg-D	49	0.0002	0.0002	0.0002	0.0001	0.001	0.0001	0.0003
2010	Hg-D	48	0.0002	0.0002	0.0002	0.0001	0.001	0.0001	0.0003
Total mercury									
2001	Hg-T	48	0.3	0.3	0.18	0.060	0.8	0.2	0.4
2002	Hg-T	35	0.4	0.2	0.98	0.031	5.8	0.1	0.3
2003	Hg-T	48	0.2	0.2	0.13	0.0002	0.7	0.1	0.3
2004	Hg-T	48	0.1	0.1	0.10	0.014	0.6	0.1	0.2
2005	Hg-T	48	0.1	0.1	0.08	0.002	0.5	0.1	0.1
2006	Hg-T	45	0.1	0.1	0.06	0.0001	0.3	0.05	0.1
2007	Hg-T	45	0.2	0.07	0.5	0.0001	3.3	0.01	0.1
2008	Hg-T	52	0.1	0.1	0.07	0.0002	0.3	0.06	0.2
2009	Hg-T	49	0.08	0.07	0.06	0.0002	0.3	0.04	0.1
2010	Hg-T	48	0.07	0.06	0.04	0.0002	0.2	0.04	0.09

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved mercury, T=Total mercury, N=Number of analyses per year, Stdev=Standard deviation.

3.3.8 Nickel

Figure 3-8A shows the box plots during 2010 for both dissolved and total concentrations of nickel. Both dissolved and total nickel values showed considerable variation throughout the year. The 2010 mean monthly concentrations for nickel are shown in Table 3-8A.

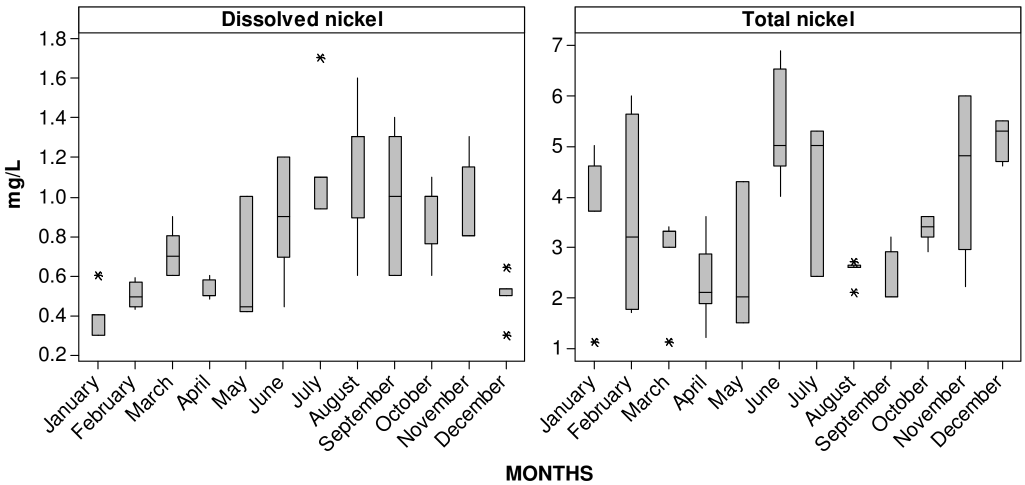


Figure 3-8A Box plots of dissolved and total nickel in tailings for 2010

Table 3-8A Mean monthly concentrations (mg/L) for dissolved and total nickel for 2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Ni-D	0.4	0.5	0.7	0.5	0.6	0.9	1.2	1.2	1.0	0.9	1.0	0.5
Ni-T	3.6	3.5	2.8	2.4	2.7	5.3	4.2	2.6	2.4	3.3	4.2	5.1

Figure 3-8B shows box plots of dissolved and total nickel in tailings from 2001 to 2010. Dissolved nickel concentrations decreased markeldy from higher levels in the early 2000s to the current lower values. Total nickel values have remained reasonably steady over the same period.

Table 3-8B gives a statistical summary of nickel annual concentrations in tailings for both dissolved and total fractions from 2001 to 2010.

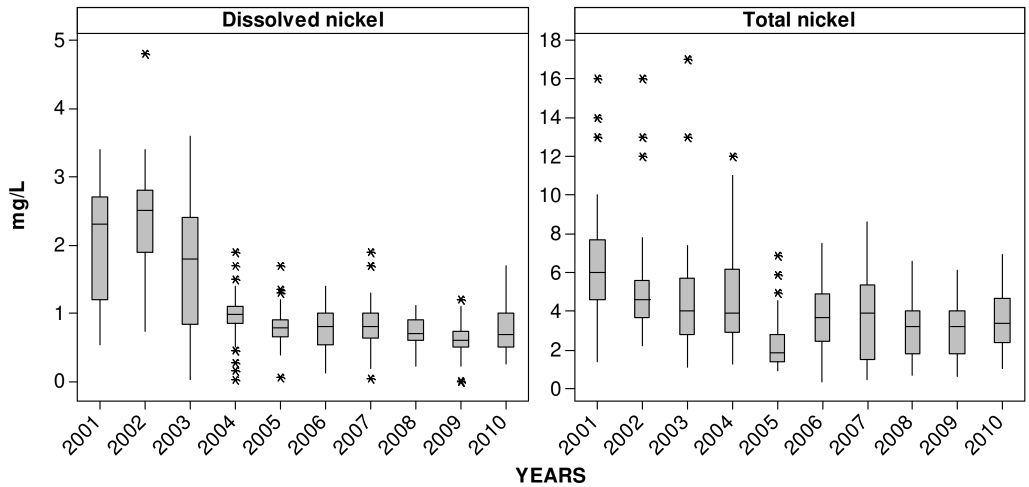


Figure 3-8B Box plots of dissolved and total nickel in tailings from 2001-2010 .

Table 3-8B Summary statistics for dissolved and total nickel concentrations in tailings since 2001 (results in mg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved nickel									
2001	Ni-D	48	2.1	2.3	0.8	0.5	3.4	1.4	2.7
2002	Ni-D	35	2.3	2.4	0.8	0.7	4.8	1.9	2.7
2003	Ni-D	48	1.8	1.8	0.9	0.4	3.6	0.9	2.4
2004	Ni-D	48	1.0	1.0	0.3	0.02	1.9	0.8	1.1
2005	Ni-D	48	0.8	0.8	0.3	0.06	1.7	0.7	0.9
2006	Ni-D	45	0.8	0.8	0.3	0.1	1.4	0.6	1.0
2007	Ni-D	45	0.8	0.8	0.4	0.04	1.9	0.5	1.0
2008	Ni-D	52	0.7	0.7	0.2	0.2	1.1	0.6	0.9
2009	Ni-D	49	0.6	0.6	0.2	0.2	1.2	0.5	0.7
2010	Ni-D	48	0.8	0.7	0.3	0.3	1.7	0.5	1.0
Total nickel									
2001	Ni-T	48	6.8	6.0	3.4	1.4	16	4.6	8.0
2002	Ni-T	35	5.4	4.8	3.0	2.2	16	3.6	6.0
2003	Ni-T	48	5.0	4.1	3.5	1.1	17	2.9	5.8
2004	Ni-T	48	4.7	4.0	2.5	1.3	12	2.9	6.2
2005	Ni-T	48	2.4	2.2	1.3	1.0	6.9	1.5	2.8
2006	Ni-T	45	3.7	3.7	1.7	0.7	7.5	2.5	4.9
2007	Ni-T	45	3.4	3.2	2.2	0.4	8.6	1.2	5.3
2008	Ni-T	52	3.3	3.2	1.6	0.7	7.1	1.8	4.3
2009	Ni-T	49	3.0	3.2	1.4	0.6	6.1	1.9	4.0
2010	Ni-T	48	3.5	3.4	1.4	1.1	6.9	2.4	4.6

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved nickel, T=Total nickel, N=Number of analyses per year, Stdev=Standard deviation.

3.3.9 Silver

Figure 3-9A shows the box plots during 2010 for both dissolved and total concentrations of silver. Dissolved silver values were at or below the detection level throughout the year. Total silver concentrations were varied throughout 2010. The 2010 mean monthly concentrations for silver are shown in Table 3-9A.

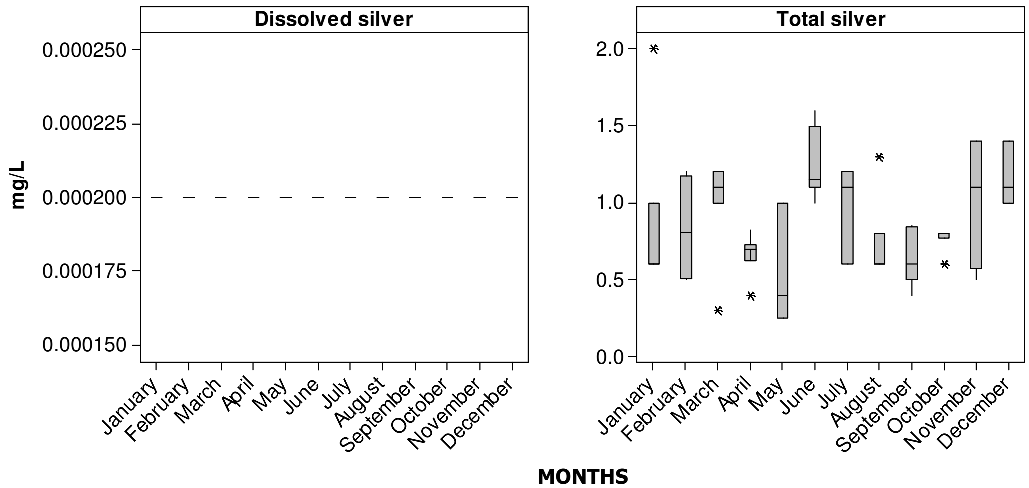


Figure 3-9A Box plots of dissolved and total silver in tailings for 2010

Table 3-9A Mean monthly concentrations (mg/L) for dissolved and total silver for 2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Ag-D	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Ag-T	1.0	0.8	0.9	0.7	0.6	1.2	1.0	0.8	0.7	0.7	0.9	1.2

Figure 3-9B shows the analyses for dissolved and total silver in tailings from 2001 to 2010. Dissolved silver concentrations rose until 2005 but have since decreased to very low levels in recent years. Total concentrations showed little variation over the 10-year period.

Table 3-9B gives a statistical summary of silver annual concentrations in tailings for both the dissolved and total fractions from 2001 to 2010.

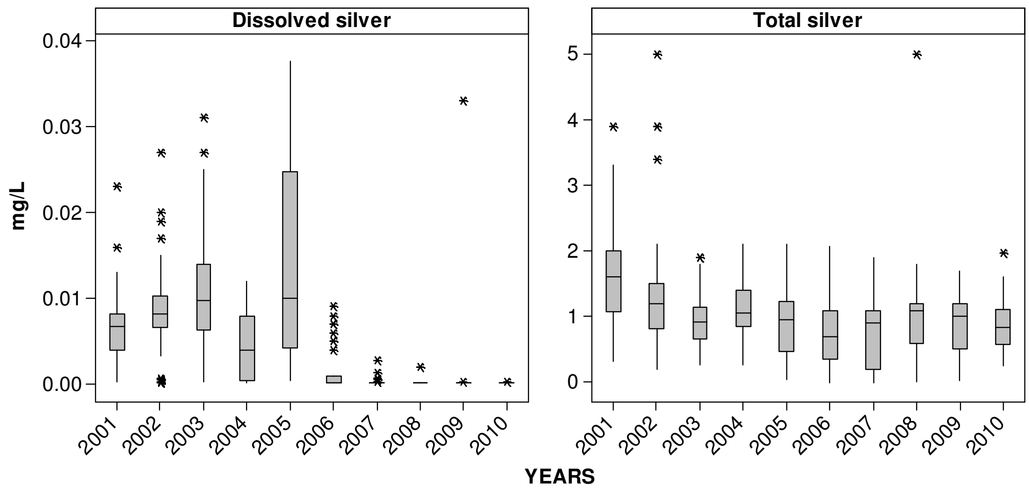


Figure 3-9B Box plots of dissolved and total silver in tailings from 2001-2010.

Table 3-9B Summary statistics for dissolved and total silver concentrations in tailings since 2001 (results in mg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved silver									
2001	Ag-D	48	0.007	0.006	0.004	0.0003	0.023	0.004	0.007
2002	Ag-D	35	0.009	0.008	0.006	0.0002	0.027	0.007	0.010
2003	Ag-D	48	0.012	0.010	0.006	0.0003	0.031	0.007	0.014
2004	Ag-D	48	0.004	0.004	0.004	0.0002	0.012	0.0005	0.008
2005	Ag-D	48	0.028	0.009	0.083	0.0004	0.50	0.004	0.025
2006	Ag-D	45	0.002	0.0003	0.004	0.0002	0.022	0.0002	0.005
2007	Ag-D	45	0.0003	0.0002	0.0004	0.0002	0.003	0.0002	0.0002
2008	Ag-D	52	0.0002	0.0002	0.0002	0.0002	0.002	0.0002	0.0002
2009	Ag-D	49	0.0002	0.0002	0.0001	0.0002	0.0003	0.0002	0.0002
2010	Ag-D	48	0.0002	0.0002	0.0001	0.0002	0.0003	0.0002	0.0002
Total silver									
2000	Ag-T	52	1.1	1.0	0.6	0.08	2.7	0.8	1.3
2001	Ag-T	48	1.6	1.6	0.7	0.3	3.9	1.1	2.0
2002	Ag-T	35	1.4	1.2	1.0	0.2	5.0	0.8	1.4
2003	Ag-T	48	1.0	1.0	0.4	0.3	1.9	0.8	1.2
2004	Ag-T	48	1.1	1.1	0.4	0.3	2.1	0.8	1.4
2005	Ag-T	48	0.9	1.0	0.5	0.04	2.1	0.5	1.2
2006	Ag-T	45	1.0	0.7	1.7	0.06	12	0.4	1.1
2007	Ag-T	45	0.7	0.8	0.6	0.0002	1.9	0.2	1.1
2008	Ag-T	52	1.0	1.1	0.7	0.002	5.0	0.6	1.2
2009	Ag-T	49	0.9	1.0	0.5	0.03	1.7	0.5	1.2
2010	Ag-T	48	0.9	0.8	0.4	0.2	2.0	0.6	1.1

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved silver, T=Total silver, N=Number of analyses per year, Stdev=Standard deviation.

3.3.10 Zinc

Figure 3-10A shows the box plots during 2010 for both dissolved and total concentrations of zinc. Dissolved zinc values rose to a peak in July before decreasing later in the year. Total zinc values showed considerable variation during the same period. The 2010 mean monthly concentrations for zinc are shown in Table 3-10A.

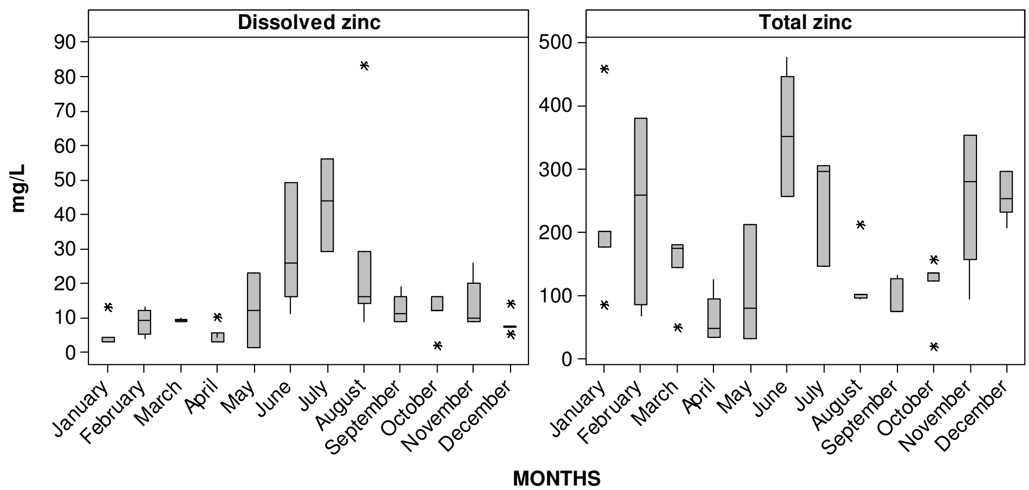


Figure 3-10A Box plots of dissolved and total zinc in tailings for 2010

Table 3-10A Mean monthly concentrations (mg/L) for dissolved and total zinc for 2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Zn-D	5.5	8.8	9.4	4.9	13	28	44	28	13	11	15	8.4
Zn-T	227	241	141	70	112	341	239	119	100	111	234	252

Figure 3-10B shows box plots of dissolved and total zinc in tailings from 2001 to 2010. Dissolved zinc concentrations were elevated during the pH trial in the early 2000s but have since decreased to lower levels. Total zinc values were elevated to a lesser extent during the same period.

Table 3-10B gives a statistical summary of zinc annual concentrations in tailings for both dissolved and total fractions from 2001 to 2010. As mentioned above, dissolved zinc concentrations were noticeably higher in the early 2000s, with total values also higher but to a lesser extent, due to the pH trial.

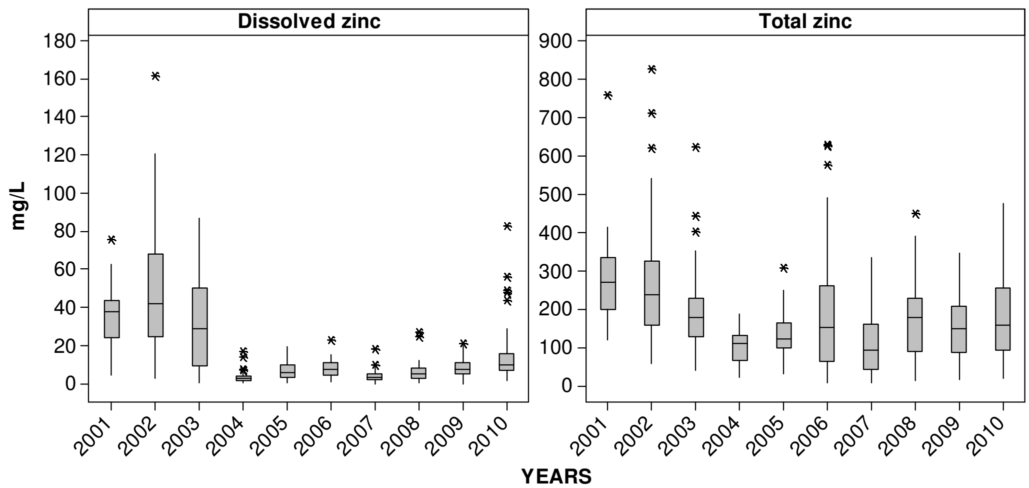


Figure 3-10B Box plots of dissolved and total zinc in tailings from 2001-2010.

Table 3-10B Summary statistics for dissolved and total zinc concentrations in tailings since 2001 (results in mg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved zinc									
2001	Zn-D	48	36	35	15	4.8	76	25	44
2002	Zn-D	35	55	45	34	11	162	30	72
2003	Zn-D	48	31	28	23	1.1	87	9.7	49
2004	Zn-D	48	3.0	2.5	2.2	0.47	14	1.8	3.7
2005	Zn-D	48	7.5	6.1	5.1	0.09	19	3.1	11
2006	Zn-D	45	7.7	7.4	4.3	1.2	23	4.4	11
2007	Zn-D	45	4.3	3.2	3.5	0.05	18	1.9	6.3
2008	Zn-D	52	6.4	5.3	5.2	0.3	27	3.0	8.2
2009	Zn-D	49	8.7	7.8	5.1	0.3	21	4.9	11
2010	Zn-D	48	15	10	14	1.3	83	7.2	16
Total zinc									
2001	Zn-T	48	282	272	109	120	761	201	338
2002	Zn-T	35	303	270	177	75	827	165	383
2003	Zn-T	48	189	178	106	40	625	128	232
2004	Zn-T	48	104	112	44	24	188	68	132
2005	Zn-T	48	135	122	54	40	308	101	308
2006	Zn-T	45	192	154	160	26	631	64	263
2007	Zn-T	45	111	93	86	7.3	336	45	163
2008	Zn-T	52	175	174	105	13	452	91	229
2009	Zn-T	49	152	149	77	17	347	89	208
2010	Zn-T	48	184	157	113	20	476	94	256

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved zinc, T=Total zinc, N=Number of analyses per year, Stdev=Standard deviation.

3.4 Cyanide Concentrations in Tailings

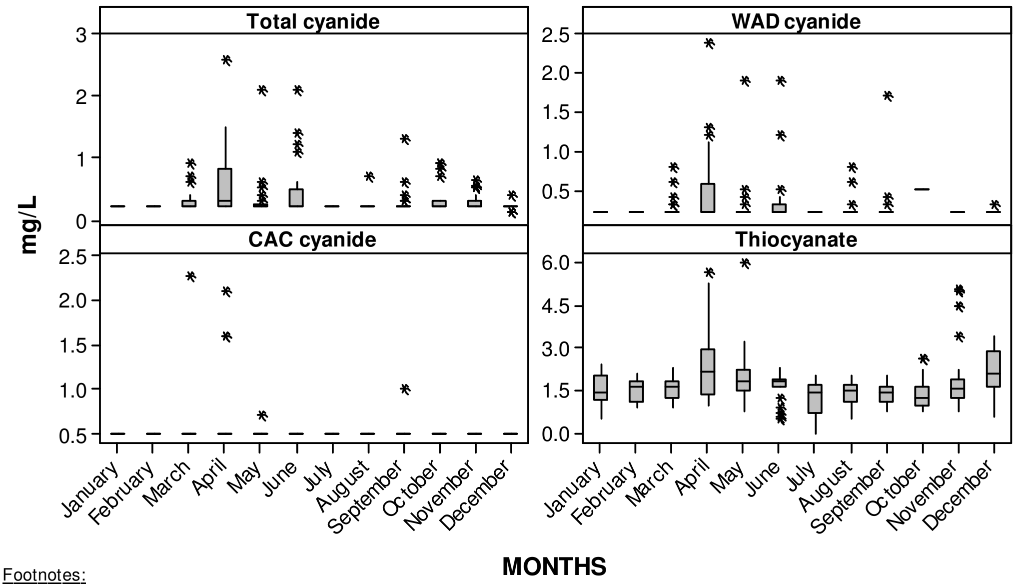
Cyanide detoxification takes place in the tailings neutralisation circuit. Free cyanide in the circuit forms insoluble metal complexes with iron, copper, nickel, lead, zinc, cadmium and silver. The cyanide complexation process with metal species in solution maximizes the reduction of free cyanide levels before discharge.

As a check on Process Plant operations during 2010, two daily snap samples were collected morning and afternoon from the tailings discharge by PJV Environment personnel and analysed for total cyanide (TCN), weak acid dissociable cyanide (WAD CN), cyanide amendable to chlorination (CAC), and thiocyanate concentrations (SCN). TCN and WAD CN analyses were conducted on unfiltered samples, while CAC and SCN required the analyses to be conducted on filtered samples.

Figure 3-11A shows the concentrations for the various forms of cyanide in tailings, i.e. total, WAD, CAC and thiocyanate for 2010. The concentrations of all four parameters remained reasonably steady during this period.

The Cyanide Destruction Plant (CDP) was commissioned in early 2009 as an integral part of the Process Plant to maximize the destruction of cyanide and to minimize the release of WAD CN to meet the criterion of 0.5mg/L for tailings release in accordance with the International Cyanide Management Code.

The CDP uses the INCO process whereby sulfur dioxide (SO_2) is introduced in gas/ liquid form (or as sodium metabisulphite at Porgera) to oxidize cyanide and thiocyanate into cyanate, which together with metal cyanide complexes are broken down resulting in precipitation of both metal hydroxides and retro cyanide solid precipitates. The reaction is catalysed by the addition of copper as copper sulfate (plus POX acid at Porgera) with air addition (or oxygen at Porgera), and caustic soda to control pH in the range 8.5-9.5. The process takes place in a stirred tank reactor and is straightforward to operate and monitor its performance.



Footnotes:
WAD cyanide: Weak acid dissociable cyanide
CAC cyanide: Cyanide amenable to chlorination

Figure 3-11A Monthly concentrations for the various cyanide forms during 2010

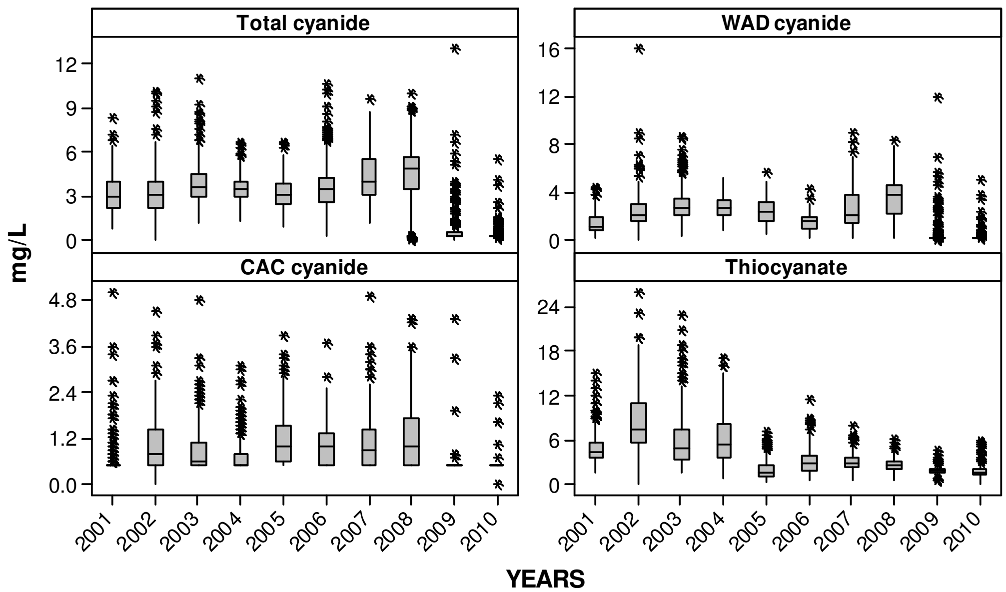
Table 3-11A shows the mean monthly results for the various forms of cyanide for 2010. Increases were noted for total and WAD cyanide, and thiocyanate especially during April for plant operating reasons, but results for most of the year were satisfactory.

Table 3-11A Mean monthly concentrations for the various cyanide forms during 2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
TCN	<0.2	<0.2	0.4	0.8	0.3	0.4	<0.2	<0.2	0.3	0.3	0.3	<0.2
WCN	<0.2	<0.2	0.4	0.7	0.3	0.3	<0.2	<0.2	0.3	0.3	<0.2	<0.2
CAC	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
SCN	1.5	1.5	1.6	2.4	2.0	1.7	1.2	1.4	1.4	1.3	2.0	2.2

TCN= total cyanide, WCN= weak acid dissociable cyanide, CAC= cyanide amenable to chlorination, SCN= thiocyanate

Figure 3-11B shows the concentrations for the various forms of cyanide in tailings, i.e. total, WAD, CAC and thiocyanate from 2001 to 2010. The concentrations of total, WAD and CAC cyanide showed a sharp decrease in 2009-10 after commissioning the CDP in early 2009.



Footnotes:
WAD cyanide: Weak acid dissociable cyanide
CAC cyanide: Cyanide amenable to chlorination

Figure 3-11B Mean annual concentrations for various cyanide forms from 2001-10

Table 3-11B Summary statistics for cyanide concentrations from 2001-2010 (mg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Total cyanide									
2001	TCN	365	3.2	2.9	1.3	0.7	8.3	2.2	4.0
2002	TCN	268	3.1	2.9	1.5	0.3	10	2.1	3.9
2003	TCN	365	3.8	3.6	1.4	1.1	11	2.9	4.4
2004	TCN	357	3.5	3.4	0.9	1.3	6.6	2.9	4.0
2005	TCN	349	3.1	3.1	1.0	0.9	6.6	2.4	3.9
2006	TCN	334	3.6	3.4	1.6	0.3	11	2.6	4.2
2007	TCN	320	4.3	4.0	1.6	1.2	9.6	3.0	5.5
2008	TCN	365	4.5	4.8	2.0	0.2	9.9	3.5	5.7
2009	TCN	345	0.7	0.3	1.2	0.2	13	0.2	0.5
2010	TCN	339	0.3	0.2	0.5	0.2	5.4	0.2	0.2
Weak acid dissociable cyanide									
2001	WAD CN	365	1.4	1.1	0.9	0.2	4.4	0.7	1.9
2002	WAD CN	265	2.3	2.1	1.2	0.1	9.0	1.5	2.9
2003	WAD CN	365	2.9	2.6	1.4	0.3	16	2.0	3.5
2004	WAD CN	357	2.7	2.6	0.9	0.7	5.1	2.0	3.3
2005	WAD CN	349	2.3	2.4	1.0	0.4	5.7	1.5	3.2
2006	WAD CN	334	1.4	1.5	0.6	0.1	4.2	1.0	1.8
2007	WAD CN	320	2.5	1.9	1.6	0.1	9.0	1.3	3.6

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
2008	WAD CN	365	3.4	3.7	1.8	0.1	8.4	2.3	4.6
2009	WAD CN	345	0.5	0.2	1.8	0.2	12	0.2	0.2
2010	WAD CN	339	0.3	0.2	0.4	0.2	5.0	0.2	0.2
Cyanide amenable to chlorination									
2001	CAC	365	0.6	0.5	0.4	0.05	5.0	0.5	0.5
2002	CAC	265	1.0	0.8	0.6	0.05	4.5	0.5	1.3
2003	CAC	365	0.9	0.6	0.6	0.05	4.8	0.5	1.1
2004	CAC	357	0.8	0.5	0.5	0.05	3.1	0.5	0.8
2005	CAC	349	1.1	0.9	0.6	0.05	3.9	0.6	1.5
2006	CAC	334	1.0	1.0	0.5	0.05	3.7	0.5	1.4
2007	CAC	320	1.1	0.9	0.7	0.05	4.9	0.5	1.4
2008	CAC	365	1.2	1.0	0.8	0.05	4.3	0.5	1.7
2009	CAC	345	0.5	0.5	0.3	0.05	4.3	0.5	0.5
2010	CAC	339	0.5	0.5	0.2	0.05	2.3	0.5	0.5
Thiocyanate									
2001	SCN	365	4.8	4.3	2.0	1.4	15	3.5	5.4
2002	SCN	265	8.5	7.4	3.9	2.5	26	5.8	11
2003	SCN	365	6.3	5.2	3.8	1.5	23	3.5	8.0
2004	SCN	357	6.6	5.9	3.5	1.2	17	4.0	8.7
2005	SCN	349	2.0	1.7	1.2	0.4	7.1	1.1	2.6
2006	SCN	334	3.0	2.7	1.7	0.2	11	1.7	3.9
2007	SCN	320	2.8	2.9	1.2	0.5	7.9	2.1	3.6
2008	SCN	365	2.5	2.5	0.9	0.4	6.0	1.9	3.1
2009	SCN	345	1.9	1.8	0.6	0.5	4.5	1.6	2.1
2010	SCN	339	1.7	1.6	0.8	0.5	6.0	1.2	1.9

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value) TCN=Total cyanide, WADCN=Weak Acid Dissociable cyanide, FCN=Free cyanide, SCN=Thiocyanate, N=Number of analyses per year, Stdev=Standard deviation.

3.5 pH of Tailings

During 2010, regular measurements of tailings pH were conducted on snap samples collected twice daily in the Process Plant, morning and afternoon, by PJV environmental personnel. These results were compared with the digital pH recorder located in the vicinity where the samples were taken. The digital recorder values are the official pH values while those measured on the composite samples in the laboratory are for verification purposes.

In previous years, a discrepancy or bias in pH readings was observed between pH values at the tailings discharge point and the results obtained in the environmental laboratory. By the time the tailings samples were taken, then delivered to the laboratory and analysed, the pH of the samples would always be higher than the actual tailings discharge pH (from the digital recorder) due to continuing chemical reactions within the sample. This situation was corrected at the end of 2001 by simply taking the recorded Process Plant values as the official results rather than those from the environmental laboratory.

From Figure 3-12A, pH monthly results remained reasonably consistent throughout 2010 and were for most of the time within the operating limits of pH variation (6.4-6.6).

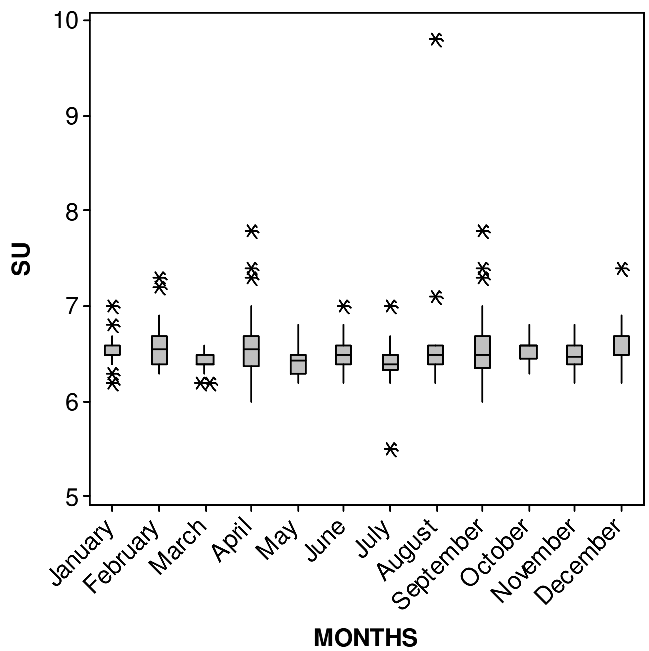


Figure 3-12A Monthly pH values for 2010

From Table 3-12A, the mean monthly values for pH were between 6.4-6.7 and remained within the pH operating criteria of 6.4 to 6.6 most of the months

Table 3-12A Mean monthly pH values for 2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
pH	6.5	6.6	6.4	6.6	6.4	6.5	6.4	6.7	6.6	6.5	6.5	6.6

From Figure 3-12B, most of the median pH values from 2001-2010 were between 6.4-6.7 (with the exception of the pH trial during the early 2000s), and the majority of the outliers were above pH 6.6, i.e. towards the conservative alkaline side.

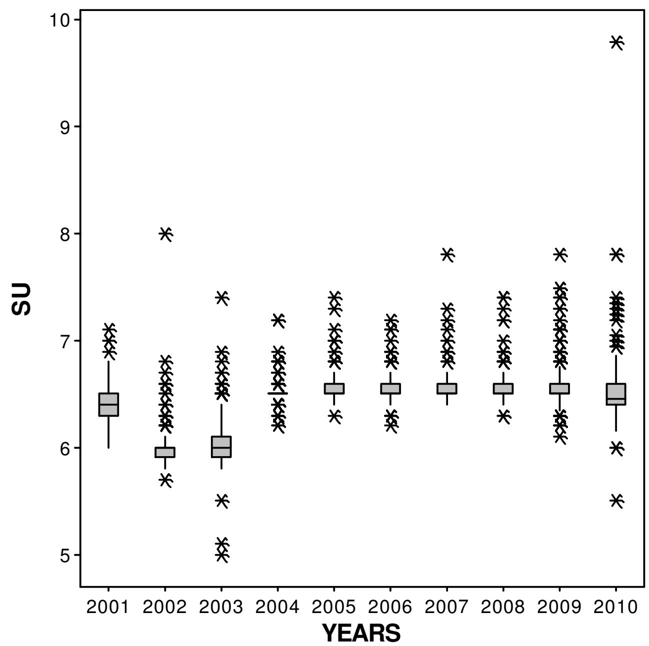


Figure 3-12B Daily pH values from 2001 to 2010

In Table 3-12B, pH values over a 10-year period are shown. The years of the pH trial, during 2002 and 2003 when the pH was lowered to 6.0, are clearly seen.

Table 3-12B Summary statistics for pH in tailings from 2001 to 2010

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
2001	pH	365	6.4	6.4	0.3	5.6	6.9	5.8	6.2
2002	pH	265	6.0	6.0	0.2	5.7	8.0	5.9	6.0
2003	pH	365	6.1	6.0	0.2	5.0	7.4	5.9	6.1
2004	pH	357	6.5	6.5	0.1	6.2	7.2	6.5	6.5
2005	pH	349	6.6	6.5	0.1	6.3	7.4	6.5	6.6
2006	pH	334	6.5	6.5	0.1	6.2	7.2	6.5	6.6
2007	pH	320	6.6	6.5	0.1	6.4	7.8	6.5	6.6
2008	pH	365	6.6	6.5	0.1	6.3	7.4	6.5	6.6
2009	pH	345	6.6	6.5	0.2	6.1	7.4	6.5	6.6
2010	pH	339	6.5	6.5	0.3	5.5	9.8	6.4	6.6

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
pH=pH units of measurement, N=Number of analyses per year, Stdev=Standard deviation.

3.6 Total Suspended Solids (TSS) in Tailings

During 2010, snap samples were collected within the Process Plant at regular times, morning and afternoon, by PJV Environment personnel to monitor for TSS in the tailings discharge.

From Figure 3-13A, the median monthly TSS values for 2010 varied between 15-21% (w/w).

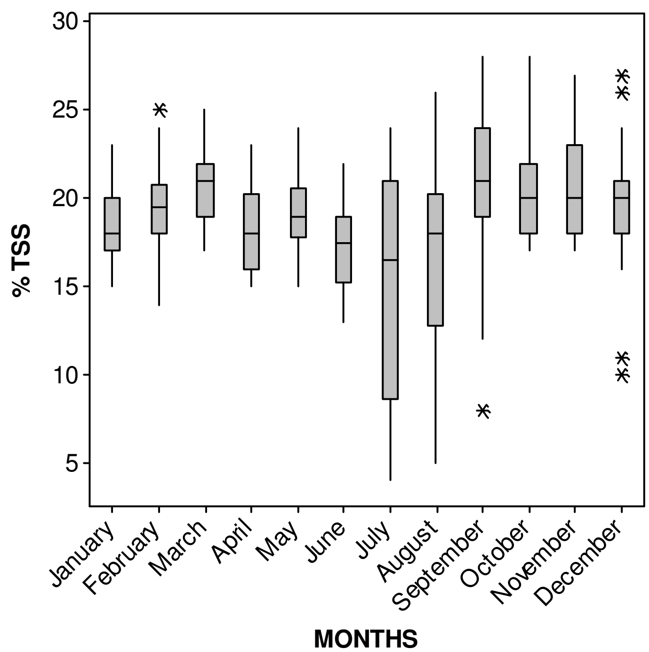


Figure 3-13A Monthly TSS levels in tailings for 2010 (% w/w)

From Table 3-13A, the mean monthly results for 2010 remained relatively consistent throughout the year, varying between 15-21% (w/w).

Table 3-13A Mean monthly TSS levels in tailings for 2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
% TSS	18	19	21	18	19	18	15	16	21	20	21	20

From Figure 3-13B, the median yearly values for TSS in tailings from 2001 to 2010 have decreased slightly over the 10-year period.

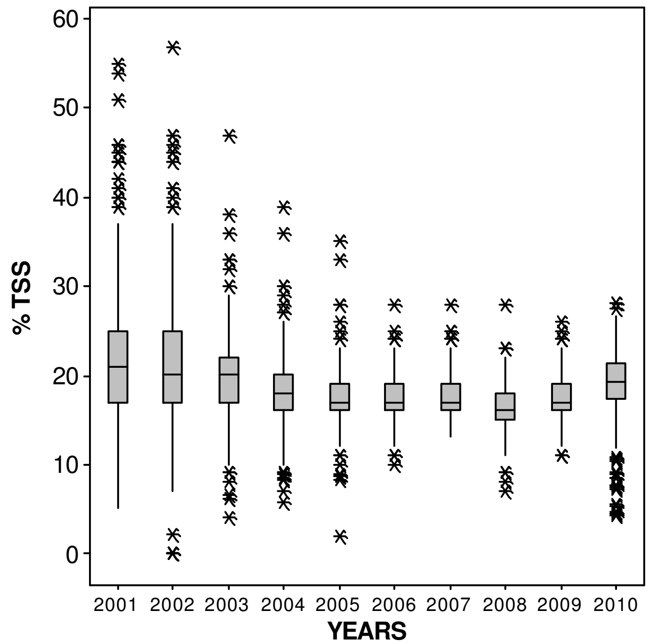


Figure 3-13B Monthly TSS levels (% w/w) in tailings from 2001 to 2010

From Table 3-13B, the mean TSS results show a slight decrease since 2001.

Table 3-13B Summary statistics for TSS values in tailings from 2001 to 2010 (% w/w)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
2001	TSS	364	22	20	7.9	5.1	55	17	24
2002	TSS	265	22	21	8.4	2.0	57	17	27
2003	TSS	365	20	20	5.0	4.0	47	17	23
2004	TSS	357	18	18	3.9	5.7	39	16	20
2005	TSS	349	17	17	3.2	1.9	35	16	19
2006	TSS	334	18	17	2.5	11	28	16	19
2007	TSS	320	17	17	2.3	10	28	16	19
2008	TSS	365	16	16	2.2	7.0	24	15	18
2009	TSS	345	17	17	2.7	11	28	16	19
2010	TSS	339	19	19	3.8	4.2	28	17	21

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
N=Number of analyses per year, Stdev=Standard deviation.

4.0 COMPLIANCE MONITORING

4.1 Introduction

Compliance monitoring station SG3 marks the end of the mixing zone for PJV. It also marks the end of the tailings and erodible rock compensation zone for people living along the river. It is important for PJV to verify compliance with permit conditions, and to anticipate and mitigate the risk of future non-compliance. This section summarizes the 2010 results for compliance monitoring at SG3 on the Upper Strickland River at Tumbudu. Box plots of trace metals and other water quality parameters are compared to compliance criteria set by the PNG Government.

4.2 Methods

During 2010, water sampling at SG3 each month involved the collection of 16 samples total, i.e. one sample every 6 hours over a 4-day period. Samples were preserved in the field (except those for total metals, ammonia and sulfate) and taken to PJV's Environmental Chemistry Laboratory at Porgera for analysis. Total suspended solids (TSS) and sulfate were analysed at Porgera while others including cyanide, ammonia, and sulfide were sent to the NMI laboratory in Sydney for analysis. Samples for total metals did not require preservation, while temperature, pH and conductivity were measured in the field immediately after each sample was taken.

Samples for dissolved metals were filtered in PJV's Environment Laboratory using acid-washed polycarbonate filtration apparatus containing cellulous nitrate polycarbonate membrane filters (0.45µm), and preserved with ultra-pure grade nitric acid before being sent to NMI. Samples for total metals were neither filtered nor preserved before sending to NMI. Results of monthly compliance monitoring that were reported to the PNG Department of Environment and Conservation (DEC) on a quarterly basis included pH, cyanide and ammonia, as well as dissolved arsenic, cadmium, chromium, copper, lead, nickel, silver and zinc. Additional non-compliance parameters reported to the DEC included total suspended solids, river flow, total mercury and sulfide.

There is no compliance value for dissolved mercury at SG3 because the mean values have always been at or below the detection limit since operations began. The PNG Government has requested that PJV measure total mercury at SG3 as an indicator of the mercury loading in the river system from natural sources and the Porgera mine.

4.3 Trace Metals and Other Parameters

The 2010 data for dissolved and total metal concentrations and other parameters for SG3 are presented as trend analyses in Figures 4-1A to 4-13A. Also presented are 10-year trend graphs from 2001-2010 (Figures 4-1B to 4-13B). The analyses were performed on individual sample results using MINITAB software to show box plots for each trace metal and other parameters. An explanation on how to interpret box plots is presented in Appendix 1. The results of previous years that summarise the statistics for each variable are presented as comparison tables in Tables 4-1 to 4-16. Other permit compliance requirements, including the results of the on-site sewage treatment and drinking water treatment plants, the permitted discharge and abstraction quantities and the autoclave stack monitoring results, are presented in Section 4.5.

4.3.1 Arsenic

Monthly dissolved arsenic concentrations remained consistently low during 2010 with the exception of August. The reason for the higher median result is unclear since there was no corresponding higher result for total arsenic. All dissolved results were well below the compliance criterion of 50µg/L (Figure 4-1A). Concentrations of total arsenic remained relatively consistent throughout the year.

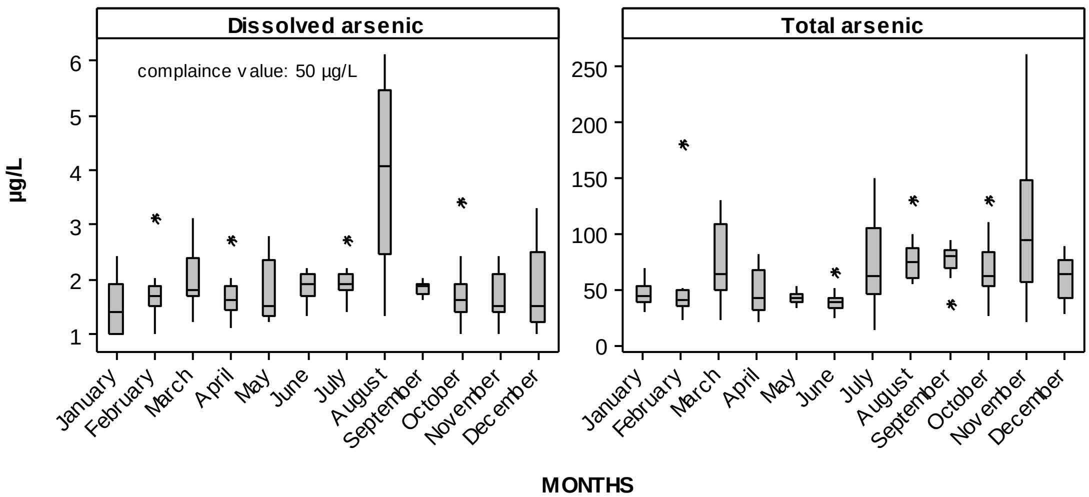


Figure 4-1A Boxplots of dissolved and total arsenic at SG3 for 2010

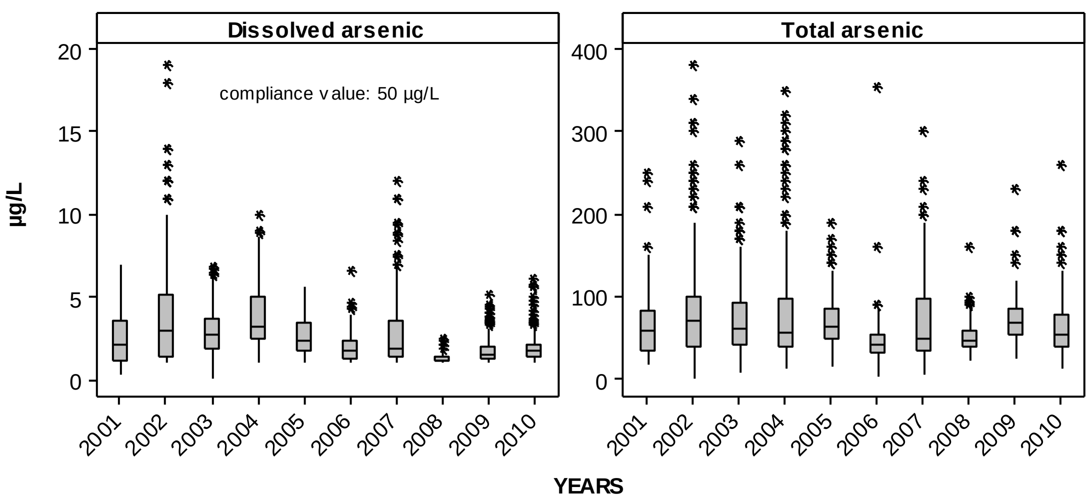


Figure 4-1B Boxplots of dissolved and total arsenic at SG3 from 2001-2010

Box plots for both dissolved and total arsenic from 2001-2010 are shown in Figure 4-1B. The results for both dissolved and total arsenic remained reasonably consistent over the 10-year period.

Annual mean dissolved and total arsenic concentrations from 2001 to 2010 are shown in Table 4-1. Dissolved mean arsenic concentrations have remained consistently low since 2001. Total mean arsenic concentrations have shown no obvious trend over the past 10 years.

Table 4-1 Summary statistics for dissolved and total arsenic concentrations from 2001 to 2010 at SG3 (all results in µg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved arsenic									
2001	As-D	192	3	2	2	0.4	7	1	4
2002	As-D	192	4	3	4	1	19	1	5
2003	As-D	192	3	3	1	1	7	2	4
2004	As-D	192	4	3	2	1	10	3	5
2005	As-D	190	3	2	1	1	6	2	3
2006	As-D	191	2	2	1	1	5	1	2
2007	As-D	178	3	3	2	1	12	2	4
2008	As-D	176	1	1	0.3	1	3	1	1
2009	As-D	176	2	2	1	1	5	1	2
2010	As-D	192	2	2	0.9	1	6	1	2
Total arsenic									
2001	As-T	192	65	58	39	17	250	36	83
2002	As-T	192	85	71	71	1	380	38	100
2003	As-T	192	77	62	51	8	290	45	92
2004	As-T	192	83	56	69	12	350	39	97
2005	As-T	190	69	64	31	15	190	50	84
2006	As-T	191	44	42	19	3	160	31	54
2007	As-T	178	69	50	53	6	300	35	91
2008	As-T	176	50	46	17	23	160	38	59
2009	As-T	176	71	68	29	25	230	53	85
2010	As-T	192	62	54	34	13	260	39	77

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved arsenic, T=Total arsenic, N=Number of analyses per year, Stdev=Standard deviation.

4.3.2 Cadmium

Monthly dissolved cadmium concentrations remained at the detection level of 0.2µg/L for most of 2010 and well below the compliance criterion of 1.0µg/L (Figure 4-2A). Total cadmium concentrations showed some variation throughout the year.

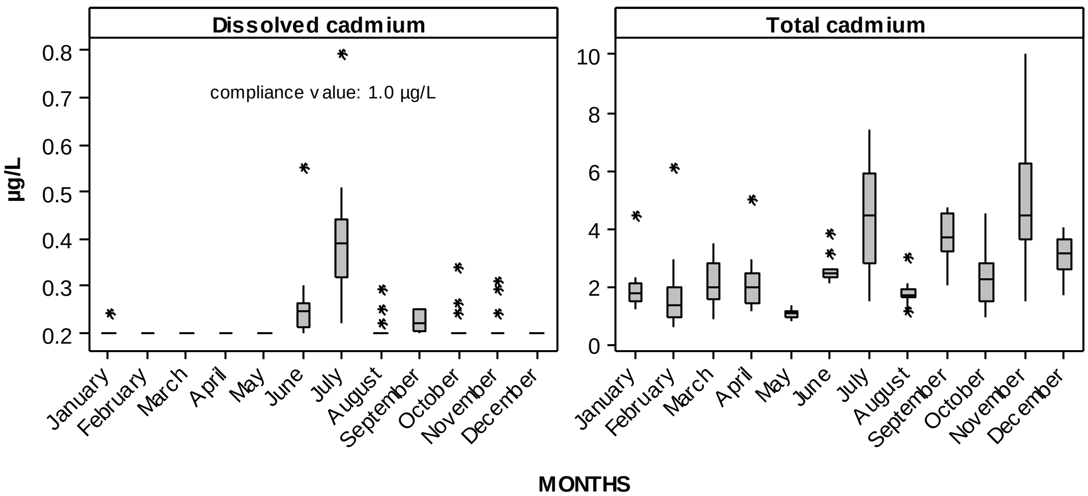


Figure 4-2A Box plots of dissolved and total cadmium at SG3 during 2010

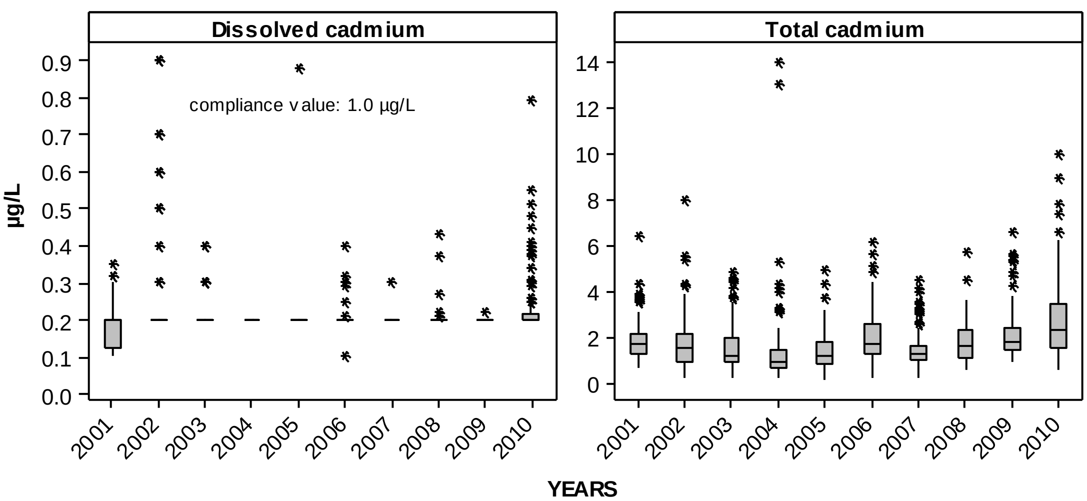


Figure 4-2B Box plots of dissolved and total cadmium at SG3 from 2001-2010

Dissolved concentrations for cadmium remained consistently low and at or near the detection limit of 0.2µg/L from 2001-2010 as shown in Figure 4-2B. Total concentrations remained reasonably steady during the same period.

Annual mean dissolved and total cadmium concentrations from 2001 to 2010 are shown in Table 4-2. Mean dissolved concentrations have remained steady since 2001. The mean total cadmium concentrations have remained consistently low for the past 10 years.

Table 4-2 Summary statistics for dissolved and total cadmium concentrations from 2001 to 2010 at SG3 (all results in µg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved cadmium									
2001	Cd-D	192	0.2	0.2	0.1	0.1	0.4	0.2	0.2
2002	Cd-D	192	0.2	0.2	0.1	0.2	0.9	0.2	0.2
2003	Cd-D	192	0.2	0.2	0.02	0.2	0.4	0.2	0.2
2004	Cd-D	192	0.2	0.2	0.02	0.2	0.2	0.2	0.2
2005	Cd-D	190	0.2	0.2	0.05	0.2	0.9	0.2	0.2
2006	Cd-D	191	0.2	0.2	0.02	0.2	0.4	0.2	0.2
2007	Cd-D	178	0.2	0.2	0.02	0.2	0.2	0.2	0.2
2008	Cd-D	176	0.2	0.2	0.02	0.2	0.4	0.2	0.2
2009	Cd-D	176	0.2	0.2	0.02	0.2	0.2	0.2	0.2
2010	Cd-D	192	0.2	0.2	0.01	0.2	0.8	0.2	0.2
Total cadmium									
2001	Cd-T	192	2	2	1	0.7	6	1	2
2002	Cd-T	192	2	2	1	0.2	8	1	2
2003	Cd-T	192	2	1	1	0.1	5	1	2
2004	Cd-T	192	1	1	2	0.2	14	1	1
2005	Cd-T	190	1	1	1	0.1	5	1	2
2006	Cd-T	191	2	2	1	0.2	6	1	3
2007	Cd-T	178	1	1	0.7	0.2	5	1	2
2008	Cd-T	176	2	2	0.8	0.6	6	1	2
2009	Cd-T	176	2	2	1	0.9	7	1	2
2010	Cd-T	192	3	2.3	2	0.6	10	2	3

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved cadmium, T=Total cadmium, N=Number of analyses per year, Stdev=Standard deviation.

4.3.3 Chromium

Monthly dissolved chromium concentrations were either at or below the detection limit of 1µg/L throughout 2010 and well below the compliance criterion of 10µg/L (Figure 4-3A). Total chromium concentrations varied throughout 2010 but showed no distinct trend.

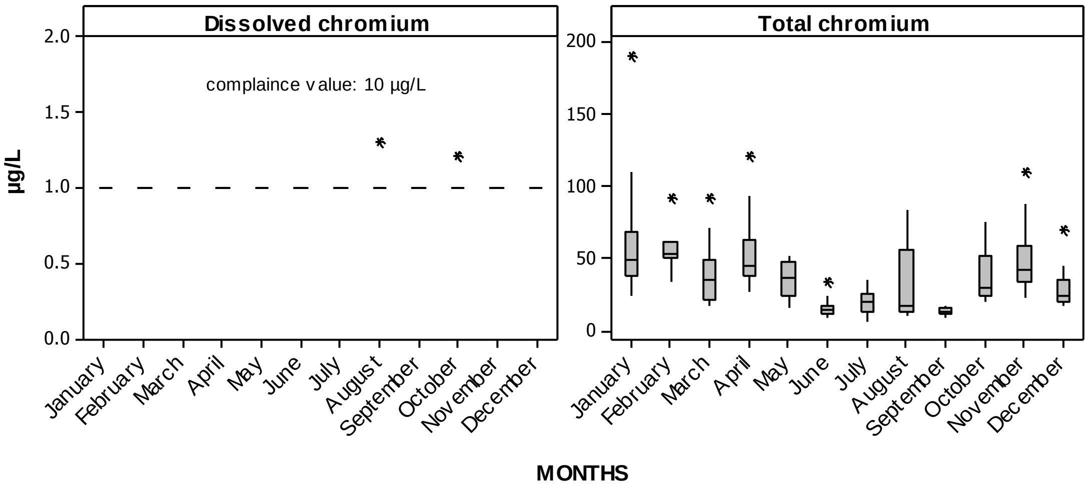


Figure 4-3A Box plots of dissolved and total chromium at SG3 during 2010

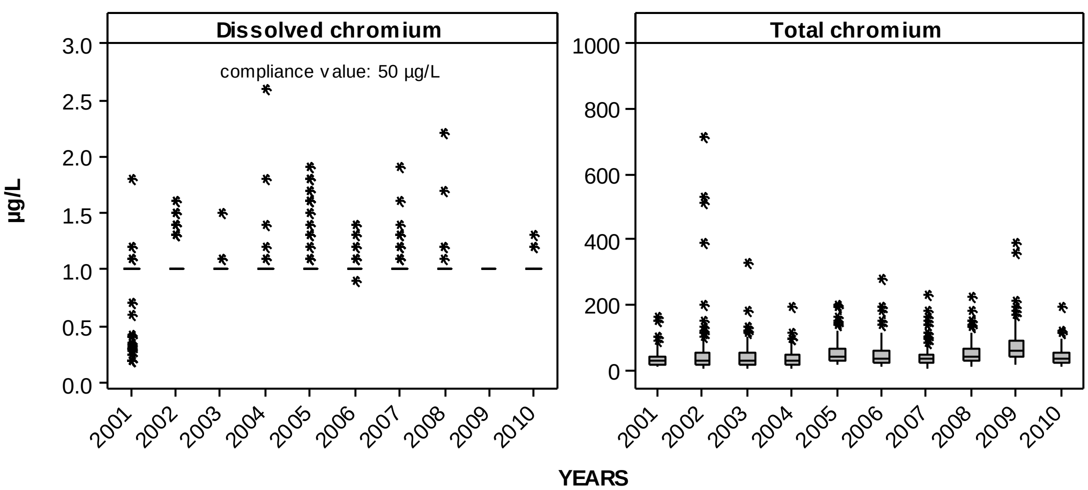


Figure 4-3B Box plots of dissolved and total chromium at SG3 from 2001-2010

Dissolved chromium concentrations were either at or below the detection limit over the 10-year period from 2001-2010 as shown in Figure 4-3B. Total chromium concentrations showed consistent results during the same period.

Annual mean dissolved and total chromium concentrations from 2001 to 2010 are shown in Table 4-3. The dissolved concentrations have remained at 1µg/L since 2002. The total chromium concentrations have shown relatively consistent results over the past 10 years.

Table 4-3 Summary statistics for dissolved and total chromium concentrations from 2001 to 2010 at SG3 (all results in µg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved chromium									
2001	Cr-D	192	0.8	1	0.3	0.2	2	1	1
2002	Cr-D	192	1	1	0.1	1	2	1	1
2003	Cr-D	192	1	1	0.1	1	2	1	1
2004	Cr-D	192	1	1	0.1	1	3	1	1
2005	Cr-D	190	1	1	0.2	1	2	1	1
2006	Cr-D	191	1	1	0.1	1	2	1	1
2007	Cr-D	178	1	1	0.4	1	6	1	1
2008	Cr-D	176	1	1	0.1	1	2	1	1
2009	Cr-D	176	1	1	0	1	1	1	1
2010	Cr-D	192	1	1	0.03	1	1	1	1
Total chromium									
2001	Cr-T	192	32	25	25	6	160	13	42
2002	Cr-T	192	45	26	80	1	710	15	49
2003	Cr-T	192	39	28	36	5	330	17	50
2004	Cr-T	192	33	27	25	4	190	16	45
2005	Cr-T	190	48	38	36	12	200	24	62
2006	Cr-T	191	45	33	37	10	280	19	58
2007	Cr-T	178	41	32	34	4	230	22	45
2008	Cr-T	176	49	41	34	10	220	25	60
2009	Cr-T	176	70	56	52	13	390	39	89
2010	Cr-T	192	37	30	25	6	190	18	50

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved chromium, T=Total chromium, N=Number of analyses per year, Stdev=Standard deviation.

4.3.4 Copper

The monthly dissolved copper concentrations during 2010 showed a three-month step-wise increase from August to October but the reason is unclear, while all results were well below the compliance value of 10 µg/L (Figure 4-4A). Total copper concentrations remained reasonably consistent throughout 2010.

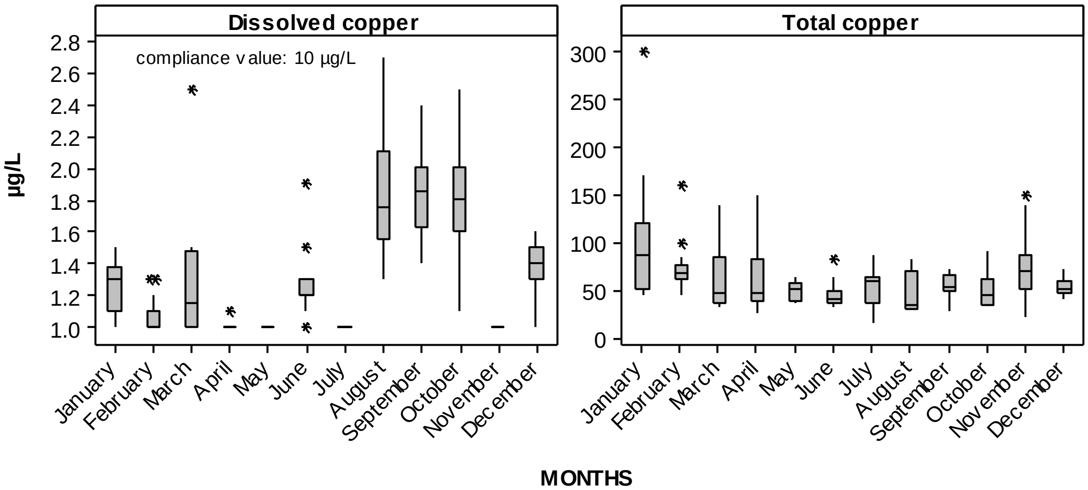


Figure 4-4A Box plots of dissolved and total copper at SG3 during 2010

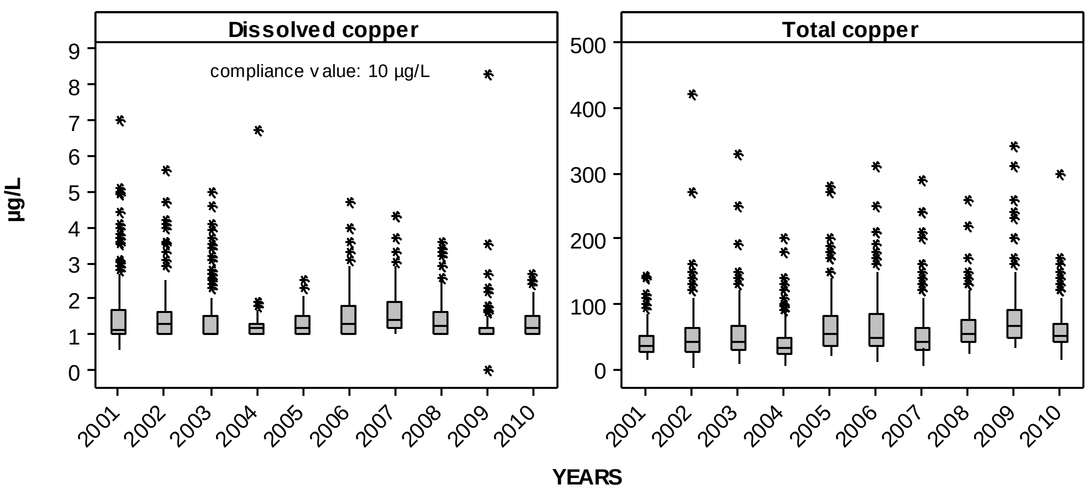


Figure 4-4B Box plots of dissolved and total copper at SG3 from 2001-2010

Both dissolved and total copper concentrations showed little variation at SG3 over the 10-year period from 2001-2010 as shown in Figure 4-4B.

Annual mean dissolved copper concentrations at SG3 showed little variation from 2001 to 2010, ranging from 1-2 µg/L as shown in Table 4-4. The total copper values varied during the same period but within acceptable limits (Table 4-4).

Table 4-4 Summary statistics for dissolved and total copper concentrations from 2001 to 2010 at SG3 (all results in µg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved copper									
2001	Cu-D	192	2	1	1	0.6	7	1	2
2002	Cu-D	192	2	1	1	1	6	1	2
2003	Cu-D	192	1	1	1	1	5	1	2
2004	Cu-D	192	1	1	0.5	1	7	1	1
2005	Cu-D	190	1	1	0.4	1	4	1	2
2006	Cu-D	191	2	1	0.7	1	7	1	2
2007	Cu-D	178	2	2	0.6	1	4	1	2
2008	Cu-D	176	1	1	0.5	1	4	1	2
2009	Cu-D	176	1	1	2	0	9	1	1
2010	Cu-D	192	1	1	0.3	1	3	1	2
Total copper									
2001	Cu-T	192	42	35	22	15	140	26	51
2002	Cu-T	192	54	41	64	1	700	26	61
2003	Cu-T	192	53	42	39	8	330	30	62
2004	Cu-T	192	41	34	30	4	200	22	49
2005	Cu-T	190	65	53	45	17	280	33	80
2006	Cu-T	191	64	47	45	11	310	35	80
2007	Cu-T	178	56	44	43	5	290	32	63
2008	Cu-T	176	63	54	33	24	260	42	77
2009	Cu-T	176	80	66	19	31	340	49	91
2010	Cu-T	192	60	52	32	15	300	41	70

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved copper, T=Total copper, N=Number of analyses per year, Stdev=Standard deviation.

4.3.5 Iron

Both monthly dissolved and total iron concentrations varied noticeably throughout 2010 (Figure 4-5A).

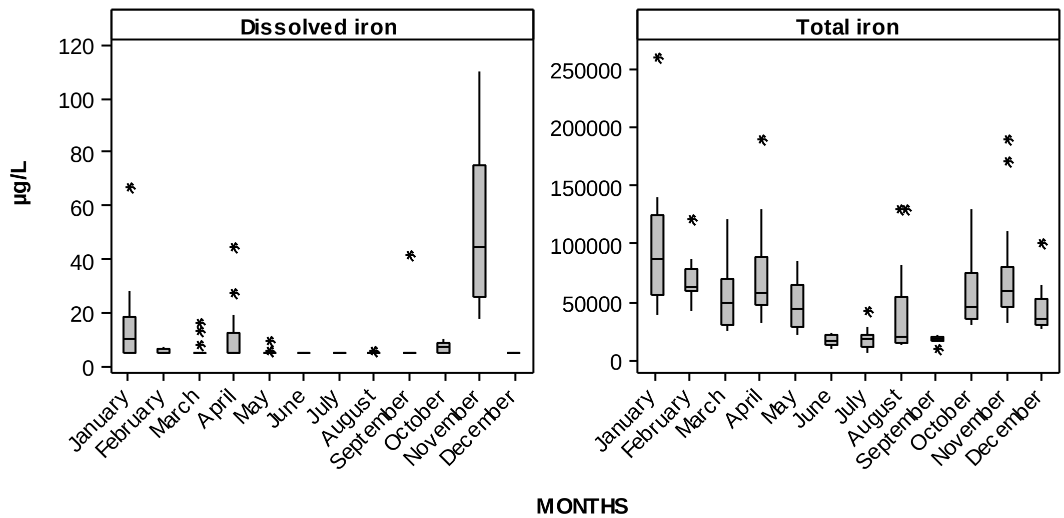


Figure 4-5A Box plots of dissolved and total iron at SG3 for 2010

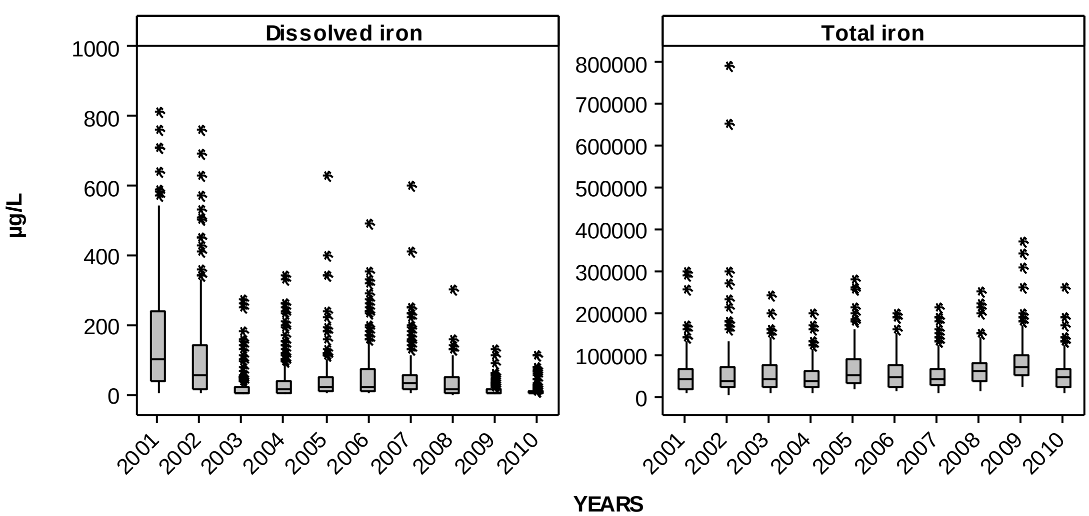


Figure 4-5B Box plots of dissolved and total iron at SG3 for 2001-2010

Dissolved iron concentrations showed some variation over the 10-year period from 2001-2010 as shown in Figure 4-5B but the dissolved values have remained reasonably consistent.

Annual mean dissolved iron concentrations decreased to lower levels in 2003 and have remained low (Table 4-5) while mean total iron values have been more consistent over the same period.

Table 4-5 Summary statistics for dissolved and total iron concentrations at SG3 from 2001 to 2010 (all results in µg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved iron									
2001	Fe-D	192	167	98	205	2	1830	39	240
2002	Fe-D	192	106	57	137	5	760	13	140
2003	Fe-D	192	28	7	49	5	330	5	27
2004	Fe-D	192	40	14	61	5	340	5	39
2005	Fe-D	190	46	22	73	5	630	9	53
2006	Fe-D	191	53	23	76	5	490	9	66
2007	Fe-D	178	55	32	71	5	600	18	64
2008	Fe-D	176	32	16	39	5	300	5	51
2009	Fe-D	176	13	5	17	5	130	5	12
2010	Fe-D	192	11	5	16	5	110	5	6
Total iron									
2001	Fe-T	192	48840	38500	43880	7400	300000	17000	62750
2002	Fe-T	192	56740	33500	83500	1700	790000	22000	68000
2003	Fe-T	192	49400	36000	38500	7400	240000	23000	65500
2004	Fe-T	192	42918	34000	31332	5400	200000	22000	57750
2005	Fe-T	190	66810	52000	48620	17000	280000	30000	85750
2006	Fe-T	191	53050	44000	37880	13000	200000	23000	73000
2007	Fe-T	178	51800	41500	38300	4800	210000	26800	61300
2008	Fe-T	176	64400	58000	41500	13000	250000	35000	80750
2009	Fe-T	176	81800	67000	54200	19000	370000	48300	97000
2010	Fe-T	192	50330	43000	38370	5600	260000	21000	64000

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved iron, T=Total iron, N=Number of analyses per year, Stdev=Standard deviation.

4.3.6 Lead

Monthly dissolved lead concentrations were at or below the detection limit of 0.5 µg/L throughout 2010, and well below the compliance criterion of 3 µg/L as shown in Figure 4-6A). Total lead concentrations varied noticeably throughout the year.

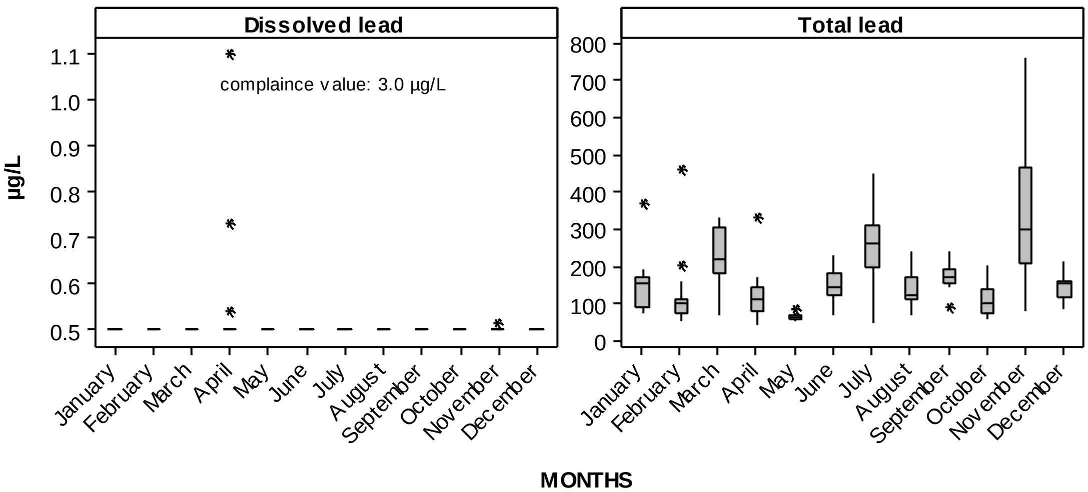


Figure 4-6A Box plots of dissolved and total lead at SG3 during 2010

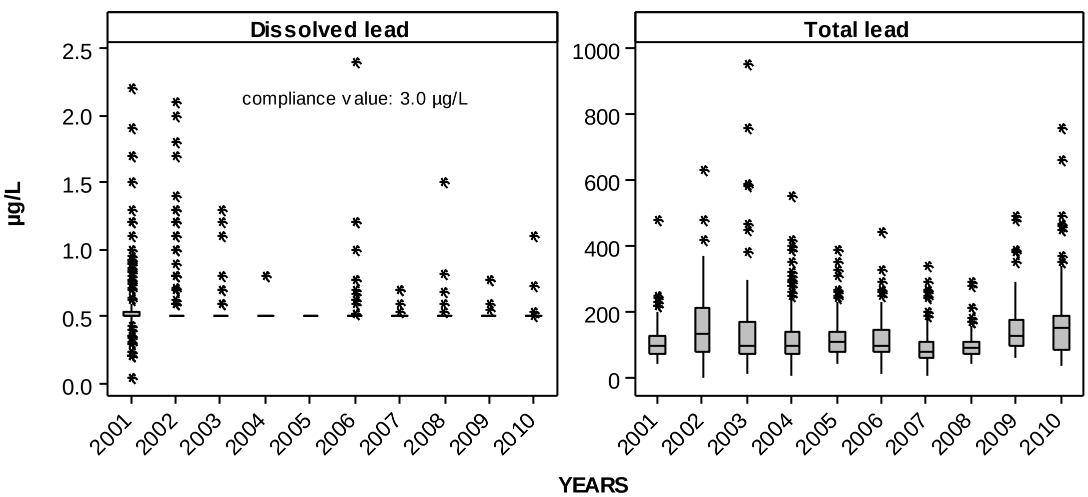


Figure 4-6B Box plots of dissolved and total lead at SG3 from 2001-2010

Dissolved lead concentrations have been at or below the detection limit of 0.5 µg/L for the 10-year period from 2001-2010, as shown in Figure 4-6B. Total lead concentrations remained relatively steady during the same period.

Annual mean dissolved and total lead concentrations at SG3 from 2001 to 2010 are shown in Table 4-6. The dissolved lead concentrations have remained steady at 0.5 µg/L since 2003. The total lead concentrations have been more varied over the same period.

Table 4-6 Summary statistics for dissolved and total lead at SG3 from 2001 to 2010 (all results in µg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved lead									
2001	Pb-D	192	0.6	0.5	0.4	0.1	3.0	0.5	0.5
2002	Pb-D	192	0.6	0.5	0.4	0.5	2.8	0.5	0.5
2003	Pb-D	192	0.5	0.5	0.1	0.5	1.3	0.5	0.5
2004	Pb-D	192	0.5	0.5	0.03	0.5	0.8	0.5	0.5
2005	Pb-D	190	0.5	0.5	0	0.5	0.5	0.5	0.5
2006	Pb-D	191	0.5	0.5	0.1	0.5	1	0.5	0.5
2007	Pb-D	178	0.5	0.5	0.02	0.5	0.7	0.5	0.5
2008	Pb-D	176	0.5	0.5	0.08	0.5	2	0.5	0.5
2009	Pb-D	176	0.5	0.5	0.03	0.5	0.8	0.5	0.5
2010	Pb-D	192	0.5	0.5	0.05	0.5	1	0.5	0.5
Total lead									
2001	Pb-T	192	109	99	52	41	480	73	130
2002	Pb-T	192	151	135	98	2	630	78	210
2003	Pb-T	192	139	110	114	10	950	75	170
2004	Pb-T	192	119	98	85	8	550	73	140
2005	Pb-T	190	123	110	63	42	390	78	150
2006	Pb-T	191	112	96	53	11	330	76	140
2007	Pb-T	178	93	80	53	8	340	62	103
2008	Pb-T	176	98	93	38	42	290	72	110
2009	Pb-T	176	149	130	70	63	490	100	178
2010	Pb-T	192	164	150	107	39	760	88	190

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved lead, T=Total lead, N=Number of analyses per year, Stdev=Standard deviation.

4.3.7 Mercury

Monthly dissolved mercury concentrations at SG3 were at or below the detection limit of 0.1 µg/L during 2010 (Figure 4-7A). Total mercury concentrations were varied but remained low throughout the year.

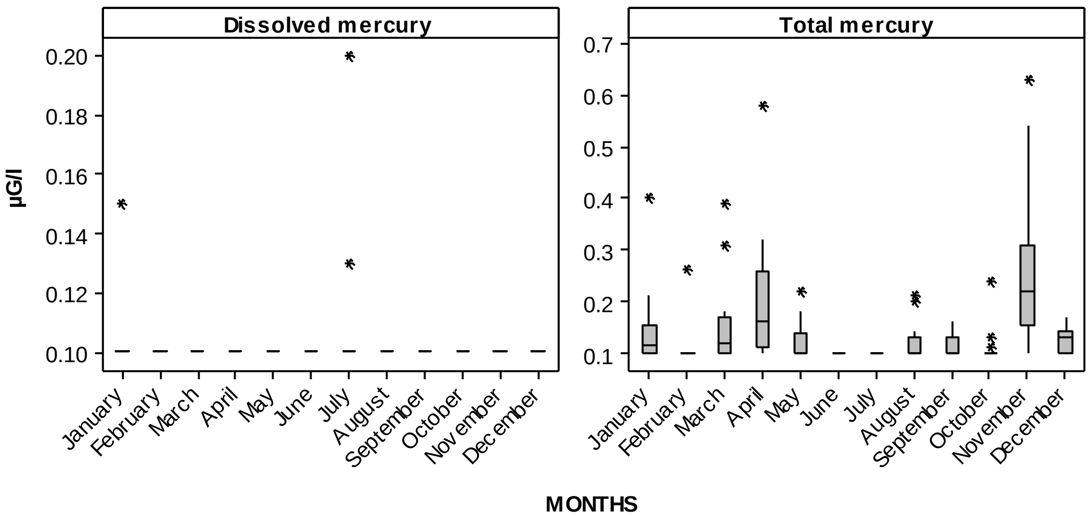


Figure 4-7A Box plots of dissolved and total mercury at SG3 during 2010

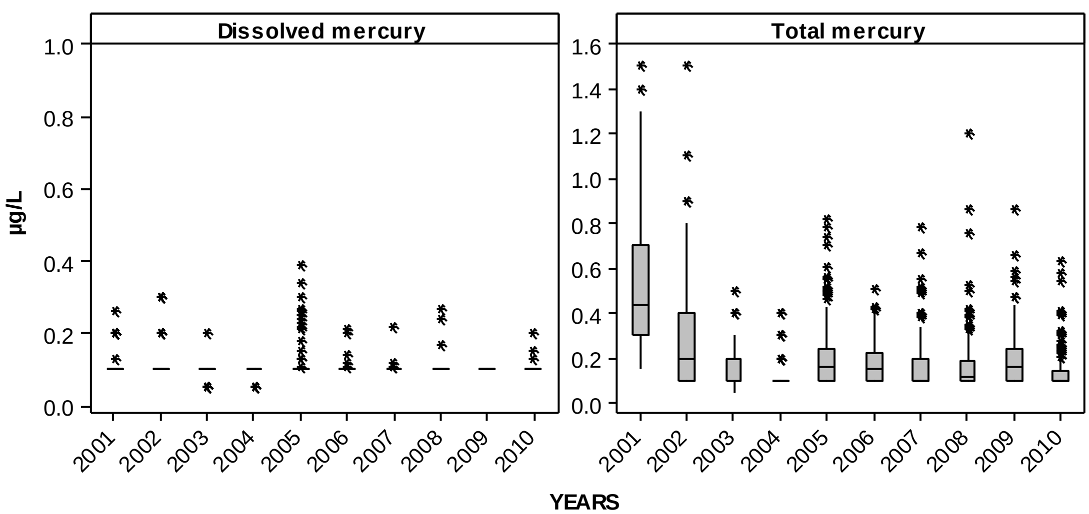


Figure 4-7B Box plots of dissolved and total mercury at SG3 from 2001-2010

Dissolved mercury concentrations were at or below the detection limit of 0.1 µg/L at SG3 during the 10-year period from 2001-2010 (Figure 4-7B). Total mercury concentrations have remained consistently low during the same period.

Annual mean dissolved mercury concentrations have shown little variation from 2001 to 2010 as shown in Table 4-7. Total mercury concentrations have decreased noticeably over the same period. Historical records show that prior to 2001, mean annual total mercury values were generally greater than 0.6 µg/L. This confirms the observations over time that there is less mercury within the ore body with increasing depth in the open pit.

Table 4-7 Summary statistics for dissolved and total mercury concentrations at SG3 from 2001 to 2010 (all results in µg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved mercury									
2001	Hg-D	192	0.1	0.1	0.1	0.05	0.1	0.05	0.1
2002	Hg-D	192	0.1	0.1	0	0.1	0.3	0.1	0.1
2003	Hg-D	192	0.1	0.1	0	0.1	0.1	0.1	0.1
2004	Hg-D	192	0.1	0.1	0.01	0.1	0.1	0.1	0.1
2005	Hg-D	190	0.1	0.1	0.04	0.1	0.4	0.1	0.1
2006	Hg-D	191	0.1	0.1	0.01	0.1	0.2	0.1	0.1
2007	Hg-D	178	0.1	0.1	0.01	0.1	0.2	0.1	0.1
2008	Hg-D	176	0.1	0.1	0.02	0.1	0.3	0.1	0.1
2009	Hg-D	176	0.1	0.1	0	0.1	0.1	0.1	0.1
2010	Hg-D	192	0.1	0.1	0.1	0.1	0.2	0.1	0.1
Total mercury									
2001	Hg-T	192	0.6	0.4	0.6	0.2	4.3	0.3	0.7
2002	Hg-T	192	0.3	0.2	0.3	0.1	1.9	0.1	0.4
2003	Hg-T	192	0.2	0.2	0.5	0.1	7.2	0.1	0.2
2004	Hg-T	192	0.1	0.1	0.1	0.1	0.4	0.1	0.1
2005	Hg-T	190	0.2	0.2	0.1	0.1	0.8	0.1	0.2
2006	Hg-T	191	0.2	0.2	0.1	0.1	0.5	0.1	0.2
2007	Hg-T	178	0.2	0.1	0.1	0.1	0.8	0.1	0.2
2008	Hg-T	176	0.2	0.1	0.1	0.1	1.2	0.1	0.2
2009	Hg-T	176	0.2	0.2	0.1	0.1	0.9	0.1	0.2
2010	Hg-T	192	0.1	0.1	0.1	0.1	0.6	0.1	0.1

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved mercury, T=Total mercury, N=Number of analyses per year, Stdev=Standard deviation.

4.3.8 Nickel

Monthly dissolved nickel concentrations for nickel were at or below the detection limit of 1 μg/L during 2010 (Figure 4-8A).

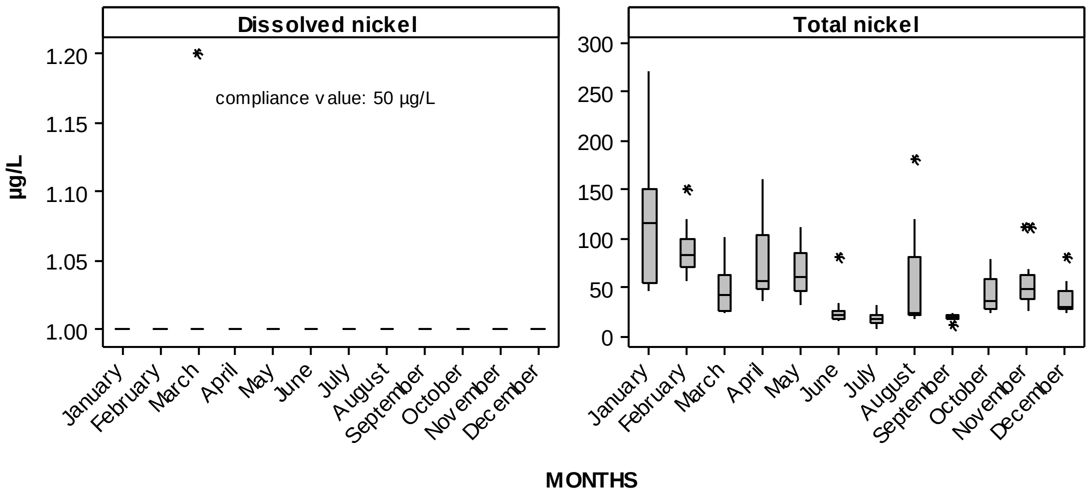


Figure 4-8A Box plots of dissolved and total nickel at SG3 during 2010

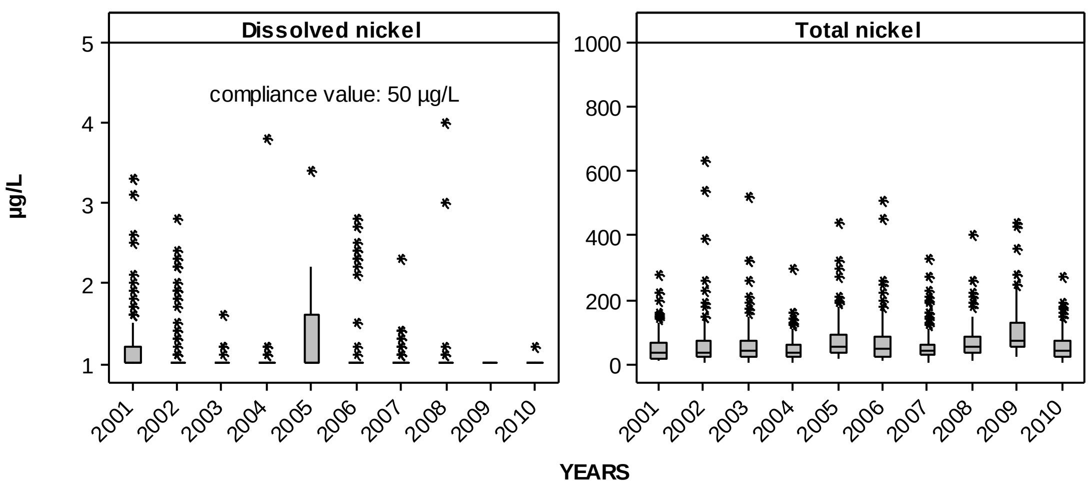


Figure 4-8B Box plots of dissolved and total nickel at SG3 from 2001-2010

Dissolved nickel concentrations at SG3 from 2001 to 2010 were mainly at or below the detection limit of 1 µg/L (Figure 4-8B). Total nickel concentrations remained reasonably steady over the same 10-year period.

Mean dissolved nickel concentrations have shown no change at SG3 from 2001 to 2010 (Table 4-8). In contrast, total nickel concentrations showed considerable variation over the same period.

Table 4-8 Summary statistics for dissolved and total nickel at SG3 from 2001 to 2010 (all results in µg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved nickel									
2001	Ni-D	192	1	1	0.7	1	9	1	1
2002	Ni-D	192	1	1	0.3	1	3	1	1
2003	Ni-D	192	1	1	0.1	1	2	1	1
2004	Ni-D	192	1	1	0.2	1	4	1	1
2005	Ni-D	190	1	1	0.4	1	3	1	2
2006	Ni-D	191	1	1	0.4	1	3	1	1
2007	Ni-D	178	1	1	0.1	1	2	1	1
2008	Ni-D	176	1	1	0.5	1	7	1	1
2009	Ni-D	176	1	1	0.1	1	1	1	1
2010	Ni-D	192	1	1	0.01	0.1	1	1	1
Total nickel									
2000	Ni-T	192	41	30	41	1	260	17	49
2001	Ni-T	192	49	36	42	12	280	20	67
2002	Ni-T	192	67	35	152	2	1900	21	70
2003	Ni-T	192	58	39	61	7	520	24	75
2004	Ni-T	192	46	36	39	5	300	21	58
2005	Ni-T	190	71	56	57	18	440	32	93
2006	Ni-T	191	65	48	62	10	510	25	82
2007	Ni-T	178	59	47	51	6	330	30	63
2008	Ni-T	178	66	56	51	13	400	34	83
2009	Ni-T	176	99	73	70	21	440	52	130
2010	Ni-T	192	53	41	40	6	270	23	70

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved nickel, T=Total nickel, N=Number of analyses per year, Stdev=Standard deviation

4.3.9 Silver

Monthly dissolved silver concentrations at SG3 were at or below the detection limit of 0.2 µg/L throughout 2010 (Figure 4-9A). Total silver concentrations were varied during the same period.

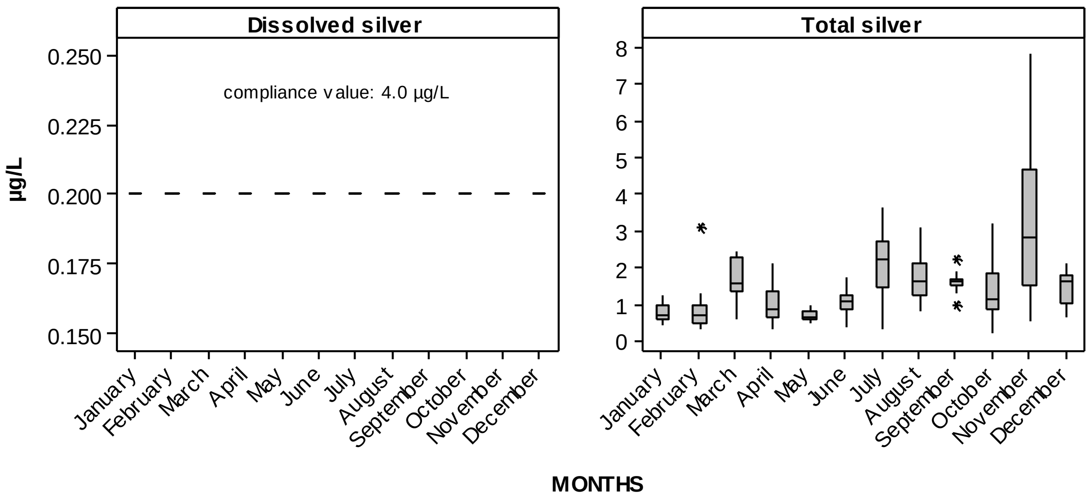
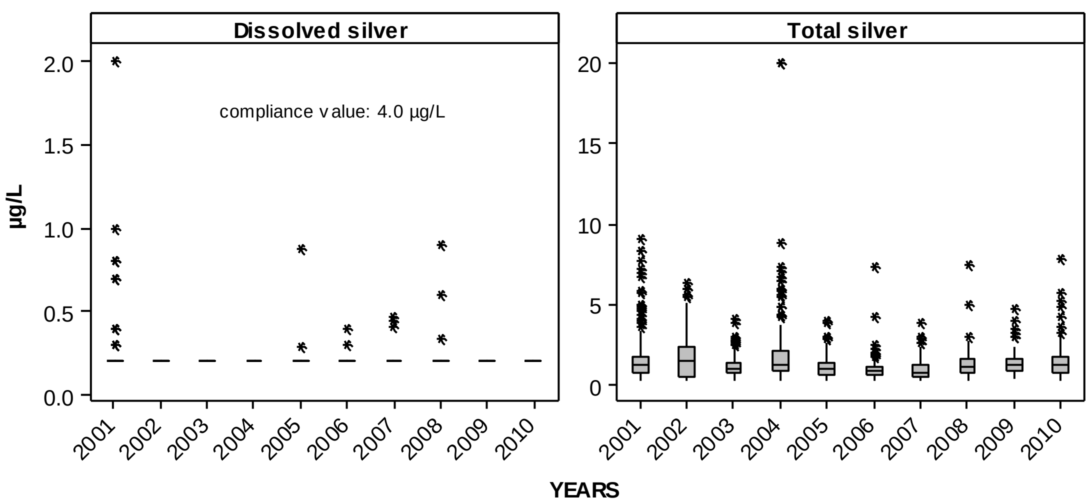


Figure 4-9A Box plots of dissolved and total silver at SG3 during 2010



. **Figure 4-9B** Box plots of dissolved and total silver at SG3 from 2001-2010

Dissolved silver concentrations at SG3 from 2001-2010 were at or below the detection limit of 0.2 µg/L (Figure 4-9B). Total silver concentrations for the same period were relatively consistent.

From Table 4-9, annual mean dissolved silver concentrations have remained at the detection level of 0.2 µg/L since 2001. Mean total silver concentrations have shown little variation over the same period.

Table 4-9 Summary statistics for dissolved and total silver at SG3 from 2001 to 2010 (all results in µg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved silver									
2001	Ag-D	192	0.2	0.2	0.2	0.2	2	0.2	0.2
2002	Ag-D	192	0.2	0.2	0	0.2	0.2	0.2	0.2
2003	Ag-D	192	0.2	0.2	0	0.2	0.2	0.2	0.2
2004	Ag-D	192	0.2	0.2	0	0.2	0.2	0.2	0.2
2005	Ag-D	190	0.2	0.2	0.1	0.2	0.9	0.2	0.2
2006	Ag-D	191	0.2	0.2	0.01	0.2	0.3	0.2	0.2
2007	Ag-D	178	0.2	0.2	0.01	0.2	0.2	0.2	0.2
2008	Ag-D	176	0.2	0.2	0.06	0.2	0.9	0.2	0.2
2009	Ag-D	176	0.2	0.2	0	0.2	0.2	0.2	0.2
2010	Ag-D	192	0.2	0.2	0	1	0.2	0.2	0.3
Total silver									
2001	Ag-T	192	2	1	2	0.2	9	0.7	2
2002	Ag-T	192	2	2	1	0.2	6	0.5	2
2003	Ag-T	192	1	1	1	0.2	4	0.7	2
2004	Ag-T	192	2	1	2	0.2	20	0.9	2
2005	Ag-T	190	1	1	1	0.2	4	0.6	1
2006	Ag-T	191	1	0.9	0.5	0.2	4	0.6	1
2007	Ag-T	178	1	0.7	0.6	0.2	4	0.5	1
2008	Ag-T	176	1	1	0.8	0.2	7	0.6	2
2009	Ag-T	176	1	1	0.6	0.4	5	1	2
2010	Ag-D	192	1	1	1	0.2	8	0.8	2

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved silver, T=Total silver, N=Number of analyses per year, Stdev=Standard deviation.

4.3.10 Zinc

Monthly dissolved zinc concentrations varied noticeably throughout 2010 with all results well below the compliance criterion of 50 µg/L (Figure 4-10A). Total zinc concentrations varied throughout the year with no distinct trend.

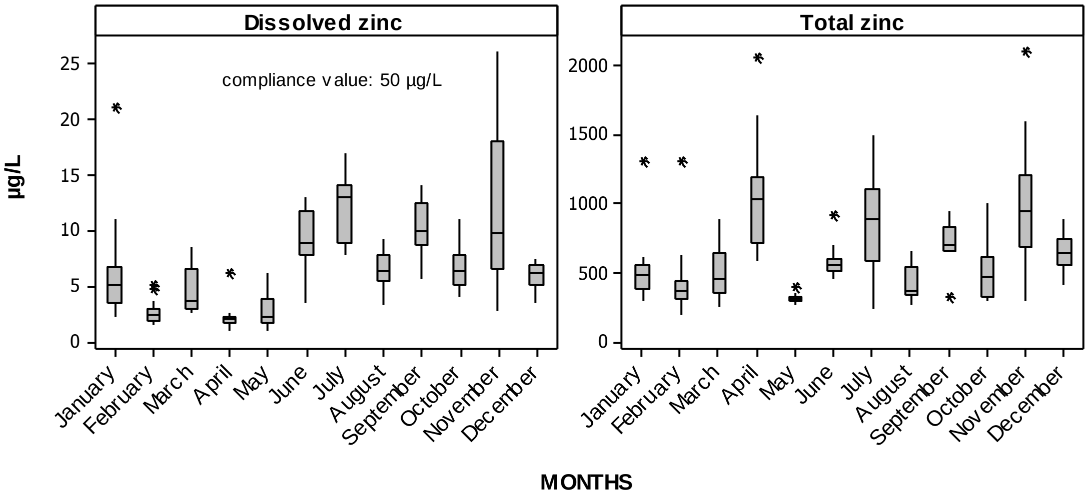


Figure 4-10A Box plots of dissolved and total zinc at SG3 during 2010

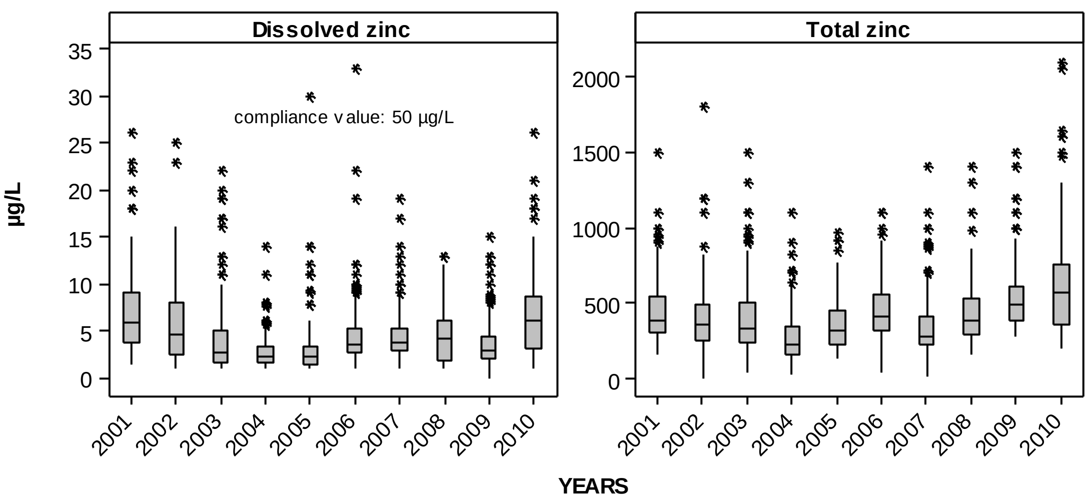


Figure 4-10B Box plots of dissolved and total zinc at SG3 from 2001-2010

Both dissolved and total zinc concentrations at SG3 showed no distinct trends from 2001 to 2010 as shown in Figure 4-10B. Mean dissolved zinc concentrations have shown only moderate variation from 2001 to 2010 as shown in Table 4-10. Mean total zinc concentrations were varied with no specific trend over the same period, and the highest recorded total zinc level in 10 years was noted for 2010.

Table 4-10 Summary statistics for dissolved and total zinc concentrations at SG3 from 2001 to 2010 (all results in µg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
Dissolved zinc									
2001	Zn-D	192	7	6	4	1	26	4	9
2002	Zn-D	192	6	5	6	1	42	3	8
2003	Zn-D	192	5	3	4	1	22	2	6
2004	Zn-D	192	3	2	2	1	14	2	3
2005	Zn-D	190	3	2	3	1	30	2	3
2006	Zn-D	191	4	4	3	1	33	3	5
2007	Zn-D	178	5	4	3	1	19	3	6
2007	Zn-D	178	5	4	3	1	19	3	6
2008	Zn-D	176	4	4	3	1	13	2	6
2009	Zn-D	176	4	3	5	1	15	2	4
2010	Zn-D	192	6	6	4	1	26	3	9
Total zinc									
2001	Zn-T	192	450	390	202	160	1500	310	540
2002	Zn-T	192	395	360	247	9	1800	258	490
2003	Zn-T	192	409	340	244	48	1500	240	500
2004	Zn-T	192	270	230	167	34	1100	163	350
2005	Zn-T	190	353	315	164	120	970	230	450
2006	Zn-T	191	444	400	191	48	1100	320	540
2007	Zn-T	178	352	300	204	22	1400	230	430
2008	Zn-T	176	438	390	196	160	1400	290	530
2009	Zn-T	176	546	490	227	280	1500	380	615
2010	Zn-T	192	630	570	337	200	2100	360	758

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved zinc, T=Total zinc, N=Number of analyses per year, Stdev=Standard deviation.

4.3.11 Summary of Metals Data

Tables 4-11 and Table 4-12 show the SG3 results of all metals compared to the PNG Government compliance criteria for 2010 and from 2001-2010, respectively.

Table 4-11 Summary Table - Mean monthly trace metal concentrations at SG3 for 2010 (all units in µg/L)

Month	As-D	As-T	Cd-D	Cd-T	Cr-D	Cr-T	Cu-D	Cu-T	Fe-D	Fe-T	Pb-D	Pb-T	Hg-D	Hg-T	Ni-D	Ni-T	Ag-D	Ag-T	Zn-D	Zn-T
Jan	1.5	45	<0.2	1.9	<1	61	1.2	99	15	94940	<0.5	149	<0.1	0.1	<1	113	<0.2	0.8	6.1	509
Feb	1.7	48	<0.2	1.7	<1	55	1.0	74	5.5	68560	<0.5	122	<0.1	0.1	<1	88	<0.2	0.9	2.6	417
Mar	2.0	74	<0.2	2.1	<1	39	1.2	62	6.3	54630	<0.5	224	<0.1	0.2	<1	48	<0.2	1.7	4.5	509
Apr	1.7	47	<0.2	2.1	<1	54	<1	60	10	71940	0.6	119	<0.1	0.2	<1	71	<0.2	1.0	2.1	1058
May	1.8	42	<0.2	1.0	<1	35	<1	49	2.3	46940	<0.5	63	<0.1	0.1	<1	64	<0.2	0.7	2.7	312
Jun	1.9	39	<0.2	2.5	<1	15	1.2	45	5.0	16560	<0.5	151	<0.1	0.1	<1	25	<0.2	1.0	9.1	579
Jul	1.9	69	<0.2	4.3	<1	19	<1	53	5.0	17450	<0.5	248	<0.1	0.1	<1	17	<0.2	2.0	12	869
Aug	4.0	77	<0.2	1.8	<1	32	1.9	45	5.0	41330	<0.5	134	<0.1	0.1	<1	53	<0.2	1.6	6.4	418
Sep	1.8	75	<0.2	3.7	<1	13	1.9	54	7.3	17560	<0.5	168	<0.1	0.1	<1	18	<0.2	1.6	10	723
Oct	1.7	68	<0.2	2.2	<1	38	1.8	50	7.0	56810	<0.5	105	<0.1	0.1	<1	43	<0.2	1.3	6.6	499
Nov	1.7	104	<0.2	5.1	<1	48	<1	77	51	74690	<0.5	340	<0.1	0.3	<1	54	<0.2	3.1	12	1014
Dec	1.9	61	<0.2	3.0	<1	29	1.4	54	5.0	42000	<0.5	143	<0.1	0.1	<1	37	<0.2	1.5	5.9	467
Criterion	**50**		**1**		**10**		**10**		**NC**		**3**		**NC**		**50**		**4**		**50**	

Note: D=dissolved metals, t=total metals NC=no criterion

Table 4 - 12 Summary Table - Mean annual trace metals concentrations at SG3 since 2001 (all units in µg/L except pH)

Year	As-D	As-T	Cd-D	Cd-T	Cr-D	Cr-T	Cu-D	Cu-T	Fe-D	Fe-T	Pb-D	Pb-T	Hg-D	Hg-T	Ni-D	Ni-T	Ag-D	Ag-T	Zn-D	Zn-T	pH-L
2001	3.0	65	<0.2	2.0	0.8	32	2.0	42	167	48800	0.6	109	<0.1	0.6	<1	49	<0.2	2.0	7.0	450	8.2
2002	4.0	85	<0.2	2.0	<1	45	2.0	54	106	56700	0.6	151	<0.1	0.3	<1	67	<0.2	2.0	6.0	395	8.2
2003	3.0	77	<0.2	2.0	<1	39	1.0	53	28	49400	<0.5	139	<0.1	0.2	<1	58	<0.2	1.0	5.0	409	8.0
2004	4.0	83	<0.2	1.0	<1	33	1.0	41	40	42900	<0.5	118	<0.1	<0.1	<1	46	<0.2	2.0	3.0	270	7.8
2005	2.6	69	<0.2	1.4	<1	48	1.4	65	46	66810	<0.5	123	<0.1	<0.1	1.2	71	<0.2	1.2	3.0	353	8.1
2006	1.9	44	<0.2	2.0	<1	45	1.5	64	53	53050	<0.5	112	<0.1	<0.1	1.1	65	<0.2	0.9	4.4	444	8.1
2007	2.9	69	<0.2	1.4	<1	41	1.6	56	55	51800	<0.5	93	<0.1	<0.1	<1	59	<0.2	0.9	4.7	352	8.0
2008	1.2	50	<0.2	1.8	<1	49	1.4	63	32	64400	<0.5	98	<0.1	<0.1	<1	66	<0.2	1.1	4.4	438	8.0
2009	1.8	71	<0.2	2.1	<1	70	1.3	80	13	81800	<0.5	149	<0.1	0.2	<1	99	<0.2	1.3	3.9	546	8.1
2010	1.9	62	<0.2	2.6	<1	37	1.3	60	11	50330	<0.5	164	<0.1	0.1	<1	53	<0.2	1.4	6.6	630	8.1
Criterion	**50**		**1**		**10**		**10**		**NC**		**3**		**NC**		**50**		**4**		**50**		**6.0-9.0**

Note: D = dissolved; T = total; NC = no criterion; L = laboratory

4.3.11 General Discussion

With the introduction of the cyanide destruction plant, dissolved metal concentrations at the compliance site, SG3, not only now meet the PNG compliance criteria, but are also below the stringent Australian and New Zealand water quality guidelines for ecosystem protection (ANZECC/ARMCANZ, 2000) as shown in Table 4-13. This is based only on the dissolved metal concentrations, and without the allowed consideration of metal bioavailability. The bioavailable metals concentration would be even lower than the dissolved values indicating that at this site and all downstream sites there are likely to be no acute or chronic impacts on aquatic biota.

Table 4-13 Comparison of 2010 mean dissolved metals concentrations at SG3 with Australian and New Zealand water quality guideline trigger values

Metal	Mean Dissolved Metals at SG3 in 2010	PNG Compliance Value	ANZECC/ARMCANZ Trigger Value*
	µg/L		
Arsenic	1.9	50	24 (As(III))
Cadmium	<0.2	1	0.2
Chromium	<1	1	1 (Cr(VI))
Copper	1.3	10	1.4
Lead	<0.5	3	3.4
Mercury	<0.1	-	0.6
Nickel	<1	50	11
Silver	<0.2	4	0.05
Zinc	6.6	50	8

* * Guidelines for Cu, Pb, Cd, Ni and Zn are hardness dependent. These values are for 30 mg/L $CaCO_3$ hardness

4.4 Other Water Quality Parameters

4.4.1 Free Cyanide

Prior to 2010, all free cyanide analyses of Strickland River samples from SG3 were conducted at Porgera by PJV's accredited Environmental Chemistry Laboratory. The analytical detection limit for this work was 20 µg/L which was higher than the PNG Government compliance criterion of 5 µg/L. All samples analysed in this manner since operations began met the 20 µg/L criterion.

Since October 2009, the SG3 free cyanide samples have been sent to the NMI laboratory in Sydney where their technique for this analysis has a detection limit of 5 µg/L, which is the compliance criterion. All free cyanide samples sent to NMI since October 2009 gave values less than this detection limit.

4.4.2 Ammonia

Ammonia levels at SG3 were either at or below the detection limits during 2010 and for the period from 2001 to 2010 as shown in Figures 4-11A and B and in Table 4-14. Note that the detection limit for ammonia improved from 25 µg/L to 5 µg/L during 2009. This is due to ammonia analyses now being conducted by NMI (instead of PJV Environmental Chemistry Lab) where the detection limit is considerably lower.

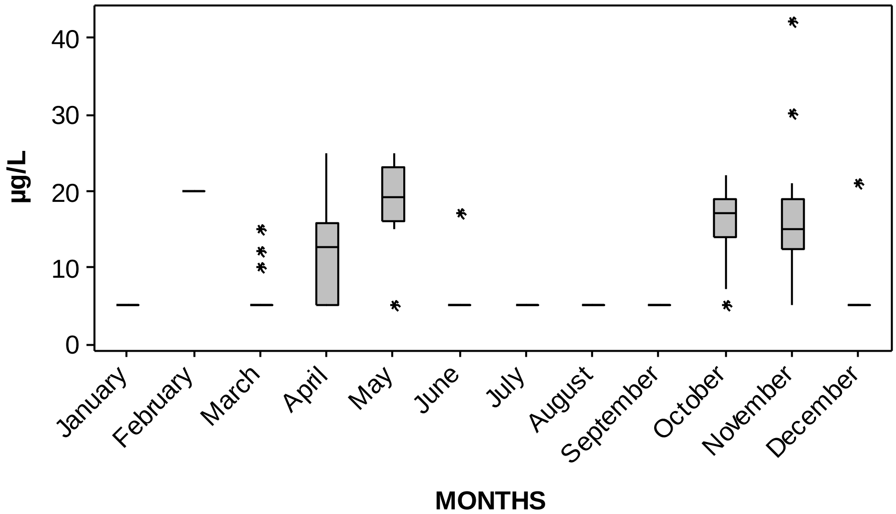


Figure 4-11A Box plots of dissolved ammonia at SG3 during 2010

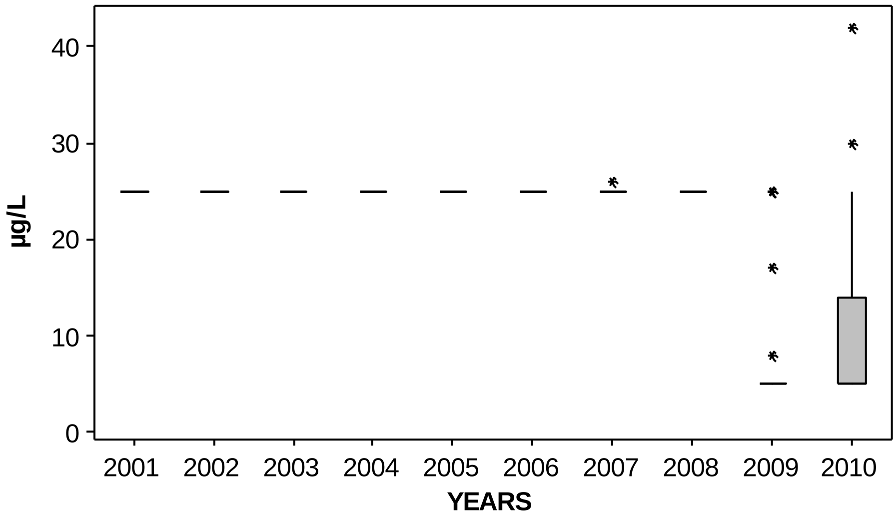


Figure 4-11B Box plots of dissolved ammonia at SG3 from 2001-2010

Table 4-14 Summary statistics for dissolved ammonia at SG3 from 2001 to 2010 (all results in µg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
2001	NH_3-D	192	<25	<25	0	<25	<25	<25	<25
2002	NH_3-D	192	<25	<25	0	<25	<25	<25	<25
2003	NH_3-D	192	<25	<25	0	<25	<25	<25	<25
2004	NH_3-D	192	<25	<25	0	<25	<25	<25	<25
2005	NH_3-D	190	<25	<25	0	<25	<25	<25	<25
2006	NH_3-D	191	<25	<25	0	<25	<25	<25	<25
2007	NH_3-D	178	<25	<25	0	<25	<25	<25	<25
2008	NH_3-D	176	<25	<25	0	<25	<25	<25	<25
2009	NH_3-D	176	<5	<5	0	<5	<5	<5	<5
2010	NH_3-D	192	9	<5	6	<5	42	<5	14

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved NH_3, N=Number of analyses per year, Stdev=Standard deviation.

4.4.3 Sulfide

For 2010, all results for sulfide concentrations at SG3 were at or below the detection limit of 10 µg/L. Currently, there is no compliance criterion for sulfide at SG3.

4.4.4 Sulfate

The monthly trend for sulfate concentrations at SG3 showed no obvious trend for 2010 (Figure 4-12A). There is no compliance criterion for sulfate at SG3. Annual values show a slight upward trend for the 10-year period from 2001-2010 in Figure 4-12B which is confirmed in the results shown in Table 4-15.

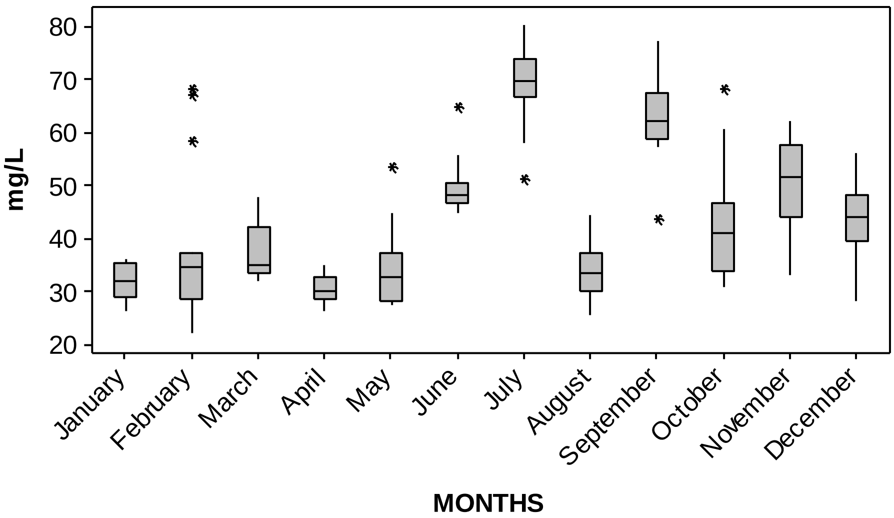


Figure 4-12A Trend analysis for sulfate concentrations at SG3 during 2010

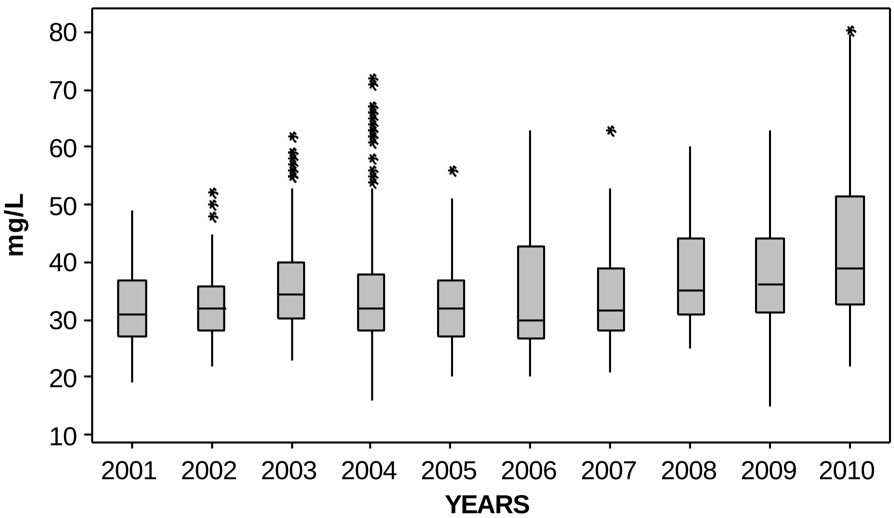


Figure 4-12B Trend analysis for sulfate at SG3 from 2001-2010 (mg/L)

Table 4-15 Summary statistics for sulfate concentrations at SG3 from 2001 to 2010 (all results in mg/L)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
2001	SO_4-D	192	32	31	7	19	49	27	37
2002	SO_4-D	192	32	32	5	22	52	29	35
2003	SO_4-D	192	38	35	9	23	64	31	44
2004	SO_4-D	192	35	32	12	16	72	28	38
2005	SO_4-D	190	33	33	7	20	56	27	38
2006	SO_4-D	191	34	30	9	20	54	8.0	8.3
2007	SO_4-D	178	35	32	8	21	64	29	40
2008	SO_4-D	176	38	35	9	25	60	31	44
2009	SO_4-D	176	38	36	10	15	63	31	44
2010	SO_4-D	192	44	39	14	22	80	33	52

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)
D=Dissolved SO_4, N=Number of analyses per year, Stdev=Standard deviation

4.4.5 pH Measurement

During 2010, the median monthly values for pH at SG3 varied between 8.0 and 8.3 (Figure 4-13A), and well within the compliance criteria of 6.0 to 9.0.

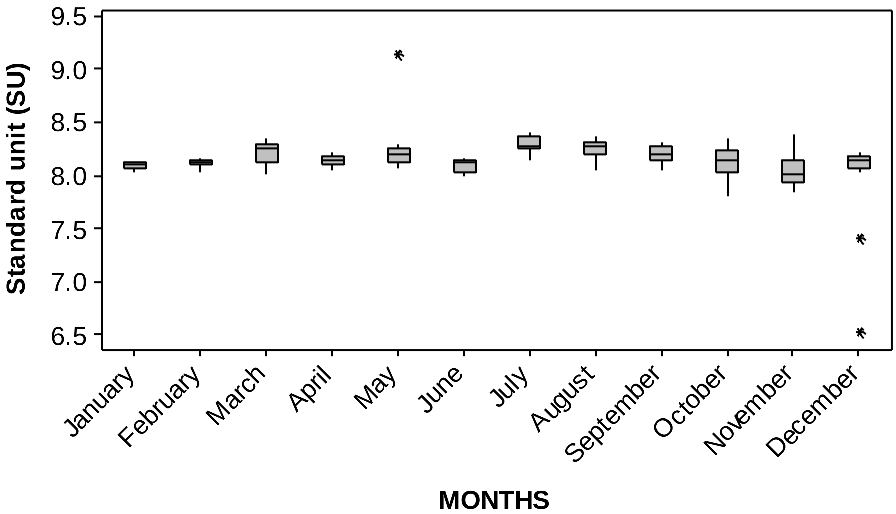


Figure 4-13A Box plots of pH measurement at SG3 during 2010

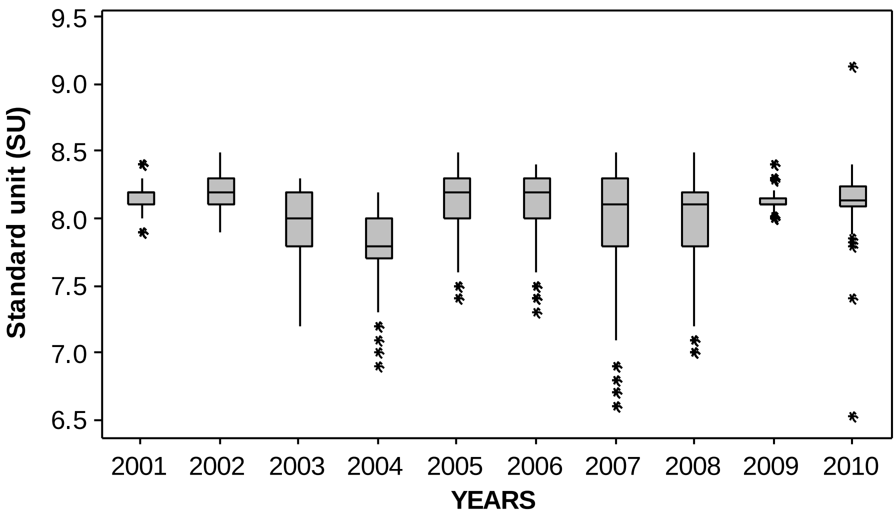


Figure 4-13B Boxplots of median pH values at SG3 from 2001-2010

The median pH values for the 10-year period from 2001-2010 showed little variation (Figure 4-13B).

From 2000 to 2010, mean pH values indicated a stable river system with values varying in the limited range from 7.8 to 8.2 (Table 4-16).

Table 4-16 Summary statistics for pH measurement at SG3 from 2001 to 2010 (all results in pH units)

Year	Parameter	N	Mean	Median	Stdev	Min	Max	Q1	Q3
2001	pH	192	8.2	8.2	0.1	7.9	8.4	8.1	8.2
2002	pH	192	8.2	8.2	0.2	7.9	8.5	8.1	8.3
2003	pH	192	8.0	8.0	0.2	7.2	8.3	7.9	8.2
2004	pH	192	7.8	7.8	0.2	6.9	8.2	7.7	8.0
2005	pH	190	8.1	8.2	0.2	7.4	8.5	8.0	8.3
2006	pH	191	8.1	8.2	0.2	7.3	8.4	8.0	8.3
2007	pH	178	8.0	8.1	0.4	6.6	8.5	7.8	8.3
2008	pH	176	8.0	8.1	0.4	7.0	8.5	7.8	8.2
2009	pH	176	8.1	8.1	0.1	8.0	8.4	8.1	8.2
2010	pH	192	8.1	8.1	0.2	6.5	9.1	8.1	8.2

Q1 Lower Quartile (25% of data below this value); Q3 Upper quartile (75% of the data below this value)

N=Number of analyses per year, Stdev=Standard deviation.

4.5 Sewage and Drinking Water Treatment

4.5.1 Sewage Treatment Plant Analyses

Results for the five on-site sewage treatment plants for 2010 are shown in Table 4-17. The main parameters tested in the on-site PJV Environmental Lab were for faecal coliforms, biochemical oxygen demand over 5 days (BOD_5) and total suspended solids (TSS). The Standard Method use for determining BOD_5 was APHA 5210B. For faecal coliforms, pre-made media obtained from overseas suppliers was used. Distilled water and the apparatus used were sterilized prior to filtering the sewage samples. The samples (100 mL each) were filtered through sterile filters and the filtrate placed in the wet media. The samples were then incubated for 24 hours after which time coloured spots (if developed) and their number confirmed the presence and quantity of faecal coliforms.

QA/QC was conducted on the BOD_5 samples using a certified reference material supplied by Graham B Jackson P/L of Australia, and which originated from the Analytical Products Group in the USA.

As shown in Table 4-17, ongoing maintenance problems with the sewage treatment plants continued during 2010 preventing a number of the faecal coliform and TSS values from achieving compliance. A consultant was engaged to review the operation of all plants and make recommendations for improvement. However, all BOD_5 results for the sewage treatment plants were within compliance. All faecal and total coliform results for the treated drinking water during 2010 were below detection limits.

Table 4-17 Results of sewage treatment plant analyses for 2010

Sites	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alipis 2	Faecal Coliform*	nil	100	275	nil	nil	nil	nil	nil	nil	100	175	500
	BOD_5	15	18	30	9	20	34	34	6	11	15	35	54
	TSS	61	52	88	79	80	90	97	65	95	45	69	76
Yoko 2	Faecal Coliform*	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	233	600
	BOD_5	11	13	6	7	12	8	7	5	4	9	31	19
	TSS	56	58	47	65	26	24	44	30	35	25	25	53
Tawasakali	Faecal Coliform*	nil	nil	nil	nil	nil	nil	nil	nil	nil	100	100	100
	BOD_5	14	9	6	8	7	21	12	7	11	12	19	10
	TSS	70	33	61	72	42	49	34	58	49	25	63	102
Plantsite	Faecal Coliform*	nil	75	1425	1000	ND	100	1000	nil	100	100	1250	100
	BOD_5	13	17	41	29	38	45	41	36	21	29	53	31
	TSS	67	39	123	99	57	119	133	111	201	43	74	124
Suyan	Faecal Coliform*	nil	nil	nil	nil	nil	2000	nil	nil	nil	100	200	150
	BOD_5	11	8	7	9	6	5	1	3	1	18	30	18
	TSS	45	18	62	10	11	24	20	36	22	33	76	54

Note: * Coliforms expressed in counts/100mL. BOD5 day and TSS expressed in mg/L. PNG Government Permit condition for treated sewage discharge is; faecal coliform = 200counts /100 mL samples, BOD5 = 100 mg/L and TSS = 30 mg/L.

4.5.2 Drinking Water Treatment Analyses

Results for the three onsite drinking water treatment plants for 2010 are shown in Table 4-18. The two main parameters tested were for faecal and total coliforms which are a measure of biological contamination.

Table 4-18 Results of drinking water treatment plant analyses 2010

Sites	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Counts/100 mL											
Suyan	Faecal Coliforms	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
	Total Coliforms	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Anawe	Faecal Coliforms	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
	Total Coliforms	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Tawisakale	Faecal coliforms	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
	Total coliforms	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil

Note: PNG Government permit condition for potable water is; faecal coliforms = zero counts/100 mL , for total coliforms = 3 counts/100 mL

4.6 Waste Discharge and Abstraction Quantities

4.6.1 Waste Discharge Quantities

Annual permitted waste discharge quantities from the mine site include the Process Plant tailings and waste rock discharges from the Anjolek and Anawe erodible dumps. Table 4-19 presents the respective discharge rates for 2010 compared to the permitted quantities. The discharge rates were obtained from the discharge quantities of 6.95 and 5.03 Mt/yr for the Anjolek and Anawe erodible dumps, respectively (see Sect 2.4.5 Sediment Transport) divided by two to obtain the same quantities expressed in Mm^3/y (i.e. at SG of 2 t/ m^3). The tailings slurry volume was calculated as explained in Tailings Monitoring, Section 3.1.

Table 4-19 Discharge quantities from erodible dumps and tailings (Mm^3/y*)

Discharge Site	Discharge Quantity 2010	Permitted Quantity
Anjolek Erodible Dump	3.48 (LTM)	5.27
Anawe Erodible Dump	2.52 (LTM)	5.58
Tailings Slurry Ex-pipe	24.10	56.35

* Mm^3/y = million cubic metres per year; LTM = long-term mean

4.6.2 Abstraction Quantities

Permitted abstraction quantities are in place for water drawn from Waile Creek dam, and from Kogai Creek at the toe of the Kogai Stable Dump for makeup water required in the process plant. Abstraction quantities and permitted amounts are shown in Table 4-20.

Table 4-20 Abstraction rates from Waile Creek Dam and Kogai Creek (Mm^3/y*)

Abstraction Site	Abstraction Quantity 2010	Permitted Quantity
Waile Creek Dam	27.81	27.95
Kogai Creek (at Kogai toe)	4.43	9.46

* Mm^3/y = million cubic metres per year

4.7 Autoclave Stack Monitoring for Sulfuric Acid Mist

PJV monitors sulfuric acid mist concentrations from the four autoclaves operated by the Processing Plant on a monthly basis. Thirty minutes of isokinetic sampling on each autoclave produced a condensate that was filtered and a colour developed using barium chloride. The intensity of the colour, measured with a UV visible spectrophotometer, enabled the concentration of sulfate and hence sulfur trioxide to be calculated. The results were compared with the Australian standard of 0.1 g/m^3 sulfuric acid mist (as sulfur trioxide SO_3) for non-sulfuric acid producing plants. The 2010 mean concentrations for sulfuric acid mist emissions from the four autoclaves are shown in Table 4-21.

Table 4-21 Mean sulfuric acid mist emissions from the autoclaves (as SO_3) for 2010

Autoclave Stack No.	Mean Sulfuric Acid (as SO_3 in g/m^3)
1	0.05
2	0.04
3	0.04
4	0.03

Australian standard: 0.1g/m^3 H_2SO_4 mist (as $S0_3$)

5.0 RIVER MONITORING

5.1 Introduction

PJV has operated a comprehensive riverine monitoring program since the start of operations in 1990 to assess riverine impacts caused by the disposal of tailings and incompetent waste rock to the river system. The principal aims of the program are to verify compliance with permit conditions and to improve understanding of the impacts of riverine disposal on the Strickland River System. This in turn will enable management strategies to be developed to reduce riverine impacts. This section reviews the 2010 riverine monitoring programs and discusses data trends.

Water quality and bed sediment monitoring of the fate of trace metals from the Porgera operations was conducted during 2010 at a number of downstream locations from the mine site to Lake Murray including SG1, SG2, Wankipe, the SG3 compliance monitoring station, Bebelubi, SG4, SG5, and SG6 on the Herbert River. Off-river control sites on the Upper Lagaip River upstream of the Porgera/Lagaip junction, and away from the main river system at Pori River, Ok Om, Kuru River, Baia River and Tomu River were included in the monitoring program.

Water quality and bed sediment samples were collected monthly at SG2, Wankipe, SG3, upper Lagaip River, Pori River, Ok Om and Kuru River. Lower Strickland River sites at Bebelubi, SG4 and SG5 were sampled quarterly as well as the control sites at Baia River and Tomu River. Also, SG6 on the Herbert River was sampled. These locations are shown for convenience on the following map, which is a reproduction of Figure 2-1.

For each monitoring location, water quality samples were analysed for dissolved and total concentrations of arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, silver and zinc, as well as for pH and total suspended solids (TSS). Bed sediment samples taken at the same locations along the river system were analysed for the above metals, plus selenium, in the <63 μm size fraction and for total metals.

Samples for dissolved metals were filtered in the PJV Environment Lab at Porgera using acid-washed polycarbonate filtration apparatus containing cellulose nitrate polycarbonate membrane filter (0.45 μm), and preserved with ultra-pure grade nitric acid. Samples for total metals were neither filtered nor preserved with acid. All samples were sent to the NMI laboratory in Sydney for analysis. The sediment samples were collected as duplicates in the field then returned to the onsite laboratory where they were temporarily stored in a refrigerator before shipment to NMI. A duplicate sample was included with every seven samples sent to NMI, and the QA/QC on these batches was conducted by NMI.

5.2 Trace Metals in the Downstream River System

Dissolved and total trace metal results are summarized in both graphical (box plot) and tabular (statistical summary) forms in this section. In addition, dissolved annual mean concentrations for metals for 2010 are presented as data maps to indicate the extent and effectiveness of dissolved metals decrease downstream of the Porgera mine. The box plot graphical presentations show the 2010 results as box plots of the trace metals and physical parameter at the various downstream monitoring sites. A brief description of how to interpret box plots is presented as Appendix 1.

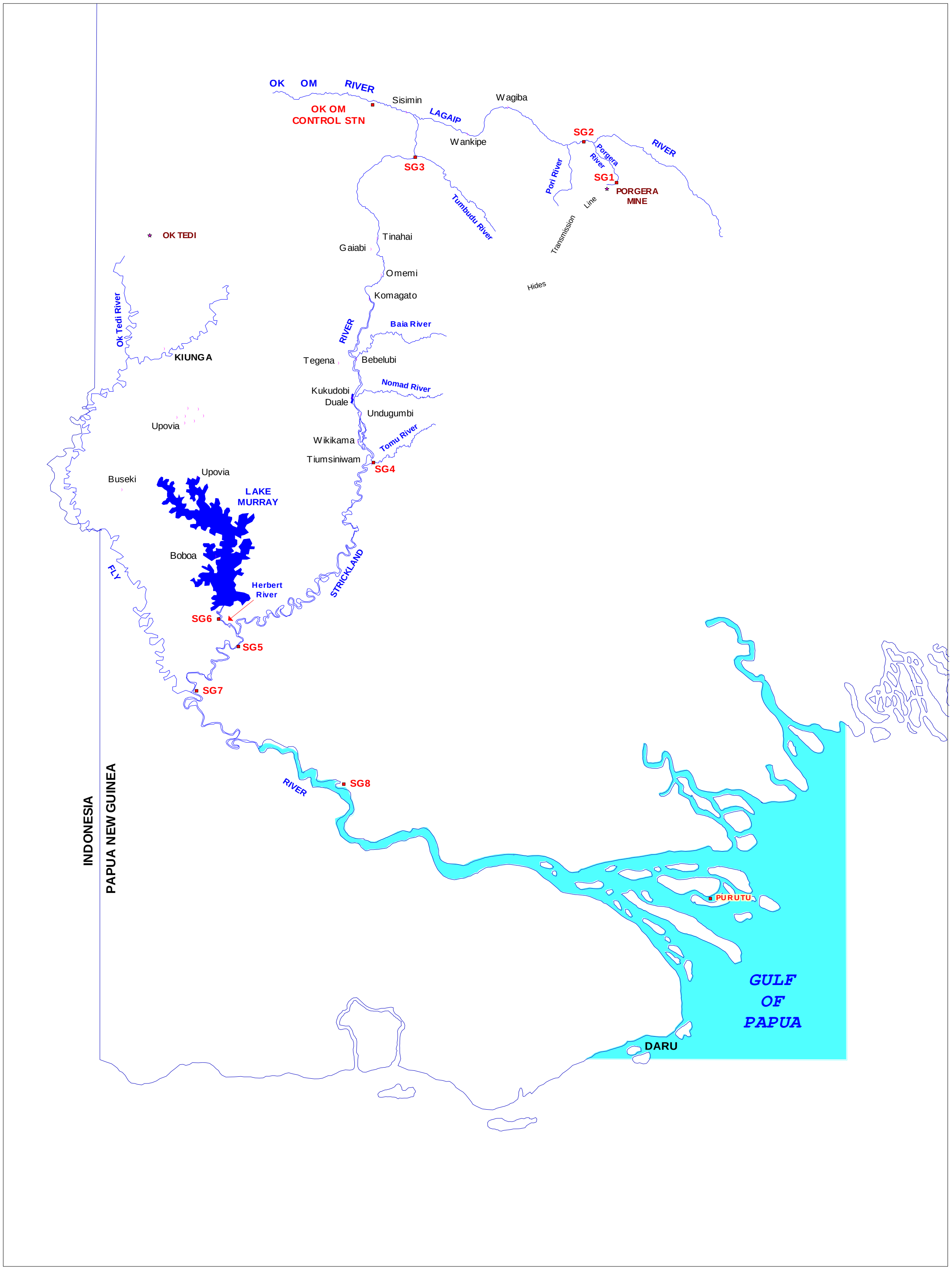
In general, a decreasing trend in dissolved and total trace metal concentrations that occurs downstream of the mine is an indication of increased river flow and sediment accumulation, and hence dilution of these potential contaminants, as tributaries progressively join the main river system.

The mean dissolved concentrations of arsenic, chromium, copper, lead, nickel and silver for 2010 were below the respective SG3 compliance criteria at all downstream monitoring stations. Cadmium and zinc were the exception with all values below the respective SG3 compliance criteria downstream of SG1. Total values of all trace metals decreased substantially from the SG1 monitoring station to the Lower Strickland region at SG5 due to dilution by natural suspended sediments from tributaries joining the main river.

The 2010 annual mean dissolved concentrations of all relevant trace metals at SG2 (i.e. arsenic, cadmium, chromium, copper, lead, nickel, silver and zinc) were lower than the respective compliance criteria set for SG3. This occurred, even though SG2 is about one quarter the down-river distance to SG3 (42 vs 165 km). The 2010 annual mean value for copper at SG2 in particular was 2.0 µg/L, which is much lower than values obtained in the years prior to 2009 and well below the SG3 compliance criterion of 10 µg/L. This change is due to commissioning the Cyanide Destruction Plant (CDP) within the Process Plant in early 2009. The CDP was installed to reduce WAD cyanide levels in tailings but it also had the additional effect of reducing some dissolved metals at SG2, especially copper.

For the 10-year period from 2001 to 2010, dissolved and total metal concentrations in the water column for all the potential metal contaminants, including arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver and zinc, have generally shown little change downstream of the mine.

Tabular presentations are restricted to the results for dissolved and total trace metals at the various monitoring locations over time, from 2001 to 2010. Detailed results and discussions for the trace metals and physical parameters at the downstream monitoring sites are presented in the following sub-sections.



Strickland River system showing downstream monitoring locations and Lake Murray

5.2.1 Arsenic in the River System

During 2010, all dissolved arsenic concentrations were low and well below the SG3 compliance of 50 µg/L at all downstream monitoring sites. Total arsenic concentrations showed a strong downward trend from SG1 to SG5 due mainly to the dilution effect of downstream tributaries (Figure 5-1A). Concentrations of dissolved and total arsenic, from 2001 to 2010 (Figure 5-1B), showed similar trends to those obtained in 2010. From the results for 2001 to 2010 in Table 5-1, the mean annual dissolved arsenic concentration remained relatively low at downstream sites compared to previous years. Total arsenic concentrations at downstream sites were consistent with previous years.

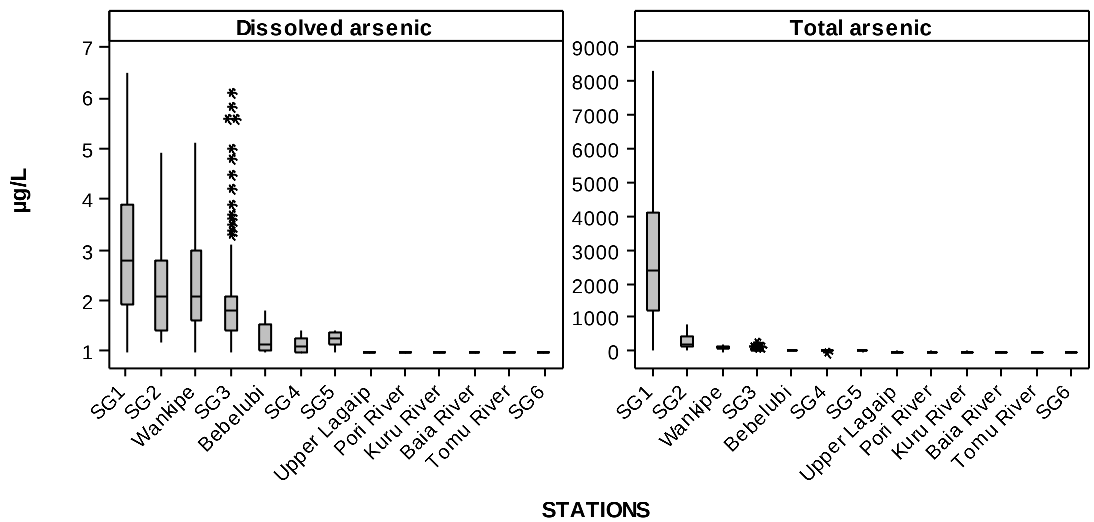


Figure 5-1A Arsenic concentrations at downstream locations during 2010

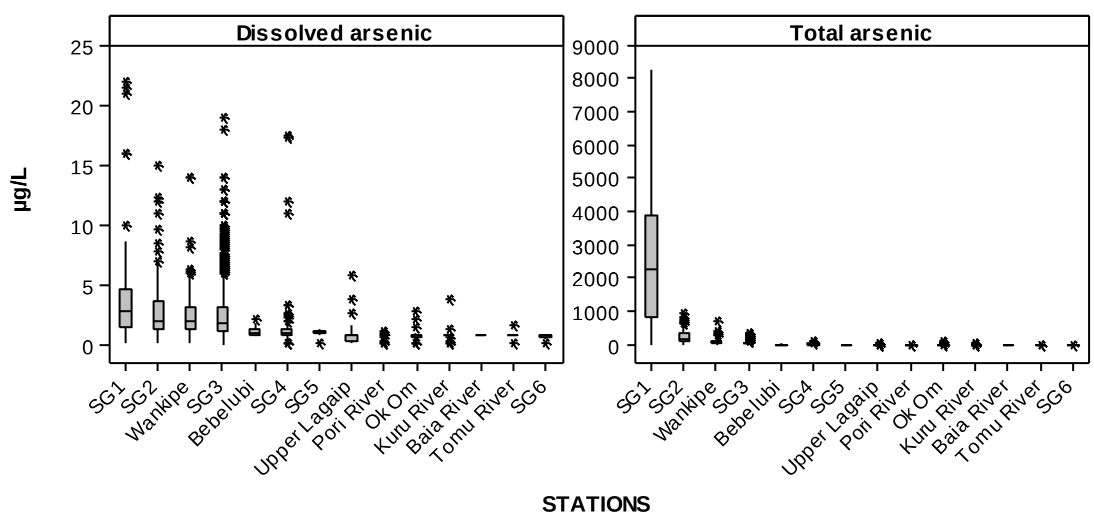
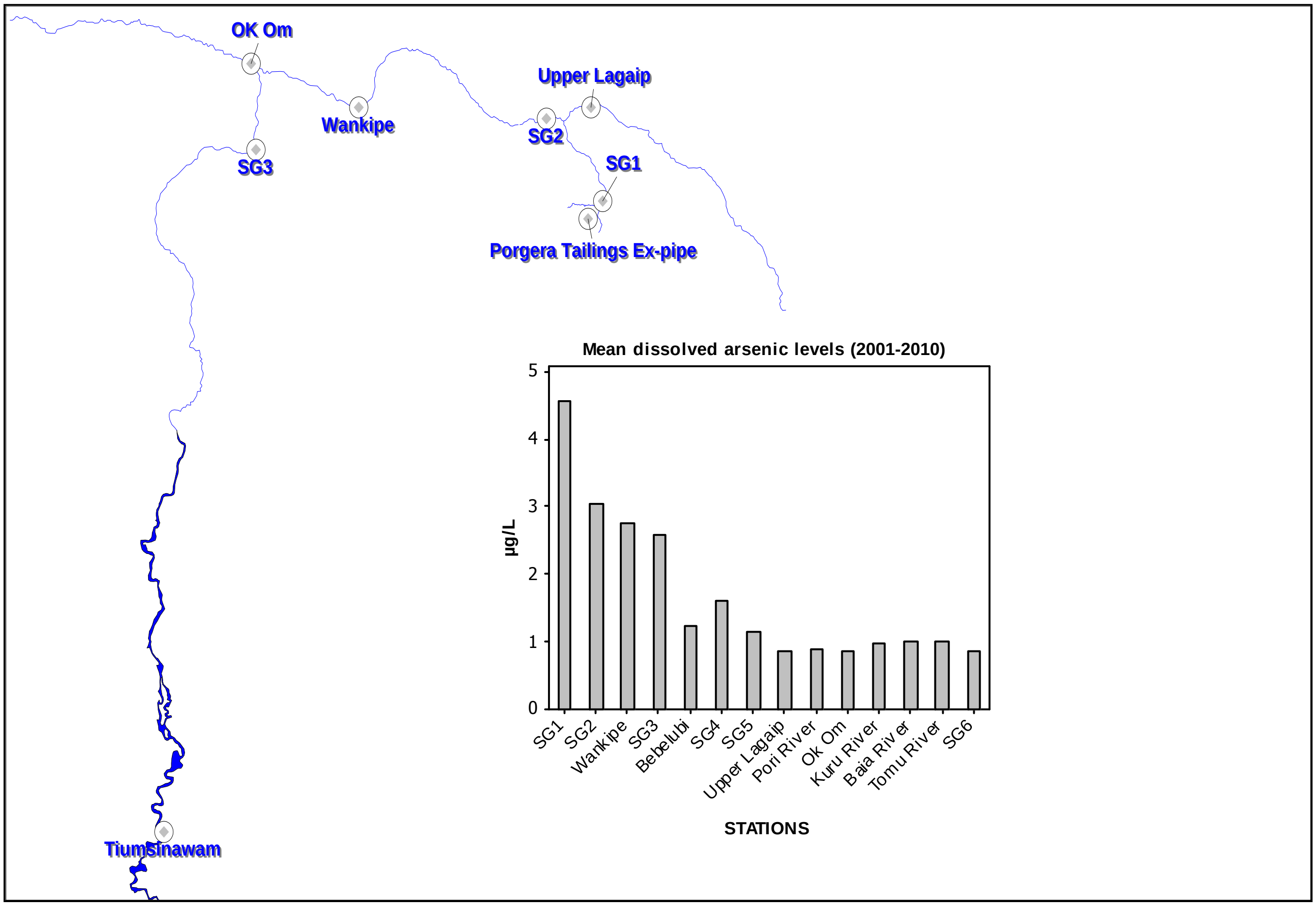


Figure 5-1B Arsenic concentrations at downstream locations from 2001 to 2010

Table 5-1 Mean annual arsenic concentrations at downstream sites from 2001 to 2010 (µg/L)

Dissolved arsenic	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Porgera at SG1	2.0 ± 1.3	3.0 ± 1.6	5.0 ± 3.1	9.0 ± 8.0	14 ± 16	2.0 ± 1.2	3.0 ± 2.1	2.0 ± 0.0	3.0 ± 0.0	2.9 ± 1.5
Lagaip at SG2	2.0 ± 1.1	3.0 ± 1.4	4.0 ± 2.9	6.0 ± 3.7	6.0 ± 4.8	2.0 ± 1.1	3.0 ± 1.9	2.0 ± 0.5	2.2 ± 1.0	2.2 ± 1.0
Lagaip at Wankipe	4.0 ± 4.2	3.0 ± 1.6	3.0 ± 2.1	6.0 ± 4.8	2.0 ± 2.1	2.0 ± 1.2	2.0 ± 0.7	2.0 ± 0.4	1.9 ± 0.4	2.3 ± 1.1
Strickland at SG3	2.5 ± 1.6	4.1 ± 3.6	3.0 ± 1.6	3.8 ± 1.8	2.6 ± 1.3	1.9 ± 0.8	2.9 ± 2.3	1.3 ± 0.3	1.8 ± 0.9	2.0 ± 0.9
Strickland at Bebelubi							1.0 ± 0.0	1.0 ± 0.0	1.5 ± 0.4	1.3 ± 0.3
Strickland at SG4	2.1 ± 3.7	0.9 ± 0.8	0.3 ± 0.07	6.5 ± 6.9	1.2 ± 1.0	1.3 ± 0.2	1.8 ± 0.5	1.1 ± 0.1	1.3 ± 0.4	1.2 ± 0.2
Strickland at SG5	1.0 ± 0.1	0.3 ± 0.0	nd	1.4 ± 0.0	1.5 ± 0.0	1.3 ± 0.0	1.2 ± 0.2	1.1 ± 0.1	1.1 ±0.07	1.2 ± 0.1
Upper Lagaip*	0.4 ± 0.3	0.4 ± 0.2	0.6 ± 0.5	0.6 ± 0.6	2.1 ± 2.0	0.9 ± 0.3	1.0 ± 0.1	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Pori River*					0.4 ± 0.3	0.6 ± 0.4	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Ok Om*	0.8 ± 0.3	1.1 ± 0.7	0.7 ± 0.5	0.5 ± 0.3	0.7 ± 0.4	0.9 ± 0.5	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.03
Kuru River*					0.5 ± 0.3	1.1 ± 1.1	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Baia River*							1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Tomu River*					0.7 ± 0.5	1.0 ± 0.0	1.1 ± 0.3	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
SG6				0.6 ± 0.0	0.6 ± 0.6	nd	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Total arsenic										
Porgera at SG1	3100±1500	2290±1500	3180±1200	4410±5000	2260±1300	2230±1500	1540±1900	730±0.0	3710±0.0	3100±2500
Lagaip at SG2	252 ± 260	214 ± 103	280 ± 170	348 ± 277	198 ± 101	210 ± 177	215 ± 229	272±207	224±113	293 ± 209
Lagaip at Wankipe	109 ± 67	171± 143	196 ± 193	144 ± 74	100 ± 39	82 ± 59	124 ± 56	80 ± 29	71 ± 51	115 ± 69
Strickland at SG3	65 ± 39	84 ± 70	78 ± 54	82 ± 69	69 ± 32	45 ± 30	69 ± 54	51 ± 20	71 ± 29	62 ± 34
Strickland at Bebelubi							24 ± 7.5	23 ± 12	30 ± 8.5	21 ± 3.1
Strickland at SG4	32 ± 16	25 ± 30	8.8 ± 4.6	53 ± 12	31 ± 9.2	16 ± 4.3	30 ± 12	17 ± 7.0	26 ± 12	12 ± 4.2
Strickland at SG5	7.3 ± 4.1	3.5 ± 0.0	nd	13 ± 0.0	13 ± 0.0	12 ± 9.9	20 ± 2.1	14 ± 7.5	6.5 ± 3.2	8.6 ± 2.7
Upper Lagaip*	3.3 ± 1.6	4.2 ± 1.7	9.2 ± 6.8	1.2 ± 1.5	18 ± 21	14 ± 17	4.5 ± 2.0	2.5 ± 2.0	5.6 ± 3.5	2.5 ± 1.8
Pori River*					1.2 ± 1.5	2.9 ± 3.3	2.0 ± 0.9	1.8 ± 0.7	1.6 ± 0.9	3.1 ± 2.4
Ok Om*	5.6 ± 6.4	11 ± 23	17 ± 21	9.5 ± 12	16 ± 24	14 ± 34	9.5 ± 7.0	9.0 ± 11	17 ± 19	5.6 ± 5.3
Kuru River*					2.1 ± 1.9	10 ± 23	2.0 ± 0.7	2.4 ± 1.4	11 ± 12	2.7 ± 2.1
Baia River*							2.4 ± 2.0	2.1 ± 1.1	2.7 ± 2.0	1.9 ± 1.3
Tomu River*					1.2 ± 0.5	1.0 ± 0.0	1.3 ± 0.6	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
SG6				12 ± 0.0	0.6 ± 0.6	nd	1.0 ± 0.0	4.8 ± 5.3	1.0 ± 0.0	1.0 ± 0.0

nd = no data available; * = control site all data is presented as: mean ± standard deviation



Note: Upper Lagaip, Pori, Ok Om, Kuru, Baia and Tomu are monitoring control sites not affected by the Porgera mine.

Figure 5-1C Mean dissolved arsenic concentrations at downstream sites from 2001-2010

The above graph within Figure 5-1C shows the decrease in the mean dissolved arsenic concentrations at the various monitoring stations downstream of the mine. All concentrations are very low and well below the SG3 compliance criterion of 50 µg/L.

5.2.2 Cadmium in the River System

Dissolved cadmium concentrations for 2010 were low and below the SG3 compliance criterion of 1µg/L at all stations beyond SG1. The total metal concentration decrease from SG1 to SG5 was due to dilution effects from natural sediments with distance downstream of the mine (Figure 5-2A). The corresponding graphs for 2001-2010 show similar trends to those for 2010. From Table 5-2, the mean annual dissolved value at SG1 and SG2 for 2010 increased noticeably over recent years, the SG1 value being more in line with those obtained in the early 2000s. The mean annual dissolved and total cadmium concentrations from 2001 to 2010 beyond SG2 show little variation over the years.

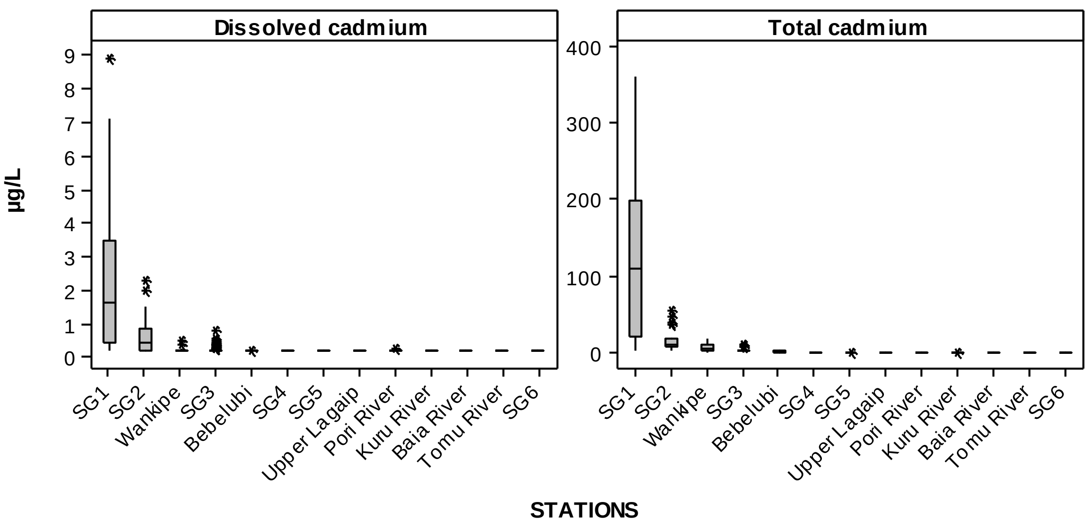


Figure 5-2A Cadmium concentrations at downstream locations during 2010

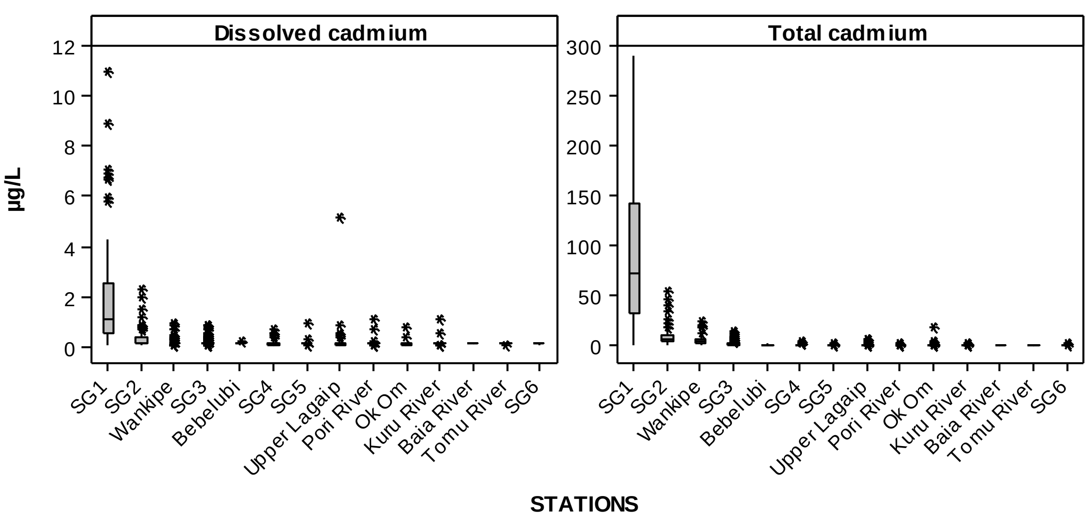
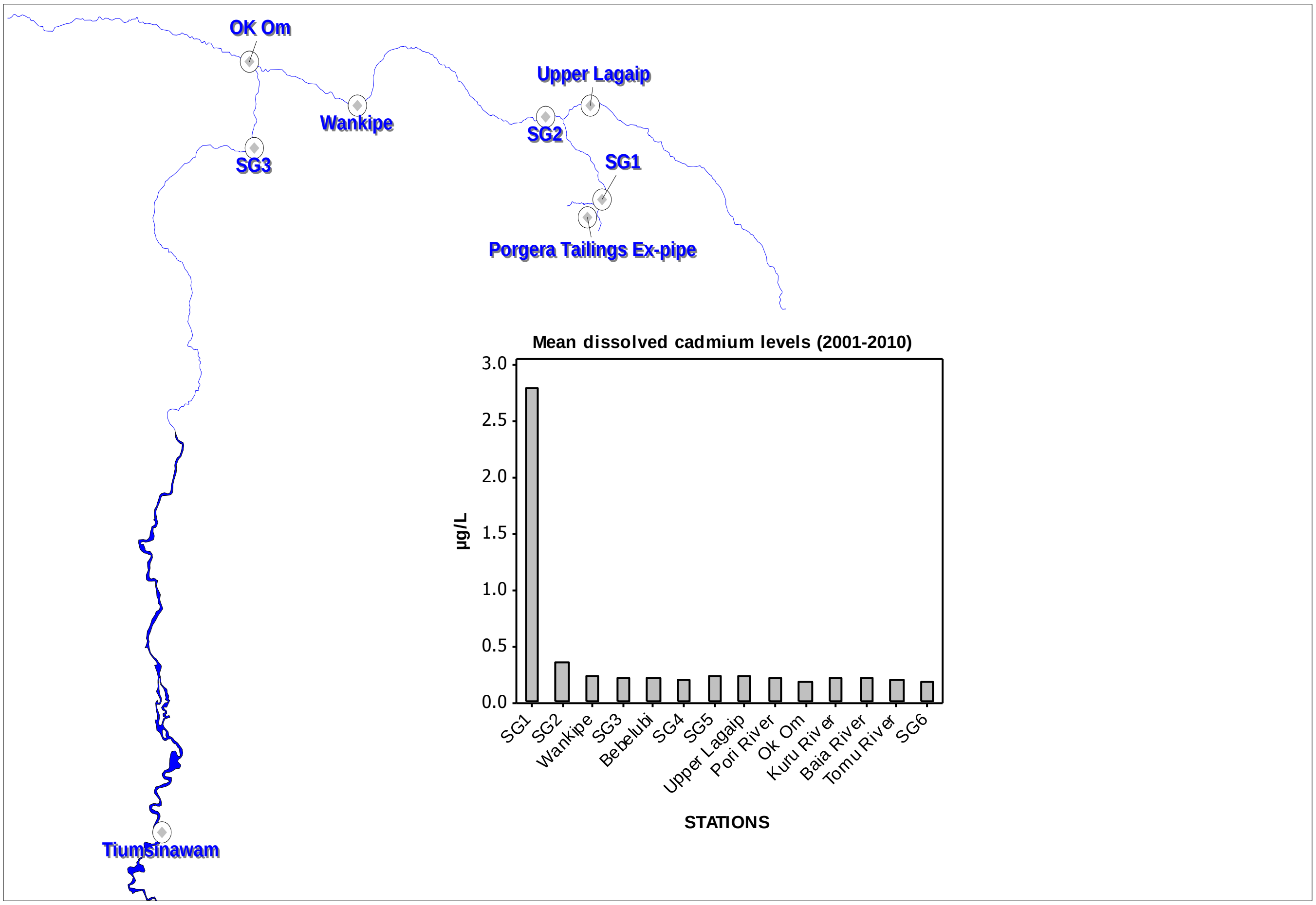


Figure 5-2B Cadmium concentrations at downstream locations from 2001 to 2010

Table 5-2 Mean annual cadmium values at downstream sites from 2001 to 2010 (µg/L)

Dissolved cadmium	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Porgera at SG1	2.7 ± 1.8	2.2 ± 2.7	2.4 ± 3.3	1.2 ± 1.0	1.0 ± 1.1	7.0 ± 17	0.6 ± 0.4	0.2 ± 0.0.	0.6 ± 0.0	2.8 ± 2.4
Lagaip at SG2	0.3 ± 0.2	0.3 ± 0.2	0.2 ± 0.2	0.3 ± 0.3	0.1 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.4 ± 0.2	0.2 ±0.1	0.7± 0.6
Lagaip at Wankipe	0.3 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.05	0.2 ± 0.2	0.4 ± 0.3	0.2 ± 0.0	0.2 ± 0.02	0.2 ± 0.0	0.3 ± 0.1
Strickland at SG3	0.2 ± 0.05	0.2 ± 0.1	0.2 ± 0.04	0.2 ± 0.0	0.2 ± 0.05	0.2 ± 0.02	0.2 ± 0.02	0.2 ± 0.02	0.2 ± 0.002	0.2 ± 0.07
Strickland at Bebelubi							0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.01
Strickland at SG4	0.2 ± 0.2	0.2 ± 0.2	0.1 ± 0.0	0.3 ± 0.1	0.1 ± 0.05	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Strickland at SG5	0.6 ± 0.6	0.1 ± 0.0	nd	0.1 ± 0.0	0.2 ± 0.0	0.3 ± 0.07	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Upper Lagaip*	0.2 ± 0.2	0.2 ± 0.1	0.1 ± 0.05	0.1 ± 0.05	0.1 ± 0.05	0.2 ± 0.1	0.8 ± 1.7	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Pori River*					0.2 ± 0.2	0.3 ± 0.4	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.02
Ok Om*	0.2 ± 0.04	0.2 ± 0.04	0.1 ± 0.05	0.1 ± 0.04	0.2 ± 0.1	0.2 ± 0.2	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Kuru River*					0.2 ± 0.2	0.2 ± 0.3	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Baia River*							0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Tomu River*					0.2 ± 0.06	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
SG6				0.1 ± 0.0	0.2 ± 0.07	nd	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Total cadmium										
Porgera at SG1	87 ± 57	49 ± 29	90 ± 49	139 ± 256	66 ± 75	385 ± 580	44 ± 44	15 ± 0.0	88 ± 0.0	140 ± 100
Lagaip at SG2	8.5 ± 4.9	3.7 ± 2.8	9.5 ± 5.7	5.0 ± 5.1	3.7 ± 3.3	5.4 ± 2.8	5.4 ± 3.2	9.1 ± 6.8	6.8 ± 2.8	15 ± 14
Lagaip at Wankipe	3.5 ± 1.1	6.5 ± 7.1	5.6 ± 5.6	1.6 ± 1.6	2.4 ± 1.8	4.5 ± 5.4	3.8 ± 1.1	3.3 ± 1.4	4.3 ± 1.8	6.4 ± 5.1
Strickland at SG3	1.9 ± 0.8	1.6 ± 1.1	1.5 ± 1.0	1.3 ± 1.5	1.4 ± 0.7	2.0 ± 1.0	1.4 ± 0.8	1.8 ± 0.8	2.1 ± 1.0	2.6 ± 1.6
Strickland at Bebelubi							0.6 ± 0.2	1.0 ± 0.2	0.7 ± 0.2	0.8 ± 0.4
Strickland at SG4	0.8 ± 0.6	0.7 ± 0.8	0.5 ± 0.1	0.8 ± 0.7	0.4 ± 0.2	0.8 ± 1.0	0.8 ± 0.3	0.5 ± 0.2	0.7 ± 0.5	0.4 ± 0.1
Strickland at SG5	0.5 ± 0.2	0.1 ± 0.0	nd	0.1 ± 0.0	0.3 ± 0.0	0.9 ± 0.4	0.3 ± 0.07	0.3 ± 0.2	0.2 ± 0.01	0.2 ± 0.04
Upper Lagaip*	1.1 ± 2.0	0.7 ± 0.5	0.5 ± 0.6	2.2 ± 3.2	0.9 ± 1.5	0.5 ± 0.8	0.8 ± 1.8	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Pori River*					0.7 ± 0.6	0.4 ± 0.4	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Ok Om*	0.2 ± 0.04	2.3 ± 5.9	1.2 ± 1.3	0.5 ± 0.6	0.4 ± 0.3	0.4 ± 0.5	0.2 ± 0.01	0.2 ± 0.02	0.3 ± 0.1	0.2 ± 0.02
Kuru River*					0.7 ± 1.0	0.3 ± 0.4	0.2 ± 0.0	0.2 ± 0.0	0.3 ± 0.1	0.2 ± 0.01
Baia River*							0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Tomu River*					0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
SG6				0.1 ± 0.0	1.2 ± 1.4	nd	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0

nd = no data available; * = control site all data is presented as: mean ± standard deviation



Note: Upper Lagaip, Pori, Ok Om, Kuru, Baia and Tomu are monitoring control sites not affected by the Porgera mine.

Figure 5-2C Mean dissolved cadmium concentrations at downstream sites from 2001-2010

The graph within Figure 5-2C shows a rapid decrease in the dissolved cadmium concentration at SG1 to considerably lower values at monitoring stations further downstream. All dissolved cadmium concentrations downstream of SG1 are at or near the detection limit of 0.2 µg/L. The concentration at SG3 is well below the compliance criterion of 1 µg/L.

5.2.3 Chromium in the River System

Dissolved chromium concentrations during 2010 were very low with all values at or below the detection limit of 1 µg/L. Total chromium values decreased noticeably downstream of SG1 (Figure 5-3A). The results for 2001-2010 in Figure 5-3B were somewhat similar to those for 2010. Mean annual dissolved chromium concentrations from 2001 to 2010 (Table 5-3) remained consistently low over the 10-year period while total concentrations varied over the same period.

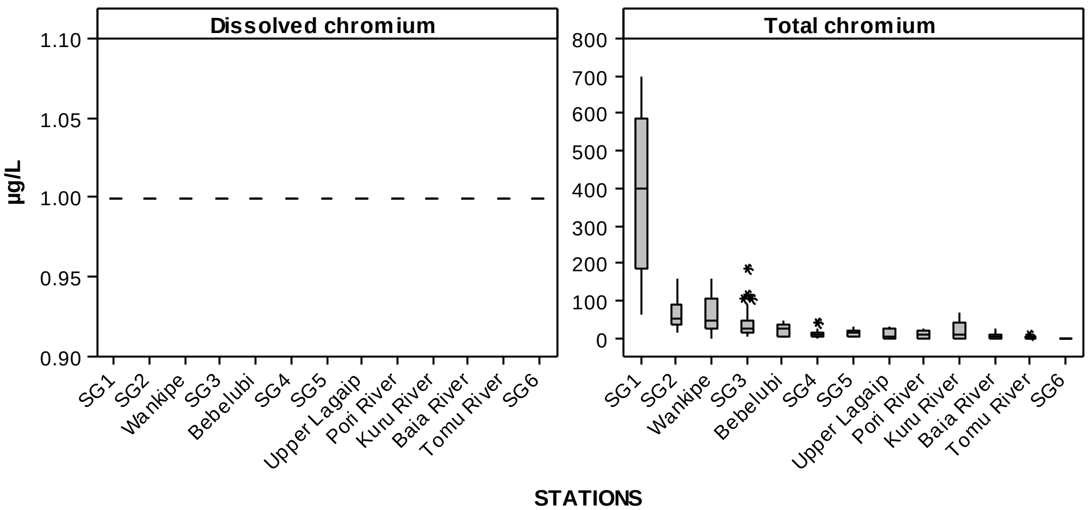


Figure 5-3A Chromium concentrations at downstream locations during 2010

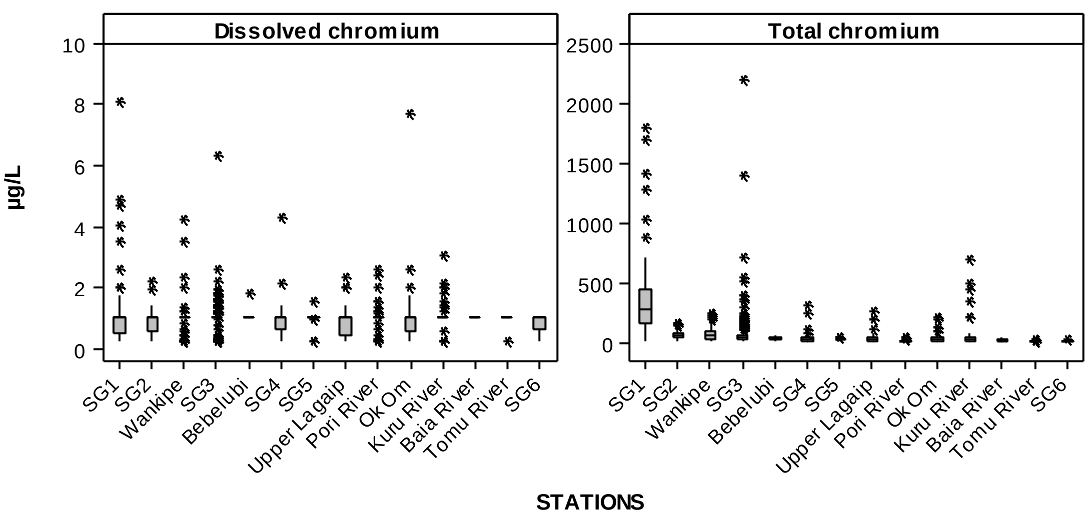
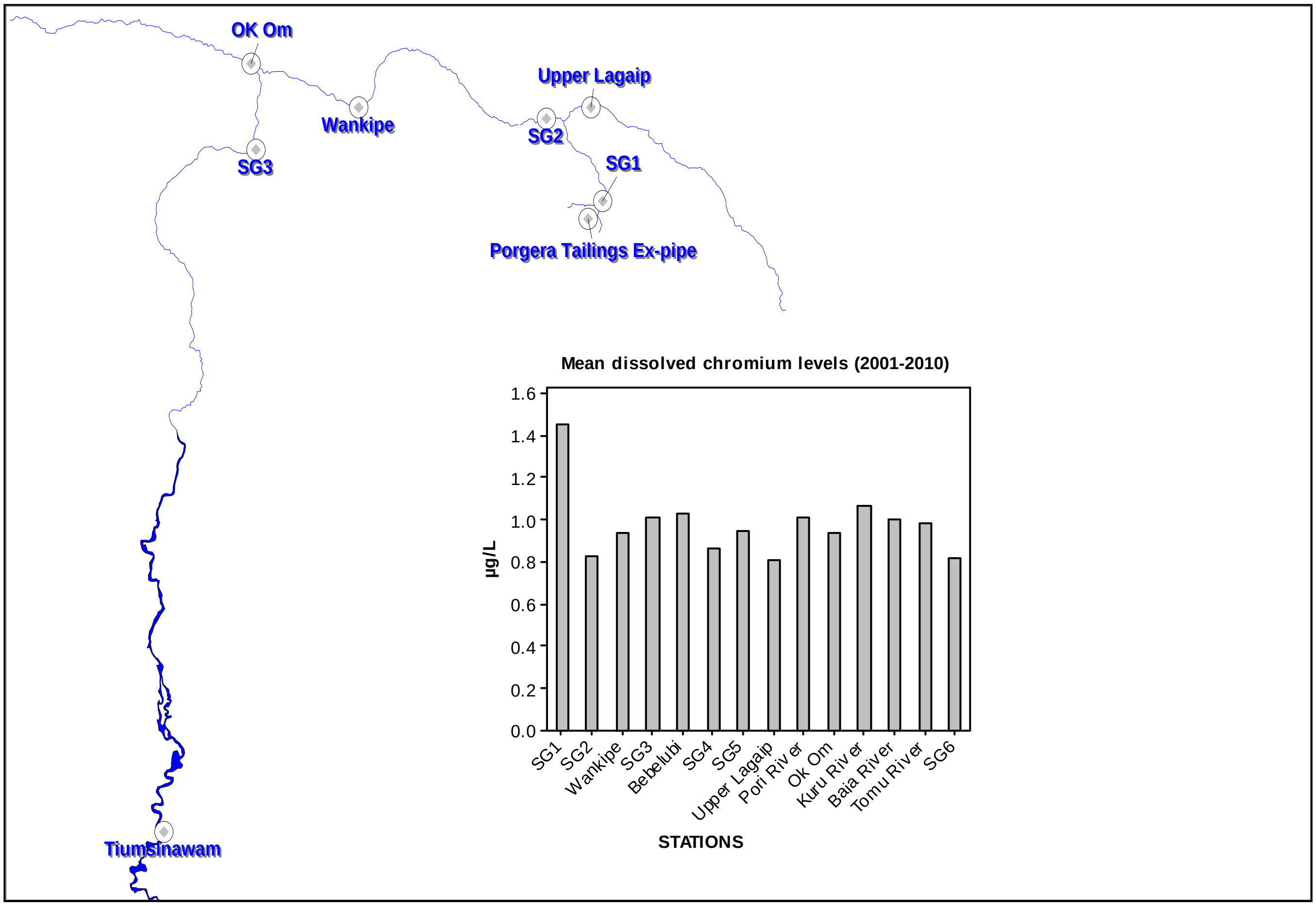


Figure 5-3B Chromium concentrations at downstream locations from 2001 to 2010

Table 5-3 Mean annual chromium concentrations at downstream sites from 2001 to 2010 (all results in µg/L)

Dissolved chromium	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Porgera at SG1	2.5 ± 6.8	1.4 ± 2.5	0.3 ± 0.1	0.9 ± 0.8	3.4 ± 3.8	1.4 ± 1.0	1.2 ± 0.5	1.0 ± 0.0	nd	1.0 ± 0.1
Lagaip at SG2	0.6 ± 0.4	0.6 ± 0.4	0.4 ± 0.3	0.4 ± 0.3	0.8 ± 0.5	1.0 ± 0	1.2 ± 0.4	1.0 ± 0	1.0 ± 0	1.0 ± 0.0
Lagaip at Wankipe	1.1 ± 0.4	1.2 ± 1.2	0.4 ± 0.3	0.5 ± 0.4	1.3 ± 1.0	0.9 ± 0.6	1.0 ± 0.06	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Strickland at SG3	0.8 ± 0.3	1.0 ± 0.1	1.0 ± 0.04	1.0 ± 0.1	1.1 ± 0.2	1.0 ± 0.06	1.1 ± 0.4	1.0 ± 0.1	1.0 ± 0.0	1.0 ± 0.03
Strickland at Bebelubi							1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.1 ± 0.2
Strickland at SG4	0.8 ± 0.6	0.7 ± 0.9	0.3 ± 0.07	0.5 ± 0.1	0.8 ± 0.4	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Strickland at SG5	1.2 ± 0.4	0.2 ± 0.0	nd	0.2 ± 0.0	1.0 ± 0.0	1.0 ± 0.07	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Upper Lagaip*	0.7 ± 0.5	0.9 ± 0.7	0.4 ± 0.3	0.5 ± 0.4	0.6 ± 0.5	1.1 ± 0.4	1.0 ± 0.07	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Pori River*					0.6 ± 0.4	1.0 ± 0.9	1.1 ± 0.2	1.0 ± 0.0	1.1 ± 0.5	1.0 ± 0.1
Ok Om*	1.1 ± 0.3	0.9 ± 0.4	1.2 ± 2.3	0.4 ± 0.3	1.0 ± 0.7	0.9 ± 0.5	1.0 ± 0.1	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Kuru River*					1.0 ± 1.2	1.2 ± 0.7	1.1 ± 0.2	1.0 ± 0.07	1.1 ± 0.3	1.0 ± 0.0
Baia River*							1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Tomu River*					0.7 ± 0.5	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
SG6				0.2 ± 0.0	0.6 ± 0.6	nd	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Total chromium										
Porgera at SG1	305 ± 117	186 ± 108	248 ± 188	497 ± 620	276 ± 251	953 ± 1506	180 ± 178	250 ± 0.0	362 ± 0.0	543 ± 440
Lagaip at SG2	52 ± 13	56 ± 29	65 ± 26	61 ± 32	53 ± 24	59 ± 44	49 ± 19	73 ± 37	60 ± 18	64 ± 38
Lagaip at Wankipe	64 ± 51	71 ± 60	67 ± 41	22 ± 14	94 ± 74	51 ± 45	74 ± 67	59 ± 41	79 ± 56	65 ± 49
Strickland at SG3	32 ± 25	45 ± 79	40 ± 37	34 ± 25	48 ± 36	46 ± 38	41 ± 35	69 ± 194	70 ± 52	37 ± 25
Strickland at Bebelubi							29 ± 8.5	29 ± 16	26 ± 10	26 ± 17
Strickland at SG4	35 ± 14	21 ± 67	15 ± 11	14 ± 6.5	49 ± 69	22 ± 17	21 ± 7.9	17 ± 14	28 ± 20	15 ± 12
Strickland at SG5	17 ± 0.6	12 ± 0.0	nd	11 ± 0.0	14 ± 0.0	31 ± 12	11 ± 3.9	23 ± 19	7.9 ± 5.0	15 ± 9.3
Upper Lagaip*	32 ± 19	31 ± 19	32 ± 17	12 ± 12	33 ± 16	58 ± 59	15 ± 15	13 ± 12	29 ± 24	13 ± 13
Pori River*					11 ± 10	4.9 ± 1.0	5.6 ± 3.3	4.6 ± 3.0	5.1 ± 4.0	12 ± 10
Ok Om*	20 ± 22	20 ± 38	25 ± 25	18 ± 19	31 ± 39	11 ± 7.5	18 ± 14	18 ± 25	62 ± 67	16 ± 20
Kuru River*					9.5 ± 9.2	10 ± 10	9.2 ± 4.5	11 ± 11	209 ± 227	24 ± 25
Baia River*							10 ± 5.2	7.1 ± 4.4	10 ± 8.9	7.8 ± 8.3
Tomu River*					1.2 ± 0.3	2.0 ± 2.0	1.9 ± 1.7	1.1 ± 0.2	1.9 ± 1.5	3.2 ± 2.8
SG6				9.0 ± 0.0	0.6 ± 0.6	nd	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0

nd = no data available; * = control site all data is presented as: mean ± standard deviation



Note: Upper Lagaip, Pori, Ok Om, Kuru, Baia and Tomu are monitoring control sites not affected by the Porgera mine.

Figure 5-3C Mean dissolved chromium concentrations at downstream sites from 2001-2010

The above graph, within Figure 5-3C, shows consistently low values for dissolved chromium concentrations downstream of Porgera. All values shown for 2010 are well below the SG3 compliance criterion of 10 µg/L.

5.2.4 Copper in the River System

Dissolved copper concentrations during 2010 showed relatively low results for SG1 and SG2, and declined further beyond SG2 (Figure 5-4A). The results for 2001-2010 (Figure 5-4B) were noticeably much higher at SG1. This effect is better shown in Table 5-4 where the 2009 and 2010 mean dissolved concentrations at SG1 and SG2 were very much lower than previous years. The reason for this appears to be the addition of a Cyanide Destruction Unit within the Process Plant which has dramatically reduced dissolved copper levels in tailings. The mean total copper level at SG1 is the highest recorded since 2001, probably because the reduction in dissolved levels has resulted in an increase in the particulate form. All other 2010 results for both dissolved and total concentrations were consistent with previous years.

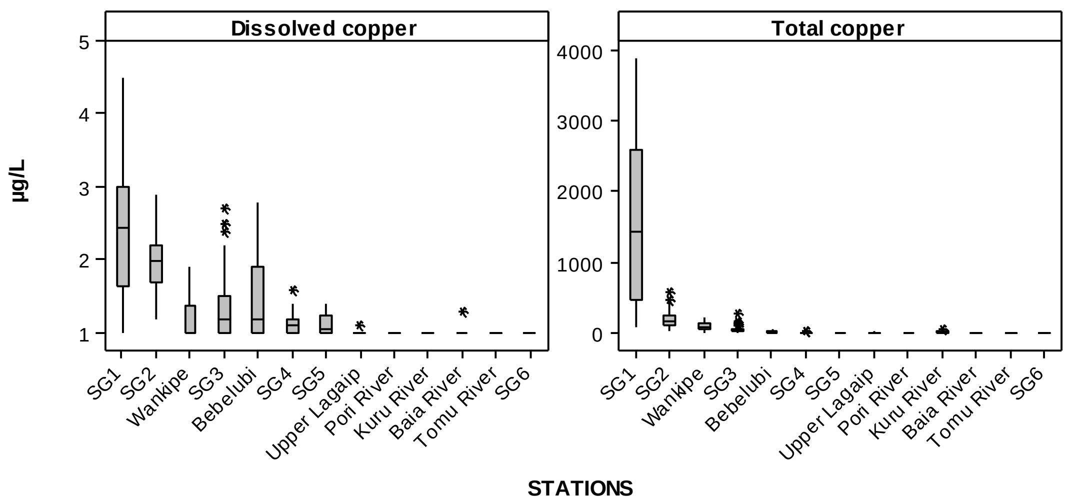


Figure 5-4A Copper concentrations at downstream locations during 2010

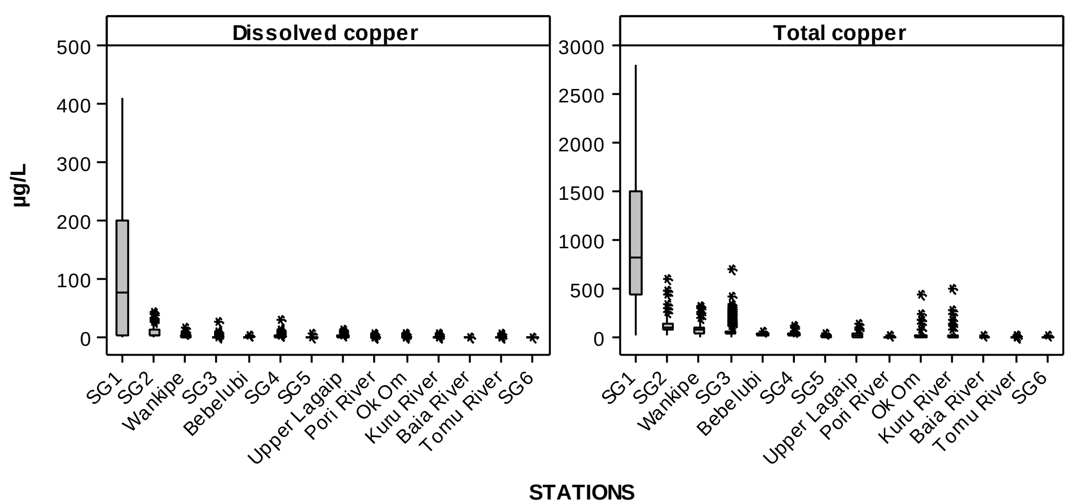
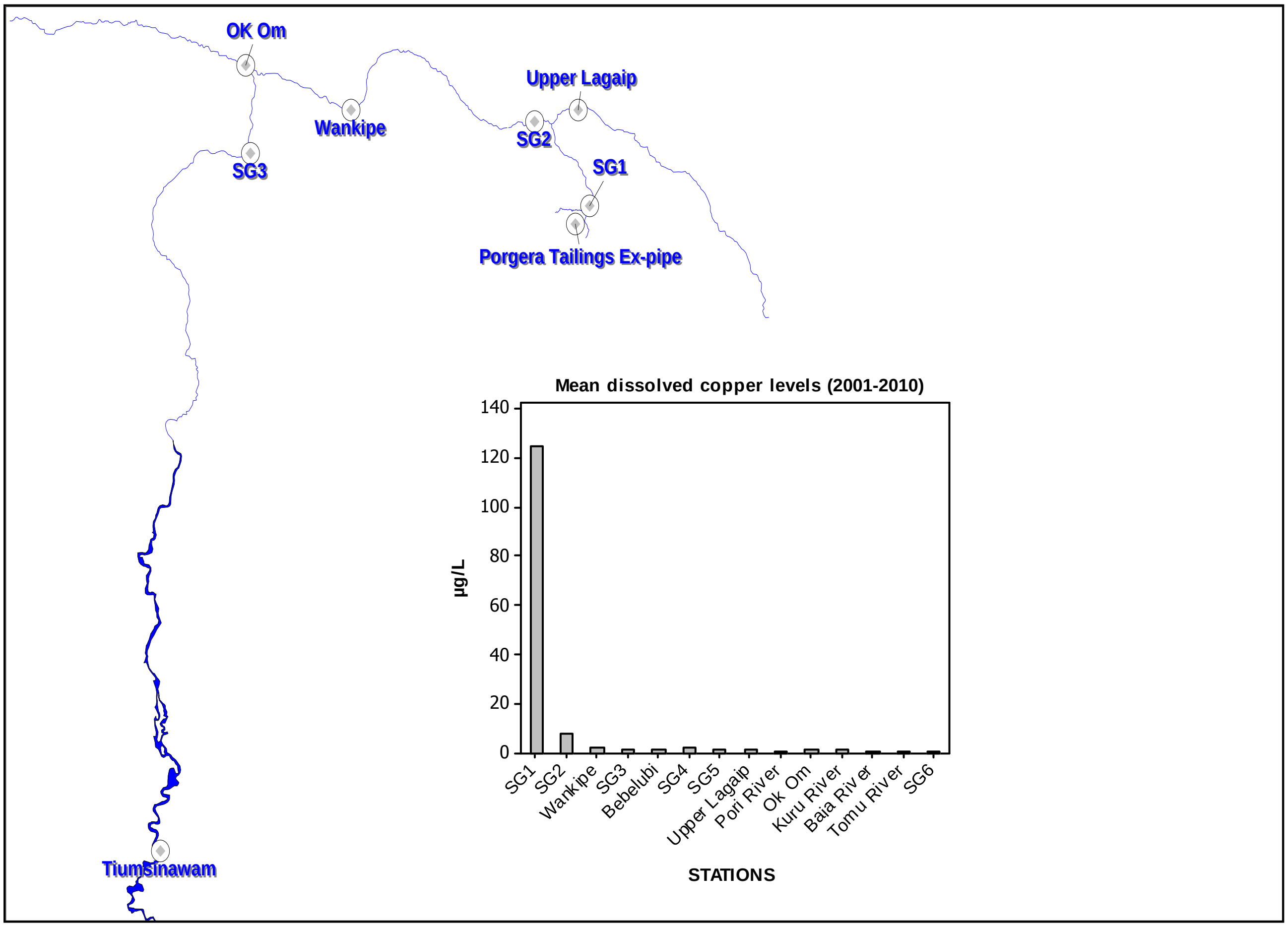


Figure 5-4B Copper concentrations at downstream locations from 2001-2010

Table 5-4 Mean annual copper concentrations at downstream sites from 2001 to 2010 (all results in µg/L)

Dissolved copper	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Porgera at SG1	138 ± 116	115 ± 129	115 ± 82	144 ± 132	203 ± 209	303 ± 236	142 ± 118	29 ± 0.0	3.0 ± 0.0	2.9 ± 1.9
Lagaip at SG2	8.8 ± 5.7	9.9 ± 11	6.8 ± 4.0	13 ± 8.5	11 ± 6.3	10 ± 8.8	14 ± 13	11 ± 11	1.6 ± 0.7	2.0 ± 0.4
Lagaip at Wankipe	4.0 ± 3.2	2.7 ± 1.6	2.4 ± 2.3	1.7 ± 0.7	5.2 ± 5.8	2.6 ± 1.5	2.3 ± 1.3	2.3 ± 2.5	1.1 ± 0.2	1.2 ± 0.3
Strickland at SG3	1.6 ± 1.0	1.5 ± 1.0	1.4 ± 0.7	1.2 ± 0.5	1.3 ± 0.4	1.5 ± 0.6	1.6 ± 0.6	1.4 ± 0.5	1.3 ± 2.0	1.3 ± 0.4
Strickland at Bebelubi							1.1 ± 0.1	2.2 ± 1.0	1.0 ± 0.0	1.5 ± 0.7
Strickland at SG4	1.7 ± 0.8	2.5 ± 2.3	1.7 ± 0.1	7.3 ± 9.0	3.7 ± 3.2	1.5 ± 0.7	2.0 ± 0.6	1.4 ± 0.6	1.1 ± 0.2	1.1 ± 0.2
Strickland at SG5	1.2 ± 0.07	0.4 ± 0.0	nd	1.1 ± 0.0	1.0 ± 0.0	3.5 ± 3.2	1.2 ± 0.07	1.0 ± 0.0	1.1 ± 0.2	1.1 ± 0.2
Upper Lagaip*	2.6 ± 2.5	4.1 ± 4.7	1.7 ± 1.3	1.2 ± 1.0	2.4 ± 1.0	1.9 ± 1.4	1.6 ± 0.9	1.1 ± 0.1	1.0 ± 0.1	1.0 ± 0.03
Pori River*					2.6 ± 2.8	1.0 ± 1.0	1.0 ± 0.1	1.1 ± 0.3	1.0 ± 0.0	1.0 ± 0.0
Ok Om*	1.4 ± 0.6	1.0 ± 0.4	1.6 ± 1.6	1.6 ± 0.7	2.3 ± 2.0	1.9 ± 1.9	1.2 ± 0.3	1.1 ± 0.2	1.0 ± 0.06	1.1 ± 0.1
Kuru River*					2.6 ± 2.3	1.7 ± 1.6	1.3 ± 0.9	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Baia River*							1.0 ± 0.0	1.0 ± 0.05	1.0 ± 0.0	1.0 ± 0.09
Tomu River*					0.8 ± 0.4	1.1 ± 0.1	2.0 ± 2.0	1.0 ± 0.03	1.0 ± 0.2	1.0 ± 0.0
SG6				0.9 ± 0.0	0.9 ± 0.0	nd	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Total copper										
Porgera at SG1	978 ± 563	573 ± 358	867 ± 380	1104 ± 1229	806 ± 693	1360 ± 842	743 ± 517	420 ± 0.0	960 ± 0.0	1815 ± 1220
Lagaip at SG2	118 ± 46	85 ± 50	114 ± 42	96 ± 51	77 ± 28	89 ± 44	103 ± 53	156 ± 75	119 ± 28	218 ± 149
Lagaip at Wankipe	58 ± 20	94 ± 51	119 ± 96	31 ± 19	114 ± 102	84 ± 100	114 ± 82	89 ± 45	112 ± 48	106 ± 64
Strickland at SG3	42 ± 22	54 ± 64	54 ± 40	41 ± 30	65 ± 44	65 ± 46	56 ± 44	63 ± 33	80 ± 49	60 ± 32
Strickland at Bebelubi							30 ± 13	32 ± 13	30 ± 11	31 ± 13
Strickland at SG4	29 ± 22	11 ± 8.7	62 ± 82	22 ± 16	24 ± 16	25 ± 19	26 ± 8.3	20 ± 16	29 ± 21	17 ± 11
Strickland at SG5	15 ± 4.0	10 ± 0.0	nd	5.7 ± 0.0	17 ± 0.0	37 ± 12	12 ± 5.4	23 ± 22	9.4 ± 4.2	14 ± 7.4
Upper Lagaip*	30 ± 22	29 ± 14	25 ± 12	32 ± 32	21 ± 18	35 ± 17	15 ± 15	12 ± 11	26 ± 22	12 ± 13
Pori River*					5.0 ± 4.0	6.5 ± 4.0	3.9 ± 1.9	2.9 ± 1.5	3.0 ± 2.3	6.6 ± 5.6
Ok Om*	19 ± 21	28 ± 61	70 ± 136	19 ± 24	33 ± 61	13 ± 13	19 ± 15	20 ± 26	60 ± 75	15 ± 22
Kuru River*					6.7 ± 5.1	9.4 ± 6.2	7.6 ± 4.2	10 ± 11	131 ± 153	19 ± 23
Baia River*							6.6 ± 3.0	4.7 ± 2.5	5.9 ± 4.7	6.3 ± 6.4
Tomu River*					4.7 ± 6.4	3.1 ± 4.1	2.6 ± 2.9	1.5 ± 0.6	2.4 ± 2.3	5.2 ± 4.8
SG6				3.0 ± 0.0	2.1 ± 1.5	nd	1.2 ± 0.2	7.5 ± 9.2	1.0 ± 0.0	1.0 ± 0.0

nd = no data available; * = control site all data is presented as: mean ± standard deviation



Note: Upper Lagaip, Pori, Ok Om, Kuru, Baia and Tomu are monitoring control sites not affected by the Porgera mine.

Figure 5-4C Mean dissolved copper concentrations at downstream sites from 2001-2010

The graph within Figure 5-4C shows the dramatic decrease over the 10-year period in mean concentrations of dissolved copper beyond SG1, which is influenced by mine discharge.

5.2.5 Iron in the River System

Dissolved iron concentrations downstream of the mine were relatively low and showed no obvious trend during 2010. Total iron declined noticeably compared to the various other downstream monitoring sites (Figure 5-5A). Similar results were obtained from 2001 to 2010. From Table 5-5, both mean annual dissolved and total iron concentrations downstream of the mine have varied noticeably over the years with no distinct trends.

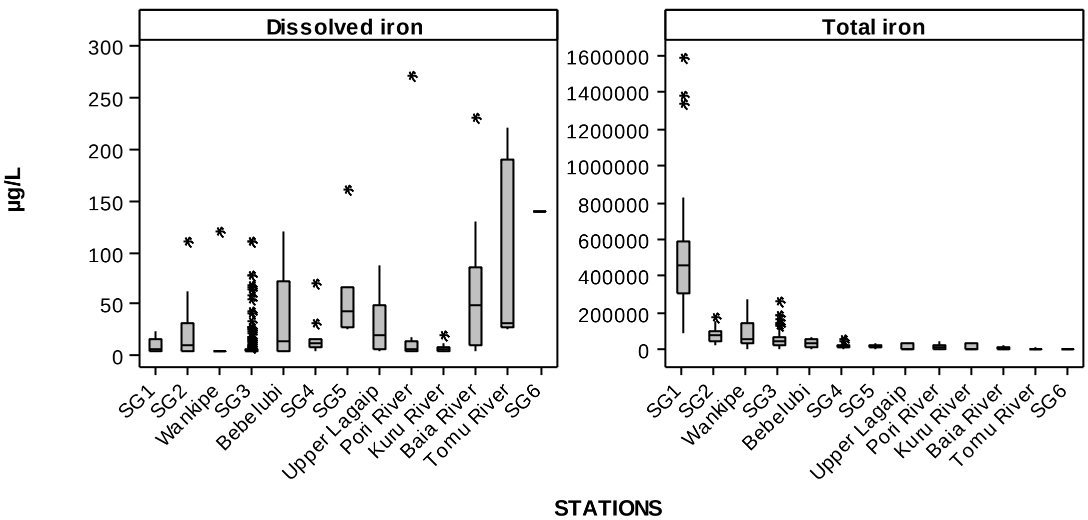


Figure 5-5A Iron concentrations at downstream monitoring sites during 2010

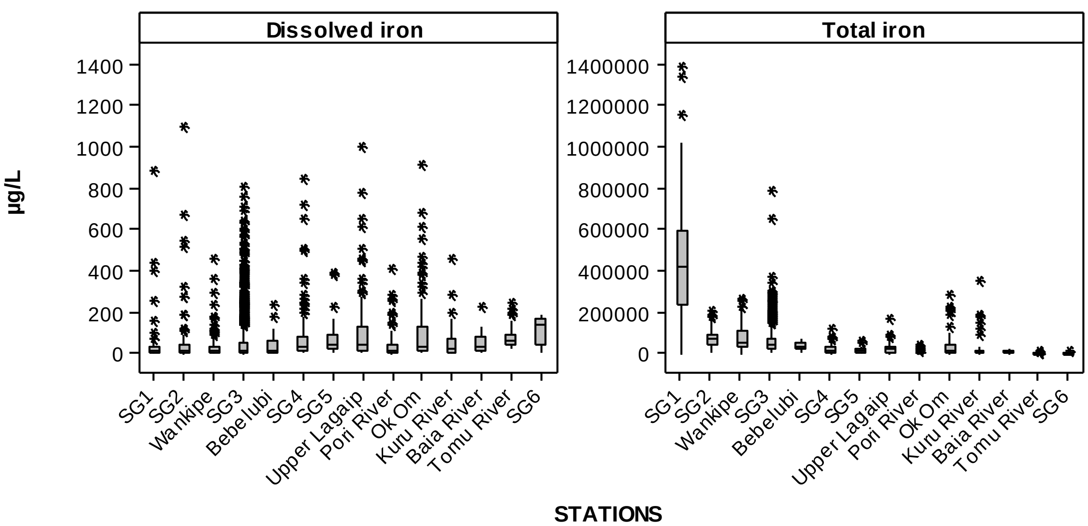
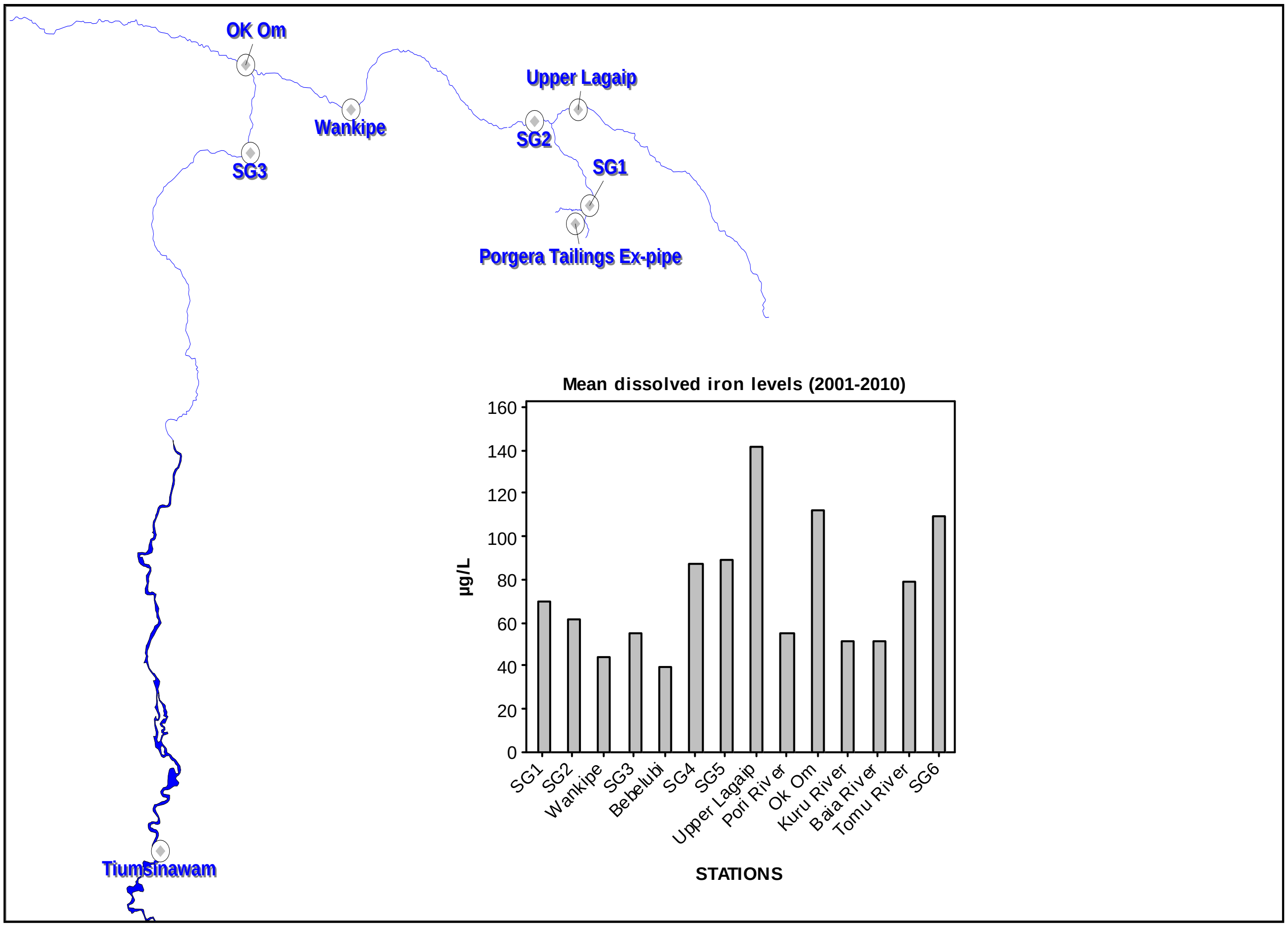


Figure 5-5B Iron concentrations at downstream locations from 2001 to 2010

Table 5-5 Mean annual iron concentrations at downstream sites from 2001 to 2010 (all results in µg/L)

Dissolved iron	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Porgera at SG1	241 ± 656	114 ± 283	18 ± 8.0	26 ± 25	77 ± 132	44 ± 84	37 ± 48	28 ± 0.0	nd	9.5 ± 6.4
Lagaip at SG2	60 ± 89	260 ± 376	81 ± 96	81 ± 157	24 ± 19	51 ± 58	36 ± 31	27 ± 36	38 ± 89	22 ± 26
Lagaip at Wankipe	123 ± 150	55 ± 95	54 ± 51	37 ± 47	81 ± 126	39 ± 52	42 ± 71	22 ± 21	5.3 ± 0.9	15 ± 33
Strickland at SG3	165 ± 203	109 ± 142	22 ± 39	41 ± 63	46 ± 74	54 ± 77	53 ± 72	32 ± 39	13 ± 17	11 ± 16
Strickland at Bebelubi							138 ± 87	15 ± 11	9.3 ± 7.7	35 ± 39
Strickland at SG4	328 ± 319	92 ± 104	126 ± 105	69 ± 59	138 ± 145	166 ± 200	96 ± 71	51 ± 56	33 ± 28	16 ± 15
Strickland at SG5	310 ± 112	40 ± 0.0	nd	16 ± 0.0	22 ± 1 0.0	58 ± 30	37 ± 20	21 ± 22	151 ± 137	58 ± 44
Upper Lagaip*	174 ± 167	541 ± 167	157 ± 172	124 ± 237	95 ± 152	127 ± 117	92 ± 98	44 ± 78	81 ± 139	29 ± 26
Pori River*					84 ± 87	91 ± 103	64 ± 85	44 ± 57	46 ± 121	30 ± 76
Ok Om*	224 ± 239	105 ± 136	198 ± 298	83 ± 94	85 ± 91	191 ± 198	174 ± 179	77 ± 79	39 ± 44	13 ± 8.7
Kuru River*					103 ± 107	128 ± 133	65 ± 32	39 ± 34	10 ± 8.8	8.3 ± 4.3
Baia River*							93 ± 2.4	29 ± 18	29 ± 26	64 ± 67
Tomu River*					82 ± 63	87 ± 22	96 ± 87	100 ± 52	60 ± 21	90 ± 82
SG6				45 ± 0.0	117 ± 64	nd	170 ± 28	93 ± 124	39 ± 0.0	140 ± 0.0
Total iron										
Porgera at SG1 ('000)	455 ± 188	339 ± 188	548 ± 236	644 ± 736	400 ± 242	559 ± 304	255 ± 270	330 ± 0.0	nd	583 ± 399
Lagaip at SG2 ('000)	78 ± 18	67 ± 39	101 ± 57	47 ± 49	59 ± 24	57 ± 18	62 ± 28	97 ± 49	83 ± 27	86 ± 43
Lagaip at Wankipe ('000)	53 ± 37	70 ± 43	84 ± 60	27 ± 14	105 ± 80	63 ± 52	94 ± 81	78 ± 53	109 ± 68	93 ±84
Strickland at SG3 (000)	49 ± 44	57 ± 83	51 ± 39	43 ± 31	67 ± 49	54 ± 39	53 ± 39	64 ± 42	82 ± 54	50 ± 38
Strickland at Bebelubi ('000)							45 ± 21	35 ± 12	36 ± 13	34 ± 22
Strickland at SG4 ('000)	41 ± 25	7.4 ± 5.7	6.9 ± 3.0	12 ± 4.9	32 ± 16	29 ± 21	18 ± 11	22 ± 21	34 ± 27	19 ± 15
Strickland at SG5 ('000)	16 ± 2.1	17 ± 0.0	nd	3.4 ± 0.0	21 ± 0.0	47 ± 28	12 ± 5.1	32 ± 27	11 ± 6.1	19 ± 10
Upper Lagaip ('000)*	26 ± 18	30 ± 18	28 ± 13	8.6 ± 8.4	29 ± 25	42 ± 19	15 ± 14	14 ± 13	34 ± 29	15 ± 16
Pori River ('000)*					6.2 ± 7.2	3.1 ± 2.0	5.3 ± 3.8	5.8 ± 3.7	5.3 ± 4.9	14 ± 15
Ok Om ('000)*	29 ± 34	35 ± 70	46 ± 69	15 ± 18	56 ± 97	18 ± 20	27 ± 21	32 ± 43	70 ± 68	23 ± 27
Kuru River ('000)*					7.4 ± 9.0	6.7 ± 7.3	6.3 ± 3.3	8.7 ± 9.3	97 ± 107	15 ± 15
Baia River ('000)*							12 ± 5.9	6.7 ± 3.9	9.7 ± 7.8	7.5 ± 8.1
Tomu River ('000)*					1.5 ± 1.6	1.6 ± 2.6	1.5 ± 2.6	1.3 ± 0.7	2.0 ± 2.2	3.5 ± 3.4
SG6 ('000)				3.7 ± 0.0	0.9 ± 0.3	nd	0.9 ± 0.2	10 ±14	1.5 ± 0.0	1.1 ± 0.0

nd = no data available; * = control site all data is presented as: mean ± standard deviation



Note: Upper Lagaip, Pori, Ok Om, Kuru, Baia and Tomu are monitoring control sites not affected by the Porgera mine.

Figure 5-5C Dissolved Iron mean concentrations at downstream sites from 2001-2010

The above graph, within Figure 5-5C, shows that dissolved iron is widespread throughout the Strickland River system and its tributaries. Catchment areas that are unaffected by mine operations, such as Upper Lagaip River, Tomu and Ok Om, generally show higher levels than downstream of the mine.

5.2.6 Lead in the River System

Dissolved lead concentrations for 2010 at downstream monitoring stations were at or below the detection limit of 0.5 µg/L with the exception of Bebelubi. The reason why this location is slightly elevated is unclear. The total lead concentration at SG1 was relatively high but declined rapidly at SG2 and beyond due to the dilution effect of downstream tributaries (Figure 5-6A). Similar patterns were seen for the 2001-2010. From Table 5-6, mean annual dissolved and total lead concentrations for 2001-2010 showed similar results to previous years.

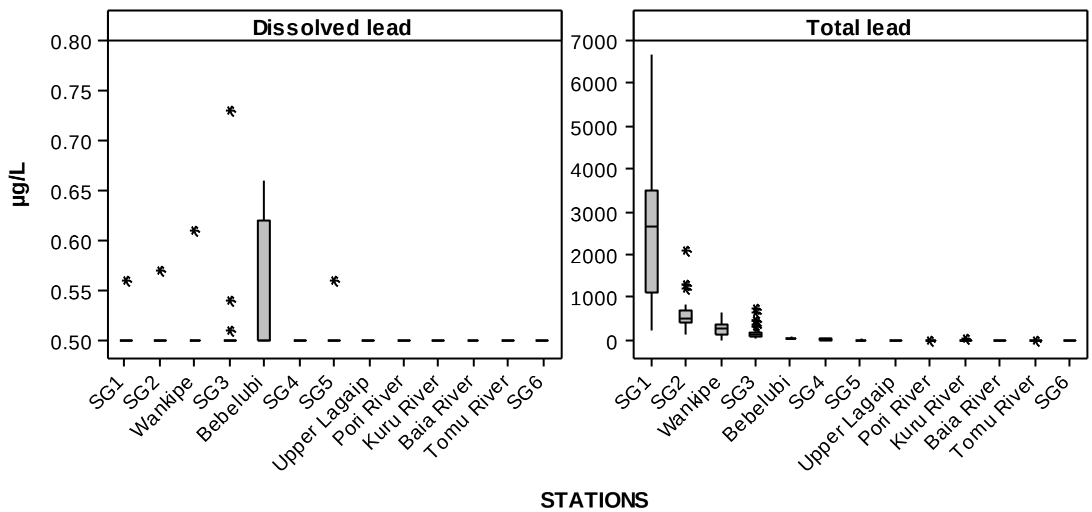


Figure 5-6A Lead concentrations at downstream locations during 2010

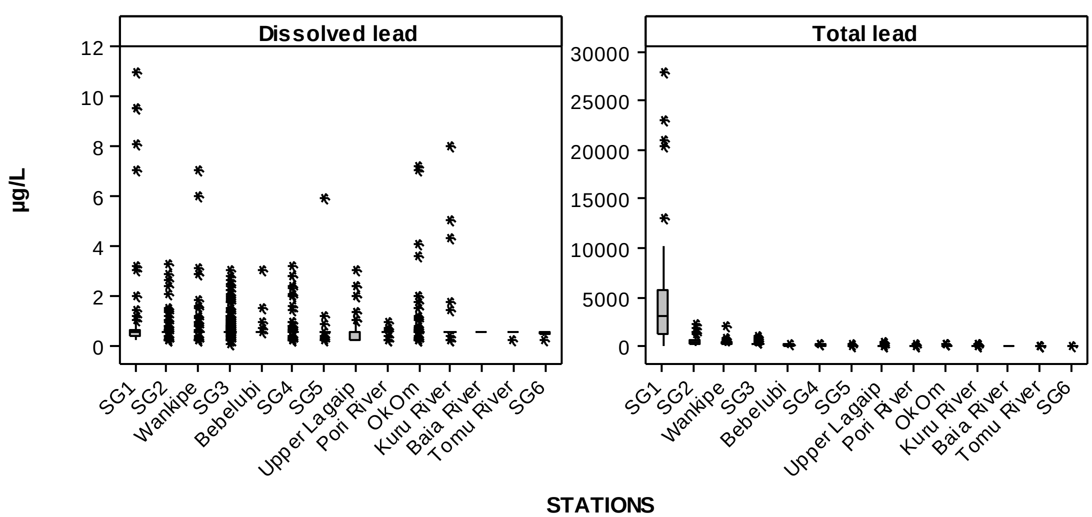
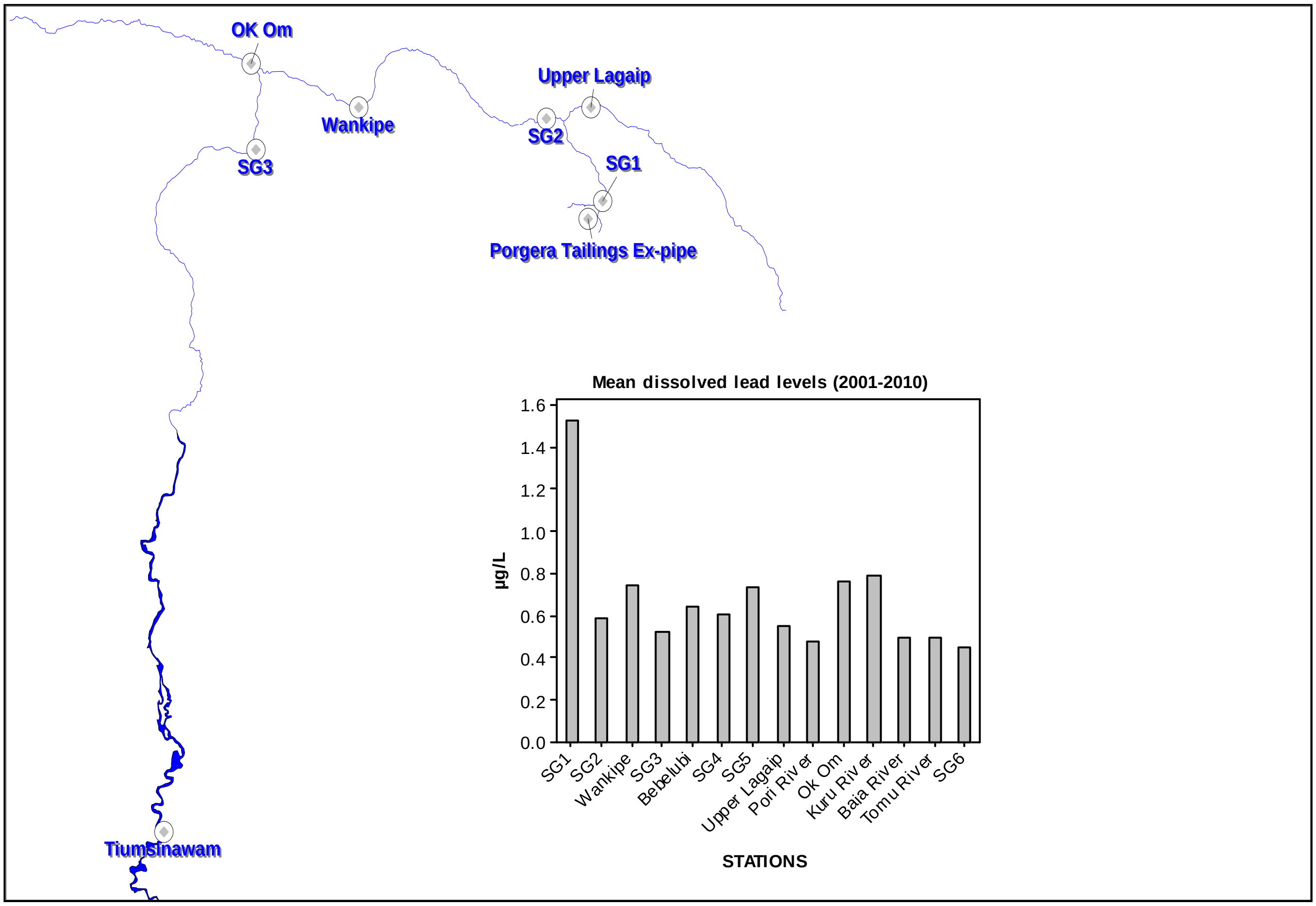


Figure 5-6B Lead concentrations at downstream locations from 2001 to 2010

Table 5-6 Mean annual lead concentrations at downstream sites from 2001 to 2010 (all results in µg/L)

Dissolved lead	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Porgera at SG1	1.3 ± 2.1	1.7 ± 3.1	4.1 ± 5.7	5.9 ± 10	0.6 ± 0.5	0.6 ± 0.2	0.5 ± 0.2	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.01
Lagaip at SG2	0.3 ± 0.1	0.8 ± 0.9	0.9 ± 1.2	0.8 ± 0.6	0.8 ± 0.7	0.6 ± 0.2	0.5 ± 0.0	0.5 ± 0.1	0.5 ± 0.0	0. 5 ± 0.01
Lagaip at Wankipe	0.6 ± 0.3	0.9 ± 0.8	0.5 ± 0.5	0.5 ± 0.3	0.4 ± 0.3	2.4 ± 2.4	0.5 ± 0.1	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.03
Strickland at SG3	0.6 ± 0.4	0.6 ± 0.4	0.5 ± 0.1	0.5 ± 0.03	0.5 ± 0.0	0.5 ± 0.2	0.5 ± 0.02	0.5 ± 0.08	0.5 ± 0.03	0.5 ± 0.05
Strickland at Bebelubi							0.5 ± 0.02	0.6 ± 0.2	0.5 ± 0.0	0.8 ± 0.8
Strickland at SG4	0.3 ± 0.1	0.7 ± 0.7	0.2 ± 0.0	1.0 ± 1.0	1.1 ± 1.1	0.6 ± 0.1	0.5 ± 0.07	0.5 ± 0.05	0.5 ± 0.0	0.5 ± 0.0
Strickland at SG5	0.3 ± 0.07	0.2 ± 0.0	nd	0.4 ± 0.0	0.5 ± 0.0	3.2 ± 3.8	0.5 ± 0.0	0.5 ± 0.0	0.7 ± 0.3	0.5 ± 0.02
Upper Lagaip*	0.8 ± 0.9	0.3 ± 0.1	0.7 ± 0.8	0.4 ± 0.3	0.9 ± 0.7	0.7 ± 0.6	0.5 ± 0.06	0.5 ± 0.0	0.5 ± 0.02	0.5 ± 0.0
Pori River*					0.3 ± 0.1	0.5 ± .1	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.0
Ok Om*	0.5 ± 0.1	1.0 ± 1.2	1.0 ± 1.1	0.5 ± 0.4	0.6 ± 0.5	1.9 ± 2.5	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.03	0.5 ± 0.0
Kuru River*					0.5 ± 0.5	2.2 ± 2.7	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.0
Baia River*							0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.0
Tomu River*					0.4 ± 0.2	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.0
Herbert River at SG6				0.4 ± 0.0	0.4 ± 0.2	nd	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.0
Total lead										
Porgera at SG1 (000)	4.8 ± 3.0	3.0 ± 2.8	4.4 ± 2.2	6.3 ± 9.9	3.0 ± 2.6	6.4 ± 6.2	1.9 ± 2.6	0.7 ± 0.0	7.6 ± 0.0	4.6 ± 6.1
Lagaip at SG2	508 ± 178	328 ± 264	363 ± 246	437 ± 471	276 ± 147	237 ± 149	228 ± 133	337 ± 183	343 ± 156	628 ± 456
Lagaip at Wankipe	190 ± 64	298 ± 171	402 ± 557	157 ± 121	161 ± 74	158 ± 123	225 ± 125	186 ± 132	306 ± 114	296 ± 207
Strickland at SG3	109 ± 52	151 ± 98	137 ± 118	118 ± 84	122 ± 62	114 ± 57	94 ± 58	98 ± 39	148 ± 70	164 ± 106
Strickland at Bebelubi							48 ± 21	42 ± 14	57 ± 21	57 ± 16
Strickland at SG4	69 ± 25	25 ± 30	35 ± 9.2	57 ± 36	39 ± 23	43 ± 32	50 ± 20	29 ± 18	52 ± 35	26 ± 11
Strickland at SG5	35 ± 13	11 ± 0.0	nd	14 ± 0.0	27 ± 0.0	56 ± 43	22 ± 11	34 ± 7.4	14 ± 7.4	19 ± 8.0
Upper Lagaip*	14 ± 9.2	13 ± 7.8	16 ± 10	7.4 ± 6.7	45 ± 102	49 ± 98	8.6 ± 6.3	5.2 ± 5.6	13 ± 10	5.0 ± 5.2
Pori River*					2.0 ± 2.1	20 ± 27	3.2 ± 2.2	2.3 ± 1.4	1.7 ± 1.4	7.1 ± 6.4
Ok Om*	15 ± 18	26 ± 54	26 ± 31	13 ± 17	32 ± 57	21 ± 30	18 ± 15	20 ± 28	51 ± 69	12 ± 15
Kuru River*					3.7 ± 3.4	14 ± 21	3.6 ± 2.3	4.8 ± 5.4	36 ± 39	7.8 ± 9.0
Baia River*							3.9 ± 2.1	2.4 ± 1.2	3.3 ± 2.7	3.0 ± 3.2
Tomu River*					2.7 ± 3.8	0.9 ± 0.8	0.8 ± 0.6	0.5 ± 0.0	0.7 ± 0.4	1.3 ± 1.3
Herbert River at SG6				5.0 ± 0.0	2.9 ± 3.4	nd	0.8 ± 0.2	8.3 ± 11	0.6 ± 0.0	0.8 ± 0.0

nd= no data available; * = control site all data is presented as: mean ± standard deviation



Note: Upper Lagaip, Pori, Ok Om, Kuru, Baia and Tomu are monitoring control sites not affected by the Porgera mine.

Figure 5-6C Mean dissolved lead concentrations at downstream sites from 2001-2010

The graph within Figure 5-6C shows varied results across the river catchments downstream of Porgera. The highest values are for the control sites, Ok Om and Kuru River, which are not influenced by mine discharge. All mean values shown in Figure 5-6C were well below the SG3 compliance criterion of 3 µg/L.

5.2.7 Mercury in the River System

Dissolved mercury concentrations at all downstream monitoring locations for 2010 were at or below the detection limit of 0.1 µg/L (Figure 5-7A). Total mercury concentrations from the mine were very low and decreased rapidly beyond SG1 (Figure 5-7A). Dissolved mercury concentrations for 2001-2010 (Figure 5-7B) were at or near the detection limit while the total values were similar to those for 2010. Mean annual dissolved concentrations for 2010 (Table 5-7) were at or below the detection level at all locations while total values were similar to those obtained in previous years.

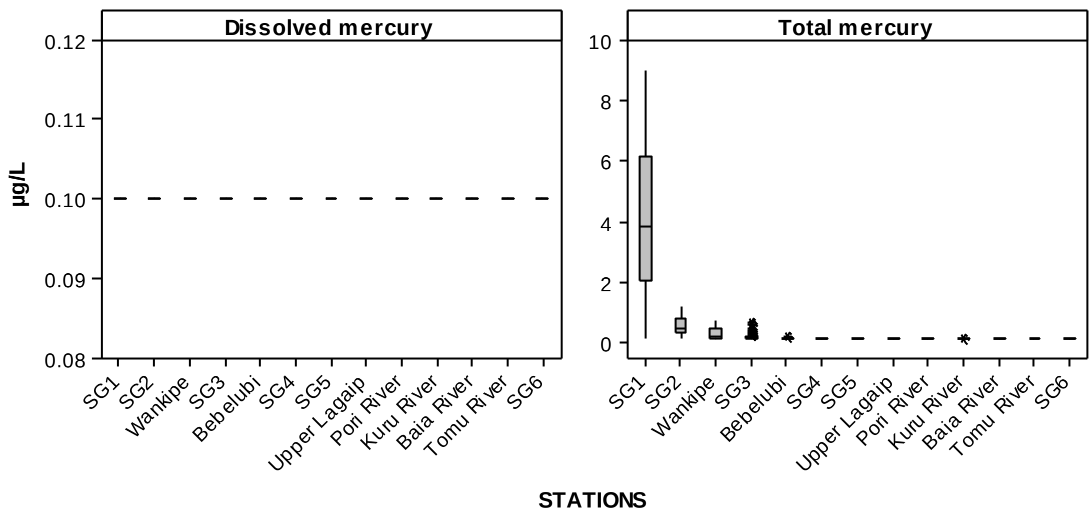


Figure 5-7A Mercury concentrations at downstream locations during 2010

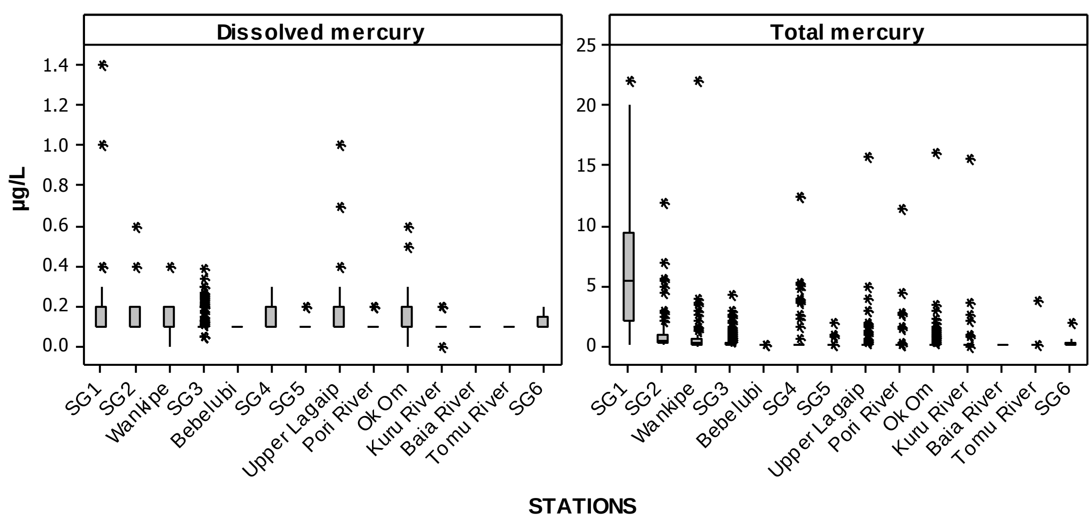
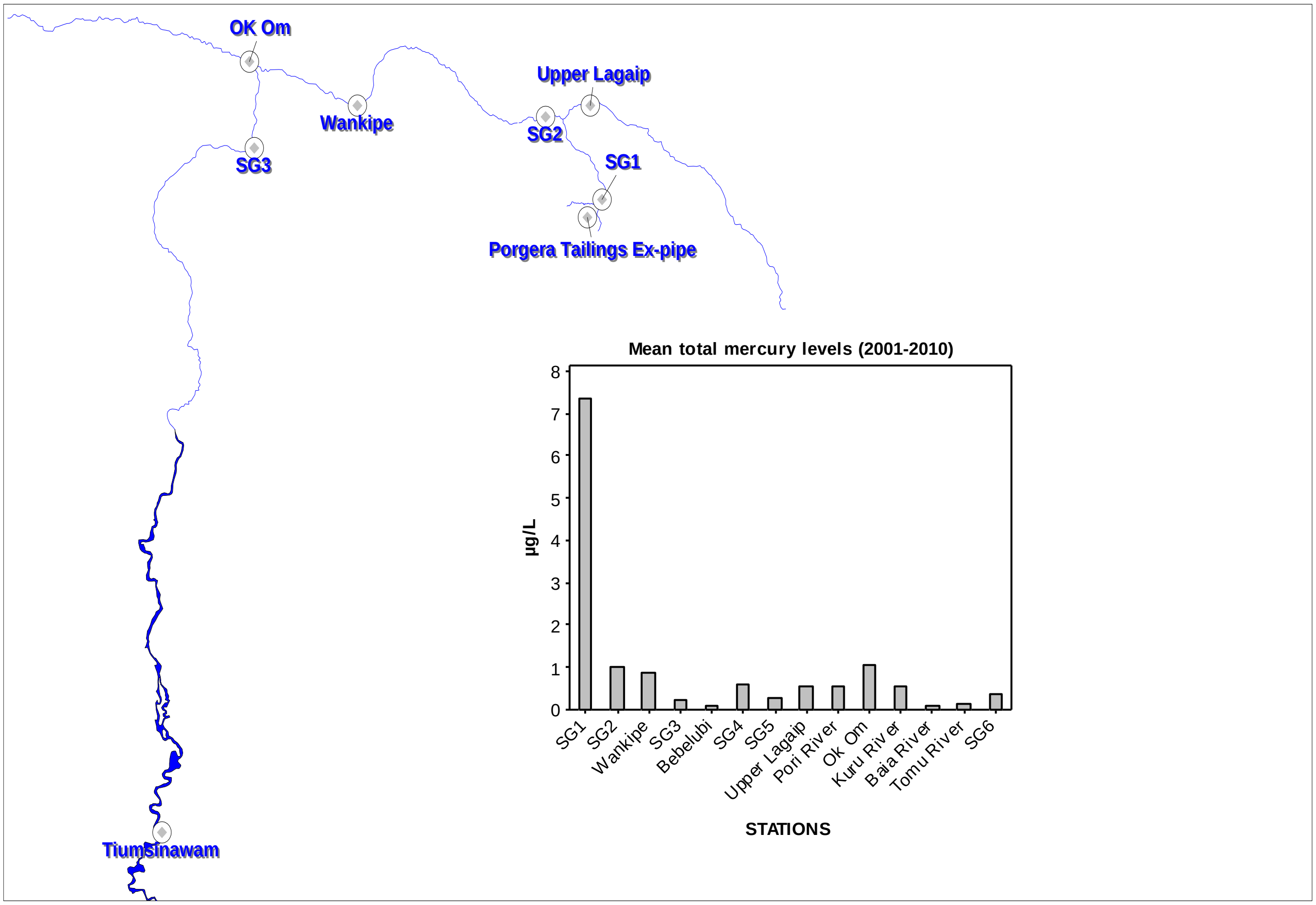


Figure 5-7B Mercury concentrations at downstream locations from 2001-2010

Table 5-7 Mean annual mercury concentrations at downstream monitoring sites from 2001 to 2010 (all results in µg/L)

Dissolved mercury	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Porgera at SG1	0.2 ± 0.06	0.2 ± 0.3	0.2 ± 0.07	0.6 ± 1.1	0.4 ± 0.4	0.2 ± 0.3	0.1 ± 0.0	0.1 ± 0.0	nd	0.1 ± 0.0
Lagaip at SG2	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.1	0.2 ± 0.0	0.1 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.01
Wankipe	0.1 ± 0.04	0.1 ± 0.05	0.2 ± 0.03	0.2 ± 0.1	0.2 ± 0.05	0.2 ± 0.05	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.03	0.1 ± 0.0
Strickland at SG3	0.1 ± 0.03	0.1 ± 0.03	0.1 ± 0.02	0.1 ± 0.01	0.1 ± 0.04	0.1 ± 0.01	0.1 ± 0.01	0.1 ± 0.2	0.1 ± 0.00	0.1 ± 0.01
Strickland at Bebelubi							0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Strickland at SG4	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.04	0.2 ± 0.04	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Strickland at SG5	1.1 ± 1.3	0.2 ± 0.0	nd	0.2 ± 0.0	0.1 ± 0.0	0.2 ± 0.07	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Upper Lagaip*	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.07	0.3 ± 0.2	0.2 ± 0.04	0.2 ± 0.3	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Pori River*					0.2 ± 0.04	0.2 ± 0.04	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Ok Om*	0.1 ± 0.05	0.1 ± 0.05	0.2 ± 0.03	0.2 ± 0.07	0.2 ± 0.2	0.2 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.3	0.1 ± 0.0
Kuru River*					0.2 ± 0.04	0.2 ± 0.07	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Baia River*							0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Tomu River*					0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Herbert River at SG6				0.2 ± 0.0	0.2 ± 0.07	nd	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Total mercury										
Porgera at SG1	11 ± 9.9	4.0 ± 4.0	9.8 ± 8.4	19 ± 12	6.5 ± 4.4	6.6 ± 6.2	3.7 ± 5.0	3.2 ± 0.0	nd	4.6 ± 3.8
Lagaip at SG2	0.8 ± 0.5	1.2 ± 1.7	1.4 ± 1.2	2.7 ± 3.4	1.3 ± 2.3	0.7 ± 0.9	0.6 ± 0.4	0.8 ± 0.6	0.5 ± 0.1	0.5 ± 0.3
Lagaip at Wankipe	0.5 ± 0.2	0.8 ± 0.9	3.5 ± 6.6	0.4 ± 0.3	0.9 ± 1.2	1.1 ± 1.4	0.3 ± 0.2	0.3 ± 0.4	0.4 ± 0.5	0.3 ± 0.2
Strickland at SG3	0.6 ± 0.6	0.3 ± 0.3	0.2 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.08
Strickland at Bebelubi							0.1 ± 0.01	0.1 ± 0.0	0.1 ± 0.01	0.1 ± 0.03
Strickland at SG4	0.2 ± 0.0	1.7 ± 3.8	0.2 ± 0.0	1.8 ± 2.2	1.3 ± 1.8	0.1 ± 0.0	0.1 ± 0.01	0.1 ± 0.0	0.1 ± 0.02	0.1 ± 0.0
Strickland at SG5	1.5 ± 0.7	0.2 ± 0.0	nd	0.8 ± 0.0	0.1 ± 0.0	0.2 ± 0.07	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Upper Lagaip*	0.4 ± 0.5	0.5 ± 0.7	0.7 ± 0.5	2.1 ± 1.9	2.3 ± 5.5	0.6 ± 1.1	0.1 ± 0.1	0.1 ± 0.01	0.1 ± 0.0	0.1 ± 0.0
Pori River*					1.1 ± 1.7	2.7 ± 4.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Ok Om*	0.1 ± 0.05	0.3 ± 0.4	6.0 ± 17	1.8 ± 4.5	0.6 ± 1.1	0.6 ± 0.8	0.1 ± 0.0	0.1 ± 0.05	0.1 ± 0.2	0.1 ± 0.01
Kuru River*					0.9 ± 1.5	2.2 ± 4.8	0.1 ± 0.02	0.1 ± 0.02	0.2 ± 0.2	0.1 ± 0.01
Baia River*							0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Tomu River*					1.3 ± 2.1	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.01	0.1 ± 0.0
Herbert River at SG6				0.7 ± 0.0	1.0 ± 1.3	nd	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0

nd = no data available; * = control site all data is presented as: mean ± standard deviation



Note: Upper Lagaip, Pori, Ok Om, Kuru, Baia and Tomu are monitoring control sites not affected by the Porgera mine.

Figure 5-7C Mean total mercury concentrations at downstream sites from 2001-2010

The graph within Figure 5-7C shows the consistent low values for total mercury concentrations beyond SG1 downstream of the Porgera mine. Dissolved mercury is not shown because all levels, including SG1, are at or near the detection limit.

5.2.8 Nickel in the River System

Dissolved nickel concentrations were at or below the detection limit at monitoring stations below SG2 during 2010 and all results were well below the compliance criterion of 50 µg/L. The total nickel concentration at SG1 was relatively high but the level at other stations decreased rapidly further downstream (Figure 5-8A). With the exception of SG1, dissolved nickel values for 2001-2010 were at or near the detection limit (Figure 5-8B) while total values were similar to those obtained for 2010. Mean annual dissolved and total nickel values for 2010 were consistent with those obtained in previous years (Table 5-8).

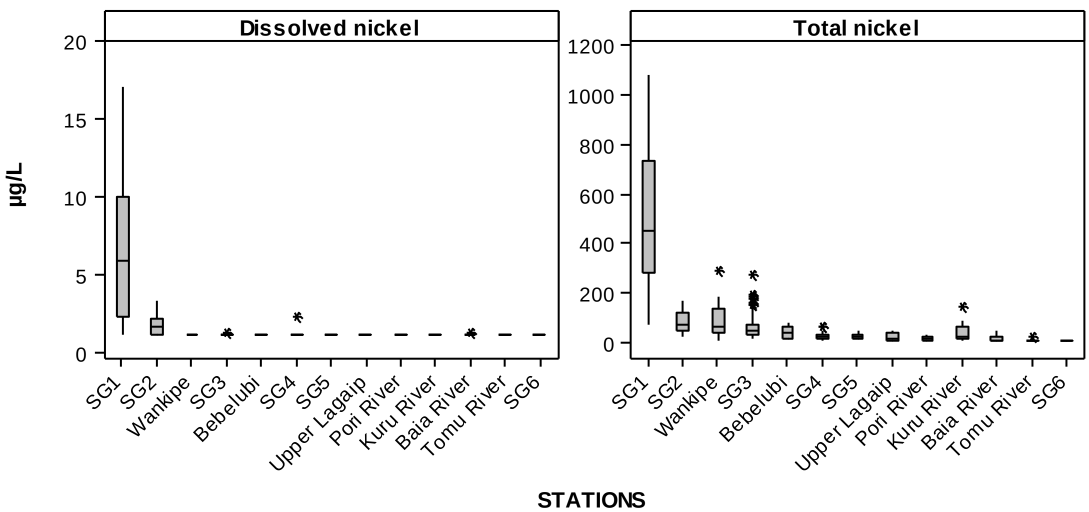


Figure 5-8A Nickel concentrations at downstream locations during 2010

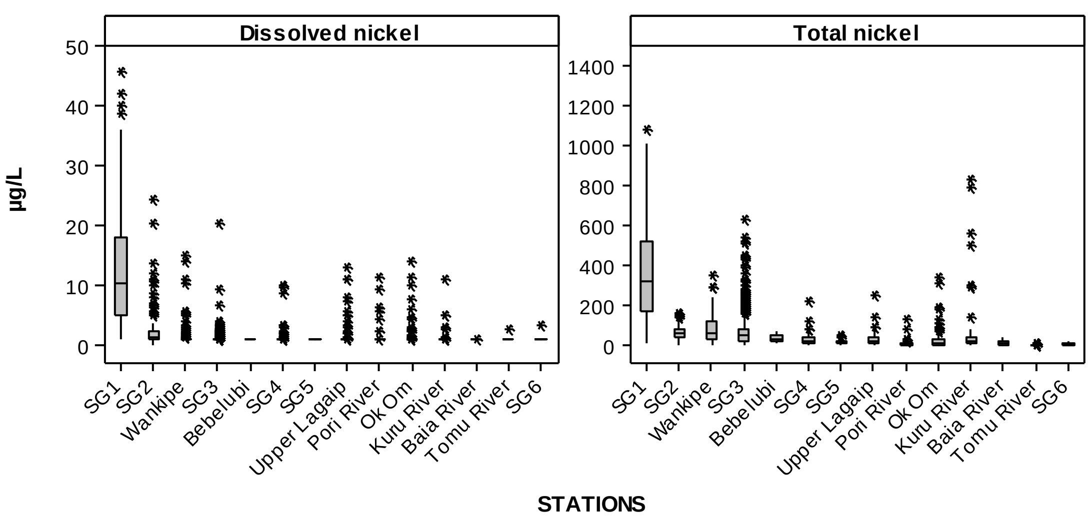
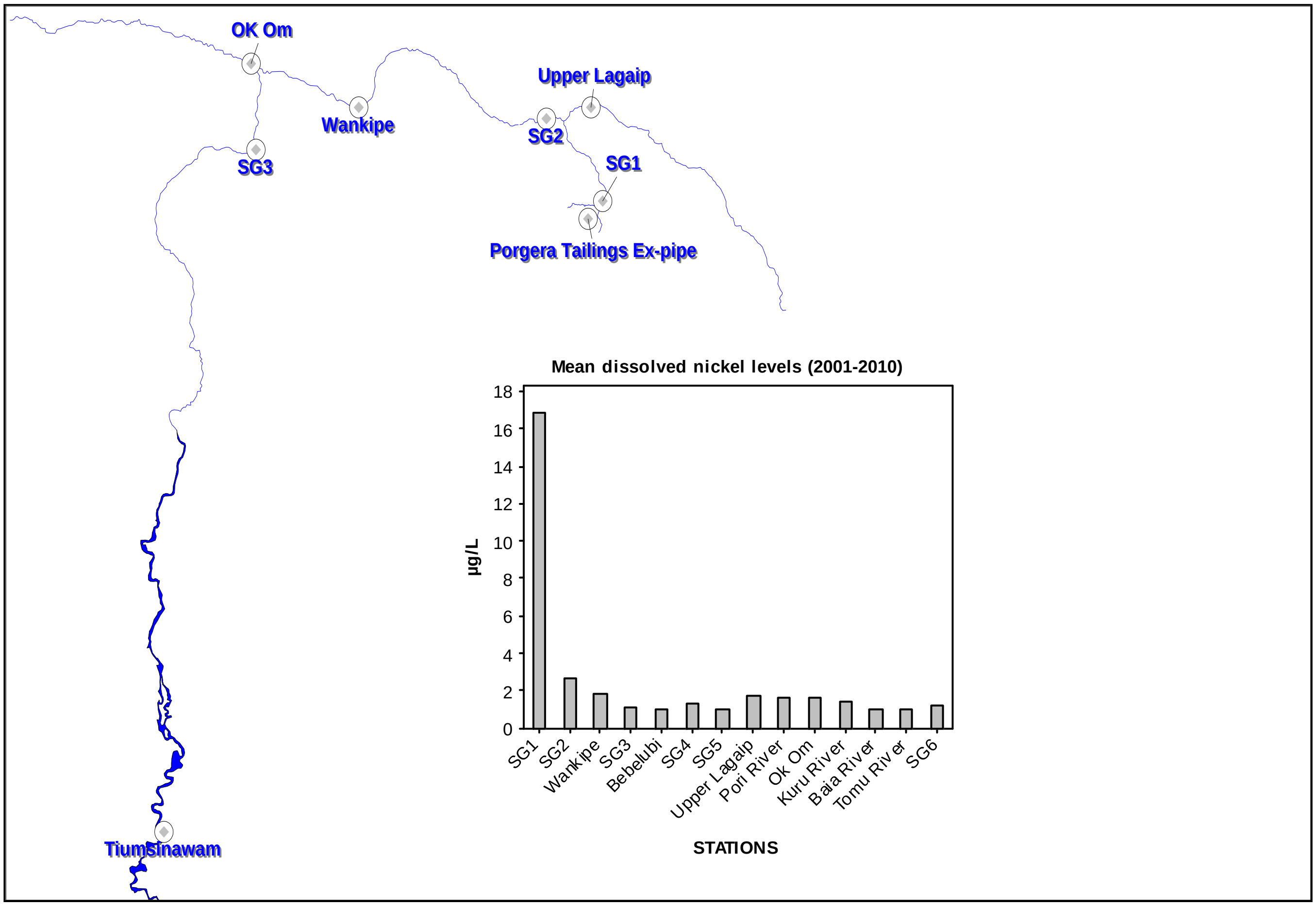


Figure 5-8B Nickel concentrations at downstream locations from 2001 to 2010

Table 5-8 Mean annual nickel concentrations at downstream sites from 2001 to 2010 (all results in µg/L)

Dissolved nickel	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Porgera at SG1	41 ± 36	15 ± 14	21 ± 20	19 ± 23	24 ± 14	10 ± 10	7.2 ± 6.6	2.9 ± 0.0	nd	8.5 ± 6.2
Lagaip at SG2	4.3 ± 1.8	2.9 ± 1.8	1.8 ± 1.5	3.5 ± 4.2	10 ± 8.3	1.2 ± 0.6	1.6 ± 0.7	1.5 ± 0.8	1.2 ± 0.7	1.7 ± 0.7
Lagaip at Wankipe	2.1 ± 1.6	2.5 ± 3.3	1.2 ± 0.6	3.2 ± 5.2	3.4 ± 3.6	2.8 ± 4.1	1.1 ± 0.2	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Strickland at SG3	1.2 ± 0.7	1.1 ± 0.3	1.0 ± 0.05	1.0 ± 0.2	1.2 ± 0.4	1.2 ± 1.5	1.0 ± 0.1	1.1 ± 0.5	1.0 ± 0.0	1.0 ± 0.01
Strickland at Bebelubi							1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Strickland at SG4	1.1 ± 0.2	1.1 ± 0.3	1.0 ± 0.0	3.3 ± 3.8	2.3 ± 2.4	1.1 ± 0.2	1.0 ± 0.0	1.0 ± 0.03	1.0 ± 0.0	1.1 ± 0.3
Strickland at SG5	1.0 ± 0.0	1.0 ± 0.0	nd	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Upper Lagaip*	2.2 ± 1.9	2.8 ± 3.2	1.1 ± 0.2	1.1 ± 0.4	4.2 ± 4.0	2.7 ± 4.5	1.3 ± 1.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Pori River*					5.2 ± 4.5	2.5 ± 2.2	1.0 ± 0.03	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Ok Om*	1.0 ± 0.0	2.1 ± 2.2	1.0 ± 0.0	3.0 ± 4.3	3.0 ± 3.7	2.1 ± 1.6	1.0 ± 0.04	1.0 ± 0.0	1.0 ± 0.1	1.1 ± 0.4
Kuru River*					4.2 ± 4.2	1.6 ± 1.3	1.0 ± 0.04	1.0 ± 0.1	1.0 ± 0.06	1.0 ± 0.0
Baia River*							1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.06
Tomu River*					1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.1 ± 0.3	1.0 ± 0.0
SG6				1.0 ± 0.0	2.3 ± 1.8	nd	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Total nickel										
Porgera at SG1	339 ± 91	215 ± 111	255 ± 153	603 ± 833	172 ± 127	505 ± 169	302 ± 223	310 ± 0.0	259 ± 0.0	556 ± 291
Lagaip at SG2	67 ± 25	61 ± 31	69 ± 27	55 ± 40	57 ± 28	55 ± 19	67 ± 28	79 ± 42	69 ± 23	79 ± 42
Strickland at Wankipe	59 ± 44	108 ± 103	86 ± 51	24 ± 9.9	110 ± 93	71 ± 56	101 ± 79	76 ± 56	114 ± 76	93 ± 81
Strickland at SG3	49 ± 42	67 ± 152	61 ± 63	46 ± 39	72 ± 57	67 ± 64	59 ± 52	110 ± 424	99 ± 70	53 ± 40
Strickland at Bebelubi							38 ± 13	37 ± 20	36 ± 13	36 ± 24
Strickland at SG4	39 ± 23	22 ± 49	18 ± 6.4	29 ± 16	31 ± 15	27 ± 18	28 ± 11	22 ± 19	41 ± 28	21 ± 17
Strickland at SG5	23 ± 3.4	14 ± 0.0	nd	3.5 ± 0.0	20 ± 0.0	35 ± 24	14 ± 5.0	28 ± 23	10 ± 6.2	20 ± 12
Upper Lagaip*	28 ± 16	41 ± 24	35 ± 18	20 ± 16	37 ± 25	42 ± 10	20 ± 21	15 ± 13	32 ± 27	15 ± 16
Pori River*					24 ± 29	24 ± 47	5.0 ± 3.2	4.7 ± 3.3	4.5 ± 4.0	9.8 ± 9.3
Ok Om*	24 ± 31	29 ± 57	36 ± 46	18 ± 19	39 ± 62	18 ± 22	24 ± 19	23 ± 31	93 ±114	21 ± 31
Kuru River*					18 ± 9.2	16 ± 13	14 ± 7.7	17 ± 16	290 ± 309	37 ± 42
Baia River*							14 ± 7.0	9.4 ± 5.7	12 ± 9.7	11 ± 12
Tomu River*					1.0 ± 0.0	2.2 ± 2.4	1.8 ± 1.9	1.2 ± 0.3	2.0 ± 1.7	3.5 ± 3.5
SG6				4.0 ± 0.0	7.2 ± 8.7	nd	1.0 ± 0.0	9.0 ± 11	1.0 ± 0.0	1.0 ± 0.0

nd = no data available; * = control site all data is presented as: mean ± standard deviation



Note: Upper Lagaip, Pori, Ok Om, Kuru, Baia and Tomu are monitoring control sites not affected by the Porgera mine.

Figure 5-8C Mean dissolved nickel concentrations at downstream sites from 2001-2010

The graph within Figure 5-8C indicates a relatively high dissolved nickel concentration at SG1 with a sharp decrease at other monitoring stations further downstream. All mean values, including SG1, are well within the SG3 compliance criterion of 50 µg/L.

5.2.9 Silver in the River System

Dissolved silver concentrations for 2010 were very low with all results at or below the detection limit, and well below the SG3 compliance of 4 µg/L (Figure 5-9A). Total silver concentrations decreased rapidly from SG1 to other downstream monitoring locations due to the dilution effect of downstream tributaries (Figure 5-9A). For 2001-2010, dissolved silver values were near or at the detection limit except for SG1. The downward trend for total values for 2001-2010 was similar to that obtained for 2010. Mean annual dissolved and total silver concentrations for 2010 (Table 5-9) showed little variation with those of previous years with the exception of total silver at SG1 which shows noticeably higher values for 2090 and 2010.

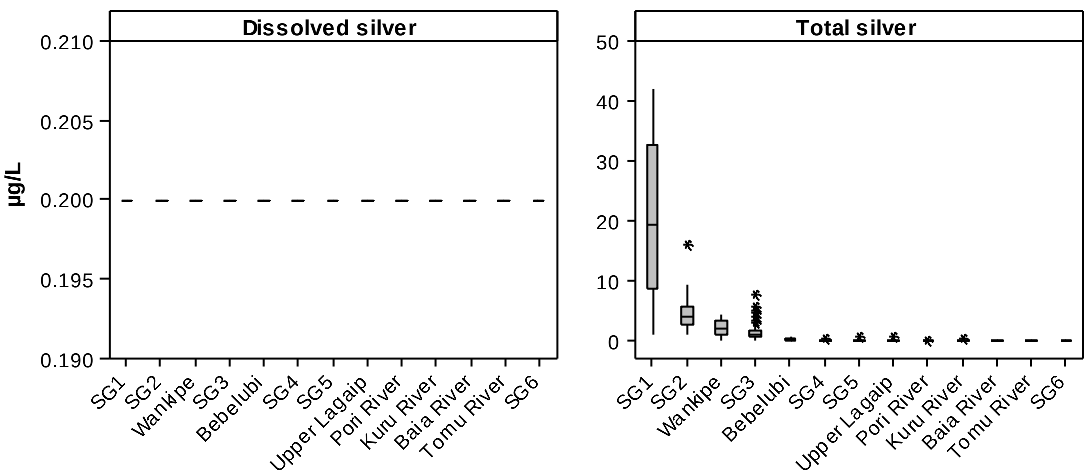


Figure 5-9A Silver concentrations at downstream locations during 2010

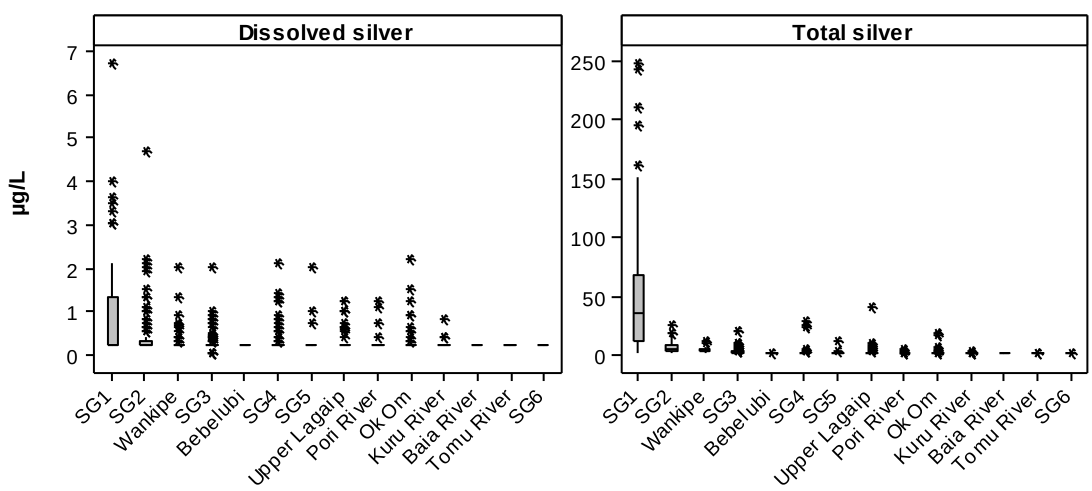
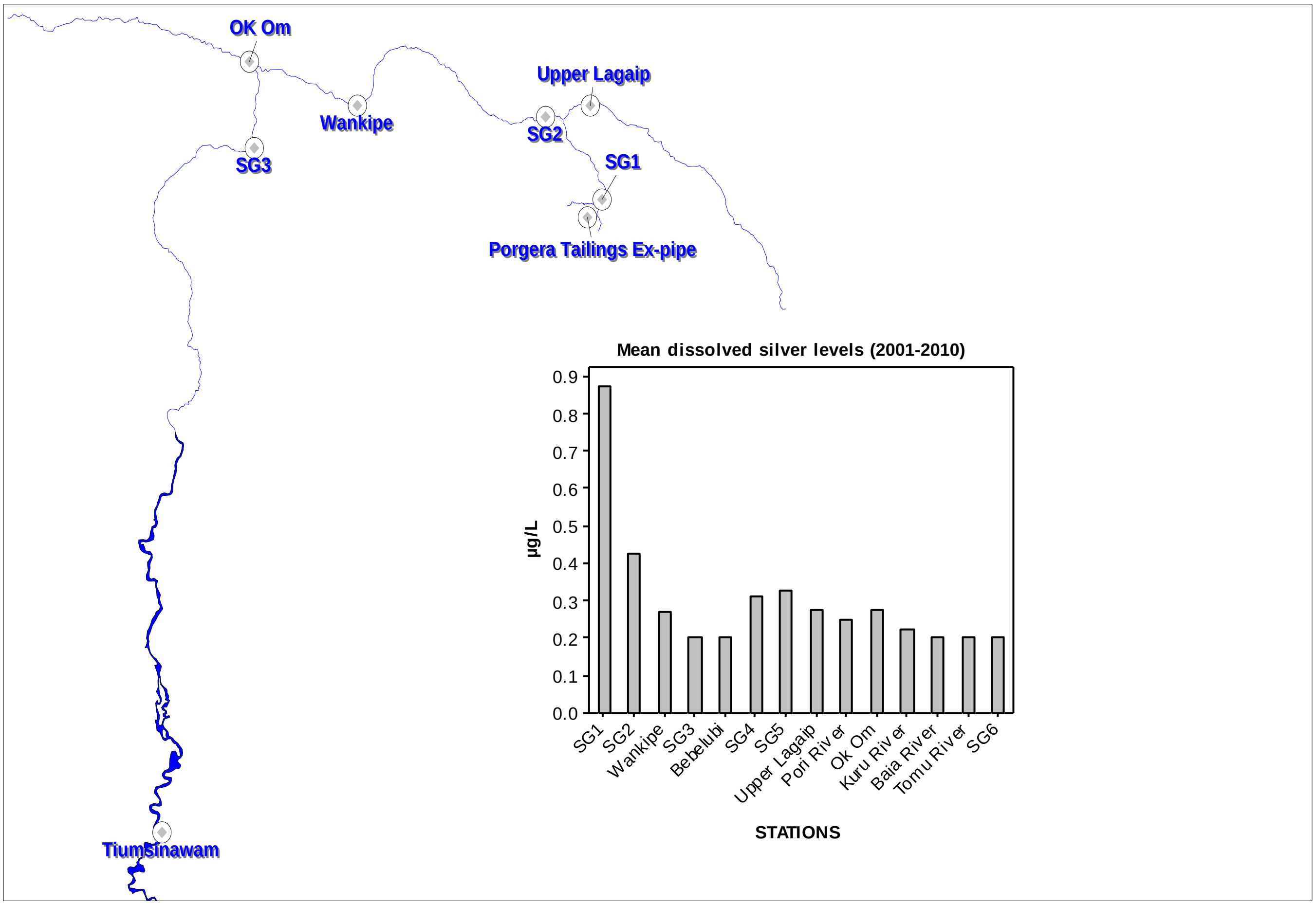


Figure 5-9B Silver concentrations at downstream locations from 2001 to 2010

Table 5-9 Mean annual silver concentrations at downstream sites from 2001 to 2010 (results in µg/L)

Dissolved silver	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Porgera at SG1	1.5 ± 1.1	2.0 ± 2.0	1.6 ± 1.0	0.8 ± 0.7	1.4 ± 1.2	0.3 ± 0.3	0.2 ± 0.0	0.2 ± 0.0	nd	0.2 ± 0.0
Lagaip at SG2	0.7 ± 0.6	1.1 ± 1.4	0.7 ± 0.8	0.7 ± 0.6	0.5 ± 0.4	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.3 ± 0.2	0.2 ± 0.0
Lagaip at Wankipe	0.3 ± 0.1	0.3 ± 0.2	0.3 ± 0.1	0.2 ± 0.04	0.5 ± 0.4	0.5 ± 0.6	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Strickland at SG3	0.2 ± 0.2	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.05	0.2 ± 0.02	0.2 ± 0.03	0.2 ± 0.09	0.2 ± 0.0	0.2 ± 0.0
Strickland at Bebelubi							0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Strickland at SG4	0.7 ± 0.7	0.5 ± 0.5	0.2 ± 0.0	0.4 ± 0.2	0.3 ± 0.2	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Strickland at SG5	1.1 ± 1.3	0.2 ± 0.0	nd	0.7 ± 0.0	0.2 ± 0.0	0.6 ± 0.6	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Upper Lagaip*	0.2 ± 0.1	0.7 ± 0.4	0.3 ± 0.4	0.2 ± 0.0	0.4 ± 0.3	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.1
Pori River*					0.2 ± 0.0	0.4 ± 0.4	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.3 ± 0.3
Ok Om*	0.5 ± 0.8	0.3 ± 0.2	0.2 ± 0.07	0.3 ± 0.1	0.3 ± 0.3	0.4 ± 0.4	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Kuru River*					0.2 ± 0.09	0.3 ± 0.2	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Baia River*							0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Tomu River*					0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
SG6				0.2 ± 0.0	0.2 ± 0.0	nd	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Total silver										
Porgera at SG1	62 ± 41	42 ± 37	57 ± 24	76 ± 79	44 ± 32	63 ± 46	22 ± 37	9.7 ± 0.0	113 ± 0.0	126 ± 113
Lagaip at SG2	8.3 ± 2.9	7.3 ± 5.7	9.0 ± 4.7	9.1 ± 5.8	4.9 ± 2.4	2.8 ± 2.2	3.3 ± 2.8	5.4 ± 4.3	4.0 ± 2.5	4.9 ± 3.3
Lagaip at Wankipe	2.5 ± 1.4	3.9 ± 2.1	3.3 ± 1.5	4.5 ± 3.2	2.9 ± 1.7	2.9 ± 1.6	1.7 ± 0.5	1.8 ± 1.1	2.7 ± 1.0	2.3 ± 1.4
Strickland at SG3	1.6 ± 1.6	1.6 ± 1.3	1.2 ± 0.7	1.9 ± 2.4	1.1 ± 0.7	1.0 ± 0.7	0.9 ± 0.6	1.1 ± 0.9	1.3 ± 0.6	1.4 ± 1.0
Strickland at Bebelubi							0.4 ± 0.1	0.4 ± 0.2	0.6 ± 0.3	0.5 ± 0.2
Strickland at SG4	9.9 ± 11	1.4 ± 1.0	0.7 ± 0.07	1.0 ± 0.4	1.1 ± 1.0	0.4 ± 0.2	0.7 ± 0.3	0.3 ± 0.1	0.5 ± 0.2	0.3 ± 0.1
Strickland at SG5	0.6 ± 0.6	1.9 ± 0.0	9.9 ± 0.0	9.9 ± 0.0	0.2 ± 0.0	0.9 ± 0.2	0.3 ± 0.1	0.2 ± 0.02	0.2 ±0.0	0.3 ± 0.2
Upper Lagaip*	0.7 ± 0.6	2.8 ± 1.8	1.1 ± 1.3	0.8 ± 1.0	8.1 ± 13	0.4 ± 0.5	0.2 ± 0.0	0.2 ± 0.0	0.3 ± 0.3	0.2 ± 0.2
Pori River*					0.9 ± 0.5	1.3 ± 1.2	0.2 ± 0.0	0.3 ± 0.2	0.2 ± 0.02	0.2 ± 0.04
Ok Om*	1.0 ± 2.0	2.1 ± 5.2	1.2 ± 1.2	2.1 ± 4.7	0.7 ± 0.7	0.6 ± 0.7	0.2 ± 0.0	0.2 ± 0.003	0.2 ± 0.1	0.3 ± 0.4
Kuru River*					0.7 ± 1.0	0.4 ± 0.4	0.2 ± 0.0	0.2 ± 0.0	0.3 ± 0.1	0.2 ± 0.1
Baia River*							0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Tomu River*					0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.06	0.2 ± 0.0
SG6				0.2 ± 0.0	0.4 ± 0.3	nd	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0

nd = no data available; * = control site all data is presented as: mean ± standard deviation



Note: Upper Lagaip, Pori, OkOm, Kuru, Baia and Tomu are monitoring control sites not affected by the Porgera mine.

Figure 5-9C Mean dissolved silver concentrations at downstream sites from 2001-2010

The above graph, within Figure 5-9C, shows the very low dissolved silver concentrations downstream of the Porgera mine. All results are well below the SG3 compliance criterion of 4 µg/L.

5.2.10 Zinc in the River System

Dissolved zinc concentrations for 2010 decreased steadily downstream of the mine, while total zinc declined rapidly beyond SG1 due to the dilution effect of downstream tributaries (Figure 5-10A). For 2001-2010, dissolved and total values show similar trends to those for 2010 (Figure 5-10B). Mean annual dissolved and total zinc concentrations for 2010 were generally higher than previous years (Table 5-10), probably due to an increase in zinc minerals from the open pit and underground workings (see results for Yakatabari Creek and Yunarilama Portal in Table 5-15).

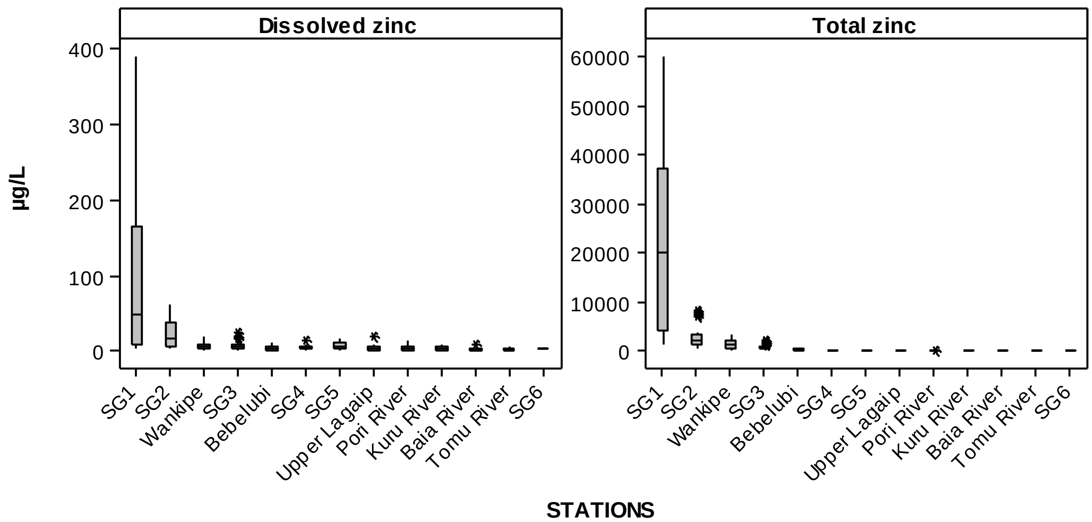


Figure 5-10A Zinc concentrations at downstream monitoring sites during 2010

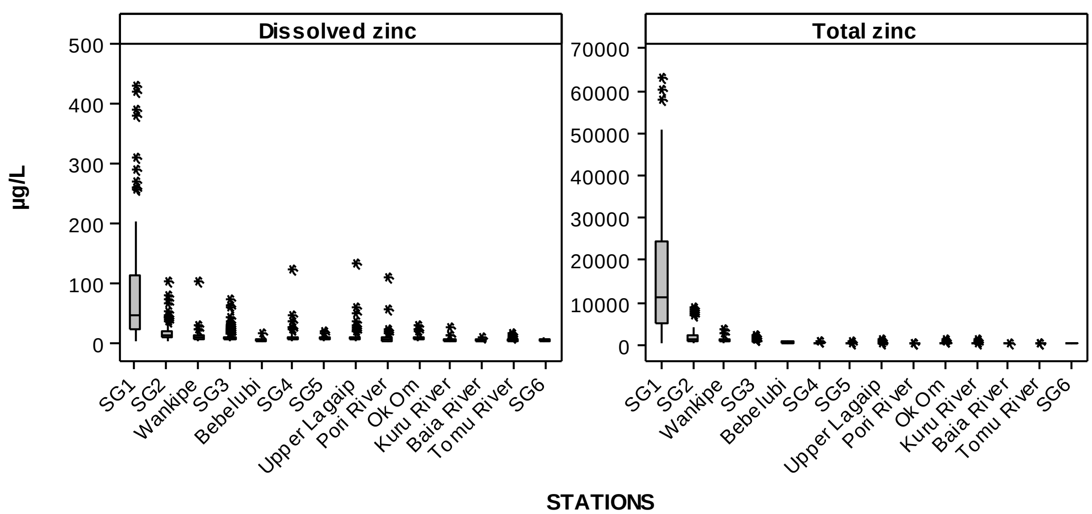
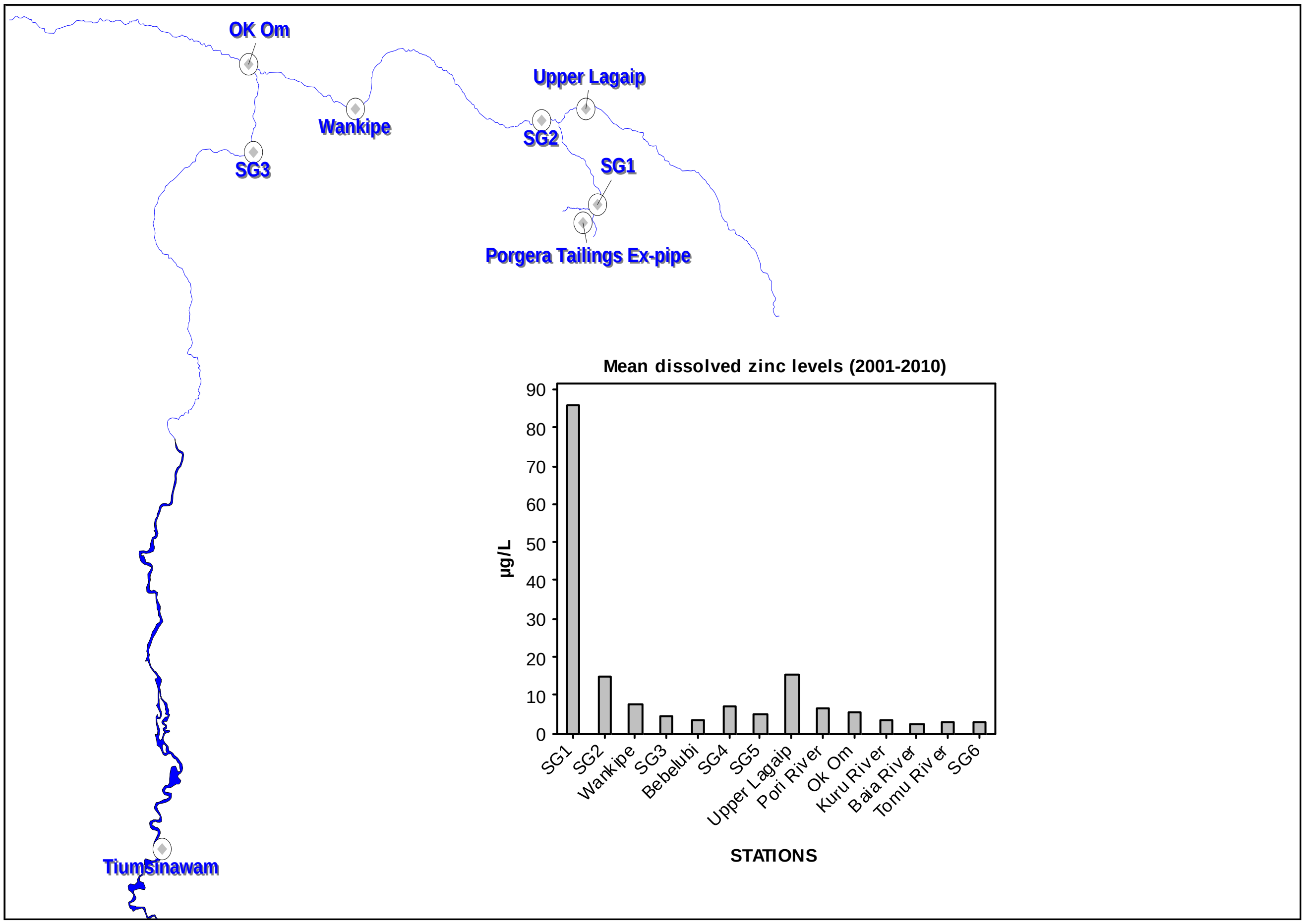


Figure 5-10B Zinc concentrations at downstream locations from 2001 to 2010

Table 5-10 Mean annual zinc concentrations at downstream sites from 2001 to 2010 (all results in µg/L)

Dissolved zinc	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Porgera at SG1	149 ± 127	76 ± 118	92 ± 128	44 ± 28	78 ± 83	42 ± 33	31 ± 37	9.7 ± 0.0	25 ± 0.0	97 ± 107
Lagaip at SG2	12 ± 6.1	21 ± 28	17 ± 9.0	12 ± 9.5	14 ± 24	8.7 ± 3.9	8.5 ± 5.9	14 ± 20	8.3 ± 5.4	23 ± 17
Lagaip at Wankipe	8.1 ± 5.0	5.2 ± 3.6	9.8 ± 9.4	10 ± 9.2	18 ± 36	8.6 ± 7.0	5.6 ± 3.3	3.7 ± 2.7	4.9 ± 2.4	7.1 ± 5.2
Strickland at SG3	6.9 ± 4.3	7.0 ± 8.3	4.3 ± 4.3	2.8 ± 1.7	3.1 ± 3.1	4.4 ± 3.4	4.7 ± 2.9	4.4 ± 2.8	3.9 ± 4.9	6.6 ± 4.4
Strickland at Bebelubi							2.6 ± 1.1	4.4 ± 1.6	2.7 ± 1.5	4.6 ± 3.6
Strickland at SG4	21 ± 39	12 ± 7.3	11 ± 3.3	15 ± 15	3.8 ± 2.3	4.0 ± 2.9	5.3 ± 2.0	2.6 ± 1.7	4.5 ± 5.1	3.1 ± 2.8
Strickland at SG5	4.3 ± 0.1	4.4 ± 0.0	nd	11 ± 0.0	5.6 ± 0.0	3.6 ± 0.4	2.1 ± 0.6	1.1 ± 0.1	5.4 ± 3.3	7.5 ± 5.3
Upper Lagaip*	14 ± 16	22 ± 41	7.8 ± 6.4	9.8 ± 11	11 ± 15	5.4 ± 5.7	91 ± 258	2.1 ± 1.2	4.1 ± 3.3	5.3 ± 5.4
Pori River*					30 ± 42	8.3 ± 7.7	2.7 ± 1.2	2.0 ± 1.7	2.8 ± 2.2	4.7 ± 3.9
Ok Om*	3.8 ± 3.1	6.1 ± 5.0	8.9 ± 8.7	9.0 ± 8.3	4.4 ± 4.4	6.7 ± 7.0	5.0 ± 1.9	3.0 ± 2.7	4.6 ± 4.2	4.6 ± 2.6
Kuru River*					3.6 ± 4.2	6.1 ± 7.3	4.5 ± 2.4	1.6 ± 1.1	2.4 ± 1.3	3.8 ± 2.4
Baia River*							3.1 ± 0.07	2.0 ± 1.3	2.4 ± 1.4	2.4 ± 2.3
Tomu River*					1.1 ± 0.5	4.0 ± 2.6	2.7 ± 1.5	1.7 ± 0.8	4.0 ± 3.6	2.9 ± 2.2
SG6				5.0 ± 0.0	3.1 ± 2.9	nd	2.2 ± 0.4	1.3 ± 0.4	5.5 ± 0.0	3.4 ± 0.0
Total zinc										
Porgera at SG1 ('000)	16 ± 9.4	8.2 ± 7.6	11 ± 6.4	14 ± 22	9.8 ± 11	22 ± 12	8.5 ± 6.6	4.0 ± 0.0	13 ± 0.0	27 ± 19
Lagaip at SG2	1621 ± 723	730 ± 467	1156 ± 791	858 ± 644	747 ± 501	1056 ± 613	927 ± 566	2064 ± 1679	1412 ± 523	2890 ± 2410
Lagaip at Wankipe	610 ± 370	860 ± 520	852 ± 871	231 ± 112	504 ± 245	573 ± 388	823 ± 362	719 ± 330	1004 ± 390	1279 ± 969
Strickland at SG3	451± 203	395 ± 247	405 ± 250	271 ± 167	354 ± 163	447 ± 189	347 ± 214	440 ± 195	545 ± 228	628 ± 337
Strickland at Bebelubi							165 ± 58	213 ± 46	190 ± 64	238 ± 61
Strickland at SG4	173 ± 88	78 ± 60	60 ± 16	134 ± 71	156 ± 56	193 ± 214	156 ± 64	119 ± 70	164 ± 112	72 ± 63
Strickland at SG5	81 ± 5.2	63 ± 0.0	nd	36 ± 0.0	110 ± 0.0	258 ± 230	61 ± 30	99 ± 72	47 ± 22	70 ± 36
Upper Lagaip*	60 ± 30	187 ± 192	83 ± 40	81 ± 83	138 ± 180	139 ± 160	129 ± 258	35 ± 28	74 ± 52	33 ± 35
Pori River*					53 ± 38	24 ± 9.9	12 ± 7.6	11 ± 7.3	13 ± 11	34 ± 40
Ok Om*	77 ± 90	118 ± 253	129 ± 142	64 ± 57	149 ± 207	52 ± 52	80 ± 64	80 ± 110	191 ± 207	59 ± 71
Kuru River*					38 ± 18	27 ± 20	15 ± 8.2	19 ± 19	229 ± 252	32 ± 33
Baia River*							22 ± 12	13 ± 7.4	19 ± 16	20 ± 21
Tomu River*					13 ± 18	3.3 ± 4.4	4.3 ± 4.4	2.8 ± 1.3	4.1 ± 3.8	9.8 ± 7.4
SG6				24 ± 0.0	58 ± 70	nd	2.7 ± 0.8	26 ± 35	43 ± 0.0	4.8 ± 0.0

nd = no data available; * = control site all data is presented as: mean ± standard deviation



Note: Upper Lagaip, Pori, OkOm, Kuru, Baia and Tomu are monitoring control sites not affected by the Porgera mine.

Figure 5-10C Mean dissolved zinc concentrations at downstream sites from 2001-2010

The graph within Figure 5-10C indicates the rapid decline in concentrations of dissolved zinc downstream of SG1 for 2001-2010. The Upper Lagaip value is anomalously high for a control site, while all values downstream of SG1 are below the SG3 compliance criterion of 50 µg/L.

5.3 Physicochemical Parameters in the River System

5.3.1 pH Measurement

The 2010 median pH values at monitoring and control sites downstream of the mine are shown in Figure 5–11. The variability is caused mainly by the differing water quality of the tributaries as they enter the main river system. The pH range is indicative of natural river values throughout the region.

Mean pH values obtained from 2001 to 2010 (Table 5-11) indicate the relatively consistent, slightly alkaline nature of the entire Porgera-Lagaip-Strickland River system downstream of the Porgera mine.

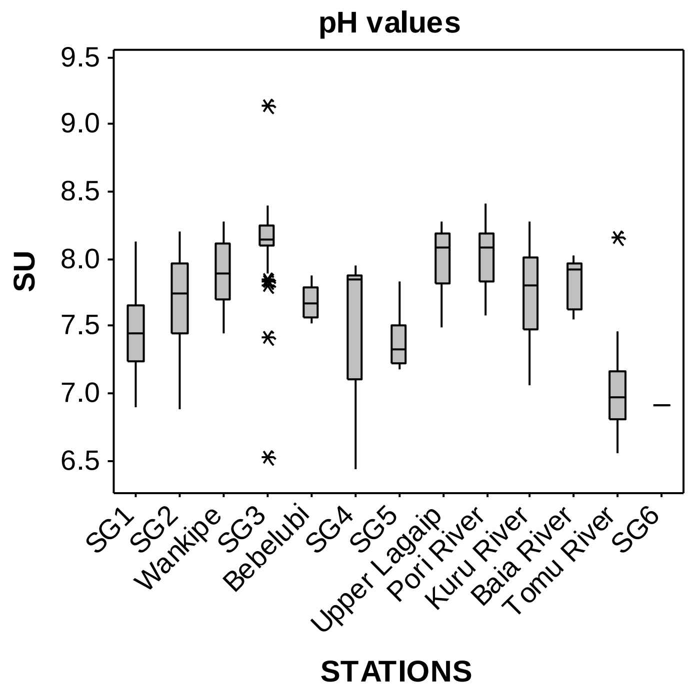


Figure 5-11 pH measurements at downstream monitoring sites during 2010

Table 5-11 Mean annual pH measurements at downstream sites from 2001 to 2010 (all results in pH units)

Location	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Porgera at SG1	7.8	7.8	7.8	7.7	7.9	7.4	7.8	7.1	nd	7.4
Lagaip at SG2	8.0	8.0	7.8	7.8	8.1	7.7	7.9	7.6	8.0	7.7
Lagaip at Wankipe	7.7	8.0	8.0	7.6	8.0	7.9	7.8	7.8	8.0	7.9
Strickland at SG3	8.2	8.2	8.0	7.8	8.1	8.1	8.0	7.9	8.1	8.1
Strickland at Bebelubi							7.7	7.7	7.7	7.6
Strickland at SG4	8.0	7.5	7.6	7.5	7.8	7.4	7.7	7.6	7.8	7.5
Strickland at SG5				7.4	8.1	7.8	7.2	7.9	7.7	7.4
Upper Lagaip River*	8.0	8.0	7.9	7.9	8.0	7.8	8.0	7.9	8.1	8.0
Pori River*					8.4	8.3	8.0	7.9	8.2	8.0
Ok Om*	7.8	8.0	7.9	7.6	8.0	7.8	7.5	7.6	8.0	7.7
Kuru River*					8.1	7.7	7.7	7.6	7.9	7.7
Baia River*							8.0	7.9	7.9	7.8
Tomu River*					7.2	7.4	7.8	7.2	7.1	7.0
SG6				7.6	6.9	nd	7.0	7.3	6.8	6.9

nd = no data available; * = control sites

5.3.2 Total Suspended Solids (TSS) in the River System

Table 5-12 shows the general decrease in TSS in the Strickland River system from 2001 to 2010 from the mine site (Porgera at SG1) to SG5. The decrease results from the deposition of coarser suspended material as the river profile flattens in its lower reaches, and as a result of natural dilution from various tributaries along the river system. Also from Table 5-12, no annual trends can be seen at each location from 2001 to 2010.

Table 5-12 Mean total suspended solids concentrations at downstream sites from 2001 to 2010 (all results in mg/L)

Location	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Porgera at SG1	14520	11570	13240	16400	10750	11950	6650	19230	10300	15200
Lagaip at SG2	2210	2210	3240	2510	1430	1730	1560	2050	1890	2060
Lagaip at Wankipe	1550	1300	2080	1390	3550	1650	1970	1710	2340	2080
Strickland at SG3	1500	1580	1580	1410	1850	1120	1340	1640	2000	1480
Strickland at Bebelubi							1390	900	815	1060
Strickland at SG4	1140	675	520	370	840	570	350	585	865	560
Strickland at SG5				185	535	595	520	780	285	330
Upper Lagaip River*	730	1055	1090	845	780	1850	1740	350	820	380
Pori River*					180	110	175	165	170	390
Ok Om*	1105	470	1915	785	1610	1285	510	835	1810	720
Kuru River*					150	255	125	225	2720	580
Baia River*							830	210	280	160
Tomu River*					38	63	160	9.5	38	125
SG6				78	15	nd	20	240	12	3.0

* = control sites

5.4 Bed Sediment Sampling in the River System

Bed sediment samples were collected during 2010 at the main downstream monitoring locations along the Porgera/Lagaip/Strickland River system using a plastic scoop to skim off the top 2 cm of recently-deposited sediment from sand bars or from river banks. The sediment samples were collected as duplicates in the field then returned to the onsite laboratory where they were temporarily stored in a refrigerator before shipment to NMI. A duplicate sample was included with every seven samples sent to NMI, and the QA/QC on these batches was conducted by NMI. The bed sediment samples were taken monthly at SG2, Wankipe and SG3, as well as the Upper Lagaip, Pori, Ok Om and Kuru control sites. From April 2010, sediment samples at SG1 were taken weekly. Further downstream, bed sediment samples were taken on a 2-monthly basis at Bebelubi, SG4 and SG5 including the Baia and Tomu control sites. Sieving with a 63 micron screen was conducted by NMI. Each 30 gm sample was washed through the sieve with 20 mL of deionised water and the process repeated until all the fines passing through the screen had been reduced to virtually nil (i.e. no further colour detected). The analytical results are shown in Fig 5-12.

Trace metal content in both the <63 µm and total fractions of the bed sediments showed considerable variability along the length of the river system from the Porgera mine to SG5 in the Lower Strickland region. In general, the concentrations of trace metals should show a downward trend downstream of Porgera as mine-derived sediments become diluted with natural sediments along the course of the Lagaip/Strickland river system and their tributaries. However, such a trend is often difficult to determine because of the relatively low number of samples taken during the year, and the existence of background levels of metals in natural sediments derived from various sources within the river catchment. With some metals, the Baia and Tomu control sites appear to be influenced by ancient volcanic activity to the east, especially Mt Bosavi in the case of Tomu.

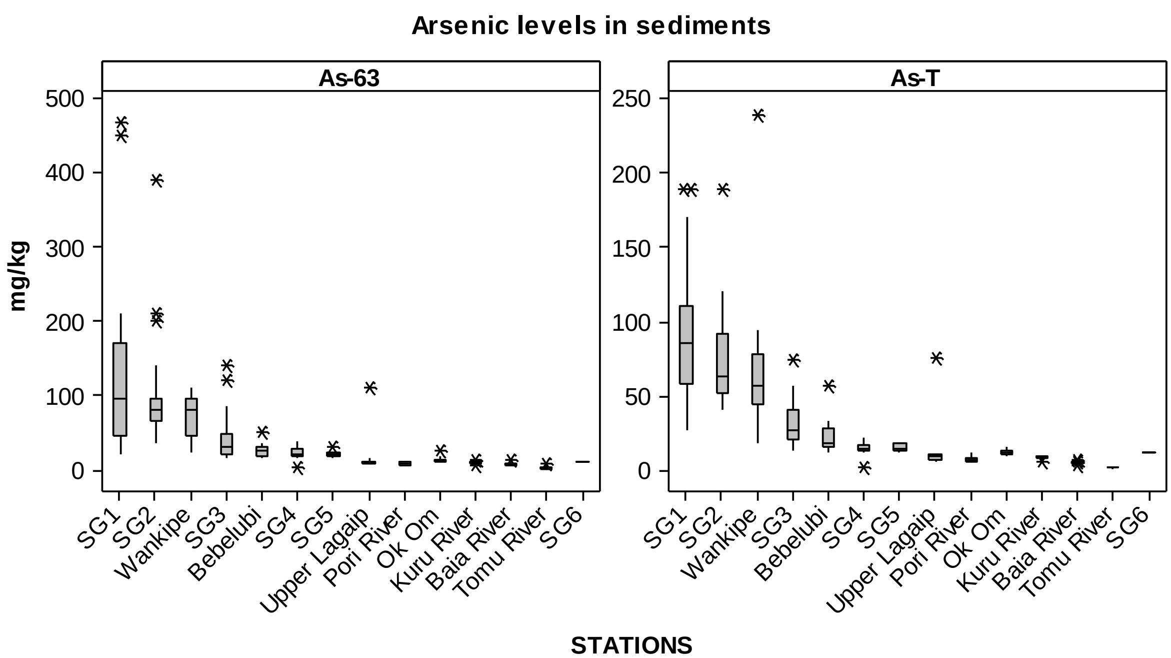
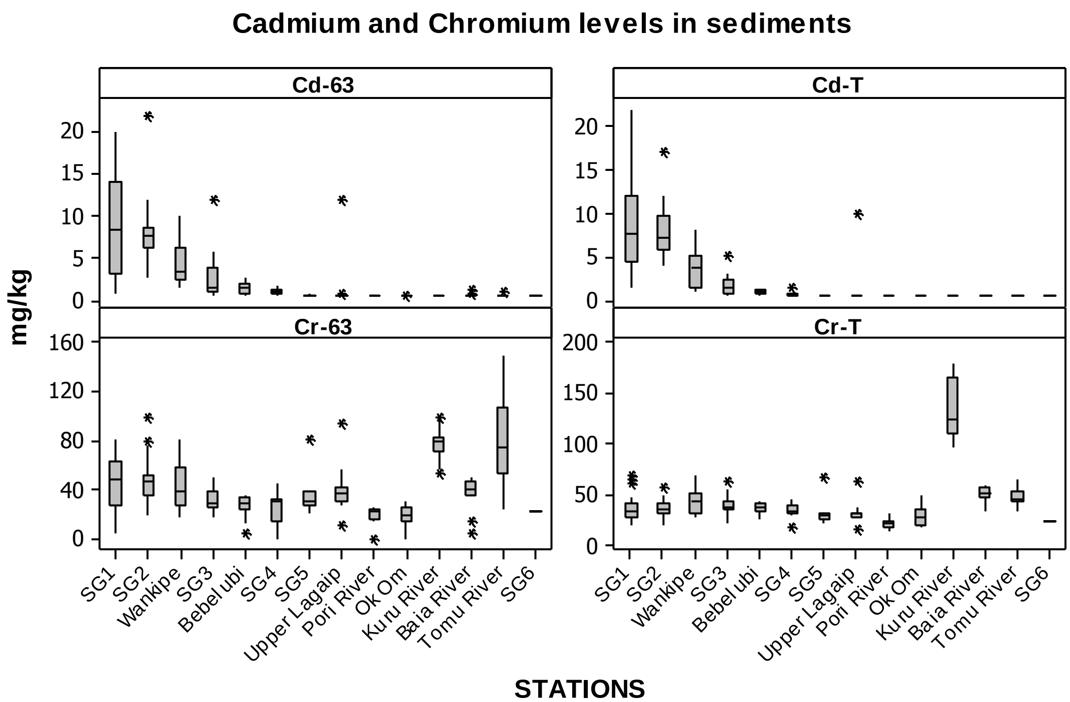


Figure 5-12 Metal content in the <63 µm and total size fractions of bed sediment samples at downstream sites during 2010



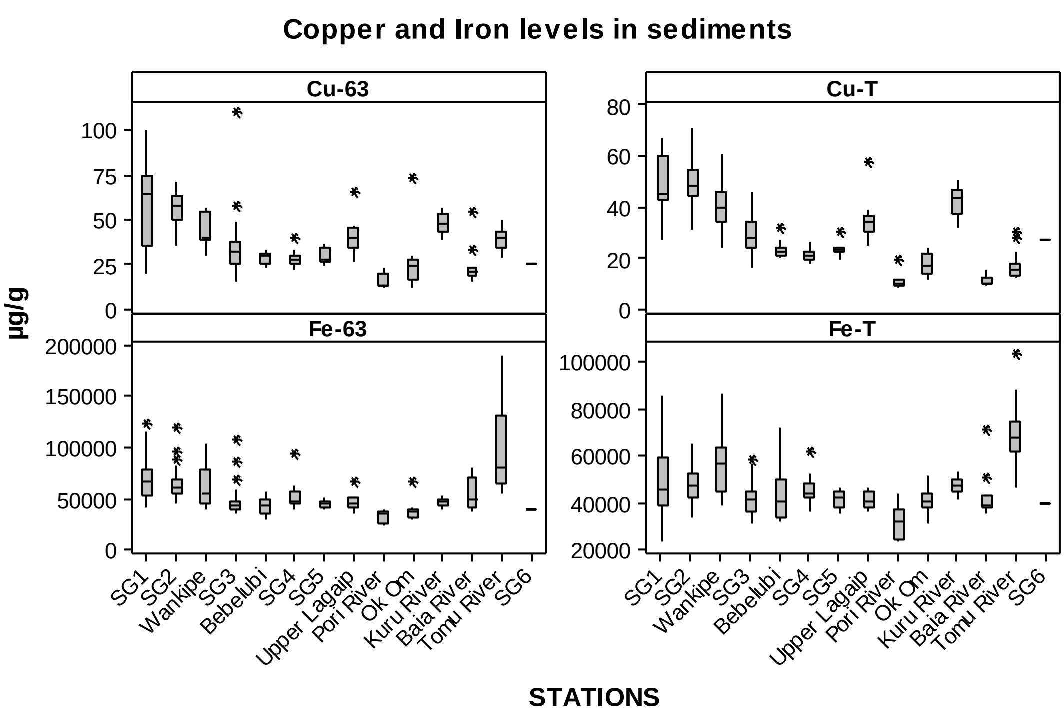
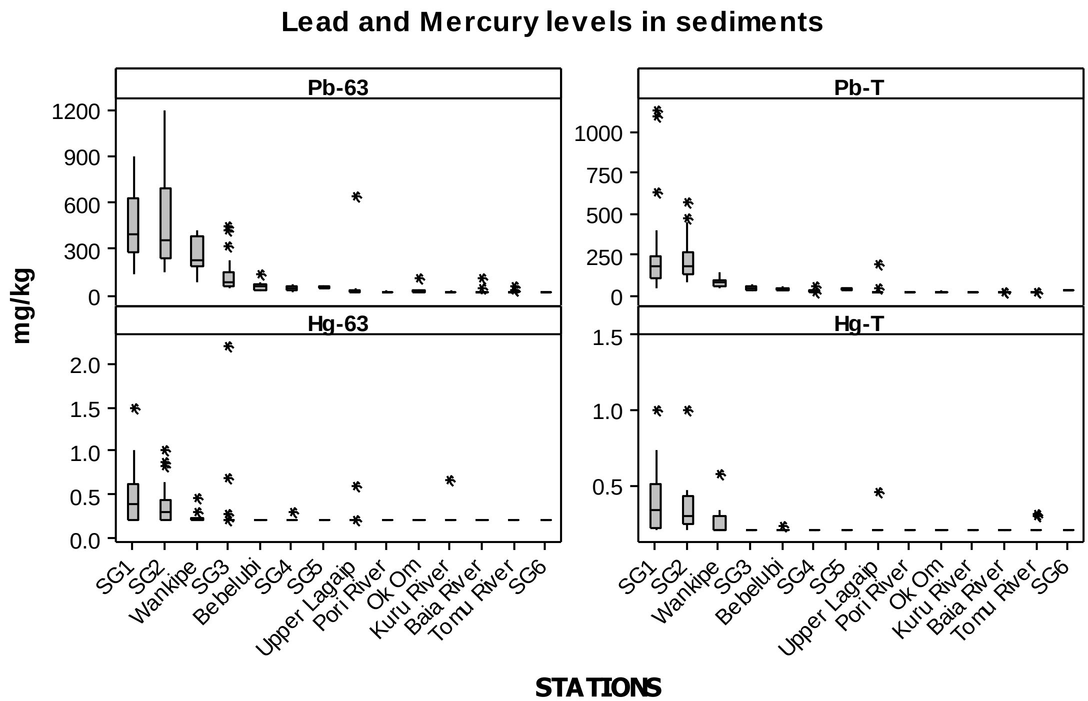


Figure 5-12 (cont.) Metal content in the <63 µm and total size fractions of bed sediment samples at downstream sites during 2010



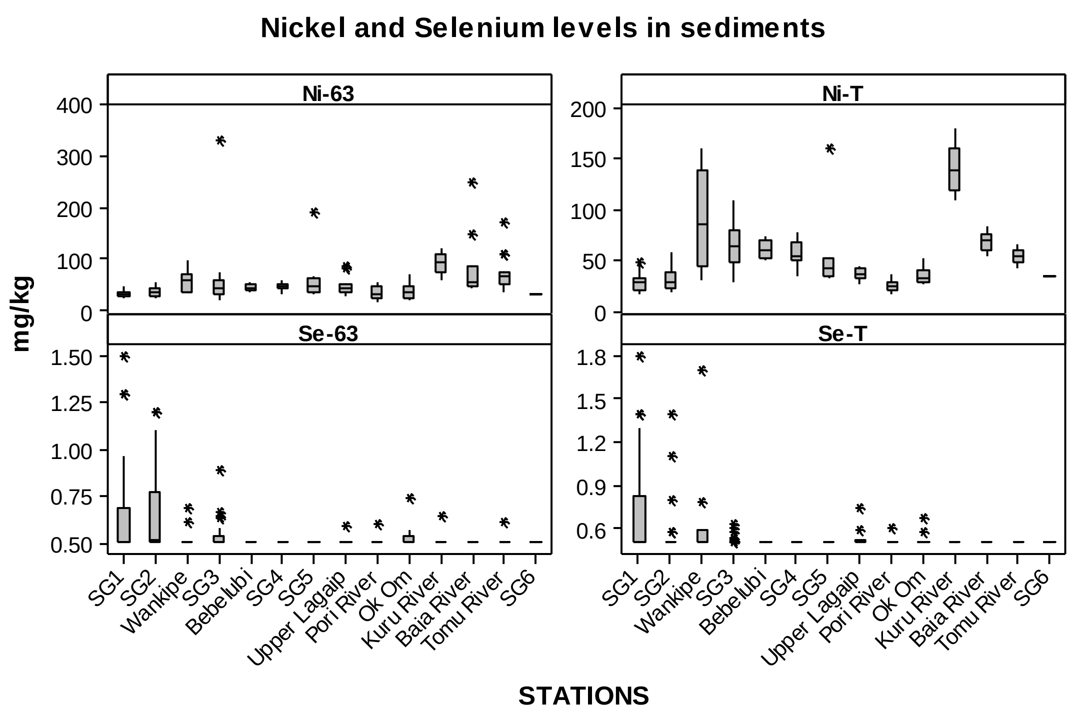


Figure 5-12 (cont.) Metal content in the <63 μm and total size fractions of bed sediment samples at downstream sites during 2010

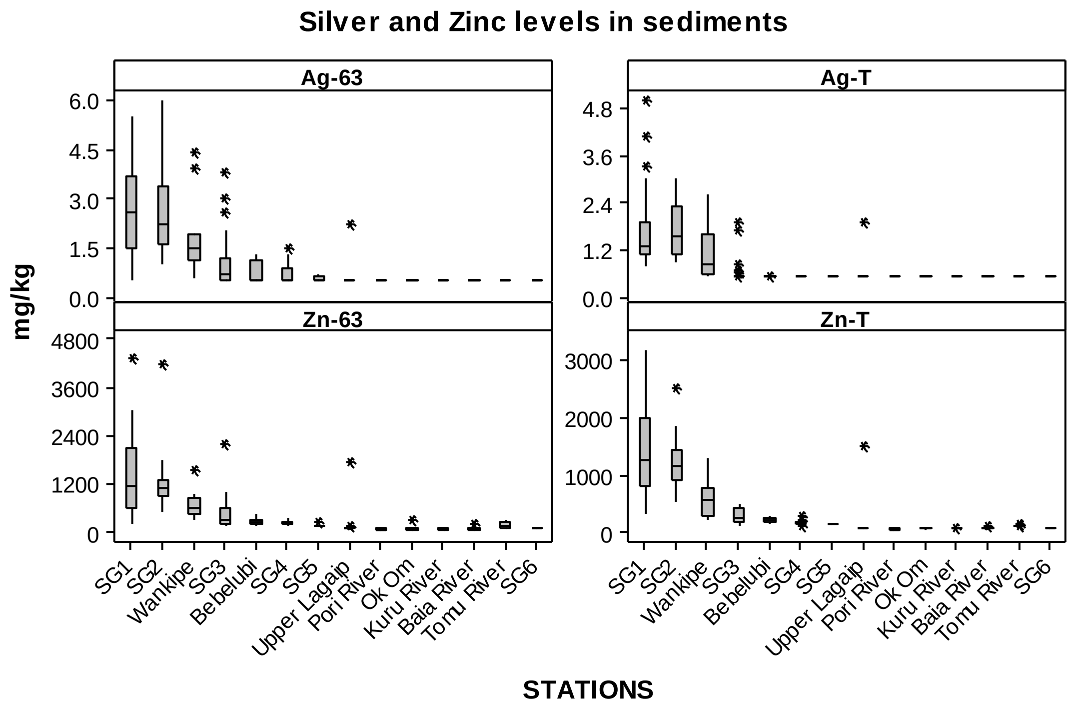


Figure 5-12 (cont.) Metal content in the <63 μm and total size fractions of bed sediment samples at downstream sites during 2010

In general, the finer sediment fraction for metal-bearing sediments possesses more downstream mobility from river turbulence, and is likely to be transported more readily to the Fly River delta; however, these sediments are also more susceptible to overbank deposition on the floodplain during high river flows.

From Figure 5-12, the <63 μm and total concentrations for most trace metals showed, as expected, a downward trend with increasing distance downstream of the mine. However, chromium, nickel and selenium showed no distinct trends for either the finer or total fractions.

Table 5-13 Mean metal concentrations in the <63 μm fraction at downstream sites. All sites from SG1 to SG3 including the control sites are sampled monthly. Those further downstream are sampled every two months. Results are in mg/kg

Station	Year	As	Cd	Cr	Cu	Fe	Pb	Hg	Ni	Se	Ag	Zn
SG1	2002	312	6.4	33	58	55300	538	1.2	33	0.35	5.2	1210
	2003	361	11	45	62	70300	658	1.5	36	0.55	5.4	1350
	2004	256	5.1	44	57	65400	398	1.0	25	0.29	4.5	769
	2005	277	10	61	64	86300	617	0.6	29	4.7	0.2	1240
	2006	158	11	45	74	57600	622	0.9	53	0.7	2.6	1670
	2007	165	11	44	75	54020	646	0.6	61	0.9	3.2	1430
	2008	213	9.0	48	67	64500	560	0.8	42	0.5	3.8	1240
	2009	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	2010	126	9.8	45	59	69000	436	0.5	32	0.6	2.6	1700
SG2	2002	125	3.6	38	42	46200	241	0.40	41	0.63	2.3	618
	2003	238	5.8	40	49	66900	467	0.82	26	0.66	3.9	709
	2004	142	4.1	44	47	54300	271	0.67	29	0.31	3.6	583
	2005	142	4.5	43	50	65600	275	0.7	20	0.2	3.0	524
	2006	89	4.7	39	53	51600	332	0.5	60	0.5	2.4	637
	2007	122	9.2	43	65	50160	300	0.6	40	0.9	2.0	1260
	2008	117	6.5	41	55	53800	281	0.6	37	0.5	2.6	940
	2009	93	8.7	36	52	57100	334	0.5	35	0.8	1.9	1270
	2010	101	7.8	48	56	65000	472	0.4	37	0.7	2.6	1240
Wankipe	2002	91	2.7	35	43	47000	160	0.39	46	0.3	2.2	441
	2003	63	2.9	30	37	53100	136	0.56	28	0.4	1.5	298
	2004	70	2.0	33	36	48400	123	0.46	40	0.4	1.7	259
	2005	52	2.4	32	40	51500	104	0.6	27	0.3	1.9	287
	2006	99	6.0	32	54	51100	206	0.6	62	0.4	1.7	521
	2007	76	14	40	103	67780	388	0.3	56	3.0	1.6	655
	2008	70	4.7	32	50	51300	172	0.5	43	1.2	1.6	396
	2009	93	6.3	44	57	64220	226	0.3	64	1.0	1.8	698
	2010	17	4.4	44	44	63000	247	0.2	59	0.5	1.9	704
SG3	2002	79	2.1	30	39	43500	111	0.34	51	0.2	1.9	304
	2003	66	2.7	33	33	50400	102	0.55	32	0.4	1.5	267
	2004	50	1.8	34	33	43900	82	0.50	34	0.4	1.4	233
	2005	40	2.1	30	32	48300	71	0.5	25	0.2	1.6	218
	2006	46	5.4	29	55	45700	121	0.5	88	0.7	1.3	327
	2007	46	3.6	31	40	42200	89	0.2	45	0.7	1.2	283
	2008	46	4.7	32	48	45200	102	0.5	50	1.8	2.0	287
	2009	30	4.0	36	44	47500	88	0.2	57	0.7	1.0	340
	2010	38	2.5	31	34	47800	0.3	0.2	44	0.5	1.0	450
Bebelubi	2007	29	2.3	22	31	42800	57	0.2	29	0.5	1.0	250
	2008	14	2.6	29	40	37600	37	0.2	40	0.5	0.7	135
	2009	45	2.3	41	40	62800	81	0.2	48	0.6	1.0	448
	2010	26	1.4	27	28	43500	59	0.2	45	0.5	0.7	282

nd = no data

Table 5-13 (cont.) Mean metal concentrations in the <63 μm fraction at downstream sites. All sites from SG1 to SG3 including the control sites are sampled monthly. Those further downstream are sampled every two months. Results are in mg/kg

Station	Year	As	Cd	Cr	Cu	Fe	Pb	Hg	Ni	Se	Ag	Zn
SG4	2002	35	1.6	33	34	40800	57	0.36	41	0.4	1.5	169
	2003	28	2.2	35	28	38200	51	0.41	35	0.3	1.2	167
	2004	31	1.5	29	28	43000	55	0.42	34	0.3	1.3	190
	2005	24	1.5	32	28	47400	32	0.2	25	0.2	1.6	157
	2006	19	1.5	25	29	43400	47	0.2	31	0.5	0.5	207
	2007	29	1.2	39	37	48900	56	0.2	45	0.8	0.8	221
	2008	26	1.7	31	36	47200	47	0.3	36	0.5	0.9	206
	2005	32	1.7	29	28	49400	51	0.2	23	0.2	1.1	166
	2007	26	1.9	27	33	37000	51	0.2	34	0.5	0.9	165
	2008	27	1.8	26	31	44200	102	0.2	30	0.4	0.9	180
	2009	31	1.8	33	33	52220	46	0.2	46	0.5	0.7	258
	2010	22	1.1	26	28	51800	42	0.2	46	0.5	0.7	240
SG5	2005	32	1.7	29	28	49400	51	0.2	23	0.2	1.1	166
	2007	26	1.9	27	33	37000	51	0.2	34	0.5	0.9	165
	2008	23	1.8	24	33	46300	204	0.2	33	0.6	0.7	210
	2009	29	0.7	29	28	41800	49	0.2	40	0.5	0.6	200
	2010	20	0.6	37	29	45300	41	0.2	64	0.5	0.5	178
Upper Lagaip*	2001	6.9	0.9	29	35	36800	10	0.04	39	0.6	nd	85
	2002	48	2.7	38	43	42500	60	0.36	48	1.4	0.6	371
	2003	18	2.8	38	38	63600	72	0.24	43	1.4	0.5	185
	2004	12	0.8	35	40	48800	16	0.12	43	1.4	0.4	99
	2005	19	1.8	32	37	39600	28	0.2	31	2.5	0.3	183
	2006	6.9	1.9	41	53	37000	16	0.3	51	0.5	0.6	95
	2007	52	3.8	39	61	42000	68	0.3	44	0.6	0.8	275
	2008	21	3.1	40	57	43000	67	0.5	43	0.5	0.9	148
	2009	10	2.2	37	40	46330	13	0.2	46	0.6	0.5	114
	2010	18	1.5	40	41	46800	71	0.2	49	0.5	0.6	240
Pori*	2005	12	1.2	23	18	37700	14	0.2	14	0.1	1.1	83
	2007	15	4.3	29	47	37800	31	0.2	44	0.8	0.5	141
	2008	11	4.3	24	37	38600	40	1.2	32	7.3	0.7	103
	2009	7.3	1.4	21	17	30100	97	0.2	23	0.5	0.5	70
	2010	7.5	0.5	19	15	33100	14	0.2	34	0.5	0.5	78
Ok Om*	2002	16	0.4	13	23	35300	15	0.06	23	0.6	0.7	71
	2003	33	2.0	17	27	55500	18	0.25	39	0.8	0.8	101
	2004	14	0.6	14	16	37700	15	0.09	21	0.4	0.5	75
	2005	24	1.1	16	26	53800	24	0.1	22	0.7	0.5	93
	2006	20	5.9	20	41	45900	55	0.5	101	0.6	0.6	152
	2007	24	5.8	24	46	38600	38	0.2	47	1.3	0.5	161
	2008	18	4.1	22	34	44800	43	0.3	48	1.7	0.5	134
	2009	13	3.8	27	30	39140	97	0.2	37	0.6	0.5	94
	2010	13	0.5	19	26	38300	26	0.2	137	0.5	0.5	101

* = control site

Table 5-13 (cont.) Mean metal concentrations in the <63 μm fraction at downstream sites. All sites from SG1 to SG3 including the control sites are sampled monthly. Those further downstream are sampled every two months. Results are in μg/g.

Station	Year	As	Cd	Cr	Cu	Fe	Pb	Hg	Ni	Se	Ag	Zn
Kuru*	2005	15	1.3	27	35	45200	23	0.4	27	0.1	0.6	98
	2007	26	2.7	43	49	39600	57	0.2	58	0.7	0.6	182
	2008	16	5.2	39	58	46200	78	0.6	55	4.1	0.6	164
	2009	9.4	3.7	94	67	45900	22	0.2	113	0.8	0.5	95
	2010	9.6	0.5	78	48	46700	17	0.2	93	0.5	0.5	89
Baia*	2007	7.0	29	41	150	51900	14	0.2	59	1.0	0.5	170
	2008	15	11	50	66	44800	29	0.2	55	1.0	0.5	162
	2009	4.6	0.5	38	15	53900	6.0	0.2	35	0.5	0.5	89
	2010	7.2	0.6	37	23	54600	20	0.2	81	0.5	0.5	115
Tomu*	2005	1.2	1.7	58	27	65800	21	1.2	26	0.1	5.7	127
	2006	1.4	0.9	77	43	87900	12	0.2	26	0.4	25	195
	2007	2.2	0.8	65	43	57200	10	0.2	66	0.7	0.5	120
	2008	1.8	3.5	69	45	70500	12	0.3	40	0.5	12	148
	2009	3.5	9.3	98	71	107470	32	0.2	82	0.6	0.5	213
	2010	2.3	0.5	81	39	99000	14	0.2	72	0.5	0.5	176
SG6	2009	4.9	0.5	25	20	34100	15	0.2	36	0.5	0.5	93
	2010	9.7	0.5	22	25	38900	15	0.2	31	0.5	0.5	86
ANZECC/ARMCANZ trigger values		**20**	**1.5**	**80**	**65**	**-**	**50**	**0.15**	**21**	**-**	**1.0**	**200**

* = control site

From Table 5-13, the mean concentrations of arsenic, cadmium, lead, silver and zinc in the <63 μm sediment fraction over the years have consistently shown a decrease with distance downstream of SG1. This trend is not obvious for results presented for chromium, copper, mercury, nickel and selenium.

Table 5-14 Mean total metal content of bed sediments at downstream sites. All sites from SG1 to SG3 including the control sites are sampled monthly. Those further downstream are sampled every two months. Results are in µg/g

Station	Year	As	Cd	Cr	Cu	Fe	Pb	Hg	Ni	Se	Ag	Zn
SG1	2002	212	9.9	33	62	52600	387	0.58	33	0.4	3.4	2090
	2003	167	8.7	33	51	51900	266	0.73	32	0.5	5.3	1150
	2004	169	5.2	28	44	44400	214	0.67	20	0.3	2.7	804
	2005	172	8.5	36	51	57100	231	0.3	13	0.2	3.2	1180
	2006	89	7.7	31	57	44600	267	0.3	25	0.5	2.4	1240
	2007	100	6.2	32	49	41700	151	0.3	32	0.7	1.4	1130
	2008	133	6.6	32	49	46100	208	0.4	23	0.4	2.4	1080
	2009	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	2010	89	8.8	37	50	50010	241	0.4	29	0.7	1.7	1460
SG2	2002	119	10	36	62	44700	174	0.37	36	0.6	2.2	1170
	2003	141	8.1	34	58	38200	240	0.74	26	0.7	3.9	1070
	2004	136	4.0	33	44	45800	171	0.36	25	0.3	2.5	617
	2005	80	3.8	30	41	48600	130	0.4	20	0.2	2.9	539
	2006	73	5.0	32	48	40400	179	0.3	31	0.5	1.6	800
	2007	73	5.2	32	46	44900	129	0.3	32	0.7	1.0	979
	2008	91	4.8	32	46	45300	143	0.4	29	0.5	1.8	834
	2009	87	5.5	30	43	47930	164	0.3	30	0.7	1.2	945
	2010	75	7.9	37	49	47200	214	0.7	31	0.6	1.7	1230
Wankipe	2002	81	3.1	42	44	45900	69	0.27	94	0.4	1.7	520
	2003	56	3.3	35	40	53100	51	0.36	98	0.2	1.9	388
	2004	60	1.9	27	31	41900	46	0.18	41	0.4	1.4	270
	2005	77	2.7	32	40	56500	56	0.2	37	0.2	2.4	368
	2006	65	3.5	32	43	50700	88	0.4	59	0.5	1.5	423
	2007	190	4.1	31	59	67400	103	0.3	93	1.7	1.6	807
	2008	77	2.7	31	40	51500	66	0.2	52	0.5	1.6	412
	2009	51	1.7	38	38	51710	49	0.2	77	0.7	0.6	360
	2010	73	3.6	44	41	56200	73	0.3	92	0.7	1.1	599
SG3	2002	61	2.1	36	32	43300	41	0.19	84	0.3	1.4	323
	2003	50	2.7	33	32	50200	35	0.32	81	0.5	1.1	397
	2004	51	1.5	31	29	42600	38	0.16	54	0.4	1.2	230
	2005	46	1.9	30	31	48500	38	0.2	40	0.2	1.5	243
	2006	41	2.9	31	36	59300	69	0.4	55	1.3	0.4	287
	2007	*50*	*1.9*	*32*	*37*	44200	72	0.2	53	1.0	0.6	280
	2008	50	1.9	32	33	50000	52	1.1	54	0.5	1.1	264
	2009	34	1.0	45	32	47750	31	0.2	76	0.6	0.5	242
	2010	30	1.7	39	29	41900	35	0.2	66	0.5	0.6	293
Bebelubi	2007	23	0.9	23	26	41600	40	0.2	33	0.5	0.5	210
	2008	11	0.6	36	19	38900	19	0.2	51	0.5	0.5	118
	2009	26	1.4	41	34	51350	25	0.2	55	0.5	0.6	295
	2010	22	1.0	37	23	43100	26	0.2	61	0.5	0.5	210

nd = no data

Table 5-14 (cont.) Mean total metal content of bed sediments at downstream sites. All sites from SG1 to SG3 including the control sites are sampled monthly. Those further downstream are sampled every two months. Results are in mg/kg

Station	Year	As	Cd	Cr	Cu	Fe	Pb	Hg	Ni	Se	Ag	Zn
SG4	2002	69	3.9	39	29	44700	76	0.25	57	0.3	1.2	484
	2003	17	1.9	33	21	38200	18	0.26	50	0.2	1.1	152
	2004	20	0.9	31	19	35900	55	0.09	47	0.2	0.9	152
	2005	22	1.5	33	24	48100	31	0.06	30	0.2	1.5	160
	2006	16	0.6	29	23	42800	33	0.2	37	0.6	0.5	173
	2007	24	1.0	41	29	50300	38	0.2	54	0.6	0.7	230
	2008	19	0.9	33	23	43600	28	0.2	43	0.4	0.7	180
	2009	15	0.7	40	22	44620	19	0.2	56	0.5	0.5	171
	2010	14	0.7	35	21	45800	21	0.2	57	0.5	0.5	175
SG5	2005	20	1.7	29	22	46900	29	0.2	17	0.1	0.6	165
	2007	27	1.5	37	41	38900	50	0.2	49	0.7	0.8	180
	2008	23	1.3	31	30	44300	40	0.2	35	0.5	0.7	190
	2009	25	0.7	31	27	41400	40	0.2	42	0.5	0.5	200
	2010	15	0.5	33	23	41900	29	0.2	56	0.5	0.5	146
Upper Lagaip*	2002	48	2.7	38	43	42500	60	0.36	48	0.6	1.4	371
	2003	18	2.8	38	38	63600	72	0.24	43	0.5	1.4	185
	2004	12	0.8	35	40	48800	16	0.12	43	0.4	1.4	99
	2005	19	1.8	32	37	39600	28	0.2	31	0.3	2.5	183
	2006	8.7	1.5	35	49	34300	16	0.8	57	0.7	0.7	80
	2007	24	1.1	32	37	37900	29	0.2	39	0.5	0.6	184
	2008	16	1.2	34	41	42100	24	0.3	43	0.5	1.1	153
	2009	11	0.5	34	36	44050	14	0.2	40	0.6	0.5	94
	2010	14	1.3	33	35	41100	30	0.2	37	0.5	0.6	199
Pori*	2005	8.5	0.9	30	14	39900	7.9	0.1	10	0.1	2.0	75
	2007	28	0.8	18	19	34400	34	0.2	24	0.6	0.8	148
	2008	15	1.0	25	16	39100	17	0.2	21	0.5	1.1	101
	2009	6.2	0.5	19	9.8	26870	7.5	0.2	20	0.5	0.5	57
	2010	6.6	0.5	22	11	31600	8.7	0.2	25	0.5	0.5	57

* = control site

Table 5-14 (cont.) Mean total metal content of bed sediments at downstream sites. All sites from SG1 to SG3 including the control sites are sampled monthly. Those further downstream are sampled every two months. Results are in mg/kg

Station	Year	As	Cd	Cr	Cu	Fe	Pb	Hg	Ni	Se	Ag	Zn
Ok Om*	2002	16	0.4	13	23	35300	15	0.06	23	0.7	0.6	71
	2003	33	2.0	17	27	55500	18	0.25	39	0.8	0.8	101
	2004	14	0.6	14	16	37700	15	0.09	21	0.5	0.4	75
	2005	24	1.1	16	26	53800	24	0.1	22	0.5	0.7	93
	2006	27	1.0	17	30	5610	36	0.3	42	0.8	0.7	103
	2007	18	0.6	18	21	38000	22	0.2	27	0.6	0.5	117
	2008	21	0.8	16	23	47600	24	0.2	28	0.6	0.6	92
	2009	20	0.5	32	26	47450	22	0.2	44	0.7	0.5	86
	2010	12	0.5	29	18	41100	14	0.2	35	0.5	0.5	70
Kuru*	2005	13	1.0	72	36	48400	18	0.1	62	0.2	0.7	99
	2007	16	0.7	72	42	46200	23	0.2	87	0.6	0.5	150
	2008	14	0.8	83	40	49300	19	0.2	84	0.5	0.6	116
	2009	7.9	0.5	143	45	46280	12	0.2	146	0.5	0.5	91
	2010	7.9	0.5	135	42	47600	13	0.2	141	0.5	0.5	85
Baia*	2007	5.5	0.5	72	13	48000	8.0	0.2	110	0.5	0.5	84
	2008	7.9	0.6	37	13	29700	8.3	0.2	56	0.5	0.5	84
	2009	3.8	0.5	55	12	50150	5.0	0.2	52	0.5	0.5	77
	2010	4.5	0.5	51	11	43000	6.4	0.2	69	0.5	0.5	73
Tomu*	2005	1.1	1.4	53	13	73000	9.9	0.04	30	0.1	0.7	123
	2006	0.8	0.2	60	17	84100	7.2	0.2	43	0.4	0.4	143
	2007	1.7	3.3	58	46	61800	8.7	0.2	61	0.5	0.5	135
	2008	1.6	1.1	61	29	77200	8.1	0.2	52	0.5	0.5	139
	2009	2.4	0.5	52	20	63020	7.1	0.2	50	0.5	0.5	105
	2010	1.2	0.5	48	17	68700	5.8	0.2	54	0.5	0.5	108
SG6 Herbert	2009	5.3	0.5	26	19	33300	14	0.2	32	0.5	0.5	91
	2010	11	0.5	24	27	39700	17	0.2	34	0.5	0.5	94
ANZECC/ARMCANZ trigger values		**20**	**1.5**	**80**	**65**	**-**	**50**	**0.15**	**21**	**-**	**1.0**	**200**

* = control site

As with the results shown for the finer fraction in Table 5-13, the mean total concentrations of arsenic, cadmium, lead, silver and zinc are similar and have consistently shown a decrease with distance downstream of SG1 (Table 5-14). This trend is not obvious for results presented for chromium, copper, mercury, nickel and selenium.

5.5 Local Creeks Water Quality Monitoring

The following local creeks, situated within the Special Mining Lease (SML) area, are monitored regularly each month for dissolved and total metals including arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, silver and zinc, as well as for pH, sulphate and total alkalinity:

- Anjolek starter dump ‘A’ (SDA) toe
- Kaiya River upstream of Anjolek erodible dump
- Kaiya River downstream of Anjolek erodible dump
- Kaiya River at Yuyan Bridge
- Yunarilama at portal for drainage tunnel
- 28 Level (underground water discharge at adit)
- Yakatabari Creek downstream of 28 Level discharge
- Kogai stable dump toe area
- Wendako Creek downstream of Anawe North stable dump
- Aipulungu River at road bridge near Porgera Station
- Aipulungu River upstream of lime plant and quarry
- Lime plant discharge upstream of Aipulungu River

The Kaiya River upstream of the Anjolek erodible dump is a control site for the waste dump montoring program. Within the mine’s influence, the Kaiya River is monitored downstream of the Anjolek erodible dump toe and further downstream at Yuyan.

Yakatabari Creek is monitored downstream of 28 Level underground water discharge before flowing into Kogai Creek, which then joins the Kaiya River further downstream. Kogai Creek downstream of the dump is monitored in the dump toe area. Aipulungu River is monitored upstream and downstream of the lime plant and quarry to determine its effect on water quality, especially in the vicinity of Porgera Station. The lime plant discharge before flowing into Aipulungu River is also monitored monthly.

Monthly water sampling at Yunarilama portal commenced late in 2001 at the exit of the underground and open pit drainage tunnel. Regular monitoring was also commenced at Wendako Creek downstream of the Anawe North stable dump. Sample collection, filtration and analysis details are presented in Section 5.1, Introduction.

Stream flow is measured at the time of each sample collection either by means of a spot gauging or the respective record from a stream gauging continuous recording instrument. The flow measurements concurrently with sample collection commenced in late 2003, with the objective of calculating the mass flux of contaminants discharged from waste rock dumps, the open pit and underground mines and general mine area runoff. Control sites, that are unaffected by mine operation are included to provide background water quality.

The location of local monitoring sites is presented in Figure 5-13. Data from monitoring in 2010 are presented in Figures 5-14 to 5-16, and compared with previous years in Table 5-15.

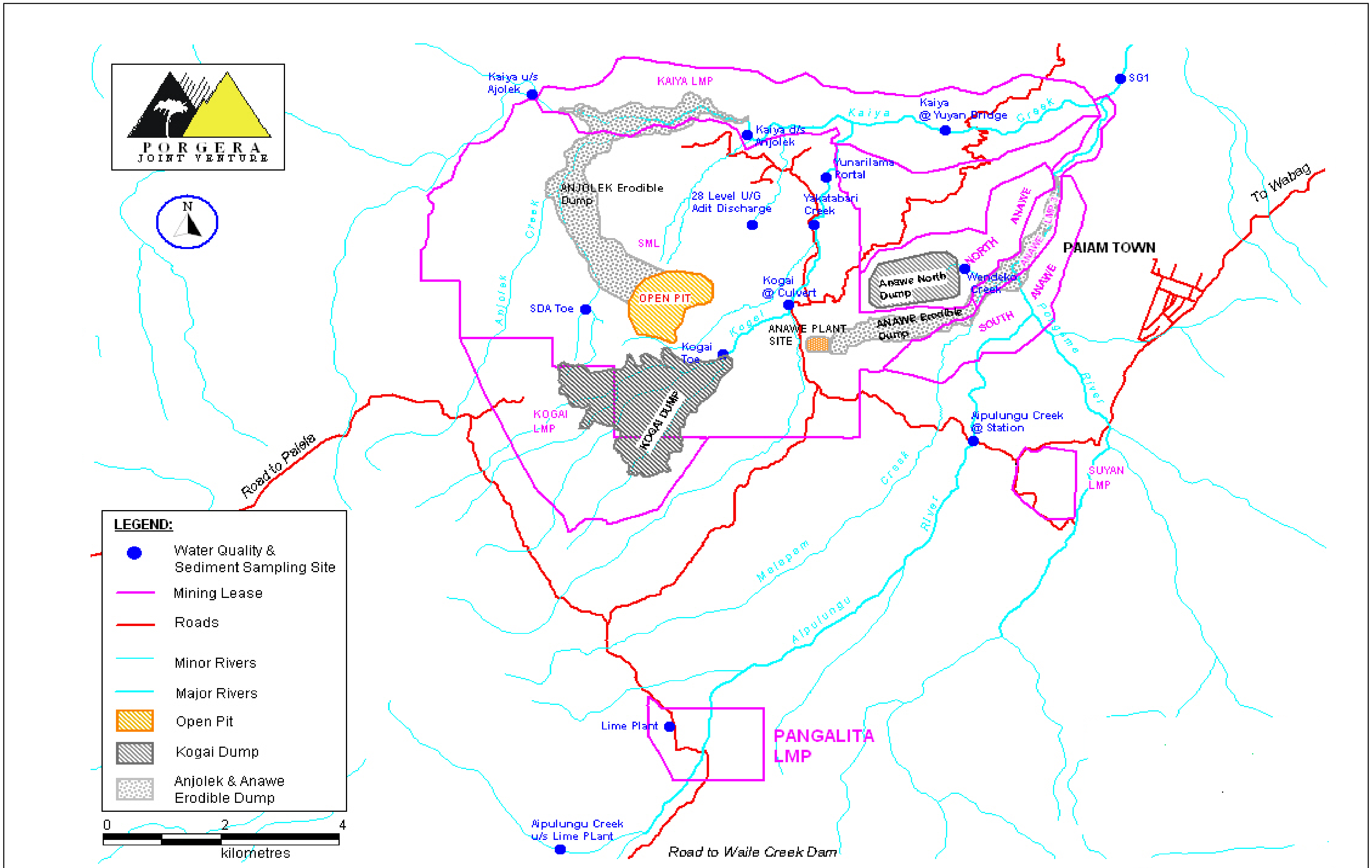


Figure 5-13 Local Creek Monitoring Stations

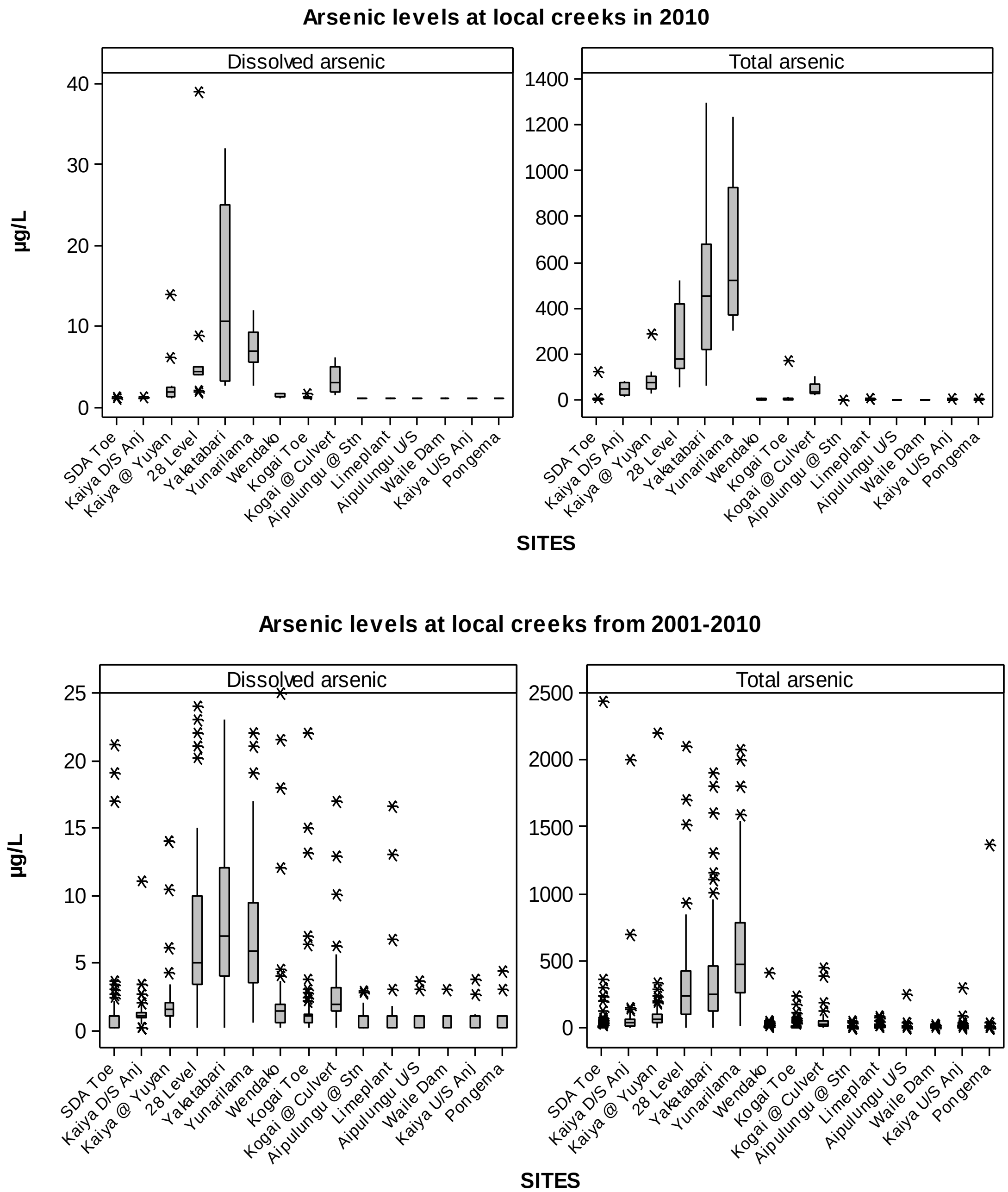
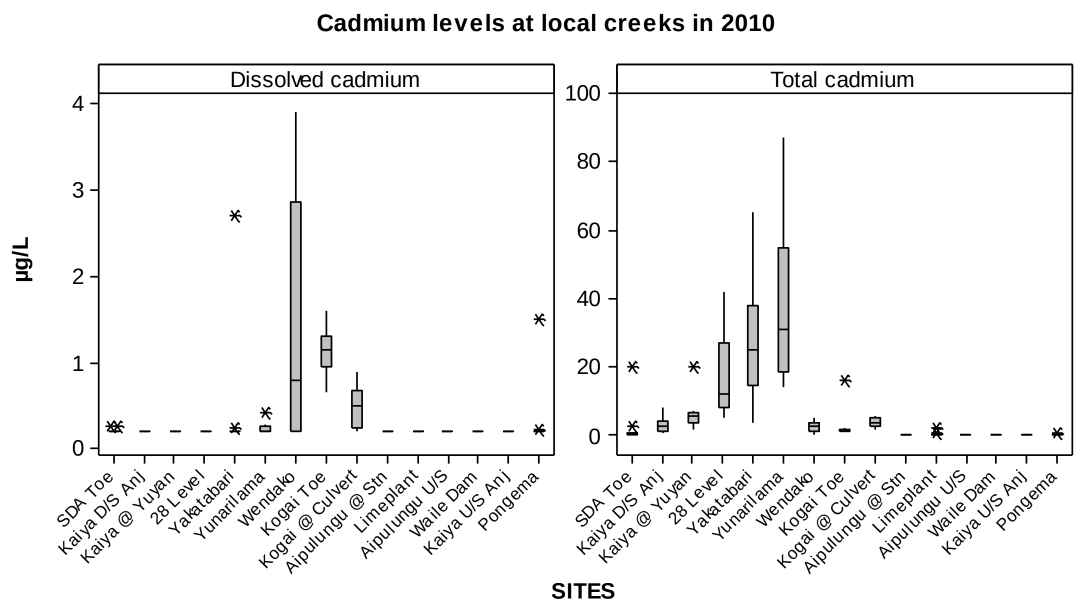


Figure 5-14 Results for dissolved and total metals in local creeks



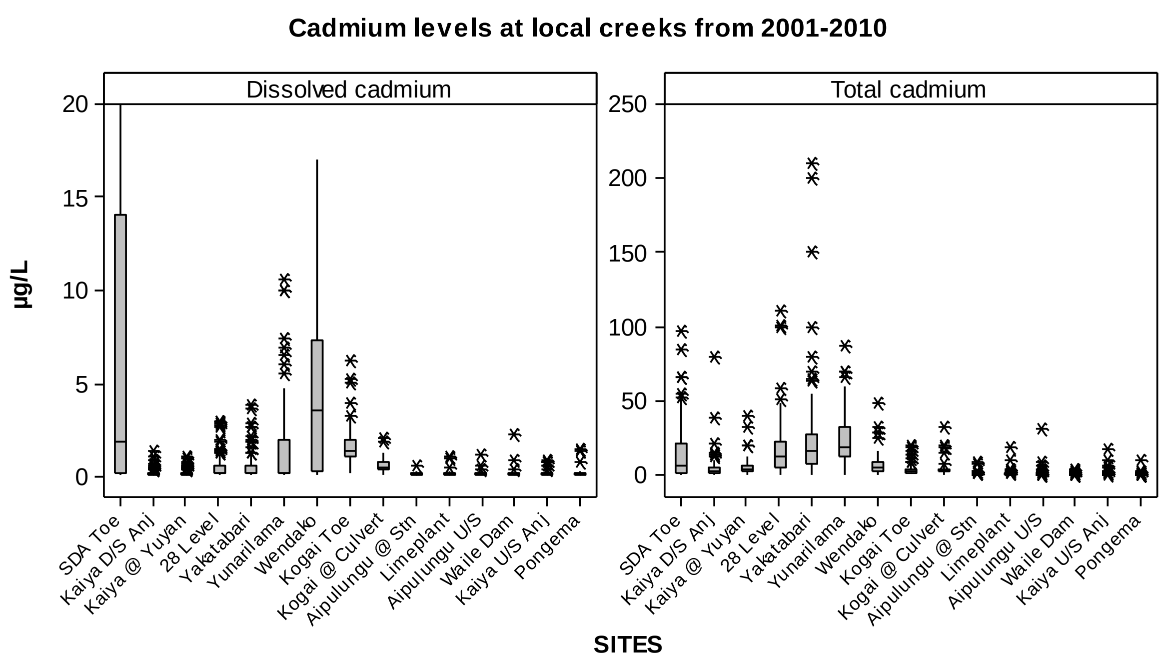
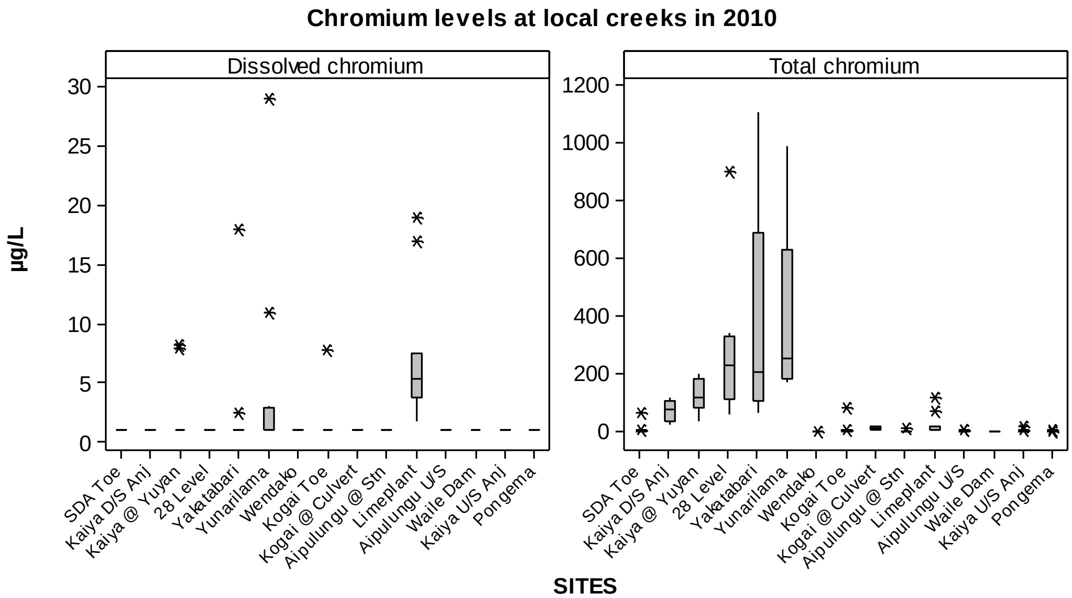


Figure 5-14 (cont.) Results for dissolved and total metals in local creeks



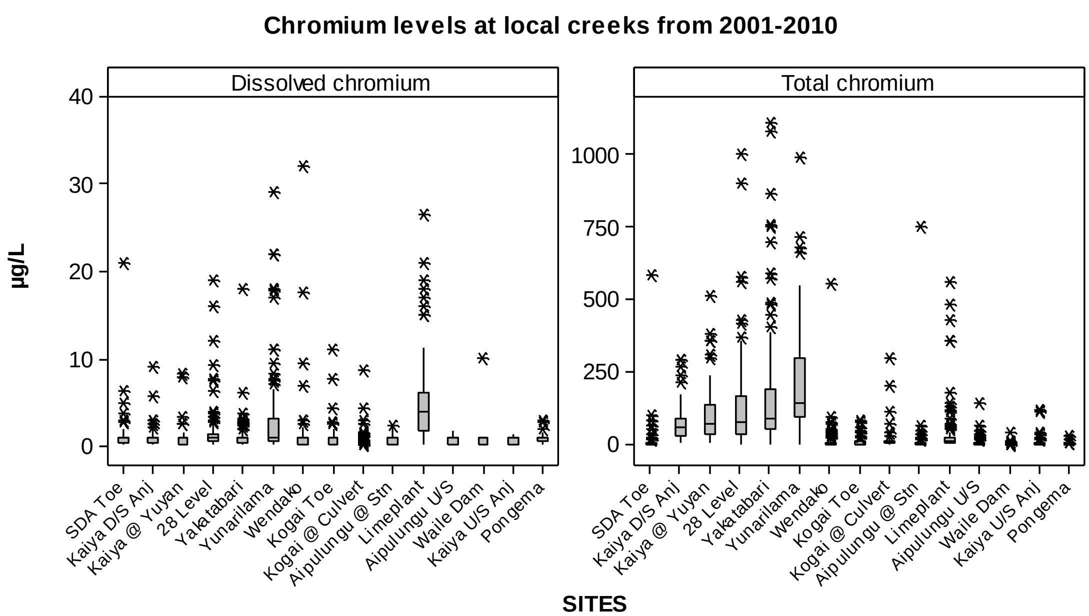
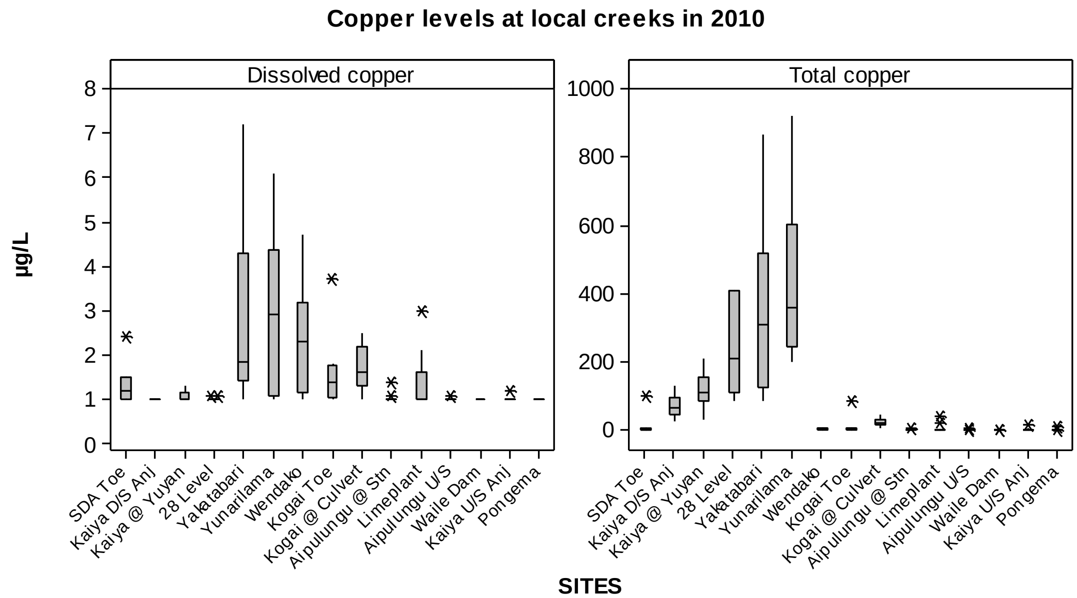


Figure 5-14 (cont.) Results for dissolved and total metals in local creeks



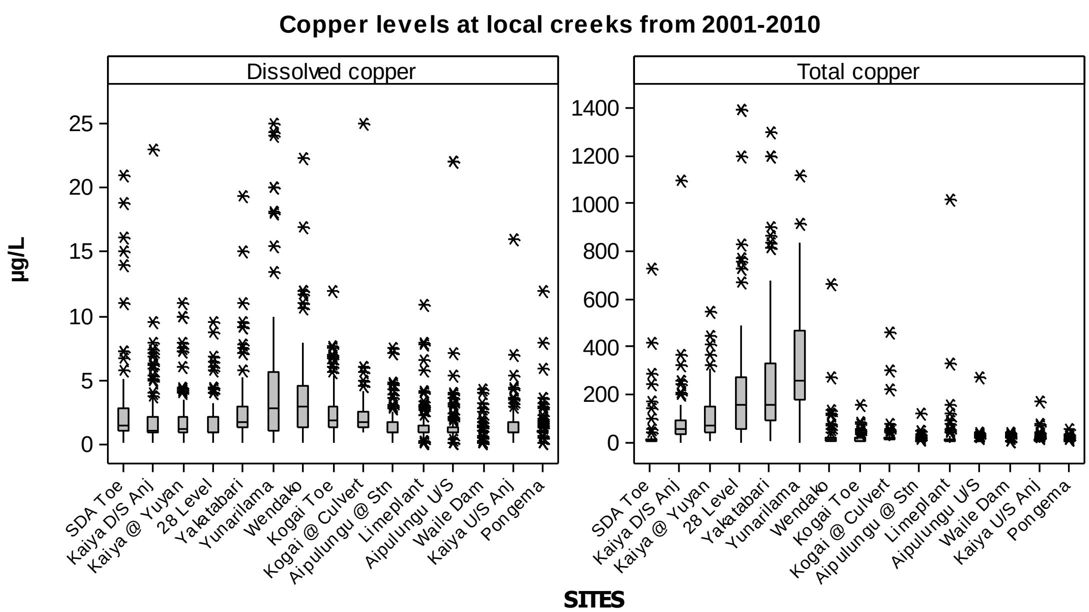
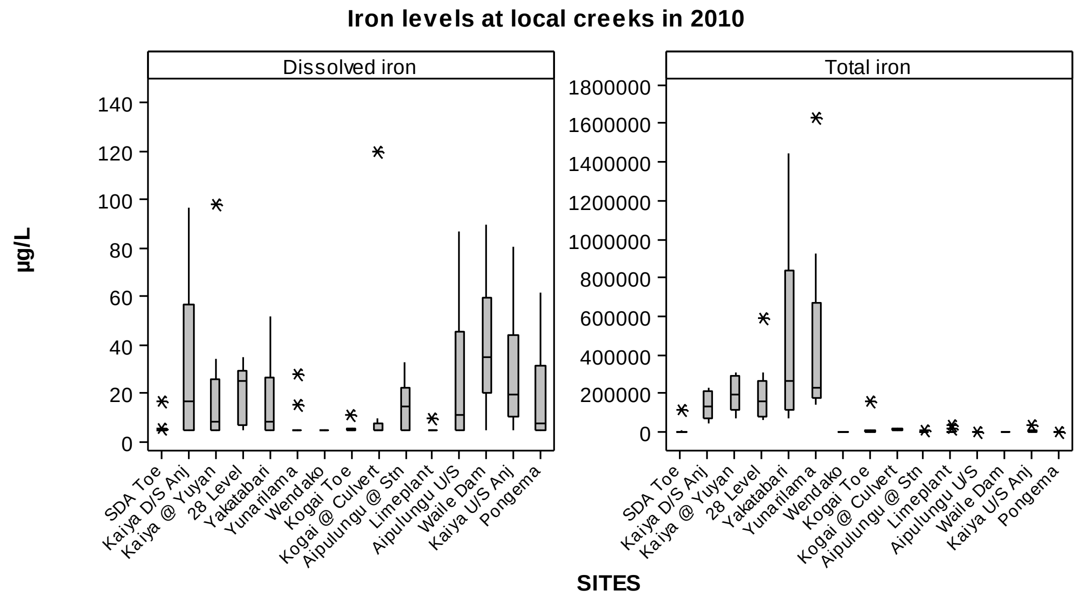


Figure 5-14 (cont.) Results for dissolved and total metals in local creeks



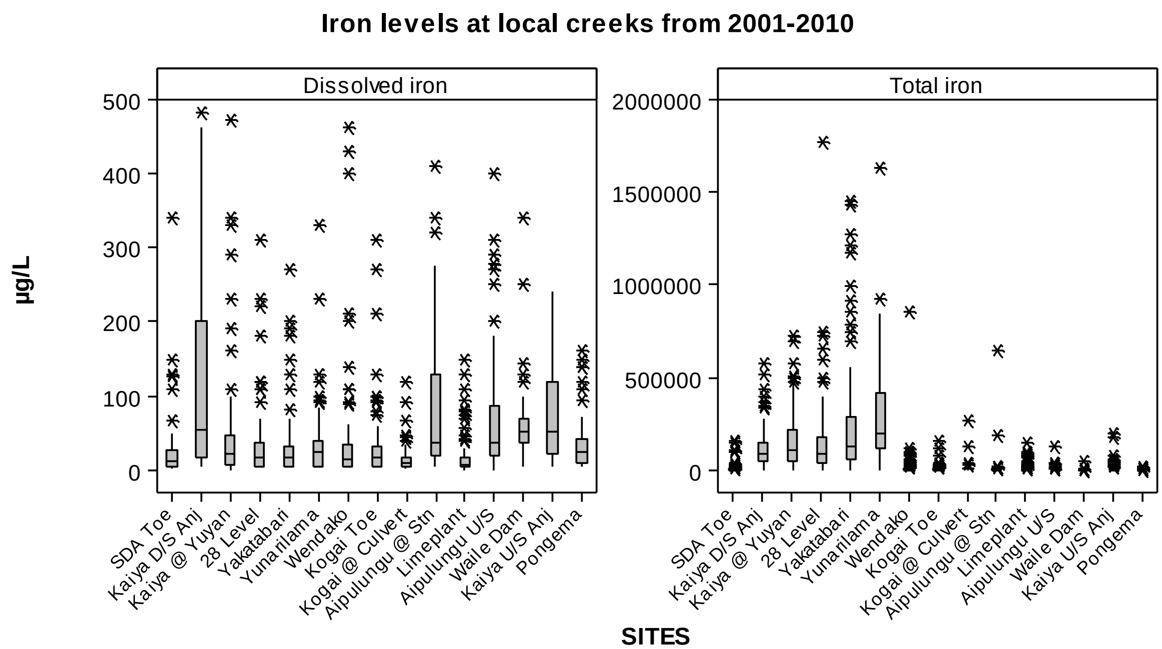
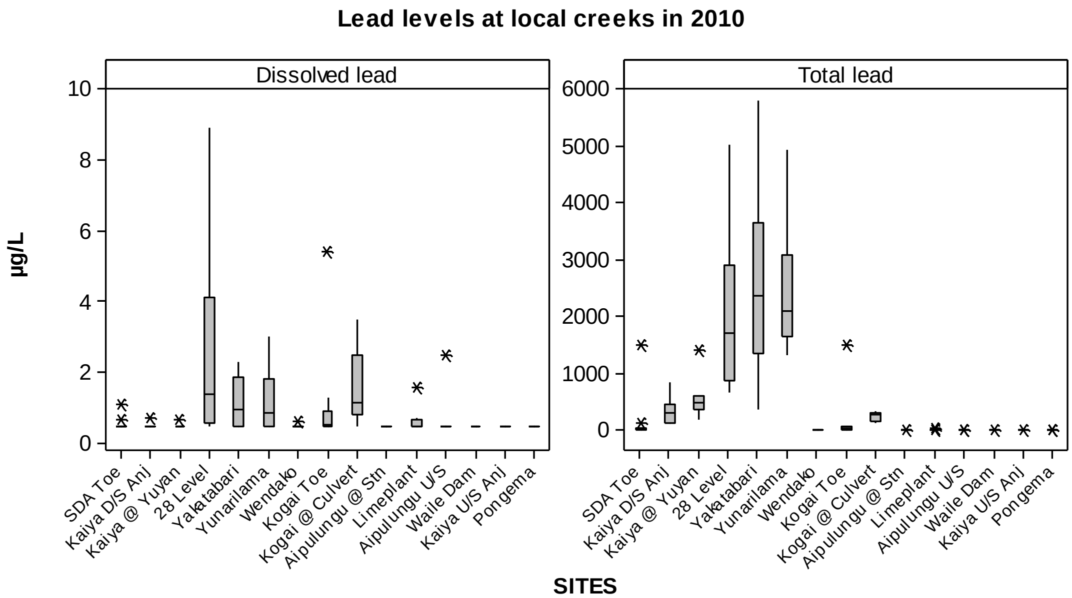


Figure 5-14 (cont.) Results for dissolved and total metals in local creeks



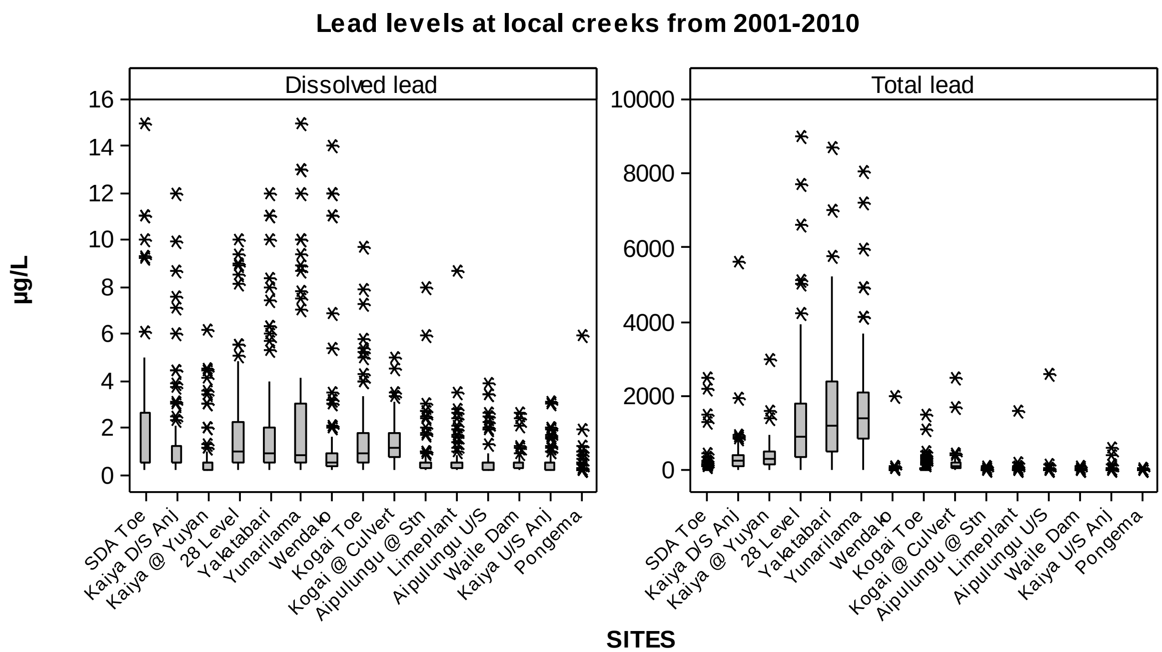
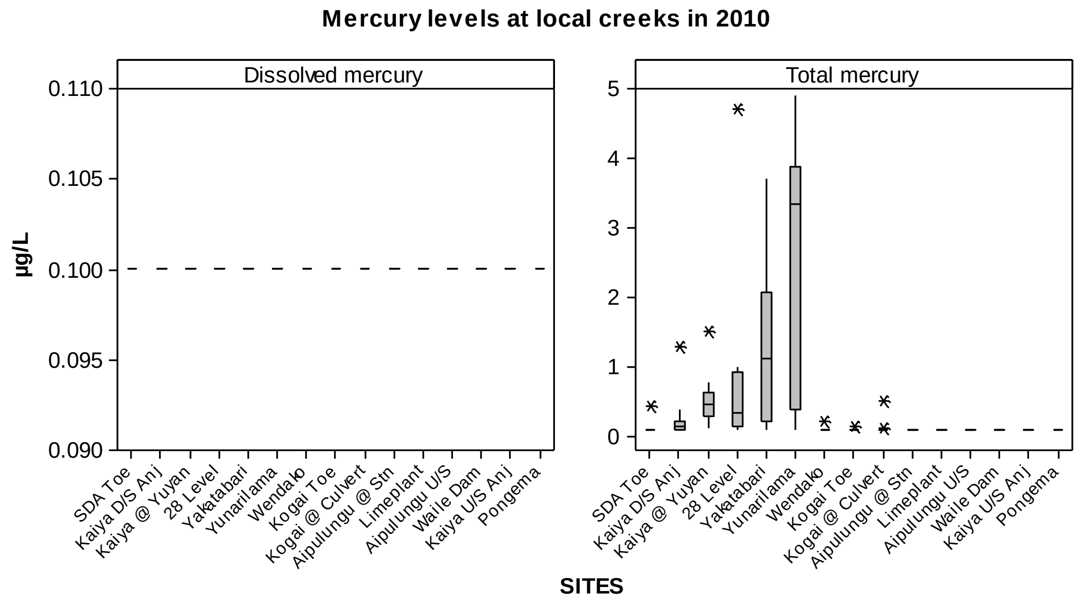


Figure 5-14 (cont.) Results for dissolved and total metals in local creeks



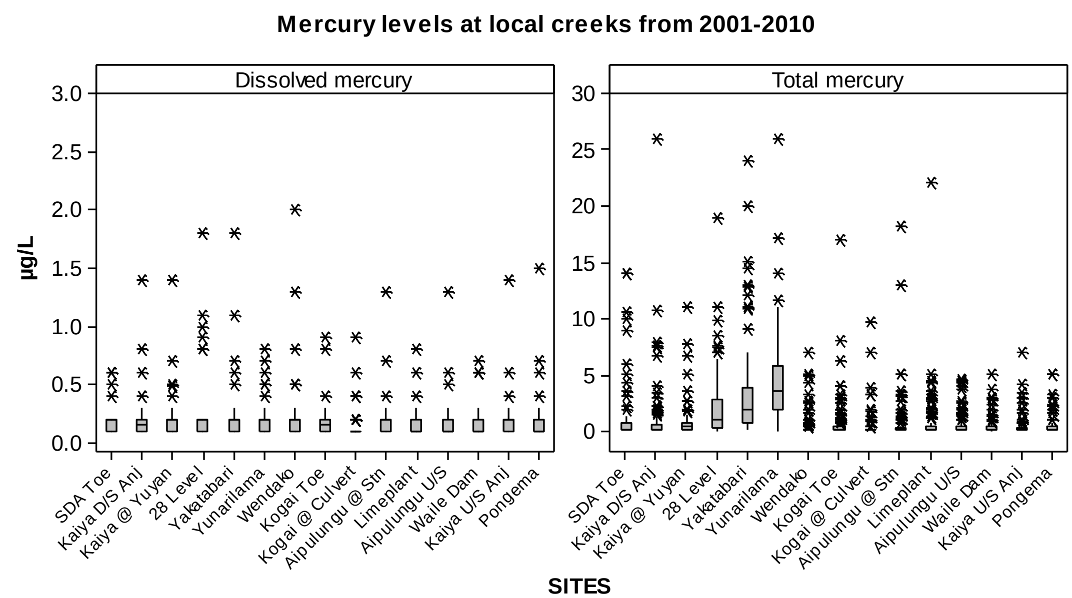
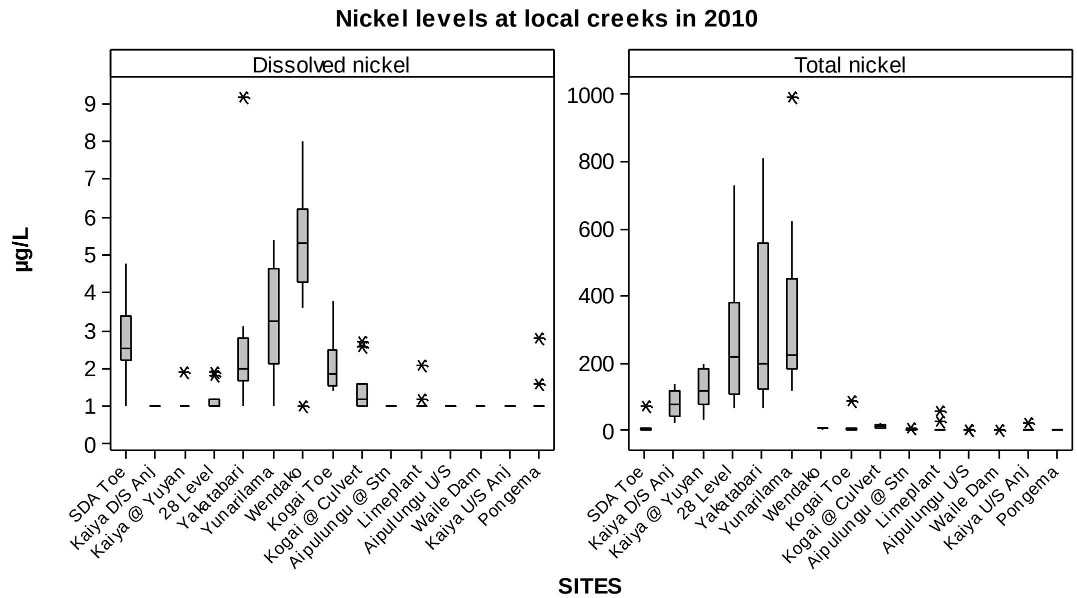


Figure 5-14 (cont.) Results for dissolved and total metals in local creeks



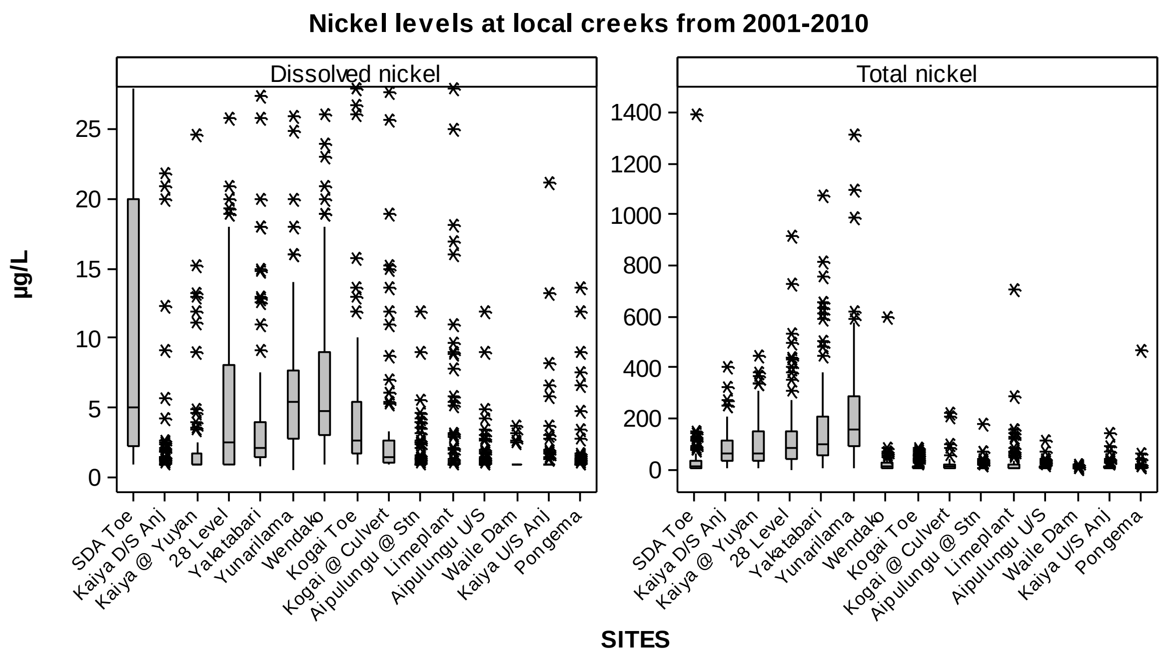
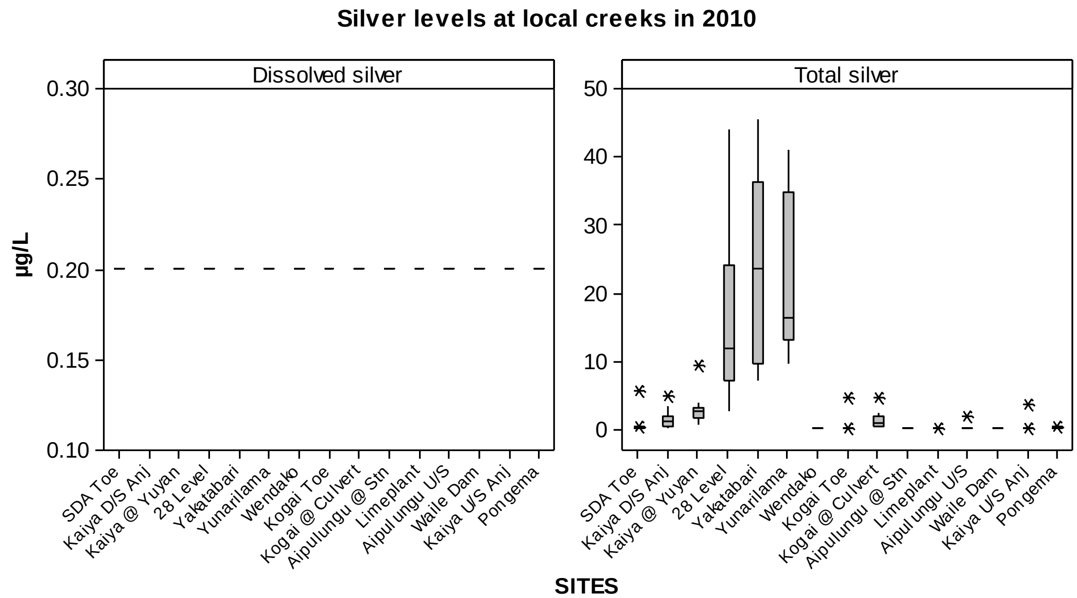


Figure 5-14 (cont.) Results for dissolved and total metals in local creeks



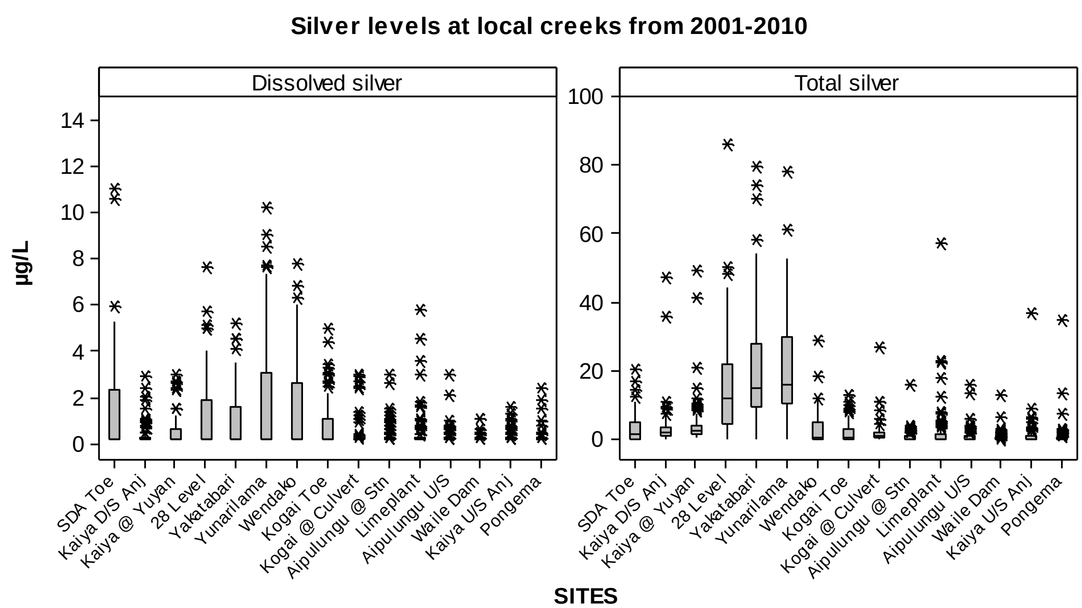
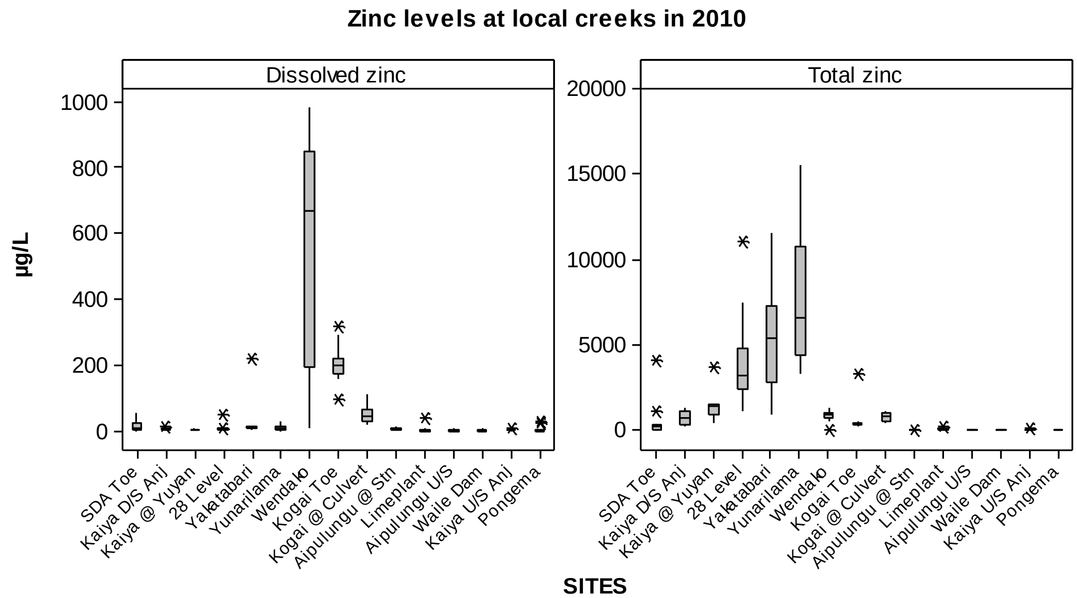


Figure 5-14 (cont.) Results for dissolved and total metals in local creeks



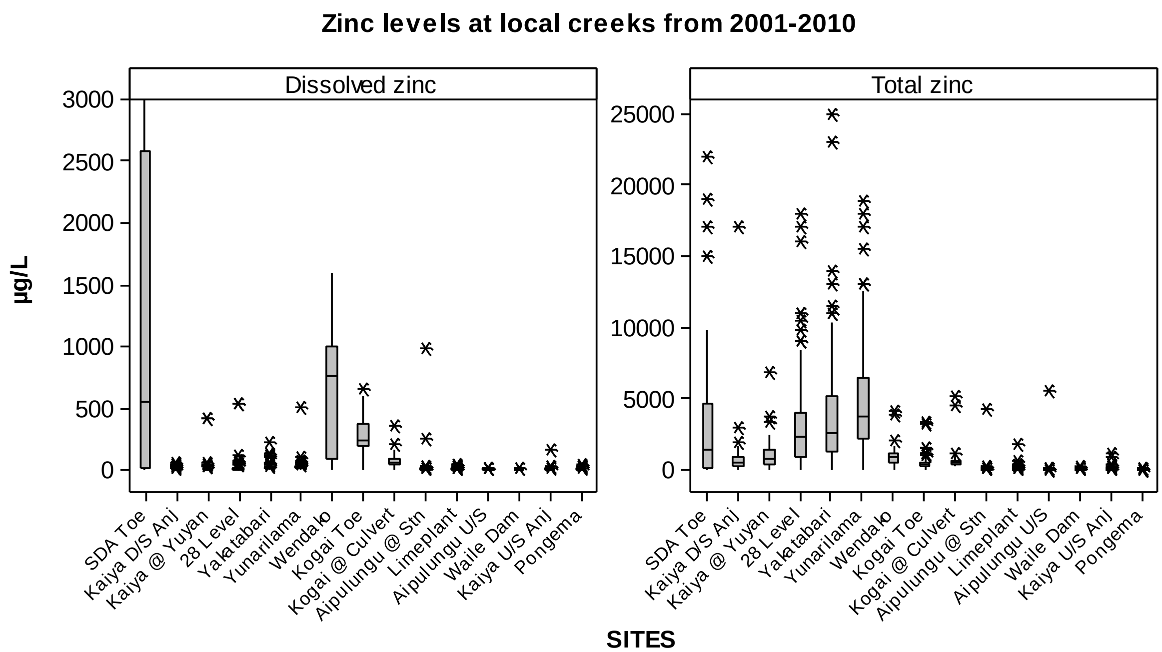


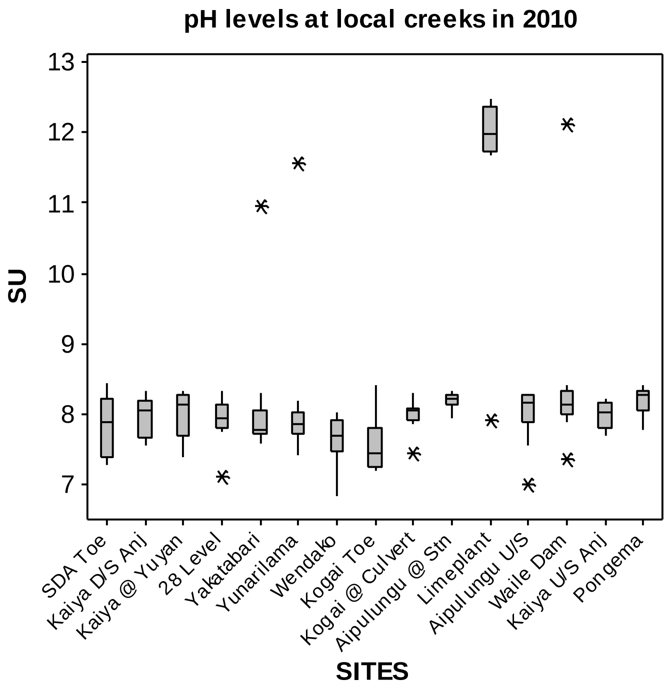
Figure 5-14 (cont.) Results for dissolved and total metals in local creeks

Box plots for dissolved and total metals in local creeks for 2010 are shown in Figure 5-14. In general, concentrations of dissolved and total metals at most local sites for 2010 were similar to those obtained over the 10-year period from 2001-2010.

The higher dissolved and total concentrations for some metals including arsenic, copper, iron, lead and nickel at 28 Level, Yakatabari Creek and Yunarilama portal were due to discharges from the open pit and underground workings. However, other metals including cadmium, chromium, mercury, silver and zinc showed higher concentrations for only total metals at these locations.

The concentrations of dissolved cadmium and zinc sampled in drainage from the main stable dumps for 2010, when compared with the 10-year period from 2001-2010, showed that metal leaching from minor sulphide oxidation within the dumps (dissolved cadmium and zinc are the main indicators of this effect) seems to have decreased. The respective 2010 median values for both dissolved cadmium and zinc in drainage from the Kogai and North Anawe stable dumps appear lower than the long-term values. This is certainly the case for cadmium, while zinc showed a marginal decrease. Since the Kogai stable dump (sampled at Kogai toe) has been capped with soil since 2003 with follow-up revegetation, it seems that sulfide oxidation within this dump is becoming minimal. The Anawe North stable dump (sampled at Wendako Ck), still being used for mining purposes, has yet to be capped and sulfide oxidation is still evident but could be decreasing. The respective dissolved cadmium and zinc median concentrations for Starter Dump ‘A’ (monitored at SDA toe), which was the original trial stable dump, showed low values and indicates that sulfide oxidation within the dump is now far less active.

Dissolved metal concentrations in local creeks decrease rapidly downstream due to river dilution from tributaries and adsorption onto natural sediments. However, total metals (i.e. metal-bearing total suspended solids mainly) decrease by natural sediment dilution from landslides throughout the catchment and from sediment-laden tributaries of the Porgera/Lagaip/Strickland river system.



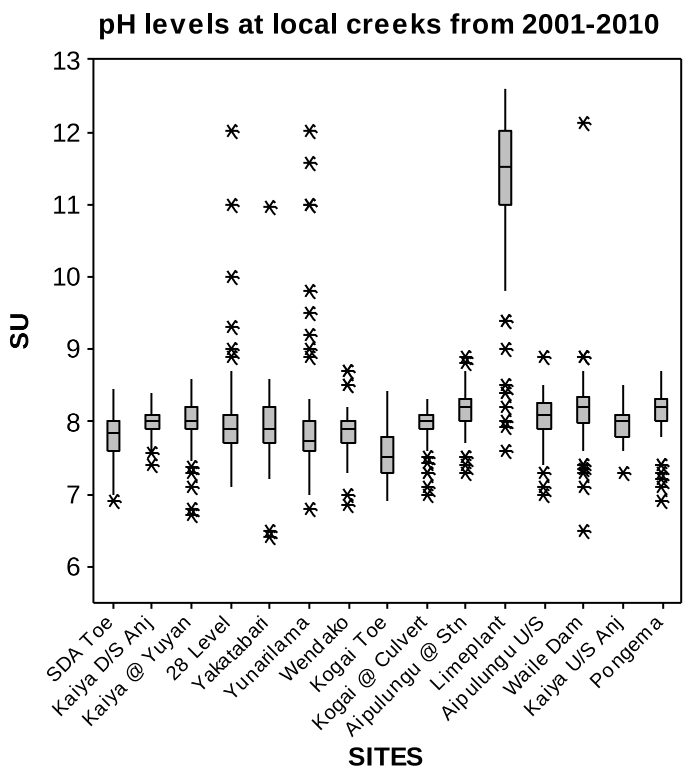
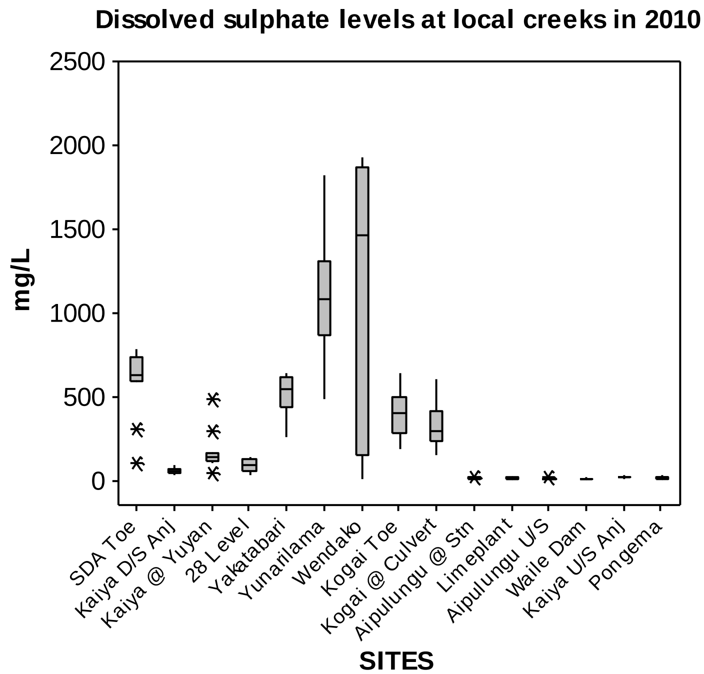


Figure 5-15 Major water quality parameters of local creeks



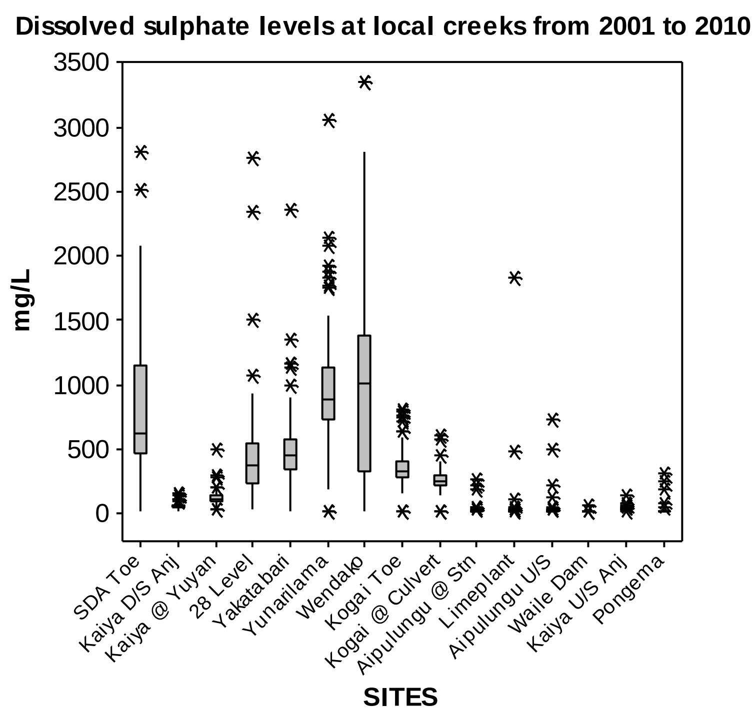
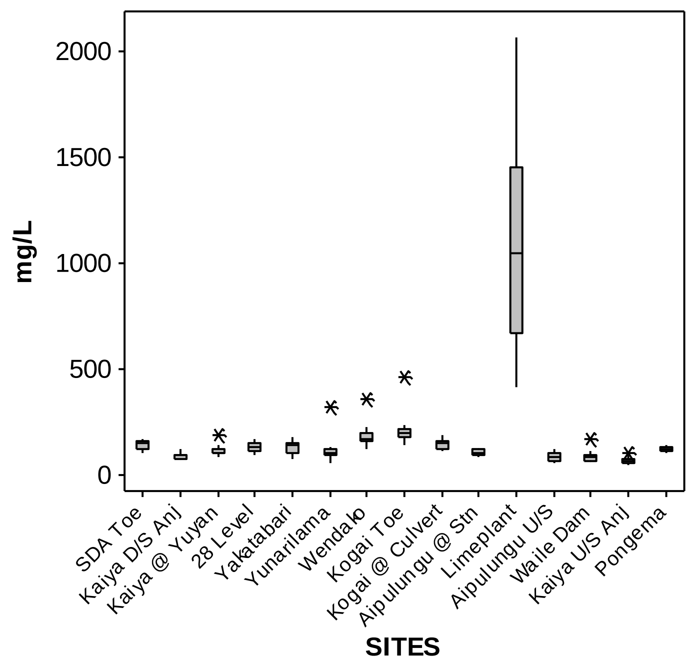


Figure 5-15 (cont.) Major water quality parameters of local creeks

Total alkalinity levels at locals creeks in 2010



Total alkalinity levels at local creeks from 2001 to 2010

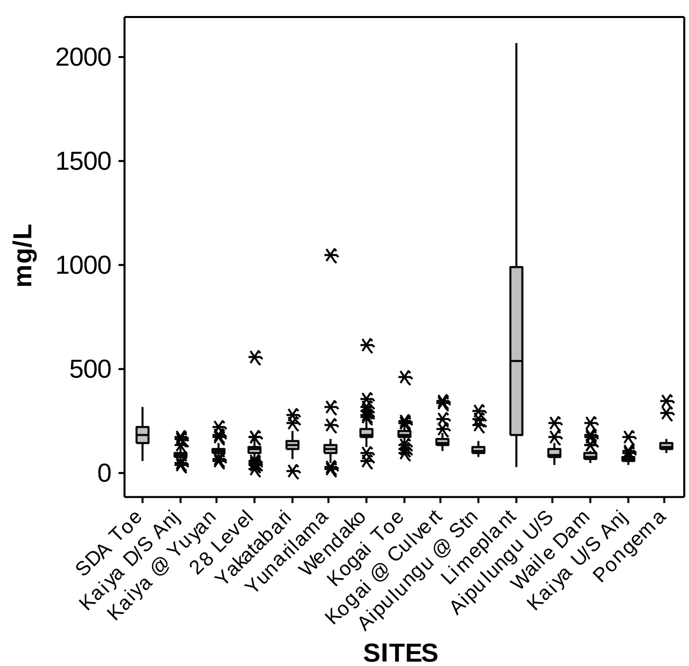
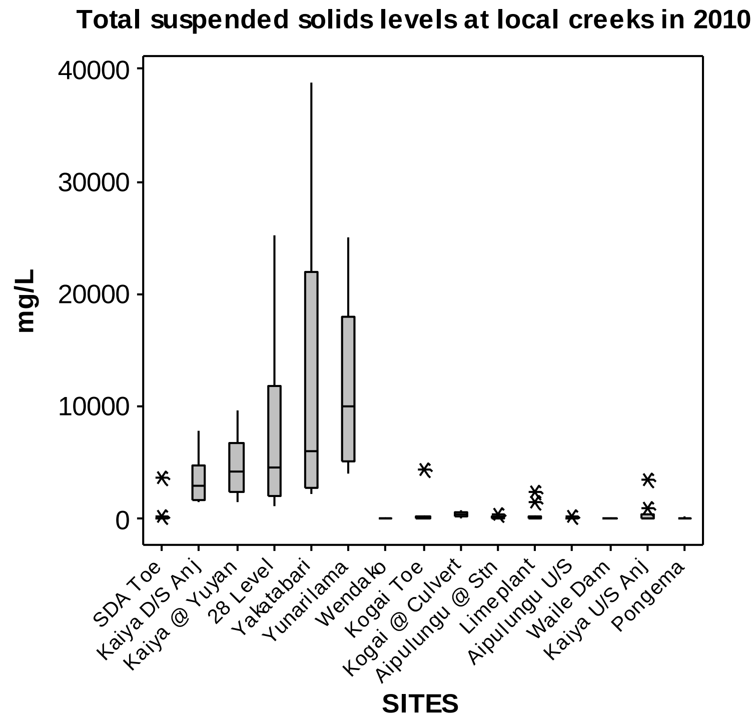


Figure 5-15 (cont.) Major water quality parameters of local creeks



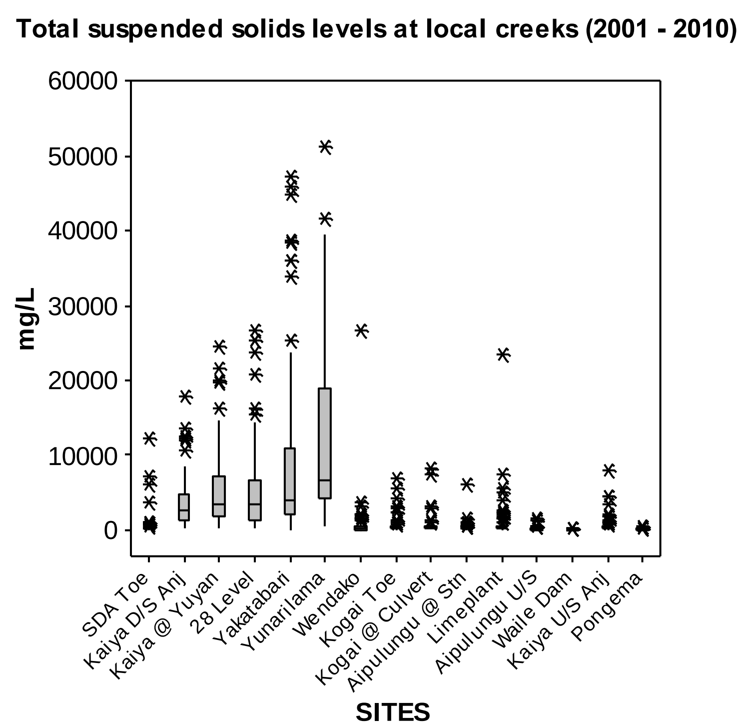


Figure 5-15 (cont.) Major water quality parameters of local creeks

Data from Figure 5-15 show that pH values for 2010 were generally consistent in the local creeks. The exception was the stream flowing from the lime plant, which was moderately alkaline. Alkalinity measurements from the lime plant showed a range of results around pH 12 depending on plant operating conditions.

Sulfate results showed elevated readings for water released from the SDA toe, Yakatabari Creek and Yunarilama portal as a result of minor sulfide oxidation in the open pit and underground areas. Wendako Creek downstream of the Anawe North dump also showed elevated results from minor sulfide oxidation within the dump.

From Table 5-15, mean annual water quality data for local creeks collected from 2001 to 2010 showed the considerable variability in results. It is difficult to determine from these results whether trends are occurring over time.

Table 5-15 Mean annual water quality data for local creeks (2001-2010). All metals concentrations in µg/L

Sites	**SDA Toe**										**Kaiya River d/s Anjolek Dump**									
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
As-D	0.3	0.5	0.4	3.3	17	1.8	1.4	1.2	1.0	1.0	0.9	1.0	1.3	0.9	1.9	1.6	1.5	1	1.2	1.1
As-T	26	2.3	24	9.3	36	616	60	8.7	1.9	12	421	220	54	14	47	30	118	37	40	45
Cd-D	29	26	19	10	8.3	1.6	1.1	0.2	0.9	0.2	0.3	0.3	0.3	0.2	0.1	0.2	0.2	0.2	0.2	0.2
Cd-T	38	33	24	14	14	118	9.2	0.9	1.3	2.3	13	7.7	6.7	1.7	2.2	3	5.7	1.9	2.2	3.0
Cr-D	2.7	1.0	0.5	0.8	3.4	1.0	1.1	1.0	1.0	2.1	0.8	1.9	0.6	0.6	0.4	0.9	1.3	1.0	1.0	1.0
Cr-T	13	13	2.1	3.0	75	454	17	2.3	1.1	6.6	95	286	61	21	57	53	91	74	59	72
Cu-D	3.6	2.1	3.0	1.5	11	3.2	1.9	2.3	1.3	1.3	4.4	2.7	2.5	1.5	2.5	3.6	2	1.1	1.1	1.0
Cu-T	29	72	7.9	43	53	687	39	6.3	2.2	11	172	295	52	28	63	65	121	95	66	70
Fe-D	27	32	21	29	33	100	24	13	5.5	6.1	319	505	389	83	68	174	303	82	63	30
Fe-T ('000)	1.4	2.7	1.0	1.1	11	45	24	2.8	1.0	11	100	168	123	27	83	129	159	119	106	108
Pb-D	4.4	3.1	8.3	3.3	2.8	4.4	1.4	0.7	0.5	0.6	2.1	1.6	2.9	1.2	0.4	0.9	1.9	0.7	0.7	0.5
Pb-T	185	20	17	23	107	7815	417	41	16	149	838	349	259	80	166	286	540	238	254	320
Hg-T	0.4	0.6	2.5	1.9	2.6	3.6	0.3	0.1	0.1	0.1	0.2	1.1	1.3	2.1	4.8	0.4	1.2	0.3	0.2	0.3
Ni-D	29	31	17	14	38	3.6	4.6	3.3	2.5	2.7	3.3	3.0	1.2	1.0	7.1	1	1.2	1	1.0	1.0
Ni-T	53	40	23	28	55	357	25	5.8	3.5	10	103	107	58	25	48	84	121	84	67	79
Ag-D	1.5	2.2	2.6	1.0	5.2	0.2	0.2	0.2	0.2	0.2	0.6	0.7	0.7	0.3	0.5	0.2	0.2	0.2	0.2	0.2
Ag-T	2.9	4.6	4.5	2.4	10	34	2.6	0.7	0.2	0.7	19	7.7	2.9	2.0	3.5	1.3	2.8	0.9	1.0	1.6
Zn-D	6500	5390	2440	1990	2710	138	212	12	137	17	7.1	10	18	13	6.8	5.1	8.2	4.7	5.3	5.0
Zn-T	7540	6710	3440	2230	3070	19280	1510	164	402	533	2317	843	586	173	432	692	935	520	502	691
pH	7.0	7.8	7.9	7.8	7.7	7.8	7.8	7.8	8.2	7.8	8.0	8.0	7.9	7.9	8.0	8.0	8.0	7.9	8.1	8.0
TSS*	767	96	99	134	558	3210	688	189	33	382	3411	5717	4462	1056	2260	3370	4670	3870	2460	3443
SO4-D*	1465	1327	818	796	1240	511	500	373	460	593	54	54	57	44	45	56	40	45	38	56
ALK-T*	198	177	219	213	204	171	199	210	157	143	86	88	93	93	85	88	96	101	78	90

Note: D= dissolved metals; T= total metals; *units in mg/L

Table 5-15 (cont'd) Mean annual water quality data, local creeks (2001-2010) (µg/L)

Sites	**Kaiya River at Yuyan Bridge**										**28 Level Underground Mine Adit Discharge**									
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
As-D	1.0	1.1	1.6	1.4	3.9	2	1.8	1.6	1.9	3.0	4.2	5.4	4.4	9.2	19	10	7.3	5.7	8.9	7.5
As-T	234	84	99	34	67	112	71	71	68	92	403	682	231	302	395	229	207	167	480	246
Cd-D	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.0	0.9	1.1	0.6	0.3	0.2	0.2	0.2	0.2	0.2
Cd-T	8.1	6.2	10	2.9	2.8	6.5	4.3	3.3	3.4	3.1	30	33	13	15	15	10	11	5.9	17	17
Cr-D	0.4	0.6	0.5	0.4	0.5	1	1.4	1	1.0	2.2	2.8	0.9	1.2	3.8	1.2	1	2.2	1	2.5	1.0
Cr-T	69	152	103	35	53	187	100	166	85	120	119	150	94	126	102	42	48	27	234	270
Cu-D	8.7	2.5	3.0	2.3	2.7	2.2	1.3	1.1	1.2	1.1	3.5	1.4	2.1	1.3	3.7	1.3	1.1	1.4	1.0	1.0
Cu-T	99	154	97	38	49	198	107	151	89	119	253	390	161	225	174	150	150	70	268	312
Fe-D	110	203	35	65	21	77	51	12	15	20	73	55	59	18	13	117	9	6.4	15	18
Fe-T ('000)	98	230	205	44	77	217	145	225	134	191	127	205	124	127	123	90	67	42	342	200
Pb-D	0.9	0.9	1.4	1.4	0.7	0.6	0.7	0.5	0.5	0.5	1.7	1.3	9.8	8.0	2.6	4	0.8	1.1	1.2	5.3
Pb-T	524	415	397	134	194	607	406	417	338	527	1820	2300	830	1230	1164	1003	689	403	2050	1980
Hg-T	0.2	0.8	2.3	1.0	1.8	0.8	0.5	0.7	0.3	0.5	2.5	3.0	2.0	4.8	3.5	1.1	1.1	0.8	1.2	0.8
Ni-D	2.5	1.6	1.6	2.1	14	1.4	1.1	1	1.0	1.1	9.6	5.8	19	6.9	28	1.9	2.9	2.1	1.1	1.2
Ni-T	66	155	91	31	62	199	124	155	88	122	122	155	90	104	96	45	64	35	234	264
Ag-D	0.6	1.2	0.8	0.4	0.7	0.2	0.2	0.2	0.2	0.2	2.1	2.4	2.5	1.1	2	0.2	0.2	0.2	0.2	0.2
Ag-T	6.9	6.1	4.9	3.5	5.1	8.3	2.5	2.2	1.9	3.0	223	22	12	16	21	7.1	6.4	4.2	33	22
Zn-D	10	90	12	15	12	5	7.7	3.9	4.2	4.9	77	55	29	20	16	9.8	11	16	6.7	11
Zn-T	1300	1190	1050	358	470	1522	915	1072	816	1410	5330	5170	2560	2570	2568	2177	1990	1269	4020	4090
pH	8.0	8.0	8.0	7.9	8.1	7.8	8	7.9	8.2	8.0	8.2	7.8	7.9	8.3	7.9	8.1	7.7	7.6	8.4	7.9
TSS*	3380	8510	6950	1640	1940	9180	4920	7350	3470	4810	5110	6990	4830	4750	4610	3020	1910	1210	7300	8270
SO4-D*	116	106	130	89	122	110	97	105	109	171	877	812	480	388	394	318	330	280	224	90
ALK-T*	109	103	103	107	103	107	111	106	99	112	151	142	113	162	107	105	113	121	80	130

Note: D= dissolved metals; T= total metals; *units in mg/L

Table 5-15 (cont'd) Mean annual water quality data, local creeks (2001-2010) (µg/L)

Sites	**Yakatabari Creek**										**Yunarilama Portal**								
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
As-D	2.6	5.7	6.6	10	21	19	7.5	8.9	10	14	3.4	3.9	8.7	22	4.6	8.2	8.1	12	7.2
As-T	208	199	206	224	320	319	840	773	526	505	116	500	1180	940	268	433	712	1026	630
Cd-D	1.1	0.6	1.2	0.5	0.6	0.5	0.2	0.2	0.2	0.4	1.8	3.3	2.6	4.0	0.2	0.2	0.3	0.2	0.2
Cd-T	39	14	14	12	16	22	46	26	19	36	10	26	49	46	12	19	20	36	37
Cr-D	0.9	0.7	0.3	0.8	1.8	1.0	1.4	1.0	1.0	2.5	0.9	0.5	1.5	5.1	1.3	6.3	5.7	9.8	4.5
Cr-T	141	86	97	120	170	133	230	212	177	368	59	234	542	406	102	127	135	281	388
Cu-D	2.5	1.8	2.5	2.9	6.8	2.6	1.8	2.0	2.0	2.7	5.7	2.8	12	17	3.8	3.5	3.3	3.4	3.3
Cu-T	341	143	146	164	191	291	510	377	259	393	96	377	713	488	224	256	298	538	433
Fe-D	63	67	39	24	22	48	64	6.5	8.8	17	52	51	28	30	80	22	21	5.0	7.8
Fe-T ('000)	135	88	139	104	328	174	317	377	415	461	70	374	663	746	155	160	158	0.9	448
Pb-D	2.3	1.4	4.9	3.8	0.9	6.7	1.4	0.8	1.0	2.6	1.5	11	7.4	0.7	2.3	0.9	5.9	1.7	1.2
Pb-T	2794	981	1025	980	977	2240	3350	2890	1820	3214	439	1620	3050	2010	942	1240	1863	2510	2820
Hg-T	3.4	4.1	3.3	3.9	5.8	4.1	3.3	3.0	2.2	1.3	1.9	6.6	16	10	4.2	2.9	5.1	3.9	3.2
Ni-D	4.4	3.0	3.3	5.3	21	2.7	2.0	2.0	2.0	2.7	7.2	7.8	11	43	4.2	3.6	4.2	2.6	3.4
Ni-T	136	74	91	107	162	145	275	239	200	317	94	209	429	298	123	121	177	294	340
Ag-D	1.4	1.7	2.1	2.2	2.3	0.6	0.2	0.2	0.2	0.2	2.7	4.3	2.1	4.7	0.5	0.2	0.2	0.2	0.3
Ag-T	30	16	16	15	17	13	43	24	28	27	11	22	39	44	8.5	12	15	29	21
Zn-D	31	17	40	15	12	10	8.7	19	7.1	27	81	24	17	19	11	15	20	6.6	13
Zn-T	6230	2100	2140	1900	2240	4853	7820	6895	4300	7660	1310	4030	7580	4960	2800	3460	6188	7710	7700
pH	7.9	8.1	7.9	8.0	8.1	7.8	7.7	7.8	7.9	8.1	7.9	7.6	7.7	7.7	7.5	8.1	8.4	8.9	8.2
TSS*	7490	3060	4840	2930	7730	9010	6040	19940	10700	12370	3630	22880	20430	27100	5750	10240	11230	14590	11460
SO4-D*	536	710	432	330	432	271	600	527	505	514	793	918	1180	1030	793	676	1064	880	1200
ALK-T*	137	147	141	139	122	130	151	132	139	132	153	151	134	126	129	113	91	173	121

Note: D= dissolved metals; T= total metals; *units in mg/L

Table 5-15 (cont'd) Mean annual water quality data, local creeks (2001-2010) (µg/L)

Sites	**Wendako Creek**										**Kogai Toe**									
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
As-D	0.6	0.7	1.8	6.1	11	1.3	1.6	1.7	1.7	1.4	0.7	1.0	1.9	1.9	7.2	1.1	1.2	1.1	1.3	1.1
As-T	3.9	7.3	5.9	12	29	60	5.8	4.0	3.3	2.1	5.4	32	18	11	21	11	13	7	9.3	18
Cd-D	1.5	2.9	9.3	8.3	7.6	3.8	4.4	2.0	2.9	1.4	1.9	2.5	2.8	1.7	1.5	1.1	1.4	1.2	0.9	1.1
Cd-T	3.4	3.9	16	14	8.7	5.2	4.8	5.0	3.8	2.4	4.3	6.3	6.1	3.4	2.9	1.6	2.6	1.8	1.7	2.7
Cr-D	2.4	0.6	0.3	1.3	3.3	1.2	1.1	1.1	1.0	1.0	1.9	0.3	0.4	0.6	0.9	0.8	1.3	1.1	1.0	1.6
Cr-T	28	29	2.5	2.9	6.4	81	1.7	1.3	1.3	1.0	16	15	15	10	3.0	2.8	6.5	2.6	4.6	8.8
Cu-D	2.6	2.2	4.4	3.8	12	1.6	2.7	5.5	3.4	2.4	3.7	2.6	3.5	3.2	4.5	1.3	2.1	1.9	1.4	1.6
Cu-T	33	53	14	14	35	98	5.6	7.1	5.1	3.4	17	29	20	14	13	8.4	10	5.9	6.1	11
Fe-D	175	31	27	39	33	35	21	8.2	5.0	5.0	40	92	297	21	26	62	15	8.0	8.0	28
Fe-T ('000)	38	42	0.9	0.4	0.4	122	1.4	1.2	0.9	0.6	5.3	18	11	4.7	5.9	2.8	6.6	3.2	18	15
Pb-D	1.4	0.8	8.0	7.7	1.5	0.6	0.5	0.6	0.5	0.5	2.2	1.8	7.5	3.9	0.8	1	0.9	0.6	0.9	1.1
Pb-T	19	23	19	13	3.8	285	9.2	15	6.3	3.8	76	166	94	40	38	24	67	36	46	145
Hg-T	0.6	0.2	1.0	1.2	1.5	0.2	0.1	0.1	0.1	0.1	0.9	1.8	0.9	1.2	1.3	0.5	0.1	0.1	0.1	0.1
Ni-D	4.5	6.0	14	11	27	2.0	3.2	4.8	4.8	5.1	4.6	5.3	5.3	5.1	17	2.3	2.3	1.8	1.7	2.1
Ni-T	25	31	20	18	41	88	4.7	7.7	5.9	6.1	17	18	21	11	34	6.8	8.3	4.0	5.7	11
Ag-D	0.8	2.7	3.2	2.2	4.1	0.6	0.2	0.2	0.2	0.2	0.6	1.9	1.7	0.8	1.2	0.7	0.2	0.2	0.2	0.2
Ag-T	1.8	5.8	5.0	6.3	9.1	2.4	0.2	0.2	0.2	0.2	4.0	4.9	3.7	1.8	3.0	0.7	0.5	0.4	0.3	0.6
Zn-D	196	319	1080	1070	1170	558	613	547	791	560	344	405	393	298	345	190	210	191	172	203
Zn-T	300	570	1210	1360	1290	1207	756	964	915	816	632	883	634	530	485	297	417	311	318	545
pH	8.0	7.7	7.9	7.9	7.9	7.7	7.9	7.8	7.8	7.6	7.9	7.7	7.5	7.4	7.4	7.6	7.6	7.6	7.5	7.6
TSS*	1110	1110	266	25	10	92	56	64	27	37	210	914	631	217	166	115	795	172	384	448
SO4-D*	79	950	856	1090	1320	1001	680	1743	1560	1130	397	399	417	329	326	290	324	290	275	401
ALK-T*	185	198	180	205	214	258	170	184	184	191	211	197	207	205	180	177	190	184	170	212

Note: D= dissolved metals; T= total metals; *units in mg/L

Table 5-15 (cont'd) Mean annual water quality data for local creeks (2001-2010). All metals concentrations in µg/L

Locations	Kogai Creek at Culvert							Kaiya River u/s of Anjolek Dump									
Year	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
As-D	2.8	6.5	16.5	1.8	1.9	2.7	3.4	0.6	0.2	0.4	0.4	0.2	1.1	1.0	1.0	1.0	1.0
As-T	121	31	30	27	26	60	45	32	1.4	2.3	2.7	2.9	14	3.7	2.3	4.0	1.1
Cd-D	0.7	0.6	0.7	0.8	0.7	0.4	0.5	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2
Cd-T	7.6	3.3	3.8	3.2	2.4	3.8	3.9	1.1	1.8	0.4	0.6	1.2	1.6	0.3	0.2	0.2	0.2
Cr-D	0.5	1.1	1.8	1.3	1	1.0	1.0	0.4	0.5	0.3	0.4	0.3	0.9	1.0	1.0	1.0	1.0
Cr-T	52	12	37	9.5	5.5	16	10	17	5.2	6.2	4.5	8.6	18	4.6	6.9	15	2.8
Cu-D	2.3	4.2	4.4	2.1	1.9	1.3	1.7	2.1	2.9	2.0	1.1	1.5	1.8	1.4	1.0	1.0	1.0
Cu-T	71	14	58	17	14	30	23	13	14	10	7.9	7.9	28	4.1	5.8	9.5	3.0
Fe-D	24	19	203	12	6.8	8.3	15	105	216	100	59	89	221	79	69	58	28
Fe-T ('000)	54	8.2	5.3	8.6	6.9	1.7	13	13	7.4	5.8	2.7	5.9	31	7.5	12	22	4.5
Pb-D	2.4	0.9	11	1.8	0.9	1.0	1.6	0.8	0.6	0.6	0.4	0.6	0.8	0.6	0.5	0.5	0.5
Pb-T	526	72	77	131	105	256	235	44	4.8	7.4	3.2	6.0	90	16	6.0	9.1	2.3
Hg-T	1.6	1.5	0.7	0.1	0.1	0.4	0.1	0.4	0.3	1.5	0.8	1.0	0.5	0.2	0.1	0.1	0.1
Ni-D	3.5	15	3.2	1.8	1.6	1.3	1.5	1.3	1.7	1.1	1.1	6.3	1.0	1.0	1.0	1.0	1.0
Ni-T	57	46	11	11	69	14	13	12	12	7.4	5.1	17	22	5.4	6.7	12	3.2
Ag-D	0.9	1	0.5	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.2	0.2	0.2	0.2	0.2
Ag-T	6.4	3.3	0.7	1.1	0.8	1.6	1.4	1.0	2.0	4.5	0.8	1.6	1.5	0.3	0.2	0.2	0.5
Zn-D	55	105	93	78	80	52	51	6.5	7.7	25	7.2	7.3	6.1	4.6	2.0	1.9	3.0
Zn-T	1310	422	420	486	456	780	758	137	30	50	34	28	180	40	30	43	11
pH	7.9	8.0	7.9	7.9	7.8	8.1	8.0	8.0	8.0	7.9	7.8	8.0	7.9	8.1	8.0	8.1	8.0
TSS*	1804	280	1090	249	477	537	383	360	600	302	148	172	1435	399	347	599	437
SO4-D*	247	233	254	257	234	206	330	21	22	22	16	16	26	38	21	21	20
ALK-T*	151	152	151	174	159	135	147	72	63	63	67	60	70	77	64	62	68

Note: D= dissolved metals; T= total metals , * units in mg/L

6.0 LAKE MURRAY

6.1 Introduction

PJV has maintained an extensive monitoring program on Lake Murray since the start of operations to verify that the practice of riverine disposal of tailings and waste rock is not having a detrimental effect on the Lake Murray ecosystem or the health of approximately 3,000 people who live near the lake. The Lake Murray people rely on the lake as an important source of fish. These people have naturally high levels of mercury bio-accumulated in their bodies through the food chain and there was concern prior to mining at Porgera that mine-derived sediment could enter Lake Murray and exacerbate this problem.

Lake Murray is an off-river water body in the Lower Strickland River region. The lake normally drains via the Herbert River into the Strickland River. However, flow reversals occur in the Herbert River approximately 15% of the time (NSR, Lake Murray Mercury and Arsenic Loads, 1995) when the Strickland River rises after heavy rainfall in the mountains, and the water level of the Lower Strickland is higher than that of the lake. This situation allows sediment from the Strickland River, including some mine-derived material, to enter the southern region of the lake where deposition of the sediment can occur. The presence of mine-derived, metal-bearing sediment in Lake Murray necessitates PJV to regularly monitor the lake for the duration of the Porgera mine life.

In 2000, a significant natural breach of the western bank of the Strickland River occurred adjacent to the Mamboi River, which flows into Lake Murray. Sediment from the Strickland River, including some mine-derived sediment, has entered the southern end of Lake Murray via the Mamboi River since that time.

The metals of concern are arsenic and mercury, and much of PJV's monitoring activities at Lake Murray are centred around the origin, movement and fate of these trace metals, while other trace metals and water quality parameters are also examined. Measurements of trace metals within the lake were conducted on bed sediments, water and biota. The analyses of sediment and biota are the most important because they provide time-integrated concentrations that are generally much higher than in water. Results of these analyses are grouped into three categories according to location, i.e. into the southern, central and northern regions of the lake. Bed sediment and water samples were collected at a number of locations throughout the lake (Figure 6-1).

Metal concentrations in bed sediments and water are presented as box plots in Figures 6-2 to 6-7 for monitoring conducted during 2010. A brief description of how to interpret box plots is presented in Appendix 1 of this report. Other parameters including pH, sulfate and chlorides are presented in Figure 6-8. Results from 2001 to 2010 for bed sediments and water quality for the southern, central and northern regions of the lake are presented in Tables 6-1 and 6-2, respectively. The results of biota samples collected at Lake Murray during 2010 are presented separately in Section 7.0.

6.2 Methods

Bed sediments were collected using a grab sampler made of stainless steel. The main objective in sampling was to collect as much of the sediment layer (top 2 cm) as possible without losing the fines. No sieving was conducted on the samples.

Duplicate sediment samples were collected in the field and packed into sealable plastic bags immediately and stored in freezer boxes containing 'dry ice'. The samples were then returned to the PJV Environment Laboratory at Porgera where they were temporarily stored in a refrigerator before sending to the NMI laboratory in Sydney for analysis. The samples were analysed for trace metal concentrations in the <63 μm size fraction and for total metals. The trace metals analysed included arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver and zinc. A duplicate sample was included with every seven samples sent to NMI, and the QA/QC on these batches was conducted by NMI.

Lake Murray water samples were collected at the same locations as bed sediments. Samples for dissolved metal analysis were filtered in the PJV on-site laboratory using acid-washed polycarbonate filtration apparatus containing cellulous nitrate polycarbonate membrane filter (0.45 μm), and preserved with ultra-pure grade nitric acid. Samples for total metals were neither filtered nor preserved with acid. All samples were sent to NMI for analysis. The trace metals analysed included those mentioned in the previous paragraph with the exception of selenium.

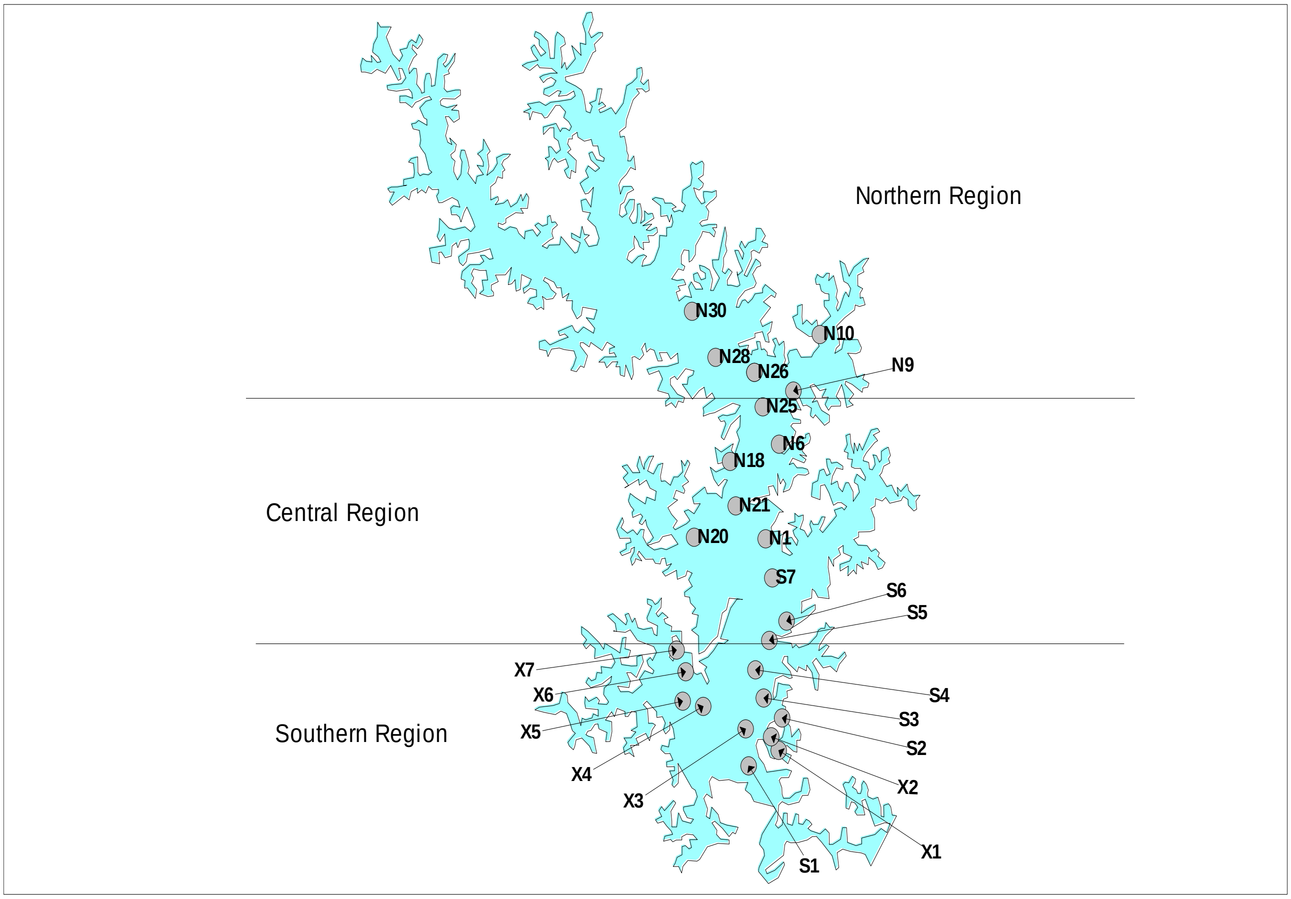


Figure 6-1 Sediment and water quality sampling locations within Lake Murray

6.3 Results

6.3.1 Bed Sediments

Arsenic

Bed sediment results for arsenic concentrations in the finer <63 μm size fraction for 2010 are presented as a box plot diagram in Figure 6-2. The <63 μm fraction was chosen because most metal-bearing sediments in Lake Murray are in the finer fraction. The results showed higher concentrations of arsenic-bearing sediments in the southern and central regions of the lake with a downward progression of concentrations heading north.

This trend has resulted from arsenic-bearing fine particulates entering Lake Murray from the Strickland River during reverse flows of the Herbert River.

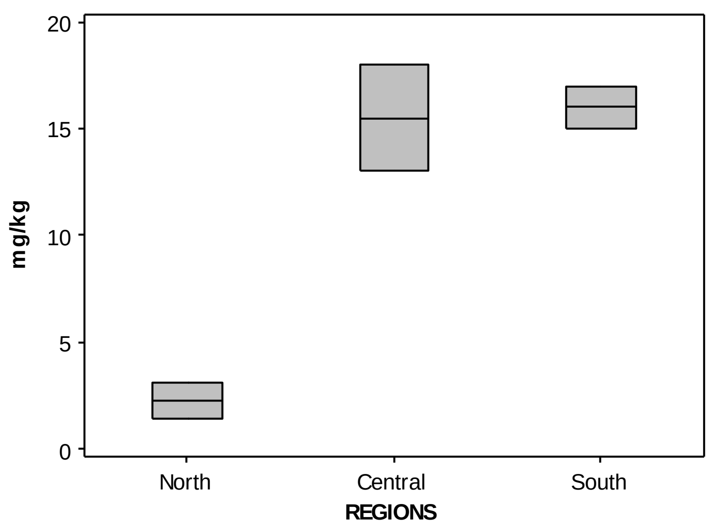


Figure 6-2 Between site differences in arsenic concentrations of <63 µm sediment fractions in Lake Murray for 2010

Mercury

Bed sediment results for mercury concentrations for the finer <63 µm size fraction are presented in Figure 6-3. In contrast to arsenic, mercury concentrations in all regions were very low and either at or below the detection limit.

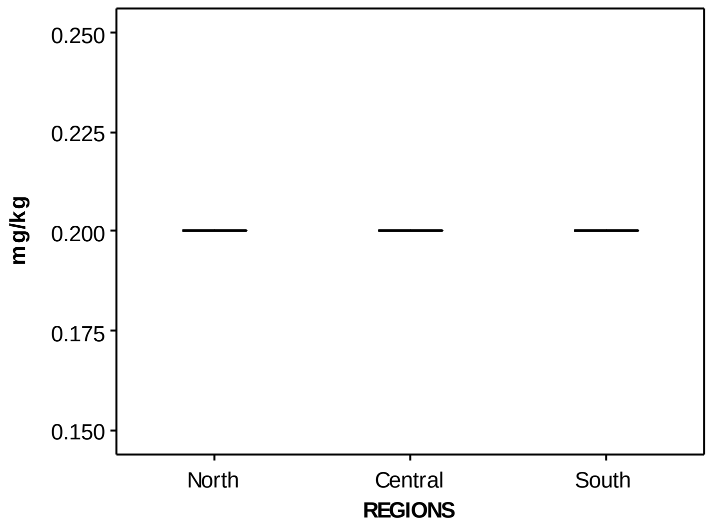


Figure 6-3 Between site differences in mercury concentrations of <63 µm sediment fractions at Lake Murray for 2010

Other Metals

Apart from arsenic and mercury, other trace metal concentrations in the <63 µm fraction of bed sediments for 2010 are shown in Figure 6-4. The results varied considerably although copper, lead, nickel, silver and zinc showed higher concentrations in the southern end of the lake similar to arsenic. Chromium and iron showed higher values in the north. Cadmium and selenium concentrations were all at or below their common detection limit of 0.5 µg/g.

Figure 6-5 shows total trace metal concentrations in bed sediments for 2010. Arsenic, copper, lead, nickel, silver and zinc showed higher concentrations in the southern end of the lake. Chromium, iron and selenium showed higher values in the northern end. Cadmium and mercury values were at or below their respective detection limits.

Mean annual bed sediment metal concentrations for the <63 µm and total fractions in the southern, central and northern regions of Lake Murray from 2001 to 2010 are presented in Table 6-1.

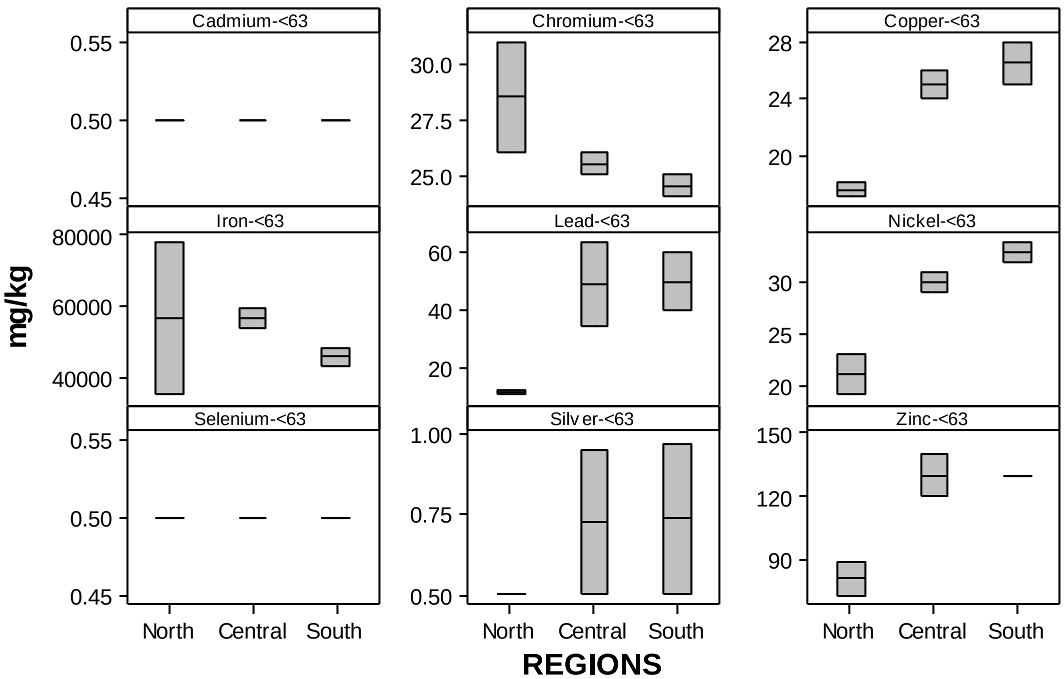


Figure 6-4 Between site differences in metal concentrations of <63 µm sediment fraction in Lake Murray for 2010

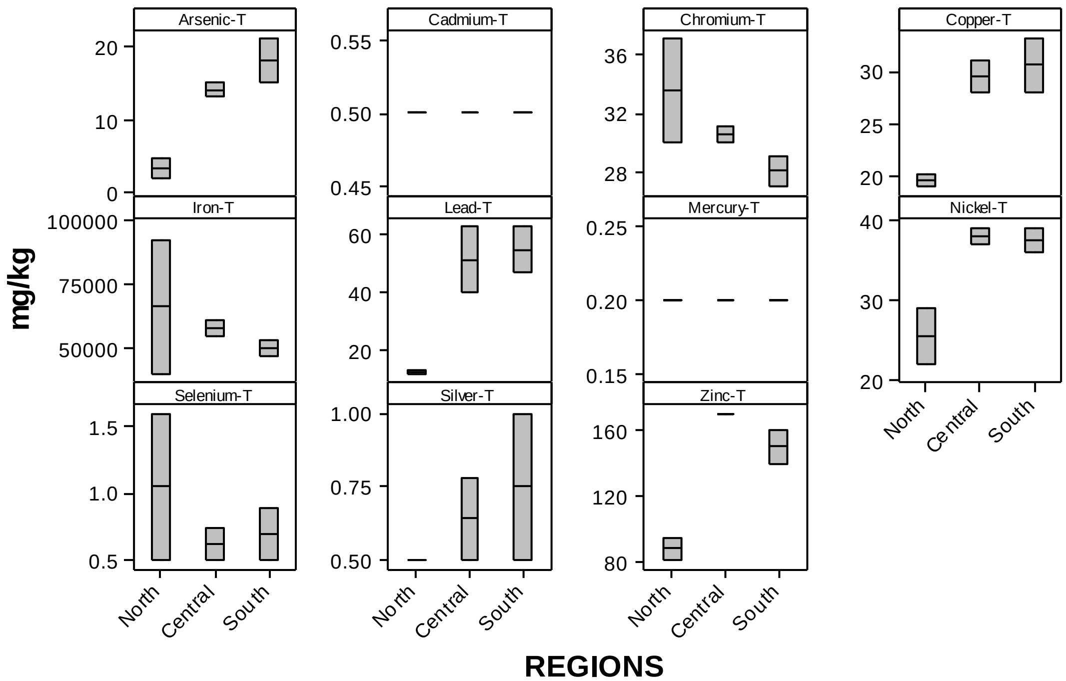


Figure 6-5 Between site differences in total metal concentrations in sediments at Lake Murray for 2010

Table 6-1 Bed sediment mean concentrations in North, Central and South regions of Lake Murray (2004-2009). All concentrations in ug/g.

Region	Year	As -63	As -T	Cd -63	Cd -T	Cr -63	Cr -T	Cu -63	Cu -T	Fe -63	Fe -T	Pb -63	Pb -T	Hg -63	Hg -T	Ni -63	Ni -T	Se -63	Se -T	Ag -63	Ag -T	Zn -63	Zn -T
North	2001	2.1	2.0	1.3	1.3	23	23	19	19	57563	58475	9.7	9.5	0.04	0.04	17	17	nd	nd	0.3	0.4	98	108
	2002	1.9	3.5	1.5	1.8	44	35	18	19	68490	67646	8.2	8.5	0.12	0.11	24	29	0.3	0.2	0.1	0.1	97	115
	2003	6.0	5.2	1.1	1.1	51	34	16	15	60360	58220	14	12	0.26	0.16	100	55	0.3	0.3	0.4	0.1	81	73
	2004	2.5	2.5	0.8	0.7	39	39	14	15	68900	70100	5.2	5.5	0.25	0.16	27	26	0.4	0.4	0.6	0.6	95	95
	2005	5.2	5.2	1.6	1.5	40	38	20	20	72000	74300	18	17	0.2	0.2	19	18	0.5	0.1	0.1	0.2	104	102
	2006	2.3	3.0	4.5	2.2	32	38	25	20	70300	75800	12	12	0.4	0.4	32	47	0.4	0.7	0.3	0.3	107	104
	2007	2.8	3.6	3.3	0.5	31	46	25	26	53400	62200	10	12	0.2	0.2	26	38	0.5	1	0.5	0.5	74	91
	2008	5.7	5.1	15	0.5	33	36	48	24	76200	83700	301	13	0.2	0.2	36	31	0.6	0.7	0.5	0.5	127	101
	2009	3.0	3.9	0.5	0.5	33	39	18	20	68000	74200	12	13	0.2	0.2	28	31	0.6	0.8	0.5	0.5	101	104
	2010	2.3	3.1	0.5	0.5	29	34	18	20	52300	66200	11	13	0.2	0.2	21	26	0.5	1.1	0.5	0.5	81	80
Central	2001	2.1	2.0	0.68	0.58	29	27	20	19	42246	39219	11	10	0.1	0.04	25	22	nd	nd	0.4	0.3	91	84
	2002	7.7	10	1.2	1.3	50	31	19	19	57836	58553	15	16	0.2	0.2	30	29	0.3	0.3	0.3	0.2	100	101
	2003	7.6	7.4	1.2	1.3	47	33	17	18	62767	64711	19	16	0.3	0.3	67	49	0.4	0.4	0.9	0.8	86	82
	2004	5.4	4.6	0.79	0.72	37	36	16	14	74600	73300	9.9	9.7	0.2	0.2	28	26	0.5	0.5	0.4	0.3	92	95
	2005	7.9	9.7	1.8	1.9	38	37	22	20	81000	84000	19	19	0.2	0.3	18	19	0.2	0.2	0.3	0.3	104	118
	2006	3.7	4.4	3.2	2.4	31	40	21	21	80600	85000	16	17	0.4	0.5	32	42	0.3	0.8	0.4	0.8	114	121
	2007	6.4	10	5.5	0.5	47	47	79	26	75200	100700	21	14	1.0	0.2	36	45	1.4	1.1	1.5	0.5	142	123
	2008	5.9	6.5	10	0.5	39	41	139	24	91600	97500	11	16	0.2	0.2	40	36	0.7	0.6	0.5	0.5	153	123
	2009	5.4	6.3	0.2	0.5	37	40	21	21	73400	78100	16	16	0.2	0.2	45	35	0.7	0.9	0.5	0.5	113	114
	2010	16	14	0.5	0.5	26	31	25	30	56500	57700	49	52	0.2	0.2	30	38	0.5	0.6	0.7	0.6	130	170
South	2001	9.0	9.9	0.8	0.9	26	25	24	24	47120	49250	24	24	0.18	0.10	24	23	nd	nd	0.7	0.7	116	153
	2002	10	15	1.1	1.0	53	28	21	21	50204	44635	20	21	0.3	0.3	33	29	0.2	0.3	0.3	0.3	108	101
	2003	11	12	1.1	1.2	46	39	18	19	52270	53336	25	26	0.3	0.3	92	88	0.3	0.3	0.3	0.4	89	89
	2004	12	13	0.6	0.6	34	33	21	21	56700	55400	20	19	0.2	0.2	32	32	0.3	0.3	0.6	0.6	112	107
	2005	15	15	1.3	1.2	31	30	25	25	52000	49600	35	34	0.2	0.2	17	18	0.2	0.2	0.6	0.4	118	116
	2006	9	11	2.3	1.9	29	32	25	24	52200	53700	38	43	0.4	0.4	32	37	0.4	0.5	0.8	0.8	128	133
	2007	14	18	11	0.5	36	42	70	32	54400	58100	33	40	0.2	0.2	37	45	0.6	0.8	0.6	0.7	128	129
	2008	12	14	2.9	0.5	33	35	36	28	66300	72400	182	36	0.2	0.2	36	37	0.5	0.6	0.6	0.6	150	145
	2009	13	14	0.5	0.5	32	35	24	26	55300	58500	35	35	0.2	0.2	43	40	0.6	0.8	0.5	0.5	137	141
	2010	16	18	0.5	0.5	25	28	27	31	45400	50300	50	55	0.2	0.2	33	38	0.5	0.7	0.7	0.8	130	150

Note; 63 = 63 µm fraction T= total fraction nd = not done

6.3.2 Water Quality

Concentrations of dissolved metals in Lake Murray water for 2010 are presented as box plots in Figure 6-6 for all the relevant metals. The concentrations of all metals except iron and zinc were at or below their respective detection levels. Neither iron nor zinc showed any distinct trend throughout the year.

Similar to above, total concentrations for all the relevant metals, except iron and zinc were at or below their respective detection limits (Figure 6-7). Total zinc concentrations showed an upward trend from north to south while iron showed no distinct trend.

Annual mean concentrations from 2001 to 2010 for dissolved and total metals and other water quality parameters for the southern, central and northern regions of the lake are presented in tabular form in Table 6-2. All these results were very low and no specific trends can be seen.

The analyses for sulfate and pH showed no distinct regional trends throughout the year, while all results for pH showed the lake water to be slightly acidic. Dissolved chloride concentrations were at or below the detection limit throughout the lake during the year (Figure 6-8).

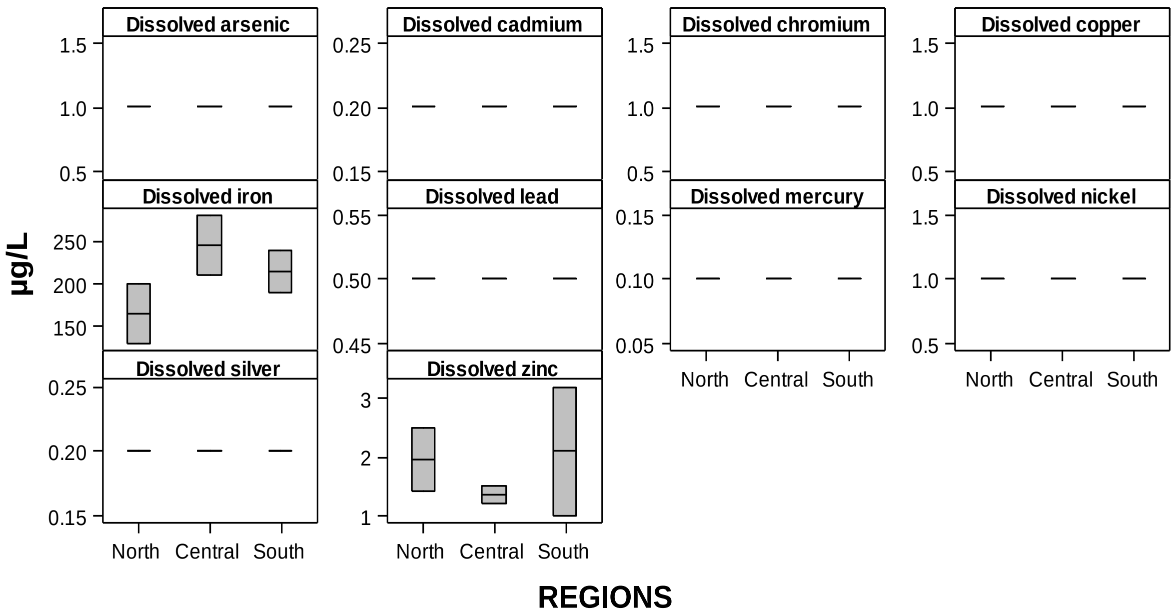


Figure 6-6 Between-site differences in dissolved metal concentrations for water samples in Lake Murray for 2010

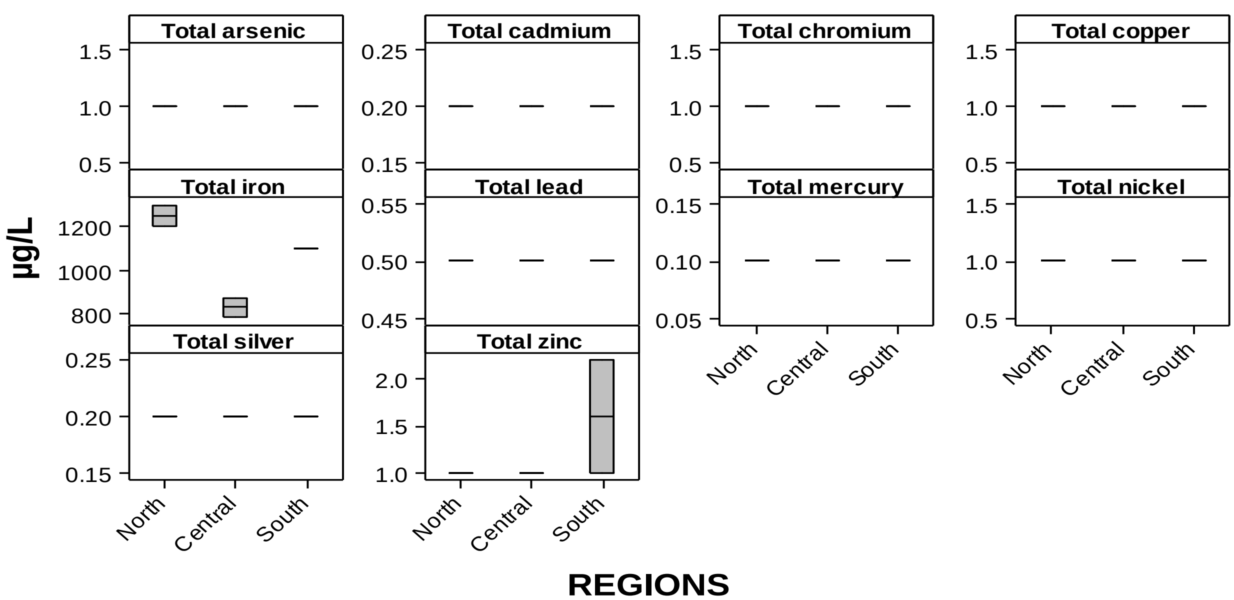
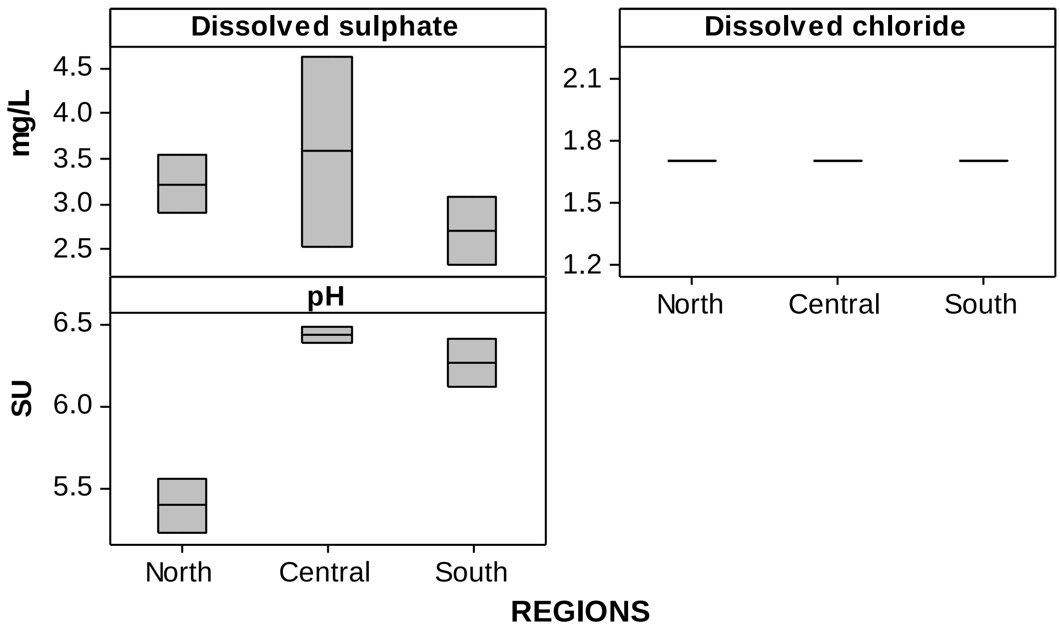


Figure 6-7 Between site differences in total metal concentrations for water samples in Lake Murray for 2010



Footnote:
SU; Standard unit

Figure 6-8 Between site differences in pH, sulfate and chloride of water samples in Lake Murray for 2010

Table 6-2 Water quality mean values in North, Central and South Regions of Lake Murray from 2001-2010 (all concentrations in ug/L)

Regions	Year	As D	As T	Cd D	Cd T	Cr D	Cr T	Cu D	Cu T	Fe D	Fe T	Pb D	Pb T	Hg D	Hg T	Ni D	Ni T	Ag D	Ag T	Zn D	Zn T
North	2001	0.2	0.2	0.1	1.6	0.4	0.8	2.0	6.7	160	550	0.2	2.2	0.2	0.2	1	3.8	0.2	0.2	4.0	9.3
	2002	0.3	0.8	0.1	0.1	0.3	3.3	0.7	3.1	260	1070	0.3	1.2	0.2	0.3	2.5	4.0	0.2	0.5	7.5	27
	2003	0.2	0.2	0.1	0.3	0.3	0.8	0.3	1.4	100	710	0.2	3.0	0.2	0.5	1.0	1.2	0.2	0.7	3.1	18
	2004	0.2	0.5	0.1	0.3	0.2	1.4	1.1	3.9	300	976	0.3	3.0	0.2	1.4	1.2	1.8	0.2	0.2	7.7	14
	2005	0.6	0.6	0.2	0.2	0.7	1.3	1.1	1.5	265	1150	0.4	0.4	0.1	0.9	1.0	1.0	0.2	1.7	9.2	21
	2006	0.6	0.7	0.2	0.3	0.7	1.3	1.5	3.1	188	1680	0.5	1.6	0.2	0.2	1.0	1.9	0.6	0.8	7.9	13
	2007	1.0	1.0	0.2	0.	1.0	1.0	1.0	1.0	214	950	0.5	0.5	0.1	0.1	1.0	1.0	0.2	0.2	1.0	2.3
	2008	1.0	1.0	0.2	0.2	1.0	1.0	1.0	1.0	212	1260	0.5	0.5	0.1	0.1	1.0	1.0	0.2	0.2	1.0	1.2
	2009	1.0	1.0	0.2	0.2	1.0	1.0	1.0	1.0	112	1540	0.5	0.5	0.1	0.1	1.0	1.0	0.2	0.2	4.8	11
	2010	1.0	1.0	0.2	0.2	1.0	1.0	1.0	1.0	165	1250	0.5	0.5	0.1	0.1	1.0	1.0	0.2	0.2	2.0	1.0
Central	2001	0.2	0.3	0.1	0.6	0.6	4.7	2.8	11	370	1600	0.2	3.8	0.2	0.2	1	5.8	0.2	0.3	4.5	25
	2002	0.2	0.4	0.1	6.3	0.3	1.1	0.4	3.0	110	880	0.8	3.6	0.2	0.8	1.0	2.2	0.2	0.9	3.0	20
	2003	0.2	0.3	0.1	3.4	0.3	1.0	0.4	3.3	87	753	0.3	3.0	0.2	0.5	1.0	1.5	0.2	0.6	2.7	21
	2004	0.2	4.2	0.2	0.4	0.3	1.1	1.7	3.9	172	699	0.4	1.1	0.2	1.4	1.1	1.5	0.2	0.2	6.9	12
	2005	0.6	0.6	0.2	0.2	0.6	0.9	1.0	1.3	269	935	0.4	0.5	0.2	1.0	1.2	1.3	0.2	0.3	9.1	29
	2006	0.6	0.7	0.2	0.3	0.7	1.6	1.7	3.1	151	1320	0.6	1.4	0.2	0.2	1.0	1.4	0.6	0.7	6.9	11
	2007	1.0	1.0	0.2	0.2	1.0	1.0	1.0	1.0	204	766	0.5	0.5	0.1	0.1	1.0	1.0	0.2	0.2	1.2	3.2
	2008	1.0	1.0	0.2	0.2	1.0	1.0	1.0	1.0	163	856	0.5	0.5	0.1	0.1	1.0	1.0	0.2	0.2	1.0	1.0
	2009	1.0	1.0	0.2	0.2	1.0	1.0	1.0	1.0	91	1274	0.5	2.1	0.1	0.1	1.0	1.1	0.2	0.2	2.5	12
	2010	1.0	1.0	0.2	0.2	1.0	1.0	1.0	1.0	245	825	0.5	0.5	0.1	0.1	1.0	1.0	0.2	0.2	1.4	1.0
South	2001	0.4	0.8	0.1	0.2	0.6	2.8	3.7	22	197	840	0.3	3.3	0.2	1.5	1	4.3	0.3	0.5	4.4	17
	2002	0.2	1.7	0.2	0.9	0.4	1.9	0.8	2.6	56	1700	0.6	4.9	0.3	0.7	2.1	4.0	0.2	0.9	5.9	30
	2003	0.2	1.8	0.1	0.5	0.3	2.1	0.7	3.1	61	2170	0.4	5.0	0.2	0.5	1.2	3.8	0.2	0.5	6.6	31
	2004	0.3	1.5	0.2	0.4	0.2	1.1	2.5	6.7	122	722	0.3	1.1	0.2	1.3	1.1	2.0	0.2	0.2	6.4	12
	2005	0.6	0.6	0.2	0.2	0.6	0.6	0.9	1.3	201	740	0.4	1.6	0.2	1.0	1.6	2.1	0.2	1.3	5.3	29
	2006	0.6	0.8	0.2	0.2	0.7	1.9	1.8	3.7	70	1400	1.0	2.2	0.2	0.2	1.0	1.8	0.6	0.7	3.9	11
	2007	1.0	1.0	0.2	0.2	1.0	1.0	1.0	1.1	158	749	0.5	0.5	0.1	0.1	1.0	1.0	0.2	0.2	1.4	3.0
	2008	1.0	1.2	0.2	0.2	1.0	1.2	1.0	1.2	145	982	0.5	0.8	0.1	0.1	1.0	1.2	0.2	0.2	1.1	3.2
	2009	1.0	1.0	0.2	0.2	1.0	1.0	1.0	1.0	146	1282	0.5	0.6	0.1	0.1	1.0	1.0	0.2	0.2	1.7	8.4
	2010	1.0	1.0	0.2	0.2	1.0	1.0	1.0	1.0	215	1110	0.5	0.5	0.1	0.1	1.0	1.0	0.2	0.2	2.1	1.6

D= Dissolved T= Total

Table 6-2 (cont.) Water quality mean values in North, Central and South Regions of Lake Murray (2001-2010)

REGIONS	YEAR	pH	Cond	TSS	Ca-D	Mg-D	Na-D	K-D	Cl-D	SO_4-D
			µs/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
NORTH	2001	6.8	23	nd	2.2	0.6	0.6	0.4	4.6	2.1
	2002	6.5	35	5.7	1.1	0.4	0.5	0.3	3.6	3.0
	2003	6.1	23	14	1.6	0.6	1.1	0.5	2.7	2.6
	2004	5.5	29	11	3.0	0.8	1.1	0.8	1.4	3.9
	2005	6.3	19	8.0	1.8	0.5	0.9	0.5	1.4	4.2
	2006	6.7	27	11	2.5	0.7	1.2	0.6	6.8	7.6
	2007	6.5	23	8.6	1.7	0.5	0.7	0.2	2.9	2.9
	2008	6.1	25	6.7	1.9	0.7	0.9	0.3	1.2	1.7
	2009	6.0	20	8.6	1.9	0.5	0.5	0.3	3.7	1.2
	2010	5.4	14	6.0	1.3	0.4	0.5	0.3	1.7	3.2
CENTRAL	2001	6.0	30	32	1.3	0.5	0.6	0.4	3.9	1.8
	2002	6.6	29	19	2.5	0.9	1.0	0.6	2.6	3.1
	2003	6.7	27	18	2.3	0.8	1.0	0.6	2.4	2.7
	2004	6.0	43	8.8	5.6	1.1	1.2	0.8	1.3	4.6
	2005	6.7	20	7.4	1.9	0.6	1.0	0.5	1.4	3.6
	2006	6.8	29	7.9	2.9	0.6	1.1	0.6	3.3	4.9
	2007	6.5	21	9.5	1.5	0.4	0.7	0.2	3.3	2.4
	2008	6.5	20	5.5	1.5	0.6	0.8	0.3	1.3	1.3
	2009	6.5	19	3.0	1.8	0.7	0.5	0.3	1.5	1.5
	2010	6.4	21	2.0	2.3	0.4	0.6	0.3	1.7	3.6
SOUTH	2001	7.1	80	24	11	1.4	1.2	0.5	5.0	4.8
	2002	6.8	63	35	7.7	1.5	1.3	0.9	2.9	5.5
	2003	6.7	58	40	8.0	2.0	1.0	1.0	3.0	6.0
	2004	6.4	77	13	12	1.8	1.5	0.8	1.4	6.0
	2005	6.9	29	9.7	3.2	0.7	1.0	0.5	1.4	3.4
	2006	7.2	66	18	8.7	1.1	1.3	0.6	2.8	5.6
	2007	6.8	24	14	2.4	0.5	0.7	0.2	3.1	2.6
	2008	6.6	33	12	3.4	0.7	0.9	0.3	1.3	1.8
	2009	6.0	19	2.5	1.6	0.5	0.5	0.3	0.9	3.7
	2010	6.3	15	3.5	1.3	0.4	0.5	0.3	1.7	2.7

D= Dissolved SU= Standard unit

7.0 Biological Monitoring

Summary

This report summarises the biological data collected between 1 January and 31 December 2010. The full report on biological monitoring is presented as Appendix 3 of this report.

The aims of the biological programs are twofold. Firstly, they provide specimens for tissue trace metal and sorbitol dehydrogenase (SDH) analyses that are useful for biomonitoring and human metal intake studies via aquatic food consumption. Secondly, they generate data to assess changes in the species richness, abundance and condition (state of health) of fish, and some invertebrates, that may have resulted from mining activities.

7.1 Species Richness, Abundance and Condition

In the upper catchment, there was no evidence to suggest any mine-related impacts to the species richness, diversity, abundance or biomass of fish or prawns between sites for the year 2010. Rank correlations did detect some significant decreases in number of species, abundance and biomass for prawns. At Wankipe, for the period 2000 to 2010, a negative trend was observed for species richness, abundance and biomass of prawns that was not matched at the reference site at Tomu. At Wasiba, a negative trend in prawn abundance and biomass was observed for the period 2000 to 2010 that was not matched at the reference site at Ok Om. Standardised sampling is not currently undertaken at the reference sites at Kuru River and Pori River due to the lack of suitable sandbank to perform seine netting. It is planned that during 2011 backpack electrofishing will be implemented at all upper catchment sites to increase the likelihood of achieving sample numbers for tissue collection and to give another standardised method to measure species richness, abundance, diversity and biomass.

At lower Strickland River sites standardised gill and seine netting did not suggest any mine-related impacts to the species richness, diversity, abundance or biomass of fish or prawns for the year 2010. Negative trends were detected for species richness, biomass and abundance for fish caught at Tiumsinawam that were not matched at the reference site at Tomu over the 2000 to 2010 period.

Hydroacoustic sampling was undertaken at the Strickland River off river water bodies, Kukufionga, Avu, Levame and Zongamange in May 2010. Results for the hydroacoustic surveys of the off river water bodies undertaken during 2010 are presented in Figure 7-1.

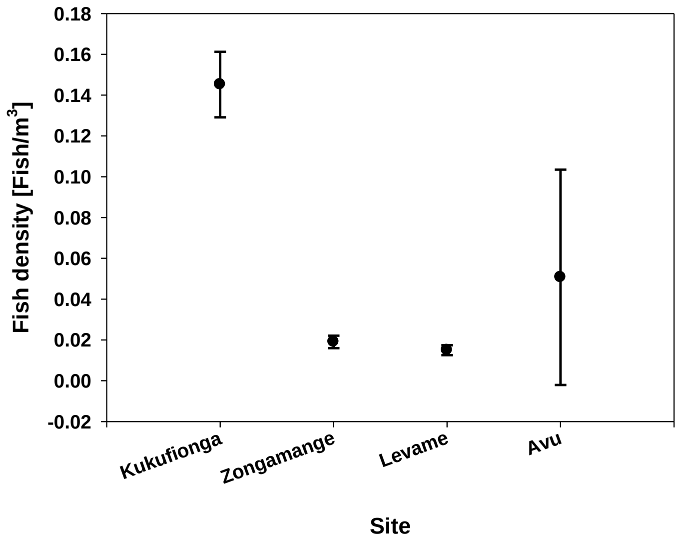


Figure 7-1 Average fish density (fish/m^3) for off river water body sites surveyed during 2010

Between site differences were detected for the fish density recorded at the off river water bodies during 2010. Fish density was found to be significantly greater ($p<0.001$) at Kukufionga than that observed at all the other off river water bodies surveyed. This result indicates that the potentially impacted site upstream of the Herbert River confluence at Kukufionga showed significantly higher fish density indicating no mine-derived effects.

Specimen condition in the upper catchment indicated a significant difference for the fish *N. equinus* at Wasiba and Wankipe when compared with fish collected at Kuru River, indicating a possible mine-related effect. This trend was not observed between Wasiba and the other reference sites at Ok Om or Pori River but should continue to be monitored keeping in mind that the differences may be an artefact of the difficulties of sampling at these sites. Spearman's rank correlations indicated that *N. equinus* condition was significantly decreasing at Wasiba which was not observed at any of the reference sites.

The condition of fish and prawns at lower Strickland River sites was not found to be significantly different between downstream-of-mine sites and reference sites during 2010. However, a significant decreasing trend in the condition of *P. macrorhynchus* collected at Tiumsinawam was detected over the time period 2000 to 2010 which was not matched at the reference site at Tomu. This was found to be the result of a number of outliers in the earlier years of the data set. Upon removal of these outliers, there was no longer a negative correlation.

Overall, the catch and abundance recorded at downstream of mine sites during 2010 did not indicate any direct impact due to mining activities, but trends detected in the upper catchment data from 2000 to 2010 or where there were data available, indicated that prawn species richness, abundance and biomass may be decreasing. Unfortunately, standardised catch methods in the upper catchment can be somewhat compromised by environmental conditions at the time of sampling. This will hopefully be rectified by the use of electrofishing methods in 2011. At sites in the lower Strickland region, there were no significant differences detected between sites during 2010 indicating no mine-related impact.

Fish condition investigations indicated that most of the species caught during 2010 were in good health. The exception to this was *N. equinus* collected at Wasiba and Wankipe when compared with fish caught at the reference site at Kuru River where the average condition at the downstream-of-mine sites was found to be significantly lower.

7.2 TISSUE METAL CONCENTRATIONS

7.2.1 Quality Assurance

Laboratory based quality assurance was acceptable for samples analysed in Quarters 1, 2, 3 and 4.

The consistent use of field blanks was a great improvement over recent years and the biological team should be commended for this effort. A total of 46 field blanks were used in 2010, a major improvement on 2008, where only seven field blanks were used, and over 2009, where 31 field blanks were used. The level of field blanks used in 2010 should be maintained. The analysis of the field blanks indicated that some contamination of samples was occurring during sample processing and/or possibly during sample preparation and analysis at the analytical laboratory. A continued effort is needed to ensure that the processing laboratory is as clean as possible and dissection of samples both in the laboratory and the field is done using clean techniques.

7.2.2 Temporal and Spatial Variation

Tissue sampling of target organisms was undertaken at all planned sites in 2010, except at Lake Murray where landowner intervention and unreasonable compensation demands prevented sampling for tissues from occurring. Prawns were sampled from a number of extra sites in the lower Strickland as part of the prawn bioaccumulation study. Samples were collected from sites, Kukufionga, Strickland River at Oxbow 3 entrance, Strickland River above Everill Junction and Fly River at Ogwa.

The extent of mine-related (and in some cases anomalous) elevation of metal bioaccumulation is discussed for each metal in turn below:

Cadmium: Average concentrations of cadmium has continued to be found at significantly elevated levels in tissues of both fish and prawns sampled during 2010 (Figure 7-2). Prawn cephalothorax samples from impact sites in both the upper catchment and lower Strickland indicated continued persistence of cadmium at elevated levels when compared with reference sites. Wasiba, Wankipe, Bebelubi, Tiumsinawam, Kukufionga, SG5, Levame and Ogwa prawn cephalothorax samples were all found to have significantly elevated levels of cadmium when compared with samples collected from both reference sites. Other tissue types that were found to be elevated at impact sites when compared with reference sites included prawn flesh at Wankipe, Wasiba, Bebelubi and Levame, and fish liver samples at Wankipe, Wasiba and Bebelubi. Increasing trends in cadmium concentrations at impact sites that were not matched at reference sites were also detected for a number of tissues, including prawn cephalothorax at Bebelubi and Tiumsinawam over the shorter term, prawn flesh at Wankipe over the shorter term, at Bebelubi over the shorter and longer term and fish liver at Tiumsinawam over the longer period.

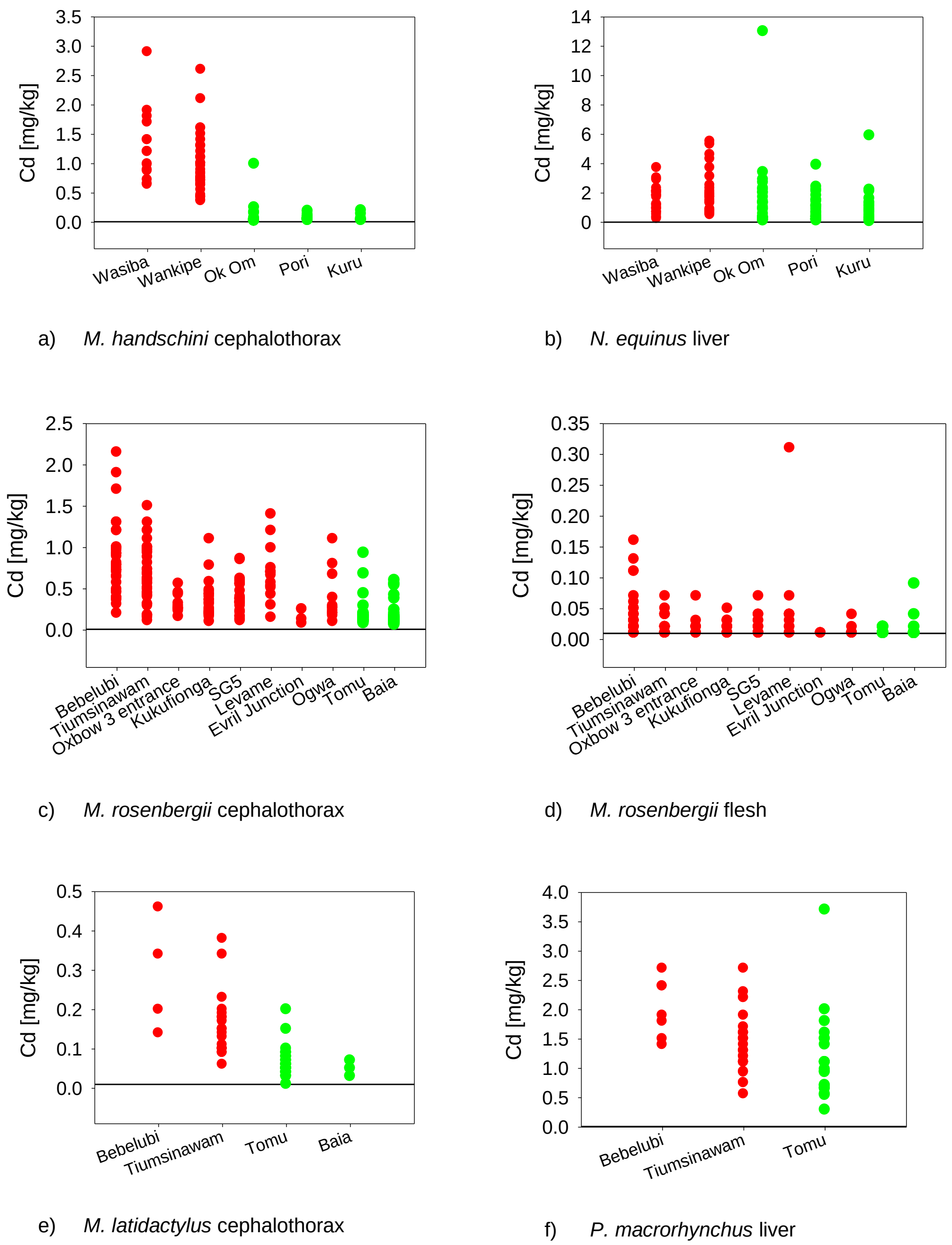
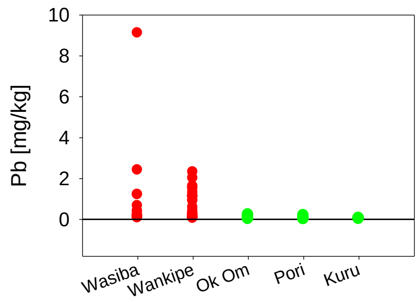


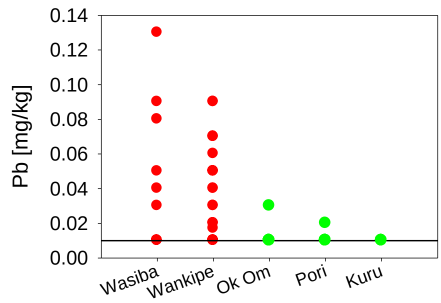
Figure 7-2 Average concentrations of cadmium observed for a) *M. handschini* cephalothorax, b) *N. equinus liver*, c) *M. rosenbergii* cephalothorax, d) *M. rosenbergii* flesh, e) *M. latidactylus* cephalothorax, f) *P. macrorhynchus* liver.

Copper: Average copper concentrations were found to be significantly elevated at impact sites compared with reference sites for prawn cephalothorax and flesh during 2010. Prawn cephalothorax samples were found to be significantly elevated at Wasiba, Levame and Ogwa when compared with samples from at least one reference site, and prawn flesh at Bebelubi was significantly elevated when compared with samples from all reference sites. Increasing copper concentration trends were identified at downstream-of-mine sites that were not matched at reference sites for a number of tissues, including prawn flesh at Wankipe and Wasiba over the longer term and at Bebelubi over both the shorter and longer term, prawn cephalothorax at Bebelubi over the shorter term and fish liver at Tiumsinawam over the longer time period.

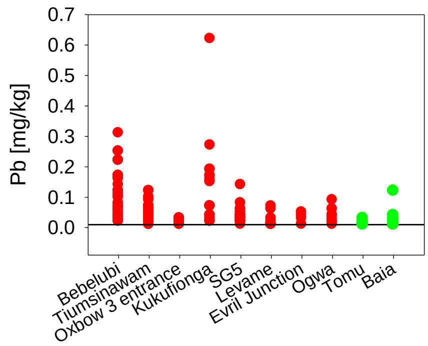
Lead: Average concentrations of lead were found to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax and flesh and fish liver during 2010 (Figure 7-3). Prawn cephalothorax samples collected from downstream-of-mine sites from both the upper catchment and lower Strickland region were found to have significantly elevated levels of lead when compared with samples from reference sites. Prawn flesh collected from Wankipe and Wasiba were found to have more elevated levels of lead than samples collected from at least one of the reference sites, and fish liver at both Wankipe and Wasiba were found to be significantly elevated in lead concentrations when compared with samples from both Pori River and Kuru River. Increasing trends were detected at downstream-of-mine sites that were not matched at reference sites. Increasing trends were detected for prawn cephalothorax at Tiumsinawam over both the short and long time period and prawn flesh at Wankipe over the long time period.



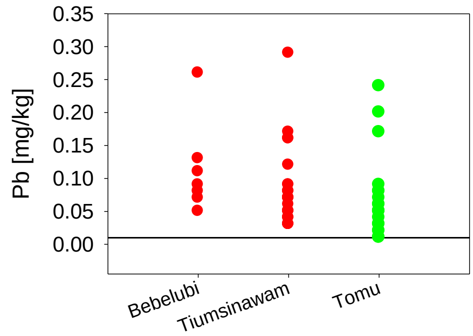
a) *M. handschini* cephalothorax



b) *M. handschini* flesh



c) *M. rosenbergii* cephalothorax



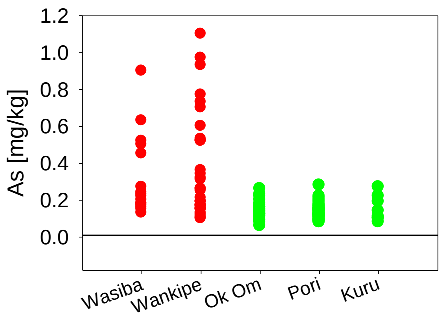
d) *P. macrorhynchus* liver

Figure 7-3 Average concentrations of lead for a) *M. handschini* cephalothorax, b) *M. handschini* flesh, c) *M. rosenbergii* cephalothorax, d) *P. macrorhynchus* liver.

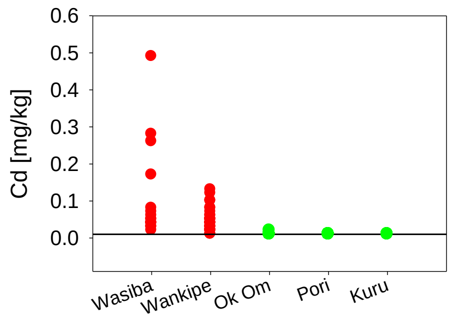
Zinc: Average concentrations of zinc were found to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax and flesh. Prawn cephalothorax samples collected from Wankipe, Wasiba, Kukufionga and Tiumsinawam were found to be significantly elevated in average zinc concentrations when compared with at least one reference sites. Prawn flesh was found to have elevated average concentrations of zinc in samples collected from Wankipe when compared with samples collected from Pori River. Increasing trends were observed at downstream-of-mine sites that were not matched by reference sites for prawn flesh at Wasiba over the short term, fish flesh at Wankipe over the longer term and fish liver at Tiumsinawam over the longer period.

Selenium: Average selenium concentrations were found to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax, prawn flesh, fish liver and fish flesh. Prawn cephalothorax was found to be significantly elevated at downstream-of-mine sites, Wankipe, Wasiba, SG5 and Levame when compared with at least one reference site, and prawn flesh was found to have significantly elevated levels of average selenium at site Wankipe, Wasiba, Levame, Everill junction and Bebelubi when compared with at least one reference site. Fish flesh samples collected from Wasiba were found to have elevated levels of average selenium when compared with samples collected from both reference sites. Increasing trends in average selenium concentrations were observed for prawn cephalothorax at Bebelubi over the longer time period and fish flesh and liver collected from Tiumsinawam were seen to be increasing at Tiumsinawam over the longer time period.

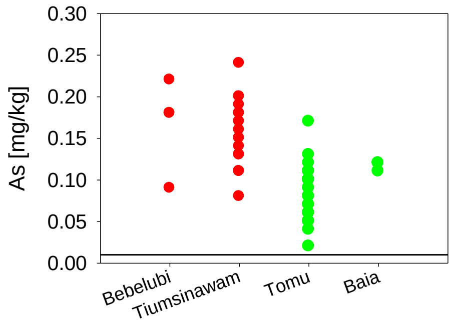
Arsenic: Average arsenic concentrations were observed to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax and flesh (Figure 7-4). Prawn cephalothorax was found to be significantly elevated at downstream-of-mine sites Wankipe, Wasiba, Bebelubi, Tiumsinawam, Oxbow 3 entrance, Kukufionga, SG5, Levame and Ogwa when compared with at least one of the reference sites. Prawn flesh was found to be significantly elevated at downstream-of-mine sites Wankipe, Wasiba, Bebelubi, Oxbow 3 entrance, Kukufionga, SG5, Levame and Ogwa when compared with samples from at least one reference site. Increasing trends were detected for arsenic in fish flesh at Wankipe over the shorter period and prawn flesh at Tiumsinawam over the shorter period.



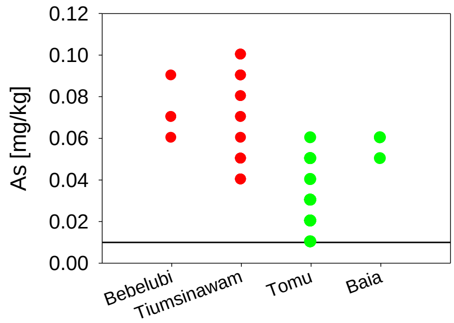
a) *M. handschini* cephalothorax



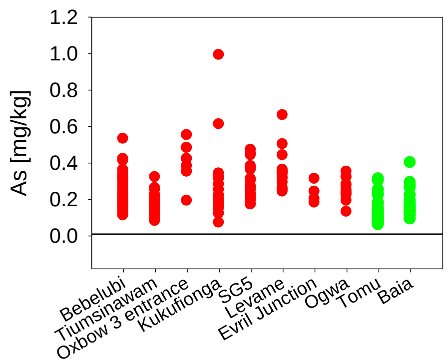
b) *M. handschini* flesh



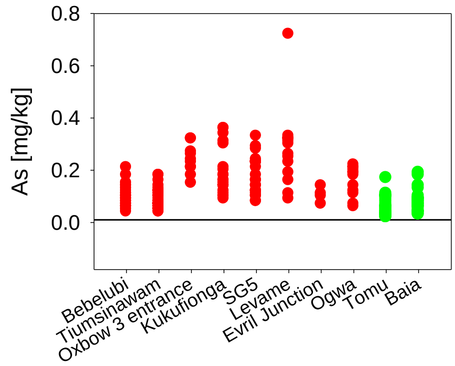
c) *M. latidactylus* cephalothorax



d) *M. latidactylus* flesh



e) *M. rosenbergii* cephalothorax



f) *M. rosenbergii* flesh

Figure 7-4 Average concentrations of arsenic for a) *M. handschini* cephalothorax, b) *M. rosenbergii* flesh, c) *M. latidactylus* cephalothorax, d) *M. latidactylus* flesh, e) *M. rosenbergii* cephalothorax, f) *M. rosenbergii* flesh.

Nickel: Average concentrations of nickel were observed to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax. Prawn cephalothorax was found to be significantly elevated at sites Wankipe, Bebelubi and Kukufionga when compared with samples from at least one of the reference sites. Increasing trends of average concentrations of nickel were observed at downstream-of-mine sites that were not matched at reference sites for prawn cephalothorax and flesh at Bebelubi over the shorter period.

Chromium: Average chromium concentrations were observed to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax and flesh. Prawn cephalothorax was found to be significantly elevated at downstream-of-mine site, Wankipe, when compared with samples from the reference site, Ok Om, while prawn flesh from the downstream-of-mine site, Bebelubi, was found to have significantly elevated concentrations of average chromium when compared with the reference site at Tomu River. Increasing trends in average chromium concentrations were observed for prawn flesh at Bebelubi over both the short and long term and samples from SG5 over the short term, while chromium in samples of fish flesh at Tiumsinawam was observed to be increasing over the short term.

Mercury: Average mercury concentrations were seen to decrease in samples collected during 2010. No significant elevations in mercury concentrations were detected for samples collected from downstream-of-mine sites when compared with samples from reference sites. Increasing trends in average mercury concentrations were also not observed for any of the tissue types and time periods. Decreasing trends were observed at the downstream-of-mine sites Bebelubi, Tiumsinawam and SG5 for fish flesh, prawn cephalothorax and prawn flesh.

The elevated levels of metals in tissues from downstream-of-mine sites in the upper catchment and the lower Strickland region observed in previous years annual reports continued in 2010. Concentrations of cadmium and lead have continued to be detected at significantly elevated levels in prawn cephalothorax tissues collected from established downstream-of-mine sites as far down river as SG5. Overall, these results indicated that the pattern of bioaccumulation of metals at downstream-of-mine sites in the Lagaip River and the lower Strickland region has continued with small alterations to the difference seen in the uptake of some metals; for example, mercury was not detected at significantly elevated levels at impact sites compared with reference sites and was also seen to have decreased in some tissues over both long and short time periods. There was also a correlation that the cyanide destruct circuit is reducing the availability of some metals downstream of the mine.

The results of the tissue metal concentrations for each tissue type and organism type were screened against the lowest observed concentration co-occurring with an effect (LOEC) from the effects database of Jarvinen and Ankley (1999). Sites where the ratio of results above:below the corresponding effects threshold for downstream-of-mine sites was found to be greater than for any of the corresponding reference sites where found at all downstream-of-mine sites down to Bebelubi for cadmium in prawn cephalothorax and to Tiumsinawam for fish liver. Other sites where the ratio found the results above the corresponding effects threshold were Tiumsinawam for copper in fish flesh, Bebelubi for copper in fish liver, Tiumsinawam and Bebelubi for zinc in fish liver and Bebelubi for mercury in fish liver.

The collection of prawn samples for SDH analysis from the upper catchment continued in 2010 and was also expanded to sites in the lower Strickland region, with samples collected from Strickland River at Oxbow 3 entrance, SG5 and Fly River at Ogwa. Results for SDH analysis in 2010 indicated that prawns collected from Wankipe in the upper catchment had significantly elevated hepatic cell damage when compared with samples collected from the reference sites at Ok Om and Pori River (Figure 7-5). This result differed from that seen in analysis undertaken in 2006 and 2009, where Wasiba was seen to also have elevated levels of hepatic cell damage indicating that prawns at Wasiba during 2010 were under less stress than seen in previous surveys most likely due to the cyanide destruct circuit reducing the amount of available metals to the prawns. Results for samples collected at sites in the lower Strickland region indicated that prawns from site Oxbow 3 entrance had significantly elevated hepatic cell damage when compared with samples collected from SG5, while samples from Ogwa were statistically similar to samples collected from both Oxbow 3 entrance and SG5 (Figure 7-6). As prawns were not collected from any reference sites in the lower Strickland region in 2010, it is not known whether the levels of hepatic cell damage observed are at levels of concern at the downstream of mine sites. This will hopefully be rectified during the 2011 program with the collection of prawns from an appropriate reference site. It is not known whether the amounts of hepatic cell damage reflected by these increased levels of SDH are tolerable by the prawn species sampled. Investigations into the relationship between these levels of SDH in the prawn abdomen and organism health would allow for a better understanding of the state of the populations in the upper catchment and lower Strickland region.

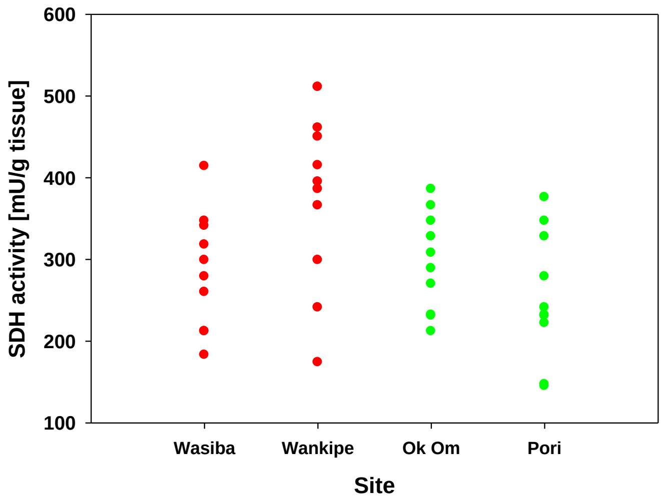


Figure 7-5 Results of SDH analysis of prawns (*M. handschini*) collected from sites in the upper catchment in 2010

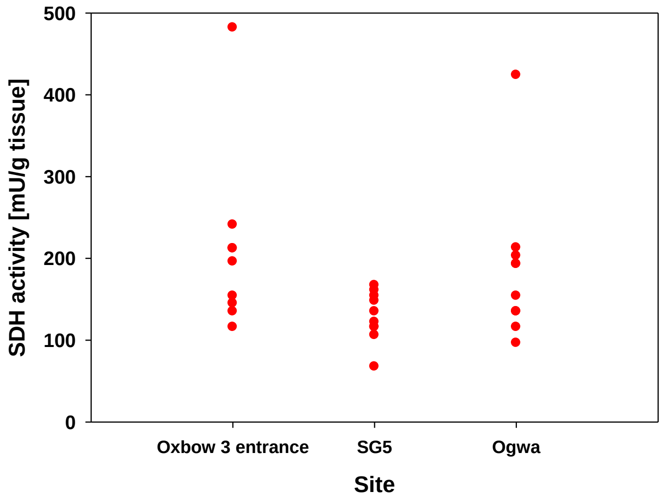


Figure 7-6 Results of SDH analysis of prawns (*M. rosenbergii*) collected from sites in the lower Strickland region in 2010

A screening of the samples of fish and prawns collected in 2010 using appropriate human health standards and guidelines indicated that none of the samples collected had concentrations of metals above the standards and guidelines. It can be stated that there is a low likelihood of human health impacts from the consumption of the edible portion of the fish and prawns in the upper catchment and the lower Strickland region.

8.0 REHABILITATION

8.1 Introduction

Mine rehabilitation is the process used to repair the impacts of mining on the environment. The long-term objectives of rehabilitation can vary from simply converting an area to a safe and stable condition, to restoring the pre-mining conditions as closely as possible to support the future sustainability of the site. Porgera rehabilitation programs comprise:

- Developing designs for appropriate landforms for the mine site
- Creating landforms that will behave and evolve in a predictable manner, according to the design principles established
- Establishing appropriate sustainable ecosystem

8.2 Progressive Rehabilitation

8.2.1 Mine Impact Areas – Waste Dumps and Open Pit

The area of land disturbed by waste dumps and open pit development was determined for 2010. There were some variations in the dump impacted areas between 2009 and 2010. Due to these variations the whole waste rock dumps and others used to calculate the impacted areas were subjected to validation and verification. Anjolek erodible dump, Anawe erodible dump, Kogai stable dump, Anawe North stable dump, mine site haul roads, open pit development areas and Pangalita lime quarry were reviewed to reconcile differences using Mine-Sight version 5.000-0. A summary of the reconciliation numbers is in Table 8-1.

Table 8-1 Environment impacted areas in hectares round up to the nearest hectare

Impact sites	Impact at the end of 2009	Impact at the end of 2010
Anjolek erodible dump	227	229
Anawe erodible dump	185	185
Anawe stable dump	113	128
Kogai waste rock dump	211	249
Pangalita lime stone quarry	18	18
Mine site haul roads	62	60
Open pit development area	332	332
Total area (ha)	**816**	**1201**

Significant disturbance changes between 2009 and 2010 include an additional 15 ha on the Anawe North stable dump, 38 ha on the Kogai stable dump and no change in the open pit area.

8.2.2 Erosion Control

Control of erosion from disturbed areas is one of the environment permit conditions that the Porgera mine addresses to ensure compliance. The erosion control measures employed include rock armouring, grass seeding on waste dumps and construction of erosion berms and bunds. Drain lines are regularly inspected and waterways maintained and de-silted, especially on rehabilitated waste rock dumps.

In 2010, a project to minimise and control sediments flowing onto stage 5B was done with the open pit operations team. One of the benches was fully seeded with grass seed mixed withfertilizer to encourage fast ground cover of the bench and minimise erosion onto the working bench below (Plates 8-1 and 8-2).

Grass established rapidly within 3 weeks. Additional topsoil from K80 will be stripped and placed on the next bench below this grassed bench for stabilization purposes.

Plate 8-1 Grass stabilization on Stage 5B bench

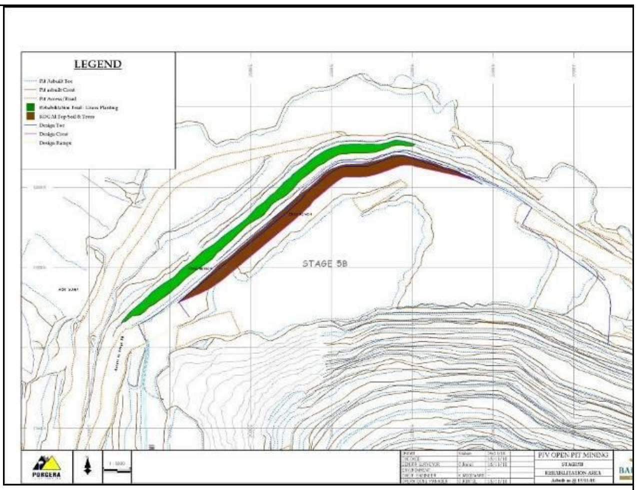


Plate 8-2 Strip topsoil placement (brown shading) for stabilization on Stage 5B bench

8.2.3 Progressive Reforestation

For reafforestation in the high altitude montane forest in the Porgera area, some 43,420 seedlings of mixed forest species, including *Nothofagus grandi*s and *Nothofagus* p*erri* (two local dominant trees) were planted on Kogai Dump. The seedlings were purchased from local suppliers who collected these from adjacent forest undergrowth. Fertilizer was applied on obvious nutrient deficient areas with the view to improving tree seedling growth and tree litter Waste rock dump rehabilitation areas with high ground cover generally were healthy and green.

A high altitude edible plant Karuka (*Pandanus jiulianettii*) is a locally grown tree with nuts that are high in protein was planted around the Porgera site.. The leaves are also used as roofing material in buildings and the stems used as house walls and flooring. Some 12,770 suckers and cuttings were purchased from local contractors for local plantings.

The significant increase in the number of trees planted is a result of the increase in the number of local contractors from the SML area taking part in supplying tree seedlings on contracts.

Previously illegal miners tresspassing on rehabilitated site normally cut and uproot tree seedlings planted but over the last three years (2008-2010) was a good year with less disturbance to the rehabilitated sites. This change is a result of the fence constructed around the mine site. Part of the rehabilitation site is inside the fenced area and the focus for rehabilitation now is to plant as much tree as possible inside the fenced area.

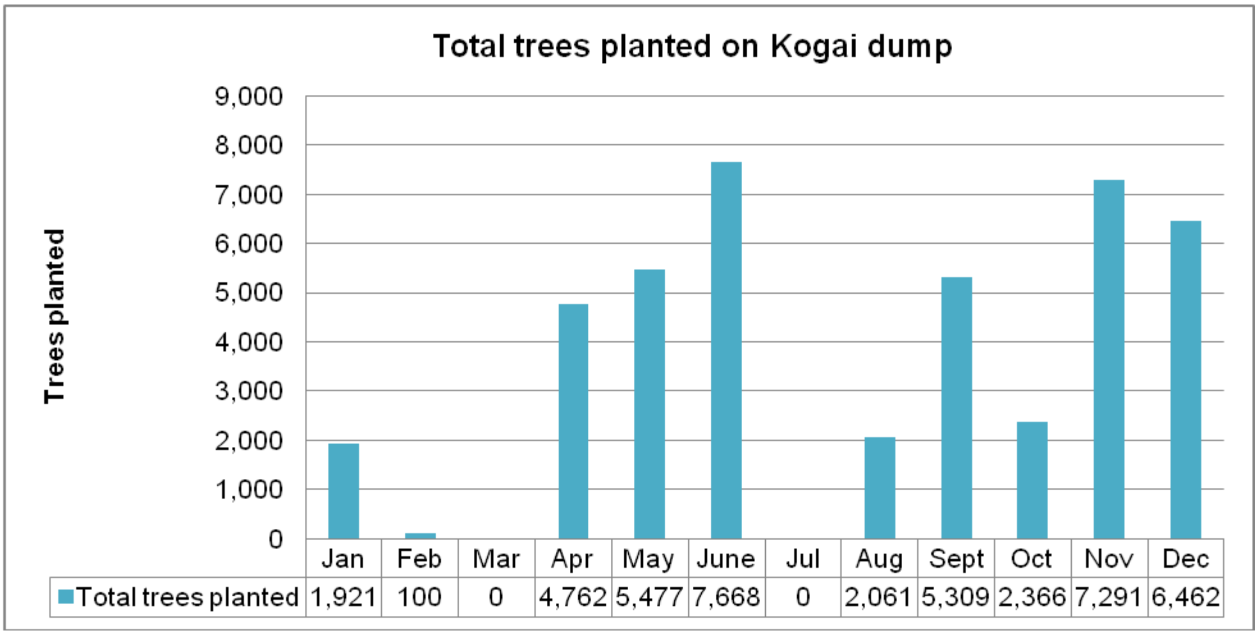


Figure 8-1 Trees planted on the Kogai dump in 2010

8.2.4 Nursery Production

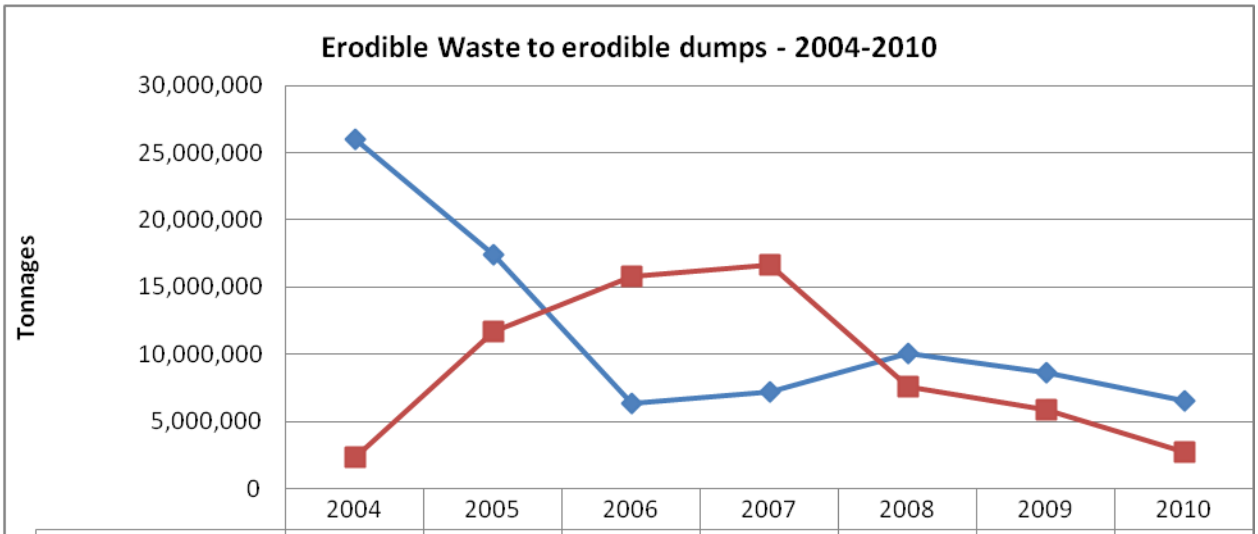
Tree seedlings are grown out in two nurseries and also purchased from local contractors from the SML area. Approximately 4,630 poly-seedling bags were filled with a potting mixture (mixture of 3 parts soil and 1 part mulch). The mulch was obtained from trees removed from the K80 waste rock dump and the former Dyno plant site. A total of 3 t of mulch and 21 t of grey topsoil was obtained from Suyan camp for use in the plant nurseries. The potting mix was thoroughly mixed prior to use in the nursery.

Some 4,400 kg of wood chips were produced for use at the nursery and as a groundcover on steep sloping rehabilitation sites.

8.3 Waste Rock Monitoring

Waste rock management has been identified as a significant environmental aspect for the Porgera project. Control measures such as ore block modelling, waste and ore characterisation, dispatch scheduling, spotter directions, and waste rock monitoring are employed to ensure that waste rock quality is managed appropriately.

Since 2007, the volume of waste rock dumped at the two erodible dumps has varied. Anjolek erodible dump has decreased from 16.6 to 2.6 million tonnes (Figure 8-2) and the Anawe erodible dump has varied between 6.5 and 10 million tonnes each year. The erodible dump footprint has changed very little over the last 4 years. Anawe erodible dump is over 5.5 km from the tip-head to the dump toe, covering an area of 185 ha in 2009 and 2010. Similarly, Anjolek erodible dump covered 227 ha in 2009 and 229 ha in 2010.

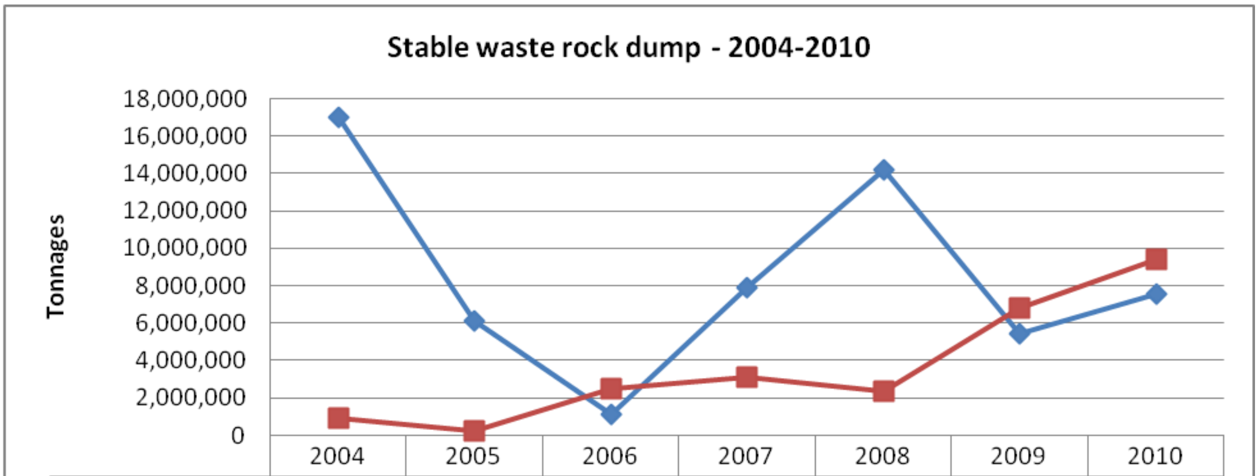


	2004	2005	2006	2007	2008	2009	2010
Anawe erodible	26,023,150	17,436,983	6,308,410	7,179,355	10,063,095	8,665,670	6,563,920
Anjolek Erodible	2,337,590	11,688,400	15,804,535	16,621,335	7,577,150	5,887,080	2,702,740

Figure 8-2 Waste rock consigned to erodible dumps between 2004 and 2010

The two stable dumps (Kogai and Anawe North) are located between the open pit and the processing plant at two different elevations. Kogai stable dump is located southeast at elevations between 2500-2800 m while Anawe North stable dump is located between 2300-2500m. Kogai dump area increased from 211 to 247 ha between 2009 and 2010 due to an extension to the southern section of the dump. Waste rock disposal increased from 6.8 to 9.4 million tonnes in those years.

Anawe North dump received 5.4 million tonnes in 2009 and 7.5 million tonnes in 2010. The increase in the waste rock disposed at Anawe North was due to a mini bench constructed between A10 and A20 and drain alignment work along the northern edge of the dump.



	2004	2005	2006	2007	2008	2009	2010
Anawe Stable	16,994,080	6,129,480	1,105,600	7,929,005	14,208,855	5,455,235	7,565,230
Kogai stable	894,180	204,860	2,506,255	3,126,100	2,384,100	6,831,765	9,434,525

Figure 8-3 Waste rock consigned to the stable dumps between 2004 and 2010

8.4 Soil Fertility and Trace Metal Studies on Kogai Rehabilitated Stable Dump

8.4.1 Introduction

The Porgera Gold Mine is located at latitude 5^0 28'S and longitude 143^0 05'E in Enga province of Papua New Guinea between 2600-2850m. The wettest months are between January and April, while monthly averages range from approximately 240 to 370 mm rainfall, and an annual average of 3,700 mm.

The main soil cover spread over the stable waste rock dumps is weathered brown sediment or mudstones and uncompacted black sediments reported commonly as calcareous sediments. The cover materials are thereafter referred to as soil in this report. The soil cover design was selected primarily to limit infiltration (hydraulic conductivity) of water and oxygen into the potentially acid forming (PAF) rocks encapsulated within the waste rock dumps. Two principal cover designs were recommended for closure of the Kogai and Anawe stable dumps. These covers were classified as double layer cover with 1.0m loose weathered brown sediments over 0.5 m of compacted weathered brown sediments and single layer cover with 1.5 m loose weathered brown sediment. However, the actual cover depth ranges from 1m to 2.5 m.

The brown mudstone or calcareous sediment is highly alkaline and has very low soil nutrient status for plant growth. Nitrogen and phosphorus are the main deficiencies for establishment of vegetation on this material. However, there is little information on the residual effects of these nutrients when fertilizer is supplied at planting. Mineral weathering and leaching can affect the physical and geochemical stability of the soil for plant growth and sustainability.

It was for this reason that a biannual soil monitoring program was established in 2005 purposely to:

- Monitor the physical changes in the soil cover used over time
- Monitor the residual changes in fertility of the soil cover on the dumps over time
- Determine appropriate fertiliser rates to support long term revegetation
- Monitor soil water characteristics and physical properties as cover materials break down over time
- Assess trace metal levels in the soil cover

8.4.2 Materials and Methods

The soil survey is conducted biannually in June/July on Kogai stable dump rehabilitated sites on benches and outer slopes. The following groundcover species were sown on these sites: Rhodes grass (*Chloris gayana*)**,** Bermuda couch (*Cynodon dactylon*)**,** Unica stylo (*Stylosanthes seabrana*), Lucerne (*Medicago sativa*) variety super 10**,** Lupin variety Merrit**,** Haifa white clover (*Trifolium repens*)**,** Maronoa annual medic (*Medicago species*) and Wimmera annual ryegrass (*Lolium rigidum*). The introduced pasture legume, silverleaf desmodium (*Desmodium uncinatum*) and the local tree, *Casuarina oligodon* (Yar tree), have colonized some parts of the areas that were sampled.

The soil samples, collected from 10 sites within each of 8 permanent transects, were randomly collected on the benches and slopes of K58, K62 and K65 sections of the Kogai stable dump. These rehabilitated sites had good tree and grass cover. Samples weighing 250 g were collected at 200 m intervals at depths of 0-10 cm and 10-20 cm. Samples were collected by clearing the grass and organic matter on the surface and taking samples with a soil auger. Samples were bagged and tagged in clear plastics, then later dried in an oven before freighting to ALS laboratory in Australia for analysis. The methods of analysis are those routinely used in agriculture for soil fertility assessment throughout Australia.

Samples were also analysed for total arsenic, chromium, copper, cadmium, mercury, molybdenum, nickel, and zinc using inductively coupled plasma atomic emission spectrometry (ICPAES).

8.4.3 Results

pH

The average pH for soil samples was 7.8 and 8.0 for the 0-10 cm and 11-20 cm soil layers, respectively. K58-B soils were slightly acidic with pH 6.6 and 6.4. It is also worthy to note that the ground cover placed on this dump was stripped from the adjacent Kogai forest during the construction period. Therefore, the soil placed here reflected the soil properties of the natural forest. The pH of these samples from the dumps surveyed is within the suggested range for plants of 5.5 and 7.5.

Soil Organic Matter

The organic matter determines the physical and chemical characteristics of the soil. Organic matter holds soil particles together and improves aeration and cation exchange capacity for macronutrients as well as metals. The mean organic matter was 2.44% and 2.62% for 10c m and 11-20 cm, respectively. Both levels were higher than the suggested value of >1.5%. As the soil covers are generally subsoil material (with exception of material used on K58-B) the high organic matter content must result from the established groundcover vegetation.

Soil Available Nitrogen

Plant-available forms of nitrogen are nitrate and ammonium. Nitrate is readily absorbed by plant roots and also leached from soil with high rainfall. Soil concentrations vary with organic matter content of soils and soil moisture and temperature. Nitrate concentrations in the soils were less than the optimal value of >10 mg/kg (Tables 2 and 3); however, this is normally the case as nitrate is rapidly absorbed by plant roots and/or leached from the surface soil.

Phosphorus

Available phosphorus levels (Olsen test) were all significantly above the suggested value of 30 mg/kg. The highest phosphorus concentration of 591 mg/kg was observed on K58-B. The very high phosphorus level will be a residual impact of the high levels of di-ammonium phosphate fertilizer (DAP) applied to tree seedling planted around this site.

Potassium

Average exchangeable potassium level observed at 0-10 and 11-20 cm depth was 0.36 and 0.34 meq/100 g. The concentration levels were slightly above the suggested value of 0.30 meq/100 g.

Cation Exchange Capacity (CEC)

CEC is a measure of soils capacity to retain and release cations such as K, Ca, Mg, and Na was above the suggested values of >10 meq/100 g for the two depths (Tables 2 and 3). The high CEC values are related to the high organic matter and clay contents of the soil cover.

Contaminant Status of Kogai Dump Cover

The contaminant status of the Kogai stable dump soil cover was compared against the Environment Investigation Limits (EIL) developed by the Queensland Environment Protection

Department (1988). Generally, metals exceeding the EIL should be subjected to further investigation to ascertain bioavailability and potential impacts on terrestrial and aquatic fauna.

Arsenic and zinc concentrations were high on K58-B and K58-S compared to the respective EIL of 20 and 200 mg/kg (Table 4). Cadmium was elevated at K58-B for the two depths compared to the EIL value of 3mg/kg. K58-B also has elevated lead levels that will be further investigated to ascertain bioavailability.

K58 rehabilitated site has high arsenic cadmium and zinc, compared to the EIL and will be closely monitored to see how these metal behave in the next sampling program in 2011 and indeed if these metals are accumulating to high levels in plants grown on the dumps or surface water draining from the dump.

8.4.4 Conclusion

The soil monitoring program provides evidence of a general improvement in soil fertility on the Kogai stable dump cover. The organic matter content of the Kogai stable dump cover soil increased from an average of 0.78 mg/kg in 2004 to 2.44 mg/kg in 2010 apparently as a result of the revegetation of the dump surface. Similarly soil phosphorus increased from 11 to 406 mg/kg over the same period. Nitrate and ammonium nitrogen have changed little and remain low. Cation exchange capacity is high, but has changed little over that period.

Soil pH has decreased from around 8.5 in 2004 to 7.9 in 2009 and 2010.

Generally the K58 dump cover has low contaminant metal levels. However, the K58-B and K58-S levels has evidence of elevated arsenic, lead, cadmium and zinc concentrations in the soil, and further investigation is required to determine the degree of bio-availability and potential impacts on plants and water draining from this area. In particular, it is of interest to assess the impact on food crops that might be grown on this soil.

Table 8-2 Fertility status of soil on Kogai stable dump at 0-10cm

Location	Organic Matter	Electrical Conductivity @ 25°C	Cation Exchange Capacity	Exchangeable Calcium	Exchangeable Magnesium	Exchangeable Potassium	Exchangeable Sodium	Chloride	Copper	Iron	Manganese	Nitrite + Nitrate as N (Sol.)	Sulfate as SO4 2-	Total Kjeldahl Nitrogen as N	Total Phosphorus as P	Zinc	pH Value
Units	%	µS/cm	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	pH Unit
K58 B	2.90	307	12	10.6	1.9	0.2	0.1	50	12.	266	160	0.4	1210	1540	591	71	6.60
K58-S	2.80	286	28	22.6	3.8	0.4	1.3	200	4.3	142	44.	3.6	500	1580	436	17	8.20
K65-S	1.80	197	2	22.2	4.2	0.4	0.1	100	2.1	78	32	0.3	380	1240	311	3.	8.00
K62-S	3.00	185	22	19.4	1.9	0.4	0.3	20	4.6	107	56	0.3	350	1740	353	11	8.00
K62-B	1.70	225	26	22.6	3.8	0.4	<0.1	100	1.3	74	38	0.7	490	1080	339	2	8.20
Average	**2.44**	**240**	**23**	**19.4**	**3.1**	**0.36**	**0.45**	**94**	**4.9**	**133**	**66**	**1.1**	**586**	**1436**	**406**	**21**	**7.80**
Stdev	0.63	54.0	6.3	5.1	1.1	0.09	0.57	68	4.3	78	53	1.4	355	268	113	28	*
Suggested value	>1.5	*	>10	6	2	0.3	<2	<600	>0.4	60	9	>10	>20	*	30	>0.8	5.5-7.5

Table 8-3 Fertility status of soil on Kogai stable dump at 11-20 cm

Location	Organic Matter	Electrical Conductivity @ 25°C	Cation Exchange Capacity	Exchangeable Calcium	Exchangeable Magnesium	Exchangeable Potassium	Exchangeable Sodium	Chloride	Copper	Iron	Manganese	Nitrite + Nitrate as N	Sulfate as SO4 2-	Total Kjeldahl Nitrogen as N	Total Phosphorus as P	Zinc	pH Value
	%	µS/cm	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	pH Unit
K58-B	6.2	339	15.7	13.2	2.1	0.2	0.2	80	9.37	256	202	0.34	1220	1520	609	83.2	6.4
K58-S	2.3	282	31.2	24.8	4.2	0.5	1.7	100	4.17	131	43.9	2.64	550	1110	383	16.8	8.4
K65-S	1.5	227	27.3	21.6	4.6	0.3	0.6	50	1.62	81	33.3	0.30	490	1030	319	2.94	8.4
K62-S	1.8	191	24.6	21.2	2.4	0.4	0.6	150	2.80	113	51.7	0.22	340	1330	379	7.66	8.4
K62-B	1.3	224	27.8	22.6	4.8	0.3	<0.1	180	1.02	70	32.5	0.26	630	1080	343	1.88	8.3
Average	**2.6**	**253**	**25.3**	**20.7**	**3.6**	**0.3**	**0.8**	**112**	**3.80**	**130**	**72.7**	**0.75**	**646**	**1214**	**407**	**22.5**	**8.0**
Stdev	2.0	58	5.9	4.4	1.3	0.1	0.6	53	3.34	74	72.7	1.06	338	206	116	34.4	
Max	6.2	339	31.2	24.8	4.8	0.5	1.7	180	9.37	256	202	2.64	1220	1520	609	83.2	8.4
Min	1.3	191	15.7	13.2	2.1	0.2	0.2	50	1.02	70	32.5	0.22	340	1030	319	1.88	6.4
Suggested value	>1.5	*	>10	6.0	2.0	0.3	<2.0	<600	>0.4	60	9.0	>10	>20	*	30	>0.8	5.5-7.5

Table 8-4 Soil contaminant status of Kogai stable dump covers at Porgera mine (all results in mg/kg)

Location	**K58-B**	**K58-B**	**K58-S**	**K58-S**	**K65-S**	**K65-S**	**K62-S**	**K62-S**	**K62-B**	**K62-B**	**Average**	**Stdev**	**EIL**	**HIL**
Depth (cm)	**0-10**	**11-20**	**0-10**	**11-20**	**0-10**	**11-20**	**0-10**	**11-20**	**0-10**	**11-20**				
Arsenic	174	157	40	43	12	13	21	20	12	12	50	61	20	100
Beryllium	1	1	<1	<1	<1	<1	<1	<1	<1	<1	1	0		
Boron	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	*	*		
Cadmium	4	4	1	1	<1	<1	<1	<1	<1	<1	2.5	1.7	3	20
Chromium	44	49	29	29	24	24	30	31	23	21	30	9	50	100
Cobalt	16	18	18	18	16	17	18	19	16	15	17	1		
Copper	51	48	27	25	17	18	24	25	17	16	26	12	60	1000
Lead	515	424	86	111	21	19	38	48	18	16	129	183	300	300
Mercury	0.2	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	0	1	15
Nickel	29	30	28	27	25	25	27	28	24	23	26	2	60	600
Zinc	841	782	260	242	128	162	182	217	122	129	306	270	200	7000

8.5 Kogai Dump Vegetation Survey

8.5.1 Introduction

A vegetation survey was conducted from 4 to 9 December 2010. The survey assessed the performance of the revegetation program on the Kogai stable dump and to measure any natural colonization in the rehabilitation areas. The survey areas were the K58, K62 benches and the K65 outer slope. The K62 slope and K65 bench areas were each divided into two sections due to the large areas involved. A survey was also made of the success of nodulation on the legumes in the rehabilitation areas.

8.5.2 Method

The study sites were similar with regard to the landforms. Being rehabilitated sites, they had undergone similar treatment of landscaping and initial rehabilitation work. However the differences were the angle of elevations of the sites and differences in soil mineralogy.

Table 8-5 Survey site and quadrates surveys

Location	Number of Quadrats
K 58 bench	4
K 62 slope (below tower)	4
K 62 slope (inside old fence)	4
K 62 bench	6
K 65 slope	4
K 65 bench (inside new fence line)	6
K 65 bench (outside fence line)	8
Total	**36**

In order to assess plant species frequency and composition 10 x 10 m quadrates were marked out at regular intervals across each site. The number of quadrates corresponded to the size and length of the rehabilitated site assessed (Table 8-5). Intervals of 50 m were used at smaller sites while 100 m separated individual quadrats at a larger site.

A number of recorders were lined up across each quadrat, and walked across the quadrate area selecting a leaf of each species encountered. A tally was then made of the number of species recorded. Species were separated as introduced species and natural species (colonization) and further subdivided into tree, grass weed and others (ferns and fungi). Legume plant roots from Silverleaf desmodium, white clover, Hunter River lucerne and pink clover were retrieved from the rehabilitation areas and examined to ascertain the efficacy of nodulation.

8.5.3 Preliminary Findings

The survey found a considerable change in the composition of the plant species present at Kogai stable dump:

- Sown species decreased from seven species (used in the seed mix) to five species in 2010. The locally adapted introduced legumes, Silverleaf desmodium and white clover were common at all sites.
- K62 slope was the only site with higher number of introduced plant species than local natural species.
- The frequency of introduced species was generally less than the frequency of local natural species.
- There a a significant decline in the number of planted tree species surviving on the K65 Bench.
- There was significant number of weeds and local species in the areas surveyed.
- There was no natural recruitment of any local tree species in the rehabilitation area.

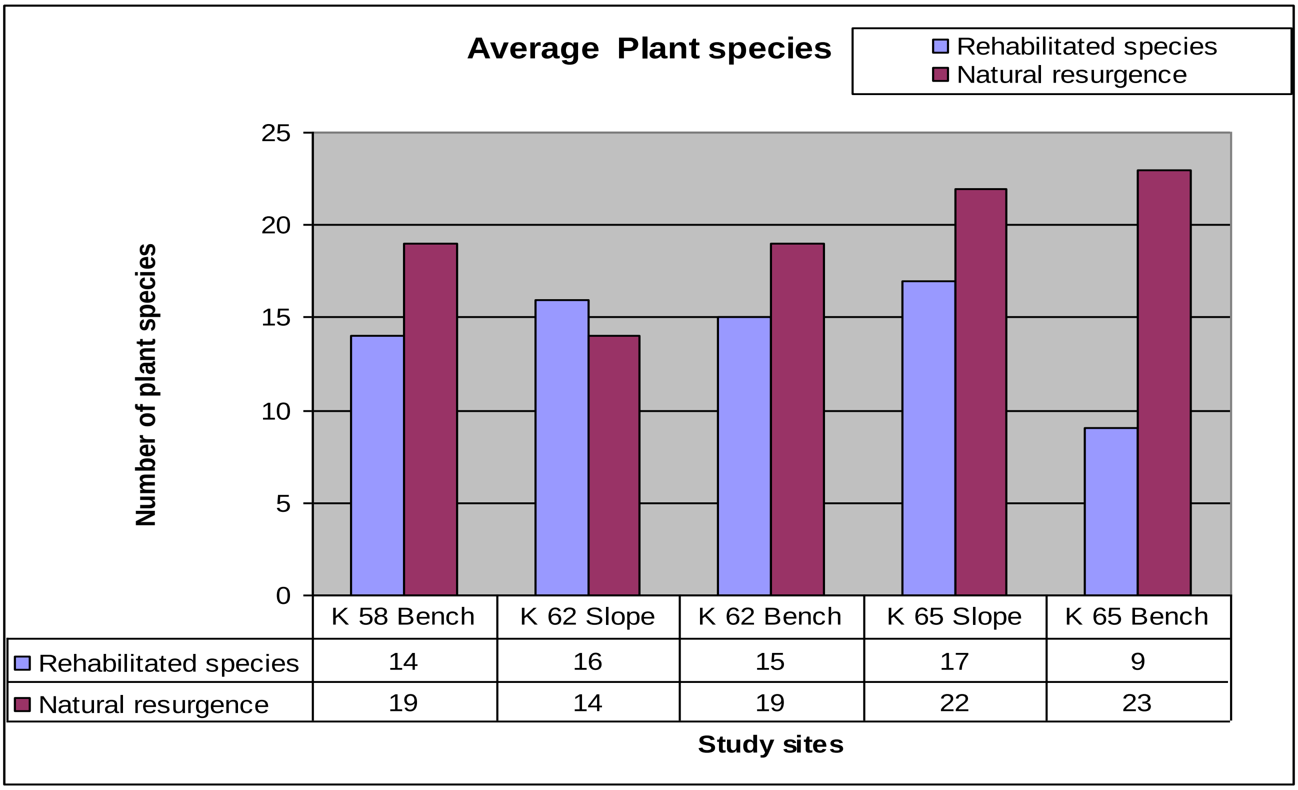


Figure 8-4 Average species frequency (observations/100 m^2)

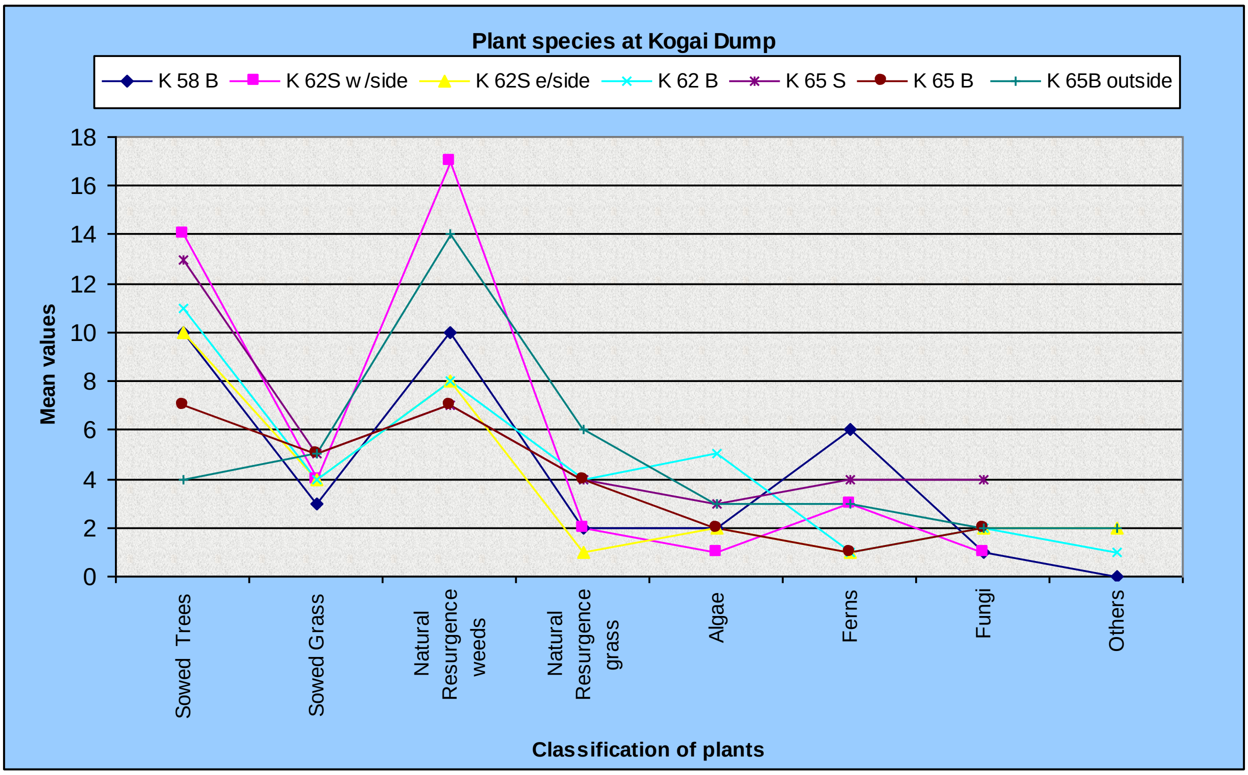


Figure 8-5 Different plant species at the Kogai stable dump

The preliminary findings revealed that the number of the sown/planted species is much less than the weeds that have successfully established themselves and eventually became the dominant plant species in the rehabilitated areas. On the contrary, K65 slope is the only rehabilitated site which has a slightly higher number of rehabilitated species of 16 plant species compared to natural colonizer which had only 14 species.

8.5.4 Rehabilitated Species (planted local tree species and sown pasture species)

The western side of Kogai stable dump rehabilitation area has performed well with high groundcover and healthy tree seedlings (see plates below).

Plate 8-3 Rehabilitation on the K62 slope

Plate 8-4 Rehabilitation on the K62 bench

These favorable results could be attributed to:

- Use of fertilizer to overcome nutritional deficiencies
- Regular rehabilitation maintenance includingslashing for weed control and application of fertilizer around planted tree seedlings

Recently, the Land Rehabilitation Section has reduced the planting spacing between trees from 5 x 5 m to 3x 3 m to reduce competition from the groundcover species and encourage rapid canopy closure.

Rehabilitation on the eastern part of the Kogai stable dump was generally poorer than on the western side. The eastern sites had less plant ground cover and trees seedlings were stunted and unhealthy. The reason for poor performance on this slope has yet to be investigated.

The slope and benches at Kogai stable dump are large and maintenance of the rehabilitation areas on remote parts of the dump is often neglected. Trees often suffer from nutrient deficiency and weed competition during the early stages of growth, so careful management is needed.

At K58 bench Q4, the sown pasture species were very vigorous. Silverleaf desmodium formed a thick groundcover which suppressed tree growth. With future rehabilitation works, consideration may be given to reducing the seeding rate of this species.

8.5.5 Weeds / Natural Resurgence

The natural recruitment of grass, weeds and herbaceous species has increase significantly over time becoming the dominant groundcover component. This effect is clearly evident on the K65 bench which has the lowest percentage of sown species and some 77% of naturally occurring grasses and weeds.

A large area of K65 bench is located outside the new security fence and is one of the least maintained rehabilitation sites. This area has little sown groundcover and few trees, and has become dominated by weeds.

The decline of sown/planted species in this area results from damage by illegal trespassers who have access to the unfenced area of the dump.

The assessment of nodules on each of the legume species present found that nodulation was effective with pink to red nodules present on each species.

8.5.6 Conclusions

Generally, weeds have become common in the rehabilitation areas on the Kogai stable dump because of favourable growing conditions. In future, rehabilitation maintenance, regular slashing and/or spraying around seedlings will greatly enhance the establishment and development of forest species on Kogai stable dump.

No data have been presented here on the success or otherwise of the tree species used in the rehabilitation program. This will be addressed in future monitoring programs.

The nodulation assessment on the legumes species in the rehabilitation areas showed that all species were effectively nodulated.

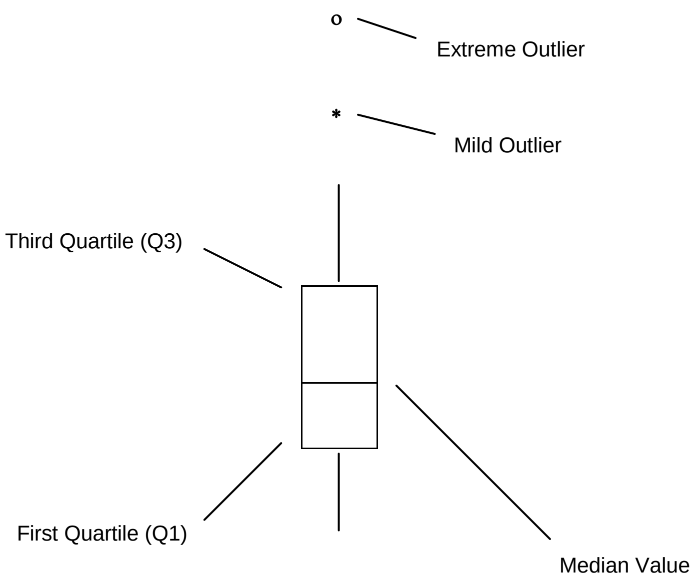
APPENDIX 1 Interpretation of Box Plots

Box Plots

In a box plot, 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)



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 2

QUALITY CONTROL FOR COMPLIANCE MONITORING

1 JANUARY – 31 DECEMBER 2010

1.0 Quality Control Report for Compliance Monitoring

1.1 Introduction

Quality assurance (QA) is an integral part of every activity within the PJV Environmental Chemistry Laboratory. A comprehensive program is in place to ensure that all environmental monitoring data meet QA and quality control requirements. Samples are collected and analysed by trained personnel in accordance to validated standard operating procedures that are designed to ensure that samples are representative and data are reliable and defensible. Quality control in the Environmental Chemistry Laboratory is maintained through instrument calibration and the inclusion of a comprehensive range of quality control samples that monitors accuracy and precision of data generated.

In 2010, the National Measurement Institute (NMI) laboratory in Australia was subcontracted to analyse trace metals, ammonia and free cyanide while the on-site Environmental Chemistry Laboratory analysed pH, sulfate, total suspended solids (TSS) and biochemical oxygen demand. The NMI laboratory is ISO17025 accredited by National Association of Testing Authorities (NATA) for all subcontracted tests and also has ISO 9001 certification. The Environmental Chemistry Laboratory is ISO17025 accredited by Papua New Guinea Laboratory Accreditation Scheme (PNGLAS) for all analysis included in this report.

Both the NMI laboratory and the PJV Environmental Chemistry Laboratory have established Quality Assurance/Quality Control (QA/QC) Programs to ensure that the accuracy, precision and reliability of environmental data are consistent with best practice. Below is a schematic that outlines the QA/QC Program that PJV has in place to assure the quality of its compliance monitoring data.

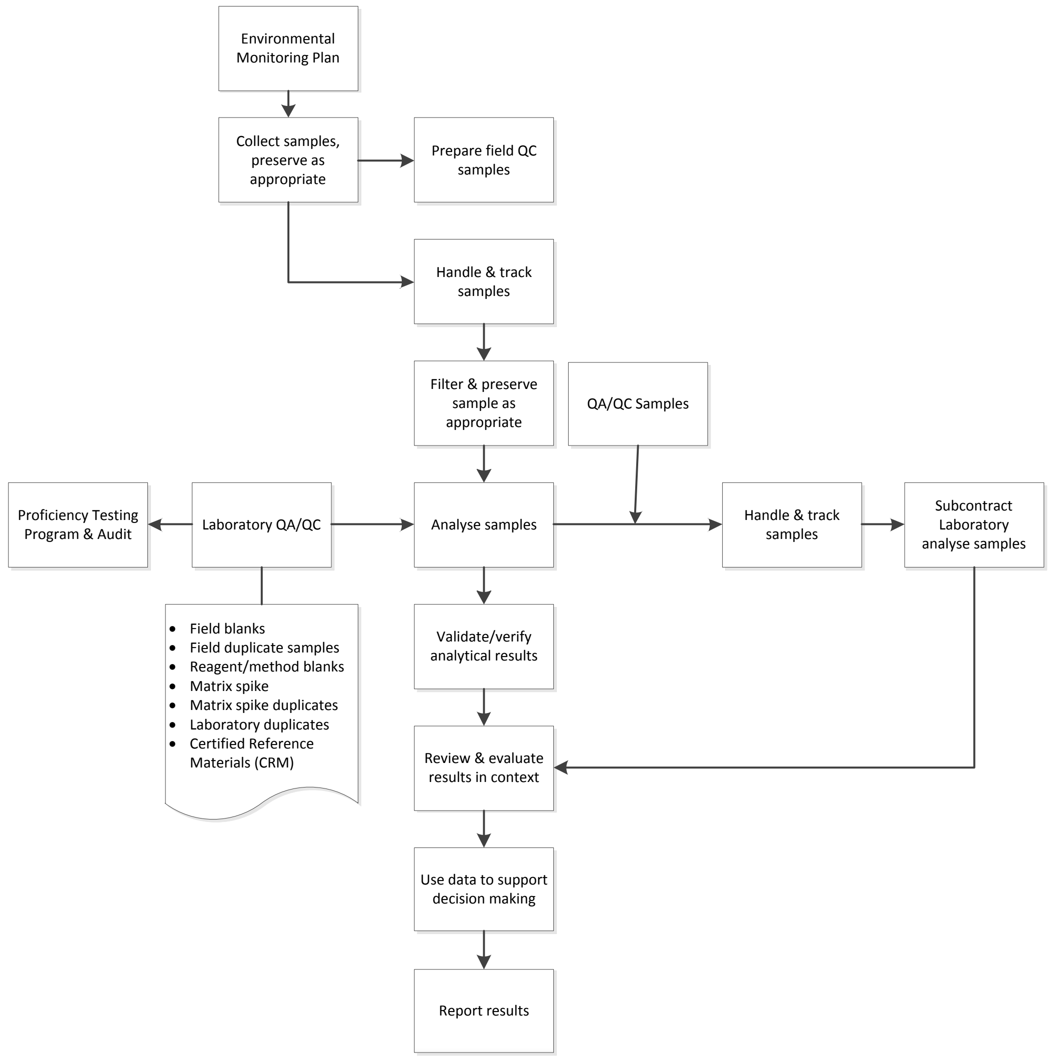


Figure 1-1 Schematic outline of PJV environmental laboratory QA/QC program
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1.2 Quality Assurance/Quality Control (QA/QC) Program

1.2.1 Sample Collection and Handling

In 2010, environmental monitoring samples were collected as specified by standard operating procedures (SOPs). These SOPs document sampling requirements, field QA/QC sample collection, acceptance criteria, sample custody requirements and data validation procedures.

Correct sampling, preservation, storage, transport and holding times are pivotal to the accuracy of our environmental compliance data. Porgera Joint Venture followed the requirements for sample storage, preservation and holding times as outlined in APHA Standard Methods for the Examination of Water & Wastewater, 21st Edition. For example, at the time of sample collection, sodium hydroxide was added to samples intended for free cyanide analysis, in order to adjust the pH to >12.0 for preservation and prevention of loss of free cyanide by volatilization.

QC checks of sampling processes included the collection of field duplicates and field blanks.

Field sampling technicians were responsible for the care and custody of samples until they are transferred to the Environmental Chemistry Laboratory. Samples requiring refrigeration are placed immediately into chilled coolers. The technician who maintains custody of the samples signs the COC form when relinquishing custody of them. The Environmental Chemistry Laboratory when receiving the samples signs the COC form when accepting custody.

The field sampling technician is also required to maintain field logbook, which is filled out when samples are collected. The field technician records sample ID, collection time, description, collection method, and COC number, as well as notes on daily weather conditions, field measurements, and other appropriate site-specific observations.

1.2.2 Field Quality Control Samples

Field QC samples collected for the environmental monitoring program include field blanks and field duplicate samples;

Field blanks are collected to check for cross contamination that might occur during sample collection. To create a field blank, deionised water is taken into the field and sample bottles are filled with the water at the sampling site. One field blank is collected for every twenty samples, or one per sampling round, whichever was more frequent. Field blanks are analysed for the same parameters as the water samples.

Field duplicate samples are analysed to check the reproducibility of sampling and analytical results. Duplicate samples are taken from the same site, at the same time, using the same method and independent analysed.

1.2.3 Laboratory Quality Control Samples

Reagent / method blanks are a volume of deionised laboratory water carried through the entire analytical procedure, including sample preparation and therefore contains the same reagent concentration as the samples. Analysis of a reagent blank verifies that interferences from contaminants in reagents, glassware and other sample processing devices are quantified.

Matrix spikes are used to assess the accuracy of an analysis by identifying matrix effects that could account for a positive or negative bias to the analytical result. Matrix spikes were prepared at the PJV Environment Laboratory for each batch of samples.

Matrix spike duplicates are sample replicates spiked with identical concentrations of target analyte(s). The spiking occurs during the sample preparation and prior to the extraction/digestion procedure. Duplicate spike blanks were prepared at the PJV Environment Laboratory for each batch of samples. They are used to document the precision and bias of a method in a given sample matrix. A duplicate spiked sample was analysed at least every 20 samples.

Laboratory duplicates are two aliquots taken from the same sample container that are processed and analysed separately. Results are used to measure analytical precision from sample preparation through analysis for a given matrix. A duplicate sample is analysed every 20 samples or per batch whichever is less.

Certified reference material is a primary reference material which is accompanied by a certificate with one or more property values accurately determined by a number of selected laboratories (with a stated method), and each certified value is accompanied by an uncertainty at a stated level of confidence.

1.2.4 Verification and Validation of Analytical Results

Environmental monitoring data are subjected to data quality assessment which occurs in two phases. The first phase consists of reviewing and determining the validity of the analytical data and the second phase consists of interpreting the data to determine its usability. Data verification and data validation are performed in accordance with established procedures with the PJV Environmental Chemistry Laboratory.

The data verification process involves checking for common errors associated with analytical data. The following criteria cause data to be rejected during the data verification process:

- Holding time missed – analysis is not initiated within documented time frame
- Preservation requirements not met – requirements identified by the specific analytical method are not met or properly documented.
- Invalid chain-of-custody – failure to maintain proper custody of samples, as documented on COC forms.
- Contamination of samples - identified from field and laboratory blanks.
- Poor recovery – analyte(s) added to samples before laboratory processing are not recovered within acceptance limits.
- Matrix interference – analysis is affected by inorganic/organic substances in the sample matrix.

Data validation is a more extensive process that includes all the verification checks as well as checks for less common errors, including calibration, transcription errors, and calculation errors.

Data usability analysis involves reviewing the data in context with site history, and historical analytical data.

1.2.5 External Quality Assurance

The routine quality assurance measures described above are performed by the PJV Environmental Chemistry Laboratory. External measures listed below are also part of the laboratory's quality assurance program:

- Audit program – performed both internally and externally. Internal audits as part of the laboratory's quality system and external audits, for example, accreditation surveillance audits where the laboratory is peer reviewed by an independent technical assessor,

- Proficiency Testing – independently assess the laboratory's test methods, quality assurance program and provides independent evidence of the validity of the laboratory's analysis. The PJV Environmental Chemistry Laboratory participated in

  two separate proficiency test programs every year for all test methods under the scope of accreditation.

1.3 Objective

The objective of this section of the report is twofold;

- to verify the reliability of the reference standard data for aqueous reference samples and
- use the reference standard data to measure performance of the subcontracted laboratory, National Measurement Institute (NMI), and the PJV Environmental Chemistry Laboratory.

The following key characteristics were used in the verification processes:

- *Accuracy* – closeness of the measured value to the true value for the aqueous reference samples.
- *Precision* – random error introduced by using the test method, a general term for the variability between repeated tests. Precision was calculated for all dissolved metal analyses.

This section presents the quality control data from the compliance monitoring programs at SG3 on the Strickland River and at sewage treatment plants located around the mine site.

Certified and internal reference standards were employed in 2010 for all the compliance monitoring activities. Internal reference standards; pH and free cyanide were prepared from primary standards and these were compared with certified reference standards that were ordered from Graham B. Jackson Pty Ltd in Australia. The standards were prepared by ERA Waters Company in U.S.A. These standards were used as quality control checks for the compliance monitoring samples.

pH, sulfate, total suspended solids (TSS) and biochemical oxygen demand were analysed onsite while trace metals, ammonia and free cyanide tests were analysed by the NMI laboratory. Dissolved arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver and zinc were the only metals monitored in the environmental management plan.

1.4 Trace Metals

1.4.1 Reference Standards

A single reference standard (ERA Lot No. 210709) for dissolved metals was ordered from Graham B. Jackson Pty Ltd in Australia and used by the laboratory during 2010. The standard was prepared by ERA Waters Company in USA. The standard was packaged in two 24mL screw-top vials containing approximately 23mL of standard concentrate in each vial and preserved with up to 10% v/v nitric acid. The standard was found to be homogenous at 95% confidence level and certified by evaluation in inter-laboratory testing programs. The standard was diluted in the laboratory following instructions from the manufacturer and used as the quality control check for compliance monitoring samples. Immediate actions were taken when results were out of the acceptance limits and records maintained as required by the laboratory quality system.

1.4.2 Field and Laboratory Blank Samples

Field duplicates and laboratory blank samples were prepared during the field sampling and laboratory filtration processes as a check of sample contamination. One field duplicate and one field blank were prepared for every 8 field samples. These samples were prepared from normal laboratory grade (de-ionised) water. Bottles were acid washed and rinsed three times with laboratory grade water and packed in zip-lok bags prior to sampling. Laboratory grade water was collected in 500mL acid washed bottle and packed in zip-lok bags. Blank samples were prepared using sterile gloves and preserved with ultra-pure nitric acid. For the field blanks they were carefully re-packed in zip-lok bags and stored in an esky containing ice before being transported back to the laboratory. The samples were sorted and stored refrigerated at 4°C ± 2°C in the laboratory prior to shipment for analysis.

1.5 Data Analysis

Basic statistical calculations of mean, standard deviation (STDEV), percent relative standard deviation *(%RSD=STDEVx100/mean*) and percentage recovery *(analytical mean x100/true mean)* were calculated on individual metals. Accuracy and precision tests were calculated on individual metal data where accuracy was expressed as percentage of recovery (%R) with acceptable range between 75-120%R and precision expressed as percentage relative standard deviation (%RSD). Statistical summaries of reference metal data are presented in Tables 1-1 and respective scatter plots are presented in Figure 1-2.

1.5.1 Reference Standard

The mean values of individual metals for the reference standard fall within their respective certified acceptance limits detailed in Table 1-1. All metal recoveries were between 85–105%R and were within acceptable limits of 75–120%R. The precision for all metals was good between 5.4–10.5%RSD except dissolved Hg which had a precision of 28%RSD. The reason for the large mercury RSD is being investigated.

From the table it can be seen that recoveries for all metals, including mercury were good.

For all dissolved metals, 85% of the data falls within the acceptance limits while 15% were outside the limits. The most notable one was dissolved Hg where six results fell outside the acceptance limits. Dissolved Cr, Cu and Zn had few results outside the accepted limits.

Table 1-1 Statistical data for Trace Metals Standard ERA Lot No. 210709 used in 2010

Certified values			Statistical Analysis of NMI Test Results		
Metals	Mean (µg/L)	Accepted Limits[4] (µg/L)	Mean[1] (µg/L)	% RSD[2]	% Recov[3]
As-D	102	90 - 114	103	5.7	101
Cd-D	11.7	10.6 - 12.8	12	5.4	102
Cr-D	274	249 - 299	265	6.5	97
Cu-D	301	272 - 329	291	8.2	97
Pb-D	88.3	79.2 - 97.3	88	5.6	100
Hg-D	1.93	1.52 - 2.34	1.6	28	81
Ni-D	274	248 - 300	268	8.0	98
Ag-D	50.4	45.3 - 55.5	51	5.7	101
Zn-D	109	98.3 - 120	115	10.5	105

Mean[1] = test mean of 13 replicates; %RSD[2] = per cent relative standard deviation; % Recov[3] = percentage recovery; Accepted Limits[4] = ERA accepted limits (control limits) and certified mean.

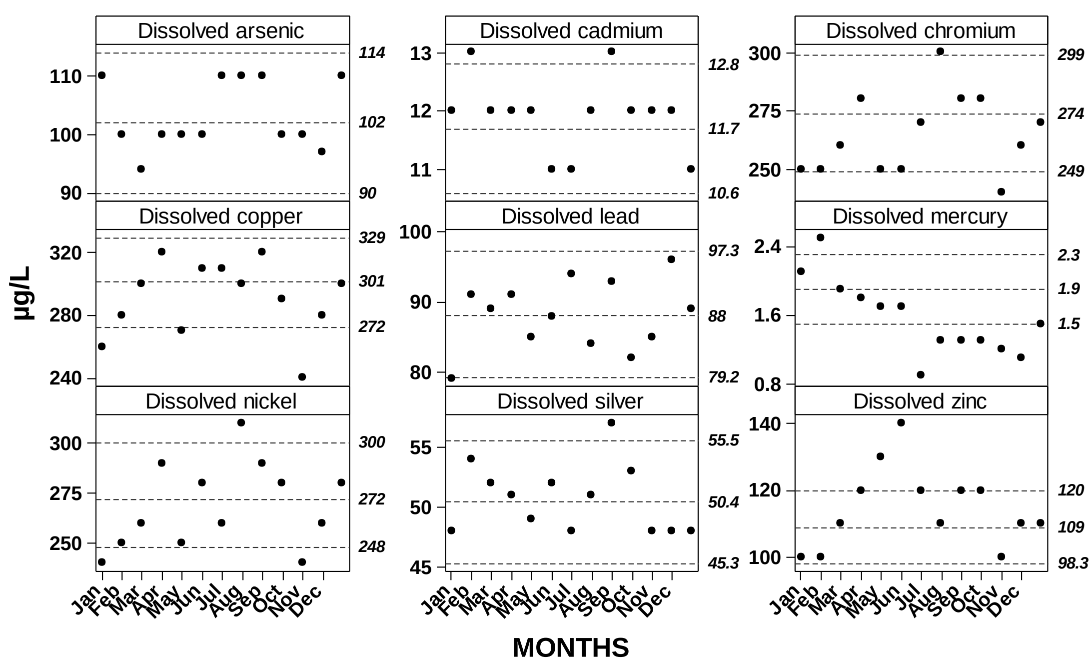

Figure 1-2 Scatter plots of metals for trace metal reference standard used in 2010

1.5.2 Field and Laboratory Blank Samples

Dissolved metal data for field and laboratory blank samples are presented in Tables 1-2 and 1-3, respectively. Essentially dissolved metal concentrations for As, Cd, Cr, Cu, Pb, Hg, Ni and Ag for both field and laboratory blank samples were below the method detection levels. Dissolved Zn concentrations above the method detection limit were seen in both field and laboratory blanks. All laboratories work hard to minimise contamination, zinc is ubiquitous, and without specially constructed clean rooms these levels are unachievable. The levels of contamination observed in the blanks do not detract from the usefulness of the analytical data.

Table 1-2 Metals Data for Field Blank Samples

Date	As-D	Cd-D	Cr-D	Cu-D	Pb-D	Hg-D	Ni-D	Ag-D	Zn-D
5-Mar-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
6-Mar-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
7-Apr-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	2
9-Apr-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.4
13-May-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
15-May-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
9-Jun-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	7.8
11-Jun-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	5.3
19-Jul-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	2.6
20-Jul-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.7
21-Aug-10	<1	<0.2	1.2	<1	<0.5	<0.1	<1	<0.2	1.1
22-Aug-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
22-Sep-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	2.3
23-Sep-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
6-Oct-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.5
7-Oct-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
6-Nov-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.2
6-Nov-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
3-Dec-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.8
4-Dec-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.9

Table 1-3 Metals Data for Laboratory Blank Samples

Date	As-D	Cd-D	Cr-D	Cu-D	Pb-D	Hg-D	Ni-D	Ag-D	Zn-D
16-Jan-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
14-Feb-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
11-Mar-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.6
14-Apr-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.2
18-May-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.7
20-Jun-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.3
24-Jul-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
28-Aug-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
26-Sep-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.9
10-Oct-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.4
7-Nov-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.1
8-Dec-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	2.9

1.6 Physicochemical Parameters

1.6.1 Internal pH Standard

Three pH standards were prepared internally by the laboratory in 2010 from high purity reagents. Different analysts conducted replicate tests on the standards and data generated were statistically analyzed to derive mean, upper and lower control limits. The standards were used internally as quality control checks for SG3 compliance monitoring samples and onsite treated sewage effluent samples for pH measurements.

Tables 1-4 to 1-6 present statistical analysis of the standard results. The mean value for the pH standard used in January, was 7.40 standard units (SU) and this value falls within the acceptable limit of 7.27–7.40 SU. The mean pH value of the standard used between February and November was 9.12 SU and falls within the acceptable limits of 9.02–9.18 SU. The standard used in December 2010 gave a pH mean of 7.41 SU and falls within the acceptable limits of 7.36–7.45 SU.

Table 1-4 Statistical Data for pH Internal Standard used in Jan 2010

pH Internal Standard (SU)			
Internal Control Limits		Statistical Analysis	
Limits	mean	Analytical mean	% Recovery
7.27 – 7.40	7.34	7.40*	NA

*Mean of 15 tests

Table 1-5 Statistical Data for pH Internal Standard used between Feb and Nov 2010

pH Internal Standard (SU)			
Internal Control Limits		Statistical Analysis	
Limits	mean	Analytical mean	% Recovery
9.02 – 9.18	9.10	9.12*	NA

*Mean of 195 tests

Table 1-6 Statistical Data for pH Internal Standard used in Dec 2010

pH Internal Standard (SU)			
Internal Control Limits		Statistical Analysis	
Limits	mean	Analytical mean	% Recovery
7.36 – 7.45	7.41	*7.41	NA

* Single sample value

1.6.2 Internal Free Cyanide Standard

Internal free cyanide standard was also prepared from high purity reagent and preserved with 0.16 % sodium hydroxide solution. Replicate tests were carried out by three different analysts and results obtained were compared against the theoretical value and control limits derived. This standard was used as quality control check for compliance monitoring samples for free cyanide analyses. The free cyanide tests for compliance monitoring samples were done by NMI laboratory.

Table 1-7 presents statistical data for the standard. The analytical mean value was 2.5 mg/L and falls within the acceptable limit of 2.1–2.8 mg/L and percentage recovery was 100%R.

Table 1-7 Statistical Data for Free Cyanide Standard used in 2010

Free Cyanide Internal Standard (mg/L)			
Internal Control Limit		Statistical Analysis	
Limits	mean	Analytical mean	% Recovery
2.1 – 2.8	2.5	*2.5	100

*Mean data for 16 tests

1.6.3 Ammonia Certified Standard

Ammonia certified standard (ERA Lot No. 137219) was ordered from Graham B. Jackson Pty Ltd in Australia. The standard material was prepared by the ERA Waters Company in U.S.A. It was packed in two 24mL screw-top vials containing approximately 23mL of standard concentrate in each vial and was preserved with 1% v/v hydrochloric acid. The sample was diluted in the laboratory according to the manufacturer instructions prior to analysis. The standard was used as internal quality control check for ammonia analyses on the compliance monitoring samples. Ammonia testing was conducted by the NMI laboratory.

Table 1-8 presents statistical data for the standard. Mean ammonia concentration was 3.6 mg/L and falls within the acceptable limits of 2.98-4.02 mg/L and percentage recovery was 101 %R.

Table 1-8 Statistical Data for Ammonia Standard used in 2010

Ammonia Certified Standard; ERA Lot No. 137219 (mg/L)			
Certified Values		Statistical Analysis	
Certified limits	Certified mean	Analytical mean	% Recovery
2.98–4.02	3.5	*3.6	101%

*Mean data for 12 tests

1.6.4 Certified Sulfate Standard

The certified sulfate standard (ERA Lot No. 137222) used by the laboratory in 2010 was ordered from Graham B. Jackson Pty Ltd in Australia. The standard was prepared by the ERA Waters Company in U.S.A. It was packed in two 24mL screw-top vials containing approximately 23mL of standard concentrate in each vial and was not preserved. The sample was diluted and prepared in the laboratory according to the manufacturer's instructions. The sample was used as internal quality control check for SG3 compliance monitoring samples for sulfate analysis. The sulfate tests were carried out onsite by the PJV Environmental Laboratory.

Table 1-9 presents statistical data for the standard. The mean sulfate concentration was 94.9mg/L from 12 replicate tests and falls within the acceptable limits of 81.8-112 mg/L. The sample recovery was 98.1 %.

Table 1-9 Statistical Data for Sulfate Standard used in 2010

Sulfate Standard, ERA Lot No. 137222 (mg/L)			
Certified Values		Statistical Analysis	
Certified limits	Certified mean	Analytical mean	% Recovery
81.8-112	96.7	*94.9	98.1

*Mean data for 12 tests

1.6.5 Biochemical Oxygen Demand Certified Reference Standard

Certified biochemical oxygen demand standard (ERA Lot No. 138908) was ordered from Graham B. Jackson Company in Australia. The standard material was prepared by the ERA Waters Company in U.S.A. It was packed in a 15mL screw top vial containing approximately 14mL of standard concentrate and was preserved with approximately 1% v/v hydrochloric acid. The sample was prepared in the laboratory according to the instructions by the manufacturer. The standard was used as quality control check for treated sewage effluent samples at the mine site for BOD analyses. The BOD tests were carried out onsite.

Table 1-10 presents statistical data for the standard. Mean BOD concentration was 28.9 mg/L and falls within the acceptable limits of 20.9–42.9 mg/L. The percentage recovery was 90.8%R.

Table 1-10 Statistical Data for Certified BOD Standard used in 2010

Biochemical Oxygen Demand; ERA Lot No. 138908 (mg/L)			
Certified Values		Statistical Analysis	
Certified limits	Certified mean	Analytical mean	% Recovery
20.9–42.9	31.8	*28.9	90.8

*Mean data for 64 tests

1.6.6 Total Suspended Solids (TSS)

Three total suspended solids standards were ordered from Graham B. Jackson Pty Ltd in Australia and used throughout the year. These standards were prepared by the ERA Waters Company in U.S.A. They were packed in 24mL screw cap vials containing solid concentrates and were not preserved. The samples were diluted in the laboratory prior to analysis per instructions given by the manufacturer. TSS standard Lot No. 310109 was used from January to May 2010, Lot No. 470409 was used from June to November 2010 and Lot No. P-178-4032 was used in December 2010. These standards were used as quality control standards for SG3 compliance monitoring samples and treated sewage effluent samples. The TSS analyses were carried out onsite.

Tables 1-11 to 1-13 present statistical data for the standards. The TSS mean for standard Lot No. 310109 was 38.5mg/L and percentage recovery was 100.8%R. The TSS mean for Lot No.470409 was 58.7mg/L and percentage recovery was 94.7%R. For Lot No P-178-4032 the mean TSS value was 37.2mg/L and percentage recovery was 92.6%R. All TSS analytical means were within the certified limits including the percentage recoveries.

Table 1-11 Statistical Data for Certified TSS Standard used between Jan and May 2010

Total suspended solids; ERA Lot No. 310109 (mg/L)			
Certified Values		Statistical Analysis	
Certified limits	Certified mean	Analytical mean	% Recovery
28.1 – 44.4	37.9	38.2*	100.8

*Mean value of 20 tests

Table 1-12 Statistical Data for Certified TSS Standard used between Jun and Nov 2010

Total suspended solids; ERA Lot No. 470409 (mg/L)			
Certified Values		Statistical Analysis	
Range	Certified mean	Analytical mean	% Recovery
49.4 – 70.0	62	58.7*	94.7

*Mean value of 25 tests

Table 1-13 Statistical Data for Certified TSS Standard used in Dec 2010

Total suspended solids; ERA Lot No. P-178-4032 (mg/L)			
Certified Values		Statistical Analysis	
Certified limits	Certified mean	Analytical mean	% Recovery
33.9 – 46.4	42.9	37.2*	92.6

*Mean value of 4 tests

1.7 Discussion

There was good precision and accuracy between metal results for the reference sample employed by the laboratory in 2010 as statically demonstrated by the data. The accuracy of standards for the physicochemical parameters was also good. The performance of the two laboratories was acceptable.

1.8 Conclusion

For the purpose of this report, there was good accuracy and precision for the quality control samples employed in 2010 for metals analyses. Therefore water quality monitoring data for SG3 were accepted.

2.0 Quality Control Report for Tailings, Local Creeks, Rivers and Lake Murray

2.1 Introduction and Objective

The objectives of this section of the report are the same as described in Section 1.2.

2.2 Trace Metals

2.2.1 Reference Standards

The same trace metals reference samples were used as quality control checks for the Tailings, Local Creeks, Rivers and Lake Murray water samples in 2010 as were detailed in Section 1 of this report.

2.2.2 Field and Laboratory Blank Samples

Field and laboratory blank samples were prepared during the field sampling and laboratory filtration processes to check for possible traces of contamination. These samples were prepared from normal laboratory grade (de-ionized) water. Bottles were acid washed and rinsed three times with laboratory grade water and packed in zip-lok bags prior to sampling. Laboratory grade water was collected in 500mL acid washed bottle and packed in zip-lok bags. Blank samples were prepared using sterile gloves and preserved with ultra-pure nitric acid. For the field blanks they were carefully re-packed in zip-lok bags and stored in an esky containing ice before being transported back to the laboratory. The samples were sorted and stored cool in the laboratory prior to shipment for analysis.

2.3 Data Analysis

Basic statistical data for mean, % RSD and % recovery are presented in Tables 2-1 to 2-3. All data were plotted against control charts as shown in Figure 2-1. As in Section 1.4 only accuracy and precision calculations were done on the reference samples employed.

2.3.1 Reference Standard

There was good agreement between the certified and analytical means of all dissolved metals as can be seen from Table 2-1. All metals showed good recoveries between 80 and 105%R and were within acceptable ranges (75%-120%R). The % RSD for most metals were between 4.4–10.5%RSD except for Hg. Overall 89% of the data fall within the acceptable limits within ±3SD while 11% of the data fall outside of the limits.

Table 2-1 Statistical data for Trace Metals Standard ERA Lot No. 210709 used in 2010

Certified values			Statistical Analysis of NMI Test Results		
Metals	Mean (µg/L)	Accepted Limits[4] (µg/L)	Mean[1] (µg/L)	% RSD[2]	% Recov[3]
As-D	102	90 - 114	102	5.2	100
Cd-D	11.7	10.6 - 12.8	12	4.4	101
Cr-D	274	249 - 299	260	4.9	95
Cu-D	301	272 - 329	291	5.7	97
Pb-D	88.3	79.2 - 97.3	89	5.2	100
Hg-D	1.93	1.52 - 2.34	1.5	22	80
Ni-D	274	248 - 300	262	6.0	95
Ag-D	50.4	45.3 - 55.5	50	4.8	100
Zn-D	109	98.3 -120	115	10.5	105

Mean[1] = test mean of 13 replicates; %RSD[2] = per cent relative standard deviation; % Recov[3] = percentage recovery; Accepted Limits[4] = ERA accepted limits (control limits) and certified mean.

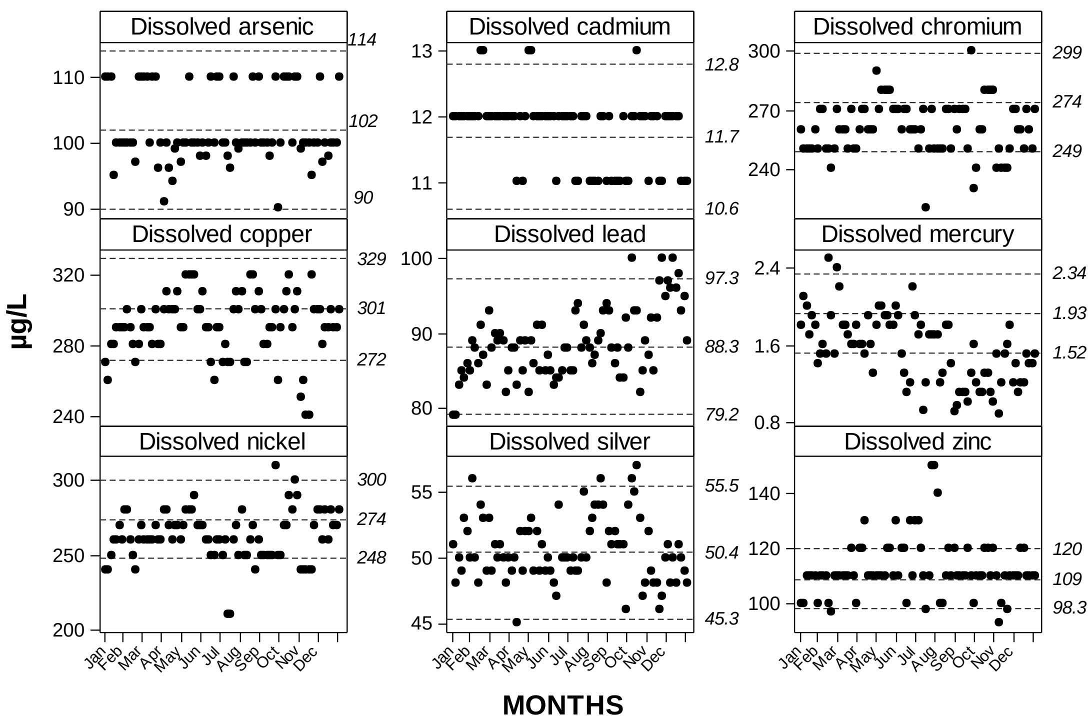

Figure 2-1 Scatter plots of metals for trace metal reference standard used in 2010

2.3.2 Field and Laboratory Blank Samples

Dissolved metal data for field and laboratory blank samples are presented in Tables 2-2 and 2-3, respectively. As discussed in Section 1.5.2, dissolved metal concentrations for As, Cd, Cr, Cu, Pb, Hg, Ni and Ag for both field and laboratory blank samples were below the method detection levels. Dissolved Zn concentrations above the method detection limit were seen in both field and laboratory blanks. All laboratories work hard to minimise contamination, zinc is ubiquitous, and without specially constructed clean rooms these levels are unachievable The levels of contamination observed in the blanks does not detract from the usefulness of the analytical data.

Table 2-2 Dissolved Metals Data for Field Blank Samples

Date	As-D	Cd-D	Cr-D	Cu-D	Pb-D	Hg-D	Ni-D	Ag-D	Zn-D
03-Mar-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	3
03-Mar-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1
10-Mar-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
02-Apr-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
07-Apr-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
07-Apr-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
05-Apr-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
05-Apr-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
10-Apr-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
20-Apr-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.1
07-May-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
29-Apr-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	3.3
30-Apr-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
01-May-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	7.8
16-May-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	2.1
01-Jun-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.2
13-Jun-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	1.7
02-Jul-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	3.8
01-Jul-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	3.8
21-Jul-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	3.2
24-Aug-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	<1
24-Sep-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	2.1
08-Oct-10	<1	<0.2	<1	<1	<0.5	<0.1	<1	<0.2	2.7

Table 2-3 Dissolved Metals data for Laboratory Blank Samples

Date	As-D	Cd-D	Cr-D	Cu-D	Pb-D	Hg-D	Ni-D	Ag-D	Zn-D	As-D
15-Jan-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
18-Jan-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
26-Jan-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
06-Feb-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	1.1
10-Feb-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
15-Feb-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
07-Mar-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	2.3
14-Mar-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	1.2
01-Apr-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	2.6
11-Apr-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
13-Apr-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
13-Apr-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
14-Apr-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	1.5
24-Apr-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
27-Apr-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
02-May-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
14-May-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
18-May-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	4.5
18-May-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	2.1
05-Jun-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	3
04-Jun-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	1.1
10-Jun-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	2.4
20-Jun-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	1.5
02-Jul-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
10-Jul-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	1.5
19-Jul-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
24-Jul-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	3.4
04-Aug-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	3.4
04-Aug-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	2.3
15-Aug-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	2.9
28-Aug-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
14-Sep-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
14-Sep-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
28-Sep-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	1.3
05-Oct-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	<1
05-Oct-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	1.7
05-Oct-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	1.8
10-Oct-10	<1	<0.2	<1	<1	<5	<0.5	<0.1	<1	<0.2	3.5

2.4 Other Physicochemical Parameters

2.4.1 Internal pH Reference Standards

Three pH reference standards were prepared internally from high purity reagents by the laboratory and used in 2010. Replicate tests were conducted by different analysts and data generated were statically analysed to derive mean, upper and lower control limits. Internal Reference Material (IRM) pHs were recorded during the calibration of the pH meter and in between sample measurements These samples were used as quality control checks for Tailings, Local Creeks, Rivers and Lake Murray water samples for pH measurements.

Tables 2-4 to 2-6 present statistical data for the standards employed. The analytical pH mean for the standard used in January was 7.36 pH SU and falls within the acceptable range of 7.27–7.40 pH SU.The mean pH of the standard used between February and November was 9.12 and falls within the recommended limits of 9.02–9.18 pH SU. For the standard used in December, the mean pH value was 7.40 pH SU and falls within the acceptable limits of 7.36–7.45 pH SU.

Table 2-4 Statistical Data for pH Internal Standard used in Jan 2010

pH Internal Standard (SU)			
Internal Control Limits		Statistical Analysis	
limits	mean	Analytical mean	% Recovery
7.27–7.40	7.34	7.36*	NA

*Mean value for 34 tests

Table 2-5 Statistical Data for pH Internal Standard used between Feb and Nov 2010

pH Internal Standard (SU)			
Internal Control Limits		Statistical Analysis	
limits	mean	Analytical mean	% Recovery
9.02–9.18	9.10	9.12*	NA

*Mean value for 195 tests

Table 2-6 Statistical Data for pH Internal Standard used in Dec 2010

pH Internal Standard (SU)			
Internal Control Limits		Statistical Analysis	
limits	mean	Analytical mean	% Recovery
7.36–7.45	7.40	*7.40	NA

*Mean value for 30 tests

2.4.2 Certified Total Cyanide Standard

Certified total cyanide standard (ERA Lot No. P162-502) employed by the laboratory in 2010 was ordered from Graham B. Jackson Pty Ltd in Australia. The standard material was prepared by the ERA Waters Company in USA. It was packaged in a 15mL screw-top vial containing approximately 14mL of standard concentrate and was preserved with 0.2% w/v sodium hydroxide. The standard was diluted in the laboratory according to the manufacturer’s instructions prior to analysis. The standard was used as a quality control check for processing plant samples for total cyanide analyses. The total cyanide analyses were carried out onsite.

Table 2-7 presents statistical data for the standard. The analytical mean concentration was 0.742mg/L and falls within the acceptable range of 0.601–0.972mg/L and percentage recovery was 87.7%R.

Table 2-7 Statistical Data for Total Cyanide Standard used in 2010

Total Cyanide Standard (mg/L); ERA Lot No.P162 - 502			
Certified Values		Statistical Analysis	
Certified limits	Certified mean	Analytical mean	% Recovery
0.601 – 0.972	0.814	0.742	87.7%

*Mean value for 47 tests

2.4.3 Internal Free Cyanide Standard

Two free cyanide standards were prepared internally by the laboratory and used as quality control check for Tailings Ex-pipe water samples. The standards were prepared from high purityreagents and were preserved with 0.16% sodium hydroxide solution. Replicate tests were carried out by three different analysts and results obtained were compared with the theoretical value The standard was used as quality control check for processing samples for free cyanide analysis. The free cyanide tests were done onsite.

Tables 2-8 and 2-9 present statistical data for the standards. The analytical mean value of the first standard used between January and October was 2.4mg/L and falls within the acceptable range of 2.15–2.84mg/L and percentage recovery was 96%R. The second standard employed between November and December had a mean of 1.58 mg/L which also falls with the recommended limits of 1.35–1.88mg/L and percentage recovery was 98.1%R.

Table 2-8 Statistical Data for Free Cyanide Standard used between Jan and Oct 2010

Free Cyanide Internal Standard (mg/L)			
Internal Control Limits		Statistical Analysis	
limits	mean	Analytical mean	% Recovery
2.15–2.84	2.5	*2.40	96.0

*Mean value for 342 tests

Table 2-9 Statistical Data for Free Cyanide Standard used between Nov and Dec 2010

Free Cyanide Internal Standard (mg/L)			
Internal Control Limits		Statistical Analysis	
limits	mean	Analytical mean	% Recovery
1.35–1.88	1.61	*1.58	98.1

*Mean value for 38 tests

2.4.4 Thiocyanate Internal Standard

Two thiocyanate standards were employed by the laboratory during 2010 which were prepared internally from high purity reagents. Replicate tests were carried out by three different analysts and results obtained were compared with the theoretical value. The samples were used as quality control check for Tailings Ex-pipe water samples. The thiocyanate tests were done onsite.

Tables 2-10 and 2-11 present statistical data for the standards employed. The analytical mean of the standard used between January and November was 5.2mg/L and falls with the limits of 4.8–5.4mg/L. The recovery was 102%R. For the standard used in December, the analytical mean was 2.6mg/L and falls within the recommended limits of 2.2–2.9mg/L. The percentage recovery was 100%R.

Table 2-10 Statistical Data for Thiocyanate Standard used between Jan and Nov 2010

Thiocyanate Internal Standard (mg/L)			
Internal Control Limits		Statistical Analysis	
limits	mean	Analytical mean	% Recovery
4.8–5.4	5.1	*5.2	102

*Mean value for 304 tests

Table 2-11 Statistical Data for Thiocyanate Standard used in Dec 2010

Thiocyanate Internal Standard (mg/L)			
Internal Control Limits		Statistical Analysis	
limits	mean	Analytical mean	% Recovery
2.2–2.9	2.6	*2.6	100

*Mean value for 38 tests

2.4.5 Total Alkalinity Certified Standard

Certified total alkalinity standard (ERA Lot No. 137222) used by the lab in 2010 was ordered from Graham B. Jackson Pty Ltd in Australia. The standard was prepared by the ERA Waters Company in USA. It was packed in two 24mL screw-top vials containing approximately 23mL of standard concentrate in each vial and was not preserved. The sample was diluted and prepared in the laboratory according to the manufacturer's instructions. This sample was used by the laboratory as quality control check for Local Creeks, Rivers and Lake Murray water quality monitoring samples for total alkalinity. All total alkalinity tests were done onsite.

Table 2-12 presents statistical data for the standard. The mean total alkalinity concentration for the standard was 64.2mg/L and falls within the acceptable limits of 59.0–70.6mg/L and percentage recovery was 97.6%R.

Table 2-12 Statistical Data for Total Alkalinity Standard used in 2010

Total Alkalinity Standard (mg/L)			
Certified Values		Statistical Analysis	
Certified limits	Certified mean	Analytical mean	% Recovery
59.0 – 70.6	65.8	*64.2	97.6

*Mean data for 65 tests

2.4.6 Certified Sulfate Standard

The certified sulfate standard (ERA Lot No. 137222) employed by the laboratory in 2010 was ordered from Graham B. Jackson Company in Australia. The standard was prepared by the ERA Waters Company in U.S.A. It was packed in two 24mL screw-top vials containing approximately 23mL of standard concentrate in each vial and was not preserved. The sample was diluted and prepared in the laboratory according to the manufacturer's instructions. The sample was used by the laboratory as quality control check for Tailings, Local Creeks, Rivers and Lake Murray water quality monitoring samples for sulfate analysis. All sulfate analyses were done onsite.

Table 2-13 presents statistical data for the standard. The mean sulfate concentration was 94.8 mg/L and falls within the acceptable limits of 81.8-112mg/L. The percentage recovery was 97.7%R.

Table 2-13 Statistical Data for Sulfate Standard used in 2010

Sulfate Standard, ERA Lot No. 137222 (mg/L)			
Certified Values		Statistical Analysis	
Certified limits	Certified mean	Analytical mean	% Recovery
81.8 - 112	97.1	94.8*	97.7%

*Mean value for 108 tests

2.4.7 Chloride Certified Standard

The certified chloride standard (ERA Lot No. 137222) employed by the laboratory in 2010 was ordered from Graham B. Jackson Pty Ltd in Australia. The standard was prepared by the ERA Waters Company in U.S.A. It was packed in two 24mL screw-top vials containing approximately 23mL of standard concentrate in each vial and was not preserved. The sample was diluted and prepared in the laboratory according to the manufacturer's instructions. The sample was used by the laboratory as quality control check for Local Creeks, Rivers and Lake Murray water quality monitoring samples for chloride tests. All chloride tests were done onsite.

Table 2-14 presents statistical data of the chloride standard. The mean concentration of the standard was 127.2mg/L and falls within the acceptable limits of 116-140mg/L. The percentage recovery was 99.4%R.

Table 2-14 Statistical Data for Chloride Standard used in 2010

Chloride Standard**, ERA Lot No. 137222 (mg/L)**			
Certified Values		Statistical Analysis	
Certified limits	Certified mean	Analytical mean	% Recovery
116-140	128	*127.2	99.4

*Mean data of 68 tests

2.4.8 Total Suspended Solids Certified Standards

Three certified total suspended solids standards were ordered from Graham B. Jackson Pty Ltd in Australia and used throughout the year. These standards were prepared by the ERA Waters Company in USA. They were packed in 24mL screw cap vials containing solid concentrates and were not preserved. The samples were diluted in the laboratory prior to analysis following instructions given by the manufacturer. TSS standard lot No. 310109 was used from January to May 2010, Lot No. 470409 was used from June to November 2010 and Lot No. P-178-4032 was used in December 2010. The samples were used as quality control checks for Tailings, Local Creeks, Rivers and Lake Murray monitoring samples for TSS tests. All TSS tests were done onsite. The TSS of the Certified Standards ranged between 37.7 and 62 mg/L, which are not representative of the wide range of TSS measured in tailings and river waters. The purchase of Certified Standards with a wider range of TSS will be attempted.

Tables 2-15 to 2-17 present statistical data for the three TSS certified standards. All standards samples produced good means and recoveries. Standard 310109 produced a mean of 37.4mg/L and recovery of 98.6%R, standard 470409 had a mean of 58.8 mg/L and percentage recovery of 94.9%R while standard P-178-4032 had a mean of 40.2 mg/L and percentage recovery of 99.9%R.

Table 2-15 Statistical Data for TSS Standard used between Jan and May 2010

Total suspended solids; ERA Lot No. 310109 (mg/L)			
Certified Values		Statistical Analysis	
Certified limits	Certified mean	Analytical mean	% Recovery
28.1–44.4	37.7	*37.4	98.6

*Mean value of 56 tests

Table 2-16 Statistical Data for TSS Standard used between Jun and Nov 2010

Total suspended solids; ERA Lot No. 470409 (mg/L)			
Certified Values		Statistical Analysis	
Range	Certified mean	Analytical mean	% Recovery
49.4–70.0	62	*58.8	94.9

*Mean value of 25 tests

Table 2-17 Statistical Data for TSS Standard used in Dec 2010

Total suspended solids; ERA Lot No. P-178-4032 (mg/L)			
Certified Values		Statistical Analysis	
Certified limits	Certified mean	Analytical mean	% Recovery
33.9–46.4	42.9	*40.2	99.9

*Mean of 18 tests

2.5 Discussion

There was good accuracy and precision between metal results for the reference standards employed in 2010 for the Tailings, Local Creeks, Rivers and Lake Murray samples. The accuracy of standards for the physicochemical parameters was also good. Therefore, the performance of the laboratories was accepted.

2.6 Conclusion

All water quality data for the Tailings, Local Creeks, Rivers and Lake Murray samples for 2010 were accepted.

APPENDIX 3

BIOLOGICAL MONITORING TECHNICAL REPORT

1 JANUARY – 31 DECEMBER 2010

PORGERA
Joint Venture

BIOLOGICAL MONITORING TECHNICAL REPORT
2010

Prepared by: PJV Biology with assistance from Hydrobiology
Date: June 2011
Report No: PJV/ENV – 2/11

EXECUTIVE SUMMARY

This report summarises the biological data collected between 1 January and 31 December 2010.

The aims of the biological programs are twofold. Firstly, they provide specimens for tissue trace metal and sorbitol dehydrogenase (SDH) analyses that are useful for biomonitoring and human metal intake studies via aquatic food consumption. Secondly, they generate data to assess changes in the species richness, abundance and condition (state of health) of fish, and some invertebrates, that may have resulted from mining activities.

SPECIES RICHNESS, ABUNDANCE AND CONDITION

In the upper catchment, there was no evidence to suggest any mine-related impacts to the species richness, diversity, abundance or biomass of fish or prawns between potentially impacted and reference sites for the year 2010. Rank correlations did detect some significant decreases over time in number of species, abundance and biomass for prawns. At Wankipe, for the period 2000 to 2010, negative trends were observed for species richness, abundance and biomass of prawns that were not matched at the reference site at Tomu. And at Wasiba negative trends in prawn abundance and biomass were observed for the period 2000 to 2010 that were not matched at the reference site at Ok Om. Standardised sampling is not currently undertaken at the reference sites at Kuru River and Pori River due to the lack of suitable sandbank to perform seine netting. It is planned that during 2011 backpack electrofishing will be implemented at all upper catchment sites to increase the likelihood of achieving sample numbers for tissue collection and to give another standardised method to measure species richness, abundance, diversity and biomass.

At lower Strickland River sites standardised gill and seine netting did not suggest any mine-related impacts to the species richness, diversity, abundance or biomass of fish or prawns for the year 2010. Negative trends were detected for species richness, biomass and abundance for fish caught at Tiumsinawam that were not matched at the reference site at Tomu over the 2000 to 2010 period.

Hydroacoustic sampling was undertaken at the Strickland River off river water bodies, Kukufionga, Avu, Levame and Zongamange in May 2010. Between site differences were detected for the fish density recorded at the off-river water bodies during 2010. Fish density was found to be significantly greater ($p<0.001$) at Kukufionga than that observed at all the other off river water bodies surveyed. This result indicates that the potentially impacted site upstream of the Herbert River confluence at Kukufionga showed significantly higher fish density indicating no mine derived effects.

Specimen condition in the upper catchment indicated a significant difference for the fish *N. equinus* at Wasiba when compared with fish collected at Kuru River, indicating a possible mine-related effect. This trend was not observed between Wasiba and the other reference sites, Ok Om or Pori River, but should be closely monitored throughout 2011. Spearman's rank correlations indicated that *N. equinus* condition was significantly decreasing at Wasiba which was not observed at any of the reference sites.

The condition of fish and prawns at lower Strickland River sites was not found to be significantly different between downstream-of-mine sites and reference sites during 2010. However, a significant decreasing trend in the condition of *P. macrorhynchus* collected at Tiumsinawam was detected over the time period 2000 to 2010 which was not matched at the reference site at Tomu.

Overall the catch and abundance recorded at downstream of mine sites during 2010 did not indicate any direct impact due to mining activities, but trends detected in the upper catchment data from 2000 to 2010 or where there were data available, indicated that prawn species richness, abundance and biomass may be decreasing. Unfortunately, standardised catch methods in the upper catchment can be somewhat compromised by environmental conditions at the time of sampling. This will hopefully be rectified by the use of electrofishing methods in 2011. At sites in the lower Strickland region, during 2010 there were no significant differences detected between sites indicating no mine related impact.

Fish condition investigations indicated that most of the species caught during 2010 were in good health. The exception to this was *N. equinus* collected at Wasiba when compared with fish caught at the reference sites.

TISSUE METAL CONCENTRATIONS

Quality Assurance

Laboratory based quality assurance was acceptable for samples analysed in Quarters 1, 2, 3 and 4.

The use of field blanks was a great improvement over recent years and the biological team should be commended for this effort. A total of 46 field blanks were used in 2010, a major improvement on 2008, where only seven field blanks were used, and over 2009, where 31 field blanks were used. The level of field blanks used in 2010 should be maintained. The analysis of the field blanks indicated that some contamination of samples was occurring during sample processing and possibly during sample preparation at the analytical laboratory, as well as instrument variation. A continued effort to ensure that the laboratory is as clean a possible and dissection of samples is done using clean techniques is needed. The results of the field blank analysis indicated that a greater margin of error should be associated with the samples analysed in 2010 and the subsequent tissue metals analysis.

Temporal and Spatial Variation

Tissue sampling of target organisms was undertaken at all planned sites in 2010, except at Lake Murray where landowner intervention and unreasonable compensation demands prevented sampling for tissues from occurring. Prawns were sampled from a number of extra sites in the lower Strickland as part of the prawn bioaccumulation study. Samples were collected from sites Kukufionga, Strickland River at Oxbow 3 entrance, Strickland River above Everill Junction and Fly River at Ogwa.

The extent of mine-related (and in some cases anomalous) elevation of metal bioaccumulation is summarised for each metal in turn below:

Cadmium: Average concentrations of cadmium has continued to be found at significantly elevated levels in tissues of both fish and prawns sampled from sites downstream of the mine during 2010. Prawn cephalothorax samples from downstream-of-the-mine sites in both the upper catchment and lower Strickland indicated continued persistence of cadmium at elevated levels when compared with reference sites. Wasiba, Wankipe, Bebelubi, Tiumsinawam, Kukufionga, SG5, Levame and Ogwa prawn cephalothorax samples were all found to have significantly elevated levels of cadmium when compared with samples collected from both reference sites. Other tissue types that were found to be elevated at impact sites when compared with reference sites included prawn flesh at Wankipe, Wasiba, Bebelubi and Levame, and fish liver samples at Wankipe, Wasiba and Bebelubi. Increasing trends in cadmium concentrations at impact sites that were not matched at reference sites were also detected for a number of tissues, including prawn cephalothorax at Bebelubi and Tiumsinawam over the shorter term, prawn flesh at Wankipe over the shorter term, at Bebelubi over the shorter and longer term and fish liver at Tiumsinawam over the longer period.

Copper: Average copper concentrations were found to be significantly elevated at impact sites compared with reference sites for prawn cephalothorax and flesh during 2010. Prawn cephalothorax samples were found to be significantly elevated at Wasiba, Levame and Ogwa when compared with samples from at least one reference site and prawn flesh at Bebelubi samples were significantly elevated when compared with samples from all reference sites. Increasing copper concentration trends were identified at downstream-of-mine sites that were not matched at reference sites for a number of tissues, including prawn flesh at Wankipe and Wasiba over the longer term and at Bebelubi over both the shorter and longer term, prawn cephalothorax at Bebelubi over the shorter term and fish liver at Tiumsinawam over the longer time period.

Lead: Average concentrations of lead were found to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax and flesh and fish liver during 2010. Prawn cephalothorax samples collected from downstream-of-mine sites from both the upper catchment and lower Strickland region were found to have significantly elevated levels of lead when compared with samples from reference sites. Prawn flesh collected from Wankipe and Wasiba were found to have elevated levels of lead than samples collected from at least one of the reference sites and fish liver at both Wankipe and Wasiba were found to be significantly elevated in lead concentrations when compared with samples from both Pori River and Kuru River. Increasing trends were detected at downstream-of-mine sites that were not matched at reference sites. Increasing trends were detected for prawn cephalothorax at Tiumsinawam over both the short and long time period and prawn flesh at Wankipe over the long time period.

Zinc: Average Zinc concentrations were found to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax and flesh. Prawn cephalothorax samples collected from Wankipe, Wasiba, Kukufionga and Tiumsinawam were found to be significantly elevated in average zinc concentrations when compared with at least one reference site. Prawn flesh was found to have elevated average concentrations of zinc in samples collected from Wankipe when compared with samples collected from Pori River. Increasing trends were observed at downstream-of-mine sites that were not matched by reference sites for prawn flesh at Wasiba over the short term, fish flesh at Wankipe over the longer term and fish liver at Tiumsinawam over the longer period.

Selenium: Average selenium concentrations were found to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax, prawn flesh, fish liver and fish flesh. Prawn cephalothorax was found to be significantly elevated at downstream-of-mine sites, Wankipe, Wasiba, SG5 and Levame when compared with at least one reference site, and prawn flesh was found to have significantly elevated levels of average selenium at site Wankipe, Wasiba, Levame, Everill junction and Bebelubi when compared with at least one reference site. Fish flesh samples collected from Wasiba were found to have elevated levels of average selenium when compared with samples collected from both reference sites. Increasing trends in average selenium concentrations were observed for prawn cephalothorax at Bebelubi over the longer time period and fish flesh and liver collected from Tiumsinawam were seen to be increasing over the longer time period.

Arsenic: Average arsenic concentrations were observed to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax and flesh. Prawn cephalothorax was found to be significantly elevated at downstream-of-mine sites Wankipe, Wasiba, Bebelubi, Tiumsinawam, Oxbow 3 entrance, Kukufionga, SG5, Levame and Ogwa when compared with at least one of the reference sites. Prawn flesh was found to be significantly elevated at downstream-of-mine sites Wankipe, Wasiba, Bebelubi, Oxbow 3 entrance, Kukufionga, SG5, Levame and Ogwa when compared with samples from at least one reference site. Increasing trends were detected for fish flesh at Wankipe over the shorter period and prawn flesh at Tiumsinawam over the shorter period.

Nickel: Average concentrations of nickel were observed to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax. Prawn cephalothorax was found to be significantly elevated at sites Wankipe, Bebelubi and Kukufionga when compared with samples from at least one of the reference sites. Increasing trends of average concentrations of nickel were observed at downstream-of-mine sites that were not matched at reference sites for prawn cephalothorax and flesh at Bebelubi over the shorter period.

Chromium:`Average chromium concentrations were observed to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax and flesh. Prawn cephalothorax was found to be significantly elevated at downstream-of-mine site, Wankipe, when compared with samples from the reference site, Ok Om, while prawn flesh from the downstream-of-mine site, Bebelubi, was found to have significantly elevated concentrations of average chromium when compared with the reference site at Tomu River. Increasing trends in average chromium concentrations were observed for prawn flesh at Bebelubi over both the short and long term and samples from SG5 over the short term, while samples of fish flesh at Tiumsinawam were observed to be increasing over the short term.

Mercury: Average mercury concentrations were seen to decrease in samples collected during 2010. No significant elevations in mercury concentrations were detected for samples collected from downstream-of-mine sites when compared with samples from reference sites. Increasing trends in average mercury concentrations were also not observed for any of the tissue types and time periods. Decreasing trends were observed at the downstream-of-mine sites Bebelubi, Tiumsinawam and SG5 for fish flesh, prawn cephalothorax and prawn flesh.

The elevated levels of metals in tissues from downstream-of-mine sites in the upper catchment and the lower Strickland region observed in previous years annual reports continued in 2010. Concentrations of cadmium and lead have continued to be detected at significantly elevated levels in prawn cephalothorax tissues collected from established downstream-of-mine sites as far down river as SG5. Overall, these results indicated that the pattern of bioaccumulation of metals at downstream-of-mine sites in the Lagaip River and the lower Strickland region has continued with small alterations to the difference seen in the uptake of some metals; for example, mercury was not detected at significantly elevated levels at downstream-of-mine sites compared with reference sites and was also seen to have decreased in some tissues over both long and short time periods. There was also evidence that the cyanide destruct circuit is reducing the availability of some metals downstream of the mine.

While the presence of some metals at elevated levels has continued in 2010, quality control measures using field blanks indicated that contamination has continued to be a problem for some metals. Taking into account the error associated with the analysis of the tissues, the results of the tissue metals analysis during 2010 were very similar to those seen in past years' programs.

The results of the tissue metal concentrations for each tissue type and organism type were screened against the lowest observed concentration co-occurring with an effect (LOEC) from the effects database of Jarvinen and Ankley (1999). Sites where the ratio of results above:below the corresponding effects threshold for impact sites was found to be greater than for any of the corresponding reference sites were found at all impacted sites down to Bebelubi for cadmium in prawn cephalothorax and to Tiumsinawam for fish liver. Other sites where the ratio found the results above the corresponding effects threshold were Tiumsinawam for copper in fish flesh, Bebelubi for copper in fish liver, Tiumsinawam and Bebelubi for zinc in fish liver and Bebelubi for mercury in fish liver.

The collection of prawn samples for SDH analysis from the upper catchment continued in 2010 and was also expanded to sites in the lower Strickland region, with samples collected from Strickland River at Oxbow 3 entrance, SG5 and Fly River at Ogwa. Results for SDH analysis in 2010 indicated that prawns collected from Wankipe in the upper catchment had significantly elevated hepatic cell damage when compared with samples collected from the reference sites at Ok Om and Pori River. This result differed from that seen in analysis undertaken in 2006 and 2009, where Wasiba was seen to also have elevated levels of hepatic cell damage indicating that prawns at Wasiba during 2010 were under less stress than seen in previous surveys, which may be a result of the cyanide destruct circuit reducing the available metals downstream from the mine. Results for samples collected at sites in the lower Strickland region indicated that prawns from site Oxbow 3 entrance had significantly elevated hepatic cell damage when compared with samples collected from SG5, while samples from Ogwa were statistically similar to samples collected from both Oxbow 3 entrance and SG5. As prawns were not collected from any reference sites in the lower Strickland region in 2010, it is not known whether the levels of hepatic cell damage observed are at levels of concern at the downstream-of-mine sites. This will hopefully be rectified during the 2011 program with the collection of prawns from an appropriate reference site. It is not known whether the amount of hepatic cell damage reflected by these increased levels of SDH is tolerable by the prawn species sampled. Investigations into the relationship between these levels of SDH in the prawn abdomen and organism health would allow for a better understanding of the state of the populations in the upper catchment and lower Strickland region.

A screening of the samples of fish and prawns collected in 2010 using appropriate human health standards and guidelines (see Section 3.6) indicated that none of the samples collected had concentrations of metals above the standards and guidelines. It can be stated that there is a low likelihood of human health impacts from the consumption of the edible portion of the fish and prawns in the upper catchment and the lower Strickland region.

RECOMMENDATIONS

- Implement electrofishing sampling at upper catchment and lower Strickland region sites to enhance the current methods used to monitor catch and to ensure adequate prawn samples are collected for tissue and SDH analysis;
- Continue to investigate and negotiate with landowners in the Nomad and Rentoul River systems to establish at least one more reference site in the lower Strickland region;
- Continue the level of use of field blank samples and ensure the cleanliness of the biology laboratory when processing samples to limit the chance of contamination;
- Introduce the use of a second laboratory as a further QA/QC procedure to help determine the source of contamination that has been seen in field blanks during 2009 and 2010;
- Remove the analysis of Ni and Cr from the program as suggested in the PJV optimisation review as there is no enrichment of these metals in the ore body;

- Continue SDH analysis of upper catchment and lower Strickland prawns to further investigate the possible effect the cyanide destruct circuit is having on the reduction in hepatocellular damage detected in prawns collected from Wasiba in 2010;
- Implement a program to benchmark the effect levels of the elevated bioavailability of metals to the prawns in the upper catchment in terms of the observed SDH and the impacts this may be having on the biological processes of the organisms;
- Consider other sub-organism and organisms level effect markers in areas where SDH analyses demonstrate increased hepatic cell loss rates. Such markers could include histopathological examination of selected tissues and markers of fecundity, such as the gonado-somatic index. Development of this approach could be done in collaboration with the existing research being conducted jointly with CSIRO and Hydrobiology; and,
- Implement seine netting at SG5 and continue to trial fyke nets in an effort to increase prawn catches.

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Introduction

This report summarises the Biological Sampling Programs (BSP) carried out by the Porgera Joint Venture (PJV) from January 2010 to December 2010 along the Lagaip and Strickland River System.

The aims of the BSP are twofold. Firstly, they provide specimens for tissue trace metal and sorbitol dehydrogenase (SDH) analyses that are used for biomonitoring and human metal intake studies via aquatic food consumption. The trace metal biomonitoring is the largest component of the BSP in terms of both effort and budget. It aims to monitor any mine-related changes in the bioavailability of metals in the Strickland River system via analysis of metal concentrations in selected tissue types from selected species collected from sampling sites that are either downstream of the mine or in reference locations in each major section of the river system. Sorbitol dehydrogenase analysis measures the levels of SDH in blood serum which is a measure of hepatic cell death due to stress from physical and chemical parameters.

Secondly, the BSP generate data to assess changes in the species richness, abundance and condition (state of health) of fish and prawns, that may have resulted from mining activities. Hydroacoustic sampling has been introduced to the BSP to replace the previously used gill net and purse seine net sampling for catchability of fishes in Lake Murray and to extend fish density monitoring to selected Strickland River floodplain water bodies. In May 2004, Hydrobiology with the aid of PJV undertook a pilot study to determine the applicability of hydroacoustics in Lake Murray and off river water body sites in the Lower Strickland River (Smith and West 2004, PJV 2005). It was concluded from this study that hydroacoustic sampling of sites in Lake Murray and the Lower Strickland was a useful tool for mapping fish densities and that the advantages of hydroacoustic sampling outweighed any disadvantages when compared with gill and purse seine netting. These advantages being:

- It is non-destructive. No fish are actually collected, so there is no risk of sampling effort affecting the fish stocks being monitored.

- The sample volume is very large. This tends to reduce the variability of the density estimates, and provide greater statistical power.

- Behavioural information is gained that is difficult to obtain by more traditional sampling methods. In 2004 diurnal vertical migrations of fishes were observed using hydroacoustic sampling. Other behavioural information could be gained using hydroacoustic sampling as the location of fishes is recorded in three dimensions to high resolution.

- Fish densities can be mapped in three dimensions within timeframes not possible for net sampling of fishes.

- In practical terms for floodplain sampling, hydroacoustics sampling is not depth limited. Purse seining can only be carried out in water depths up to 6 m for the net that PJV uses. At greater depths fish will escape under the net where it does not reach the lake bed, making density estimates inaccurate.

Hydroacoustic sampling was continued in 2010 in Strickland River off river water bodies.

Methods

Abundance Sampling

A detailed description of the methods is provided in the Biology Procedures Manual (PJV 2004b). These sampling procedures were largely followed during 2010. A brief description of the major sampling techniques is provided below, with notes regarding any substantial deviations from the standard methods.

Beach seining

Beach seine net sampling (Figure 0-1) in the Lagaip/Ok Om river system is difficult, as the nature and extent of exposed sand and/or gravel bars suitable for this sampling technique are highly dependent on the river level at the time of sampling. Lower than normal river levels for seine net sampling may result in the only available sand bars having silt deposits below the water line, making seine netting difficult. Higher than normal river-levels may result in no exposed sand bars at all, or very limited extents of suitable areas.

The standardised beach seine sampling involves collection of six replicate hauls per site. All prawns and juvenile and small bodied fish caught in each net haul are put into separate polyethylene sample bags, taken to the laboratory (or field processed for remote sites) and sorted by species, counted, measured and weighed. Prawns may be kept alive for purging of gut contents for tissue sampling (see below). Braille poles are attached to the net, and the net is hauled perpendicular to the bank to full stretch, with the central cod end downstream. It is then hauled fully open for approximately 10 m, and then swept to the bank to cover an area of approximately 100 m^2.
Beach seine sampling in the Strickland River at Tiumsinawam is done similarly, using the same net, but with a 20 m haul length.

Figure 0-1 Hauling in a beach seine net at a site in the upper catchment.

Hook-and-line

Hook-and-line sampling (Figure 0-2) is used only to provide specimens for tissue samples. It is not used as a method for assessing population densities or relative abundance because it is not based on standardised effort. Fishing lines, consisting of approximately 20 m of approximately 6 kg breaking strain nylon monofilament fishing line, a size 6 fishing hook, usually of a mustard, suicide, or O'Shaughnessy style, and a small lead sinker, are given to local villagers. The villagers are then instructed to collect bait and use the fishing lines to collect the target species from the sampling site area. Although it is known to be a variable effort procedure, it is effective at meeting the objective of catching sufficient numbers of the targeted fish species for tissue metal concentration analysis, which is otherwise difficult to achieve.

Supervision of the villagers is sometimes required to ensure that the sampled fish have in fact originated from the sampling site. Care is taken to ensure that the origin of the catch is known, so fish caught by villagers from other areas or streams are not included in the specimens collected for tissue sampling. This is routinely checked by interviewing the fishers when they return with their catch, but is confirmed where possible by direct observation of their activities.

All mountain tandans (*Neosilurus equinus*) are put into polyethylene sample bags, and brought to the laboratory where they are measured, weighed and dissected to remove tissue samples, or are processed in the field.

Figure 0-2 Hook-and-line sampling of mountain tandan.

Gill netting

The standard sampling effort for gill nets (Figure 0-3) differs between sites. However, the standard effort for gill net sampling for all sites involves one set period only. If the nets remain in the water after this time, it is recorded as non-standard effort, and used for tissue specimen collection only. An unreplicated net set incorporating a greater range of mesh sizes was used up to 1995 at the Lake Murray sites and 1997 at Tiumsinawam and the Tomu River.

Replicated gill net sampling at Tiumsinawam/Tomu since 1997 has consisted of up to three sets containing one each of 76, 90 and 100 mm stretched mesh size gill nets. Three replicate sets have been used consistently since 2001, but fewer than three sets were typically used before 2001. The nets are set for a 24 h period, with smaller meshed nets set upstream of the larger nets. Each net is firmly tied to the bank in an area away from the main current, or at the upstream end of a backwater where available. The net is set approximately 30° to the bank, and a float tied to the end of the head-rope, and a weight to the end of the lead-line.

Figure 0-3 Gill net sampling in the Tomu River

Prawn trapping

Prawn trap sampling (Figure 0-4) commenced as a routine sampling method in 2002. Collapsible box traps, 400×250×250 mm, with funnel openings at each end, are used to collect prawns, *Macrobrachium* spp., at the upper catchment and lower Strickland region sites. The traps are baited, usually with tinned fish, and deployed around snags and backwaters. The traps are left for varying periods depending on water conditions and catch rates, to obtain sufficient specimens for tissue sampling, with checking of the catch occurring in the morning and periodically during the day and night between other sampling activities. Ten traps are set at each site. Prawn trap sampling is not conducted in a quantitative manner, and is not used for comparison of catch rates between sites.

Figure 0-4 Collapsible box traps, with funnel openings at each end, and a bait pocket used to collect prawns. Two prawns can be seen in the trap.

Fyke netting

Trial sampling was carried out at Baia reference site, Fly River at Ogwa and Strickland River at SG5 in 2010. Although no sampling was carried out in the upper catchment for any of the sites in 2010, the method will be trialled in 2011 to assess its efficiency as an alternative standard method that can be used as an additional sampling method in the upper catchment as well as the lower Strickland sites.

The fyke net (Figure 0-5) consists of 3 mm multifilament mesh with 500 mm diameter hoops, two no-return funnels/cones within the 1st and 2nd hoop are used to hold the catch after entering the catch pocket and 5m wings for funnelling the catch towards the catch pocket. The two wings are 5 m in length, 1m drop, with floats and sinkers. The small fyke net functions similarly to seine hauls in that they sample shallow water, but can be set in areas that cannot be sampled with seines, such as heavily vegetated areas or habitats with a lot of woody debris. In addition, these nets provide a more integrated sample over a number of hours (typically 2 - 24 h) compared with “single-point-in-time” estimates obtained from seine hauls.

Figure 0-5 Typical set up of fyke net used for sampling prawns and fish during 2010

Hydroacoustics

Sampling was conducted during May 2010 using a Biosonics DTX split-beam echosounder with a frequency of 200 kHz and a beam angle of 6.4°. A differential GPS unit was used to achieve accurate position recording for the transducer for all pings.

The hydroacoustic equipment, which is powered by a 12 V battery, was set up in a PJV 6 m fibreglass dinghy. A portable transducer mount was fixed to the gunwale by clamps, and the sounder and signal processing equipment housing placed on a wooden crate to keep them above the bilge water. The boat was equipped with a tarpaulin to provide the instrumentation with shelter during rain storms. Figure 0-6 shows the instrumentation setup. The transducer was set at a shallow angle downward from horizontal, to maximise the effective range that could be sampled, while maintaining sufficient echo-signal strength from the bottom for reliable bottom detection. Typically this angle was 20 25° from horizontal. Therefore, range in subsequent analyses is correlated with depth, but is not equivalent to depth from the water surface.

Figure 0-6 Typical hydroacoustic set up

Hydroacoustic sampling at each floodplain site consisted of establishing a standard transect track in a part of the lake that was found to be as clear of macrophytes and snags as possible, and then at least five night-time transects were recorded along that track. Selection of the sites was based on those sampled during the 2004 project and whether access was possible for the floodplain oxbow sites.

Sampling was undertaken at four Strickland River floodplain sites in May 2010. These sites included, Oxbow 3, Zongamange, Avu and Levame. During the afternoon of each day of sampling the team moved out to the area of each site where GPS coordinates for a 15 minute transect were recorded. The average speed of the dinghy during data collection was approximately 2.5 – 3 kt equating to approximately 1100 to 1400 m transects.

The data were analysed using Visual Analyzer Version 4.1.2.42 (Biosonics 2004). This program allows the user to visually check the files for accurate bottom tracking (to ensure fish at the bottom of the water-body are recognised) and any objects that remained stationary between transects (these are discounted as being snags or macrophytes). After the files were adjusted for bottom tracking and stationary objects an analysis of fish density in grams per cubic metre (g/m^3) was undertaken. Between-site comparisons were made using ANOVA designs with the S-Plus statistical software (Insightful 2007), using plots of residuals to check the assumptions of homogeneity of variance and normality of residuals.

Tissue sampling

Fish

Sampling of liver and muscle tissue from fish was done in the field in most instances for Lake Murray and the Strickland/Tomu samples, but mountain section samples were generally returned to the laboratory for dissection but field processing is not uncommon. Fish dissections were performed on fresh polyethylene sheets. Precautions were taken during dissection to prevent contamination of tissues by changing scalpel blades between fish batches, having the dissector and assistants wear vinyl surgical gloves, and washing all tissues and dissecting equipment with distilled/deionised water before and after each dissection.

Liver samples were collected by first using a lint-free cloth and/or tissue paper to remove surface slime. The body cavity was opened with a clean surgical stainless steel scalpel blade or stainless steel knife, taking care to avoid touching the liver. Stainless steel forceps were used to expose the liver. A clean surgical stainless steel scalpel, rinsed in high purity water, was used to remove the liver. The excised liver was placed in a newly labelled plastic bag and frozen. Usually, the whole liver was removed for analysis.

Approximately, 5 - 50 g of the dorso-lateral muscular tissue of targeted fish species was dissected after the skin was removed.

Prawns

Prawn samples were prepared in two ways. All prawns were individually washed in clean water at the sampling location. Some samples, particularly specimens that died or were damaged during collection, were individually bagged and frozen immediately. These samples are referred to as unpurged and were not used in this report. Specimens in good condition were held in aerated containers of water from the collection site for 48 h after collection. After purging the specimens were individually bagged and labelled. These samples, collected after evacuation of the gut contents, are referred to as purged samples.

Prawn samples were dissected while partially frozen, so that thawed fluid from individual tissues did not mix. The cephalothorax was separated from the abdomen, and then the exoskeleton was removed from the latter. After separation, the tissues were thoroughly rinsed with distilled/deionised water, weighed separately, and packed individually in plastic bags before re-freezing. The frozen samples were transported back to the laboratory on ice and then forwarded to the National Measurement Institute in Sydney for tissue metal concentration analysis

Laboratory Analysis & QA/QC

All tissue samples were submitted to the National Measurement Institute Laboratories (NMI, formerly the Australian Government Analytical Laboratories, AGAL) in Sydney. At the NMI laboratory, tissue samples were freeze-dried and microwave digested using double distilled nitric acid, prior to chemical analysis. The concentrations of the nine elements of concern were measured using Inductively Coupled-Plasma Mass Spectrometry (ICP-MS).

NMI internal standard reference material samples were included by NMI in the sample batches submitted during 2010. The percentage of the expected metal concentration was recorded for each standard reference material analysis.

Additionally, the standard reference material samples were analysed in duplicate by the laboratory as part of their quality control program. For the duplicate analyses, for each metal the relative proportional difference (RPD) between the analyses was calculated as:

$$RPD = \frac{2 \times \left| \text{determination } 1 - \text{determination } 2 \right|}{\left(\text{determination } 1 + \text{determination } 2 \right)}$$

As a primary acceptance criterion, an up to 35% variation was considered acceptable for analyses more than three times the detection level. As a secondary acceptance criterion, a batch of duplicates was considered acceptable provided no more than one of the samples or 10% exceeded the primary criterion, whichever was the greater.

Blank samples and sample matrix spike samples were reported by NMI for each sample batch. Up to 25% variation in recovery of the spiked concentration was considered acceptable.

Data Analysis

Abundance and diversity calculations were restricted to data collected by standard sampling methods at each site. For the purpose of statistical analysis on seine net catches, the area sampled was standardised to 100 m^2 in the upper catchment and to 200 m^2 in the lower Strickland region. Fish and prawn condition were calculated by use of the fish condition factor, K=(weight $_{(g)}$/length $_{(mm)}{}^3$) x10,000 as used by PJV (2000). The data used in these calculations were not restricted to standard sampling methods, but also included fish and prawns caught using additional sampling at each site.

Most statistical analyses were performed using the SPlus for Windows statistical package (Insightful Inc. 2007). Unless otherwise stated, a significance level of α=0.05 was used in all cases. Correlation analyses used the Spearman rank correlation coefficient, which tests for monotonic rather than strictly linear relationships. One-tailed tests were used for the rank correlations to test whether or not the catches had declined. Where multiple rank correlations were performed simultaneously for a section, Bonferroni corrections(by adjusting the p-value) were used to control the overall Type I error rate. The fit of data to ANOVA and ANCOVA model assumptions was checked by visual examination of plots of residuals.

When significant differences between means were found for linear models, post-hoc multiple range tests were used to distinguish between groups of means using the best.fast procedure of SPlus. As most of the ANOVAs were unbalanced, where closely proximal means in rank order gave conflicting contrasts with a third mean, preference was given to the mean with greatest N. Some data were neither normally nor log-normally distributed. When the assumptions of the linear modelling procedures were not met and any covariates were not significant, the non-parametric Kruskal-Wallis or Wilcoxon tests were used. Where the assumptions of the ANCOVA model were not met, but the covariate or covariate×main effect interaction term was significant, quasi-likelihood models were fitted where the variance was not correlated with the independent variable, otherwise an appropriate nonparametric procedure was applied to the dominant size class to remove the covariate effect.

The tissue metal concentrations were log transformed prior to analysis, as metals may accumulate with age, and length is related to age by a growth curve, usually of the form:

$$Length = Length_{\max} - \left(Length_{\max} - Length_{0.age.class}\right)e^{-Kt}$$

Where t is age and K is the instantaneous growth rate. Thus, where metal concentration is linearly correlated with age, it would be log-correlated with length. Therefore, length was included as a covariate in the analyses with log transformed metal as the dependent variable. The assumptions of traditional ANCOVA, equality of variance and normality of the residual variance, were checked by examination of graphs of the residuals against the model values, and normal probability plots of the residuals.

In the trend analyses, extreme outlier values from years prior to 2010, as determined by graphical inspection, were excluded from the analyses.

Results

Fish Abundance

Upper Catchment

Sampling in the Upper Catchment was achieved at all sites for each quarter during 2010. Table 0-1 shows the dates that sampling was undertaken at Upper Catchment sites.

Table 0-1 Dates sampling was undertaken at Upper Catchment sites during 2010.

Site (Site code)	Site type	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
Wasiba (124)	Potential Impact	23/03/2010	20/05/2010	17/08/2010	10/11/2010
Wankipe (15)	Potential Impact	07/03/2010	18/06/2010	25/09/2010	06/11/2010
Ok Om (80)	Reference	17/02/2010	29/05/2010	29/09/2010	26/10/2010
Kuru River (211)	Reference	20/02/2010	27/05/2010	28/05/2010	24/10/2010
Pori River (210)	Reference	08/03/2010	15/06/2010	27/09/2010	04/11/2010

Table 0-2 presents the total catch of aquatic species from the upper catchment sites in 2010. The Pori River reference site recorded the greatest species richness, followed by Wankipe, Ok Om, Kuru River and Wasiba. Mountain tandans, *Neosilurus equinus,* and freshwater prawns, *Macrobrachium lorentzi,* were the most abundant species caught at each site.

Table 0-2 Species richness, abundance and biomass of aquatic species caught in the upper catchment during 2010.

Site	Wasiba	Wankipe	Ok Om	Kuru River	Pori River
Site code	124	15	80	211	210
Genera	3	3	3	4	5
Number of species	4	6	6	6	8
Number of specimens	239	283	202	139	390
Biomass (kg)	7.38	9.41	8.74	5.57	7.16

A total of 239 fish and prawns were caught in the Lagaip River at Wasiba by seining, trapping and angling in 2010. Mountain tandans and freshwater prawns were the main two species caught. *M. lorentzi* was the dominant species caught, comprising 56% by numbers and 8% by weight of the combined total catch, while *N. equinus* comprised 35% of the catch by number and 89% by weight. There were no significant differences in fish catches at Wasiba between years, but the number of prawns were significantly different in 2004 ($P = 0.001$) compared with the other years of sampling (Figure 0-1). Spearman's rank correlation identified a significant decreasing trend in the number of species, number of specimens and biomass for prawns at Wasiba over the 2000 to 2010 period. The catches tend to be variable at this site due to limited areas of suitable sandbars exposed during extreme high and low flows which may be having an effect on numbers and biomass. This will hopefully be corrected with the introduction of electrofishing at these upper sites.

At Wankipe, standardised seine netting and non-standardised prawn trapping and angling caught a total of 283 fish and prawns, comprising six species. Mountain tandans, *N. equinus*, and the freshwater prawn, *M. lorentzi* were the dominant species caught during the 2010 sampling period. *M. lorentzi* constituted 28% of the catch by numbers and 5% by weight, while *N. equinus* constituted 48% of the total catch by numbers and 90% by weight. By Kruskal - Wallis rank sum test, species richness, abundance and biomass of fish caught by standardised seine netting have not changed over time. Prawn abundance, species richness and biomass have not changed over time with exception of 2005 when there was an increase in the number of prawns caught.

At the Ok Om reference site, a total of 202 fish and prawn specimens were caught by both standardised and non-standardised sampling. Mountain tandans, *N. equinus* and freshwater prawns*, M. handschini*, were the dominant species caught. *N. equinus* comprised 58% of the total catch by numbers and 93% by weight, while *M. handschini* comprised 24% of the total catch by numbers and 3% by weight. Standardised sampling at Ok Om during 2010 was no different from sampling undertaken in previous years of monitoring.

Table 0-3 Spearman's rank correlation analysis results of significant correlations for species richness, abundance and biomass for prawn catches using Beach Seine from 2003 to 2010 (or where data was available) in the three main upper catchment sites.

Site	Wasiba	Wankipe	Ok Om
Species richness	-	-0.200	-
Abundance	-0.165	-0.195	-
Biomass (g / haul)	-0.189	-0.223	-

At the Kuru River reference site, a total of 129 specimens were caught by the non-standardised sampling methods of trapping and angling during 2010. *N. equinus* and *M. lorentzi* were the dominant species caught. *N. equinus* comprised 46% of the total catch by number and 95% by weight, while *M. handschini* constituted 8% of the catch and 0.8% by weight. No standardised seine net sampling is carried out at this site because there are no sandbars.

At the Pori reference site, a total of 390 fish and prawns were caught during the 2010 sampling period. Freshwater prawns, *M. handschini* and, mountain tandans, *N. equinus,* were the dominant species caught. *M. handschini* comprised 26% of the total catch by numbers and 11% by weight, while Mountain tandans comprised 25% of the total catch by numbers and 71% by weight. Standardised seine net sampling is not possible at this site because there are no sandbars.

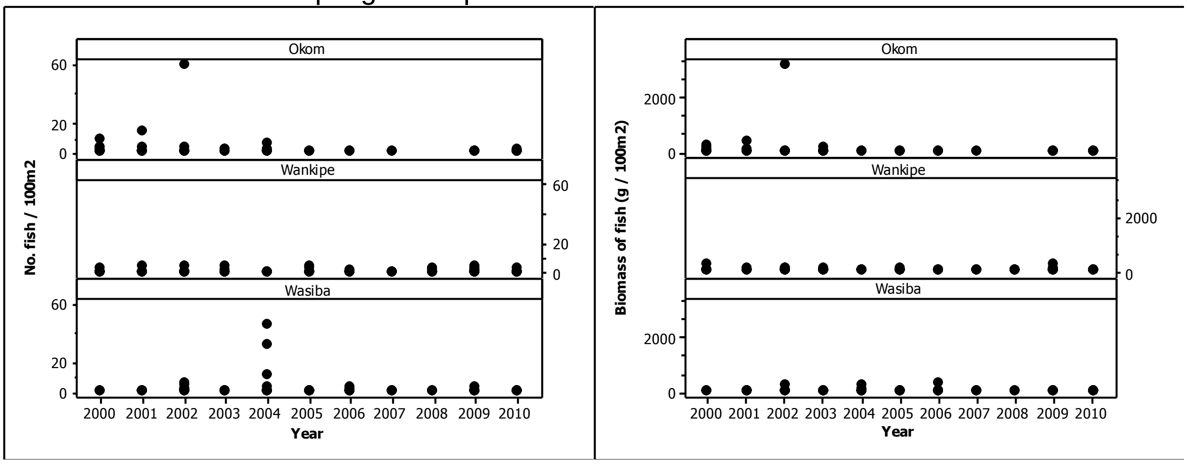


Figure 0-1 Abundance and biomass of fish in standard seine net catches at the three main upper catchment sites over time.

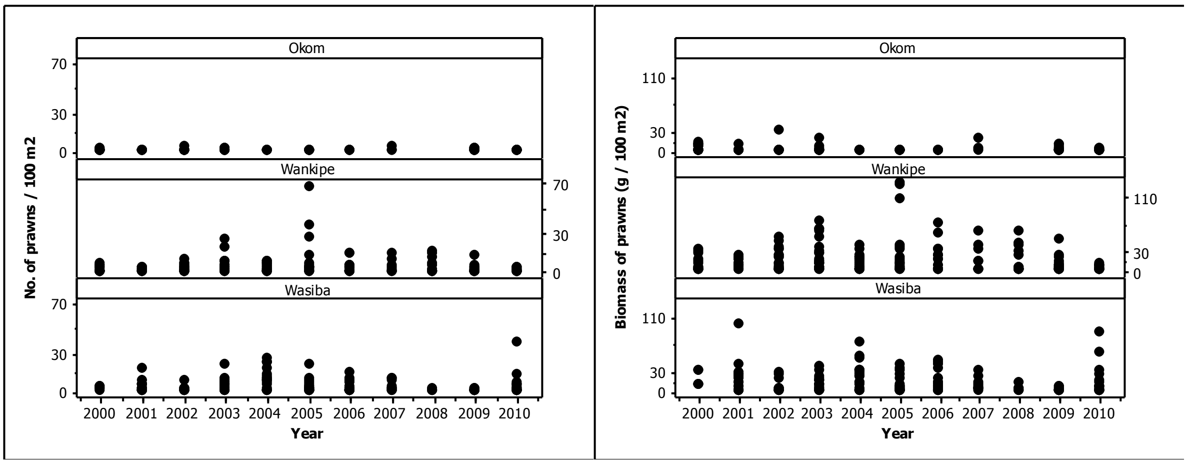


Figure 0-2 Abundance and biomass of prawns in standard seine net catches at the three main upper catchment sites over time.

Lower Strickland

Sampling during 2010 in the Lower Strickland was not undertaken at all sites for each of the four quarters although the main sites of Tiumsinawam and Tomu were sampled in each quarter. Table 0-4 shows the dates that sampling was undertaken at Lower Strickland River sites throughout 2010. Sampling at Bebelubi and Baia River were only completed in the second, third and fourth quarter of 2010.

Table 0-4 Dates sampling was undertaken at Lower Strickland sites during 2010

Site (Site code)	Site type	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
Tiumsinawam (19)	Potential Impact	25/01/2010	07/04/2010	30/07/2010	13/11/2010
Bebelubi (213)	Potential Impact		04/04/2010	29/07/2010	11/11/2010
Tomu (121)	Reference	26/01/2010	08/04/2010	31/07/2010	14/11/2010
Baia (214)	Reference		06/04/2010	28/07/2010	12/11/2010

Table 0-5 summarises the total catches at the four lower Strickland sites quantitatively sampled during 2010 and indicates that more species and genera were caught at Tiumsinawam than the Tomu River, Baia River and Bebelubi.

The giant freshwater prawn, *Macrobrachium rosenbergii*, was the numerically dominant species caught from the Strickland River at Tiumsinawam, comprising 55% by numbers and 2% of the total weight. The next most abundant species was the sharp-snouted catfish, *Potamosilurus macrorhynchus*, which constituted 14% by numbers and 55% by weight of the total catch.

M. rosenbergii was the most numerically abundant species caught at the upstream Strickland River site, Bebelubi, comprising 56% of the catch by numbers, and 1.5% of the total weight. *Macrobrachium lorentzi was* the second most commonly caught species, contributing 12% by numbers and 0.2% by weight.

In the Tomu River, the prawn, *M. lorentzi* was the most abundant species caught, contributing 30% of the total catch by numbers and 0.18% by weight. *P. macrorhynchus* was the most abundant caught species by weight from the Tomu River, constituting 23% by numbers and 49% by weight.
In the Baia River, the upstream Strickland River reference site, *M. rosenbergii* was the most abundant species, comprising 47% by numbers and contributing 1.6% of the catch by weight, with the prawn, *M. lorentzi,* the second most abundant species, contributed 27% by numbers and 0.5% by weight.

Table 0-5 Biomass and species richness for aquatic species caught in the lower Strickland River sites in 2010.

Sampling site	Tiumsinawam	Bebelubi	Tomu	Baia
Site code	19	213	121	214
Genera	5	6	5	5
Number of species	13	12	12	10
Number of specimens	511	173	264	191
Biomass (kg)	54.70	23.70	88.10	24.30

Gill Net Sampling

Gill net sampling in the lower Strickland region was conducted in the Strickland River at Tiumsinawam, Bebelubi and reference river sites at Tomu and Baia during 2010 for the first, second, and third quarter. There was no standard gillnetting done in the fourth quarter at all sites due to theft of standardised gill nets. There were no significant between-site differences in the number of species, Margalef's diversity, and number of fish caught per net set or the average biomass per set (Figure 0-3).

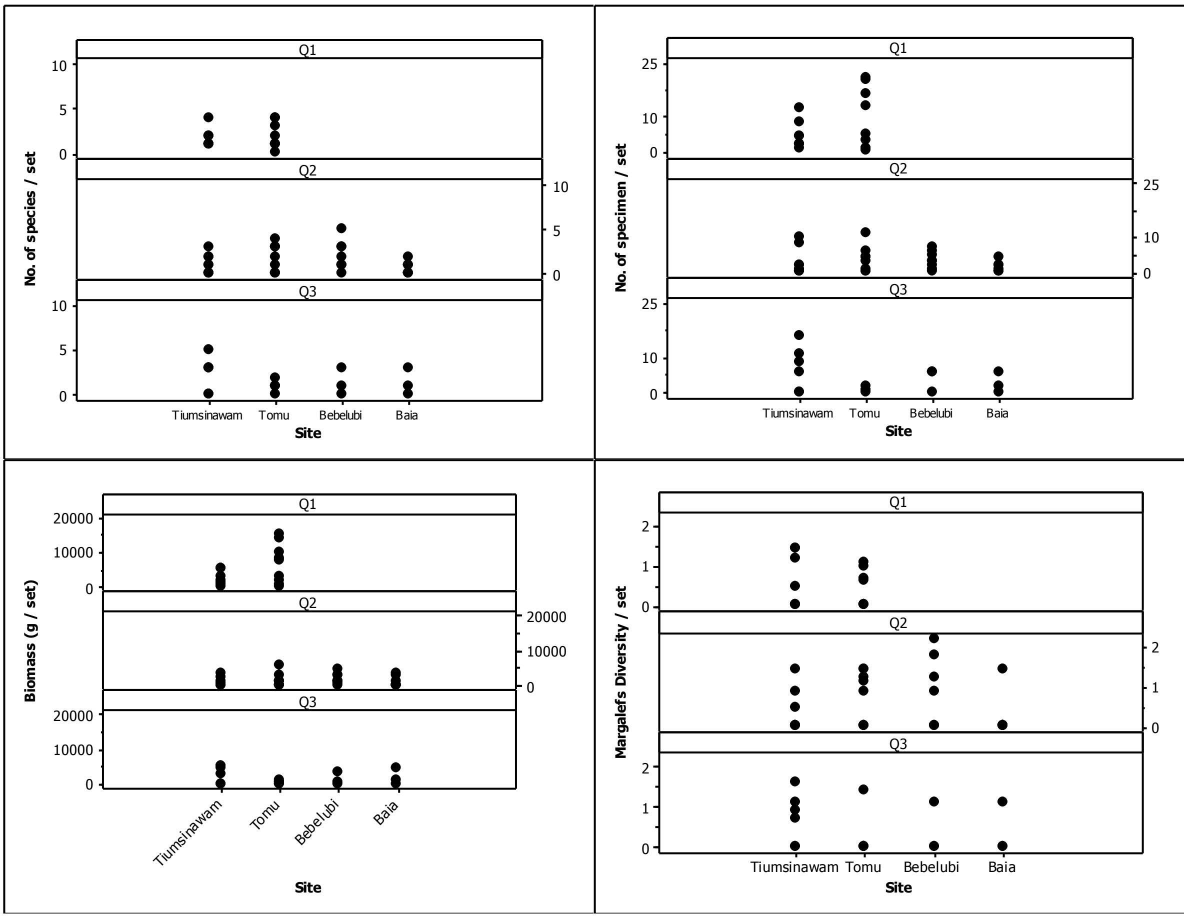


Figure 0-3 Gill net catches (per standard set of three nets) for the Strickland River at Tiumsinawam Bebelubi, Tomu River and Baia River during 2010.

The catches for both Tomu River and Tiumsinawam were typical of the majority of catches in recent years (Figure 0-4). There were decreasing trends detected for biomass and the number of species caught at Tiumsinawam from 2000 to 2010 using Spearman's rank correlation test that were matched by the reference site at Tomu River.

Table 0-6 Spearman's rank correlation analysis results of significant correlations for species richness, abundance and biomass for fish catches using gill nets from 2000 to 2010 (or where data was available) in the lower Strickland region sites.

Site	Tiumsinawam	Bebelubi	Tomu	Baia
Species richness	-0.191	-	-0.285	-0.518
Abundance	-0.282	-	-0.334	-0.489
Biomass (g / haul)	-0.311	-	-0.353	-0.497

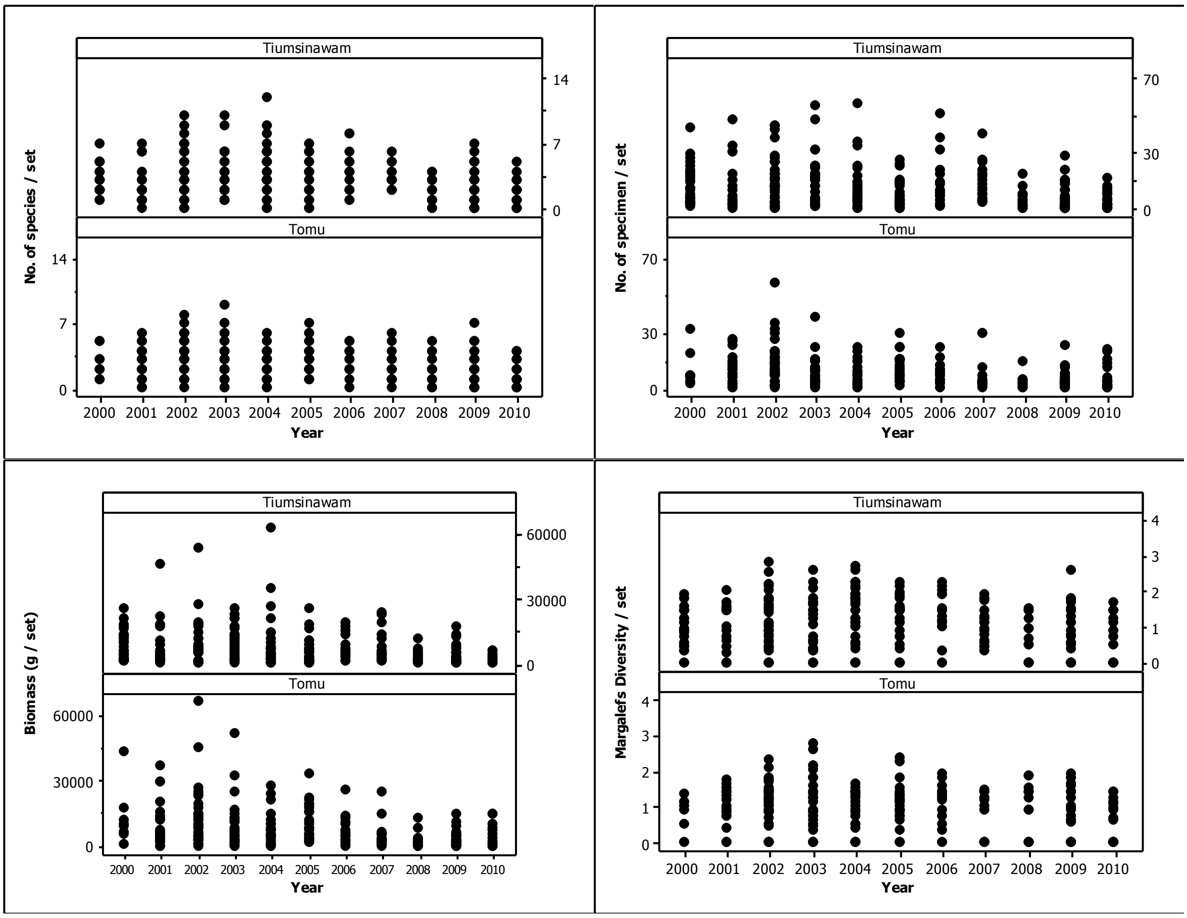


Figure 0-4 Gill net catches for the Strickland River at Tiumsinawam and the Tomu River between 2000 and 2010.

Beach Seine Sampling

Beach seine net sampling in the lower Strickland River region during 2010 was conducted at Tiumsinawam, Baia River and Bebelubi (Figure 0-5 and Figure 0-6). No significant differences were detected between sites for fish, but prawns were significantly different (P = 0.028) in terms of number of species, with more species at Tiumsinawam than Bebelubi and Baia River (ANOVA and Kruskal-Wallis rank sum test presented in Appendix 1). The difference does not indicate mine related impacts but was rather the product of different habitats at the sites.

Rank correlations on the number of species of fish per haul, Margalefs diversity index per haul, and the number and biomass of fish per standardised haul (200 m^2) were carried out for the period 2000 to 2010 for Tiumsinawam (Table 0-7). As prawns were not identified to species before 2003[1] these analyses were performed only for the number and biomass of prawns per standardised haul for the 2000 to 2010 period. For fish, there were significant negative trends in species richness, biomass and the number of fish caught (P < 0.05) at Tiumsinawam between 2000 and 2010 (Figure 0-7). For prawns, there were significant positive trends for number and biomass of prawns

[1] Before this time, *Macrobrachium rosenbergii* was recognised, but all other species were identified as *Macrobrachium* sp

per haul (P = 0.0001 and P = 0.005 respectively) at Tiumsinawam (Figure 0-8). There were no significant trends detected at Bebelubi for fish and prawns for 2006 to 2010 sampling period (Figure 0-9, Figure 0-10, Figure 0-11 and Figure 0-12).

Table 0-7 Spearman's rank correlation analysis results of significant correlations for species richness, abundance and biomass for prawn catches using Beach Seine from 2000 to 2010 (or where data were available) in the lower Strickland region sites.

Fish			
Site	**Tiumsinawam**	**Bebelubi**	**Baia**
Species richness	-0.224	-	-0.348
Abundance	-0.213	-	-0.318
Biomass (g / haul)	-0.210	-	-0.337
Prawns			
Site	**Tiumsinawam**	**Bebelubi**	**Baia**
Species richness	0.317	-	-
Abundance	0.274	-	-
Biomass (g / haul)	0.203	-	-

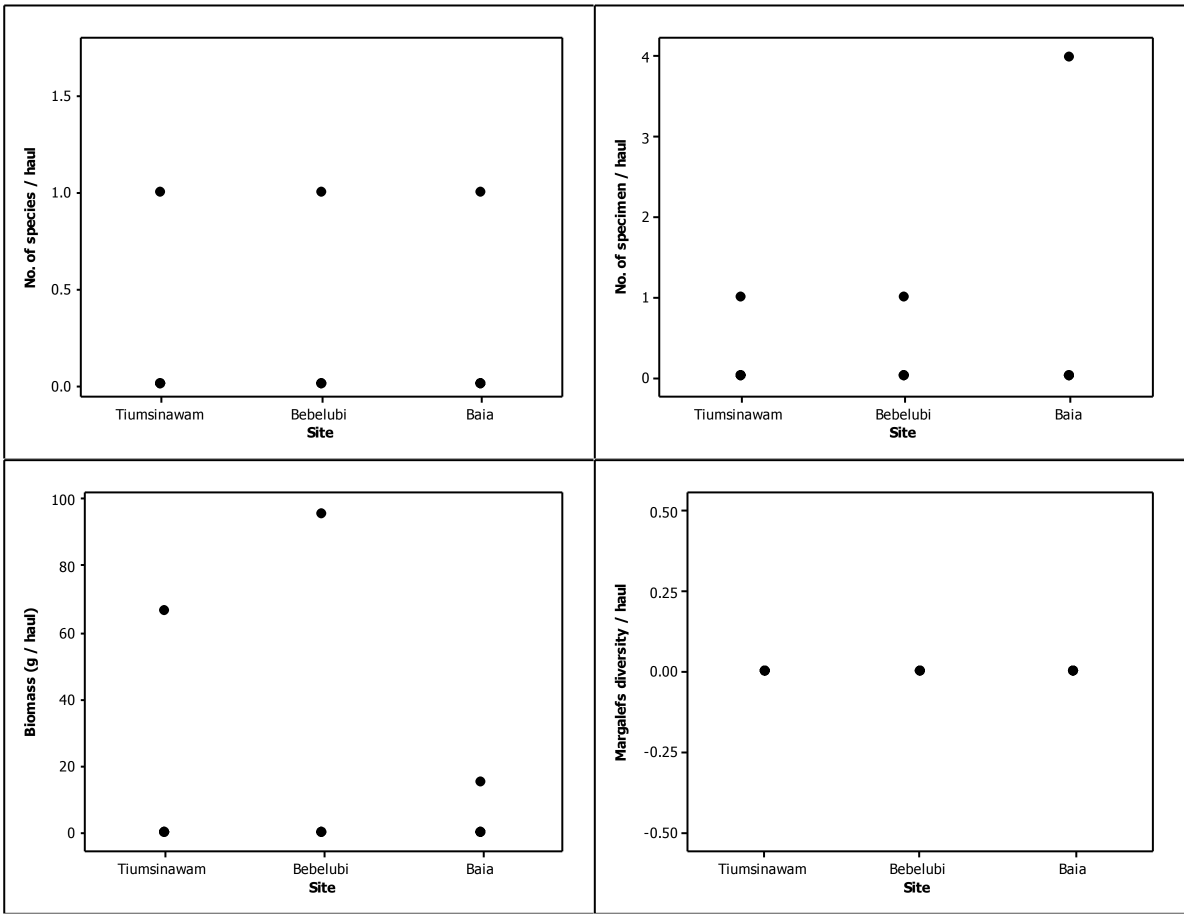


Figure 0-5 Seine net fish catches (per standard haul) for the Baia River and at the Strickland River at Tiumsinawam and Bebelubi during 2010.

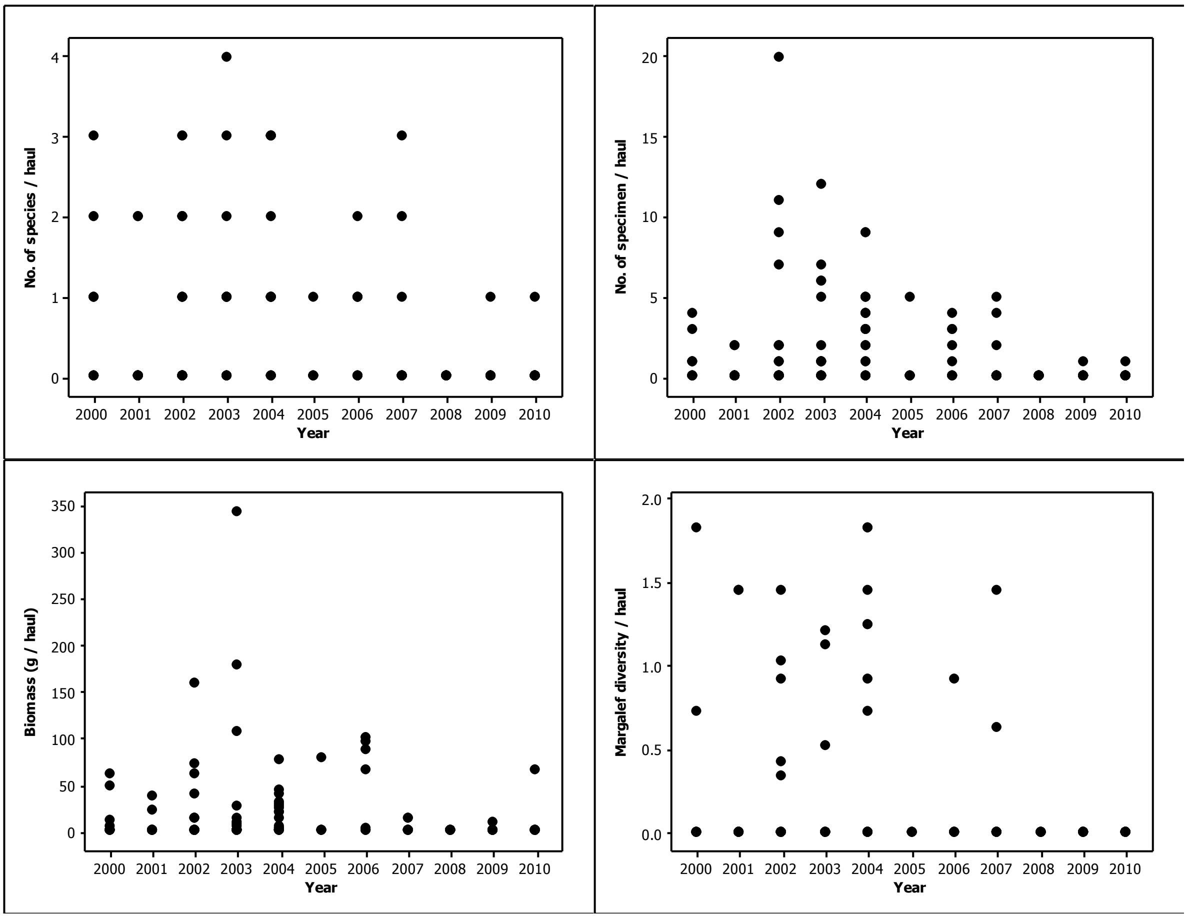


Figure 0-6 Seine net prawn catches (per standard haul) for the Baia River and at the Strickland River at Tiumsinawam and Bebelubi during 2010.

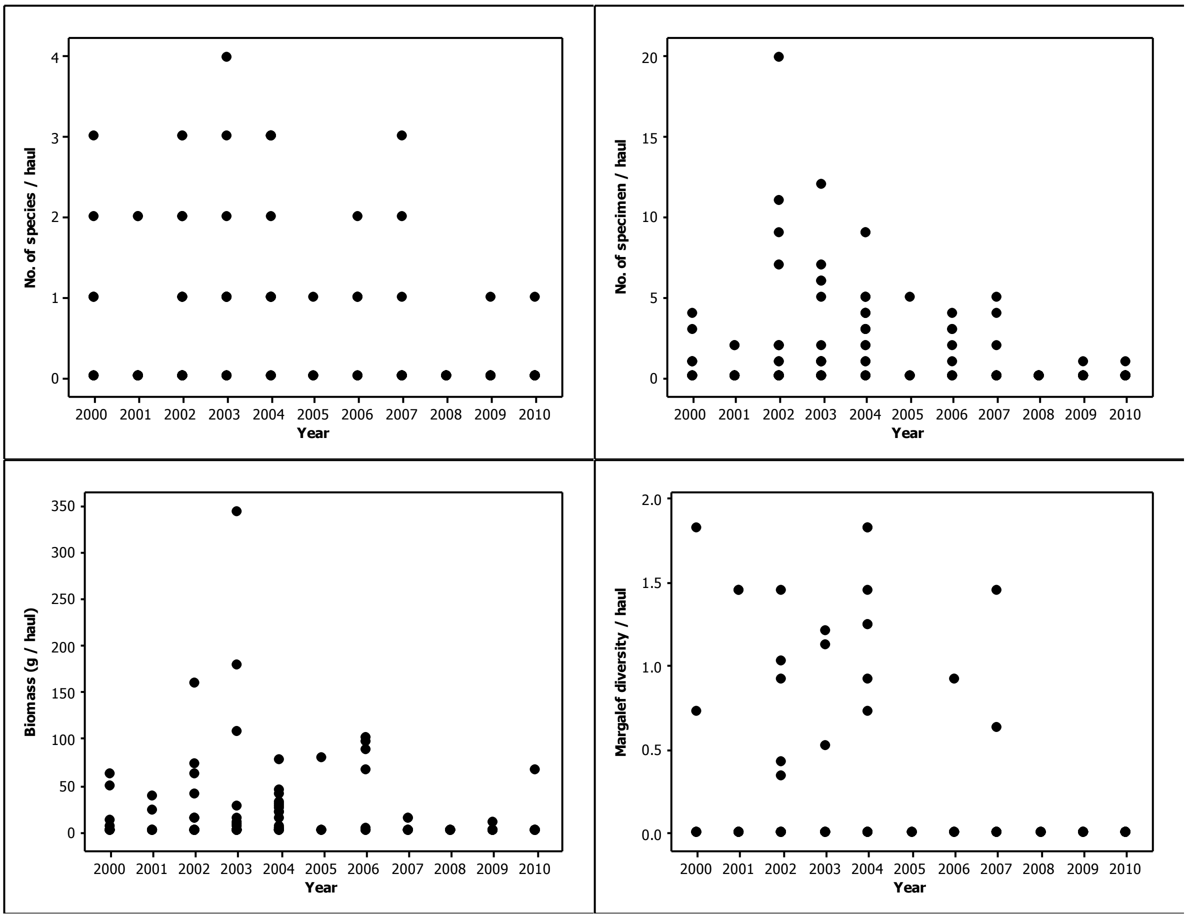


Figure 0-7 Number of species, Margalef's diversity, number and biomass of fish in beach seine sampling at Tiumsinawam between 2000 and 2010.

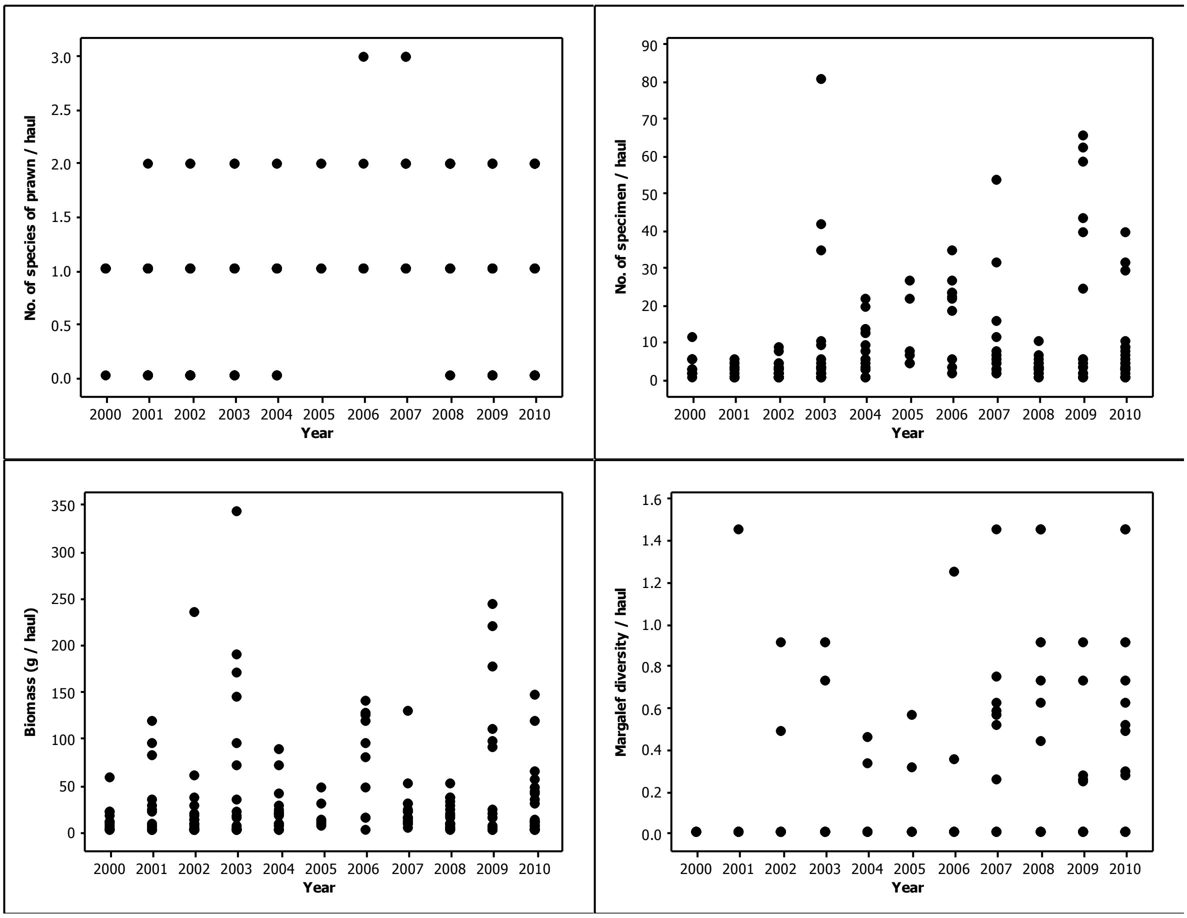


Figure 0-8 Number of species, Margalef's diversity, number and biomass of prawns in beach seine sampling at Tiumsinawam between 2000 and 2010

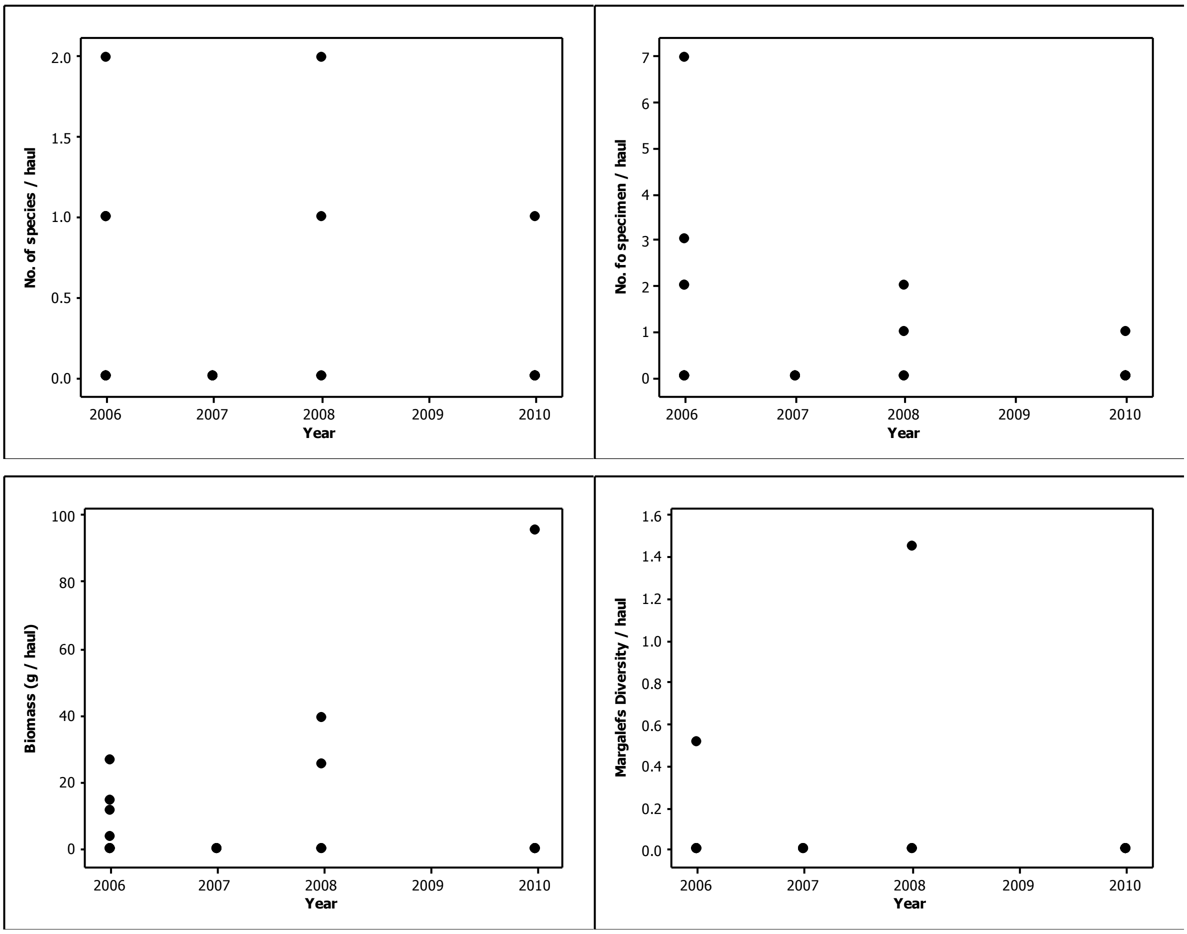


Figure 0-9 Number of species, Margalef's diversity, number and biomass of fish in beach seine sampling at Bebelubi between 2006 and 2010

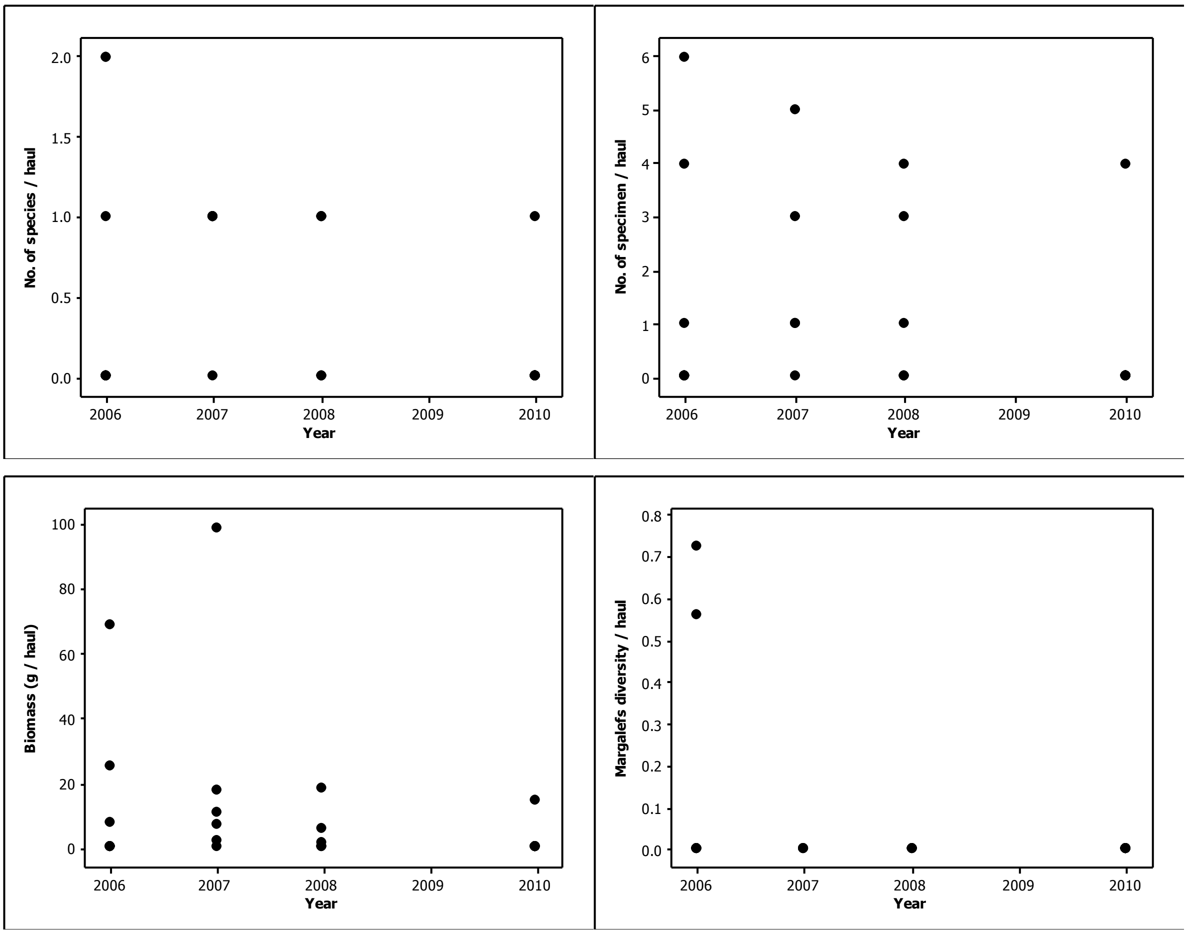


Figure 0-10 Number of species, Margalef's diversity, number and biomass of fish in beach seine sampling at Baia between 2006 and 2010.

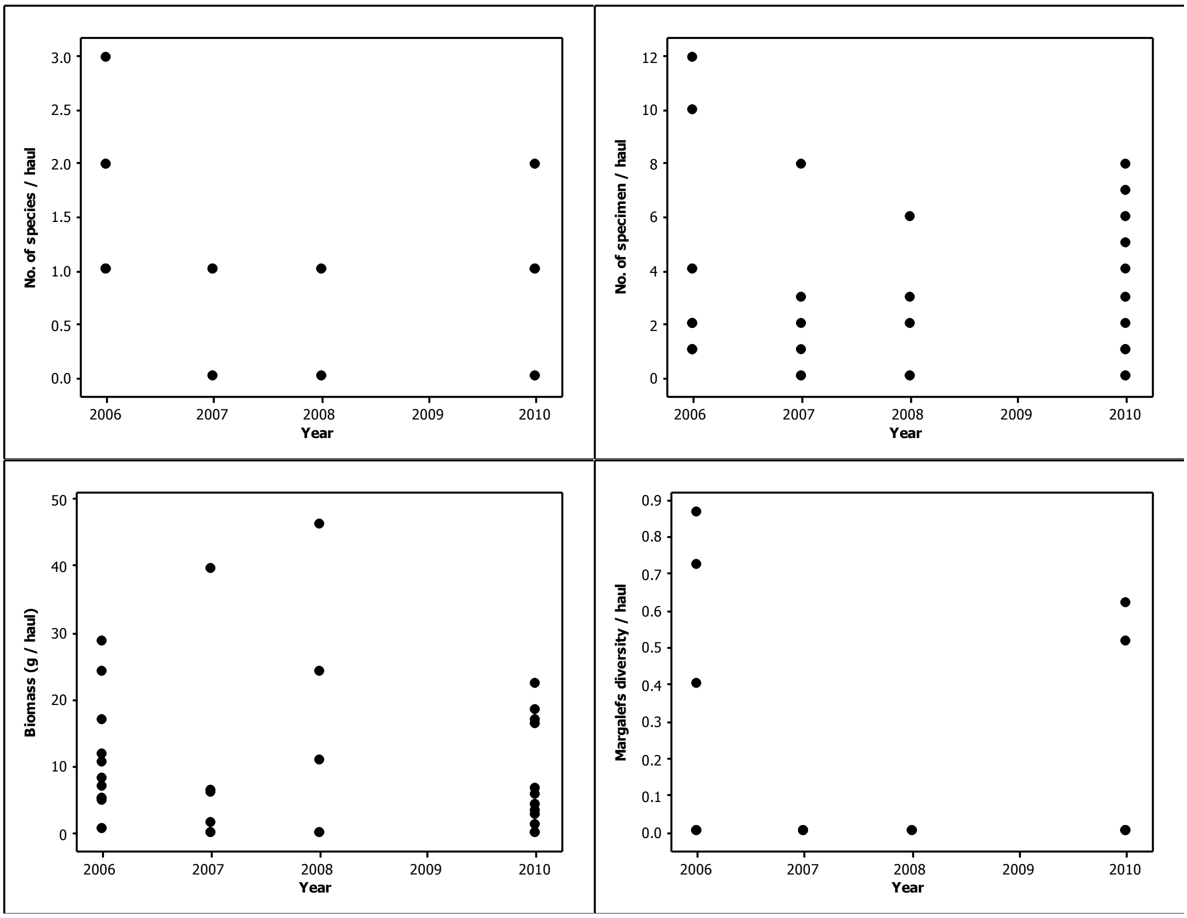


Figure 0-11 Number of species, Margalef's diversity, number and biomass of prawn in beach seine sampling at Bebelubi between 2006 and 2010.

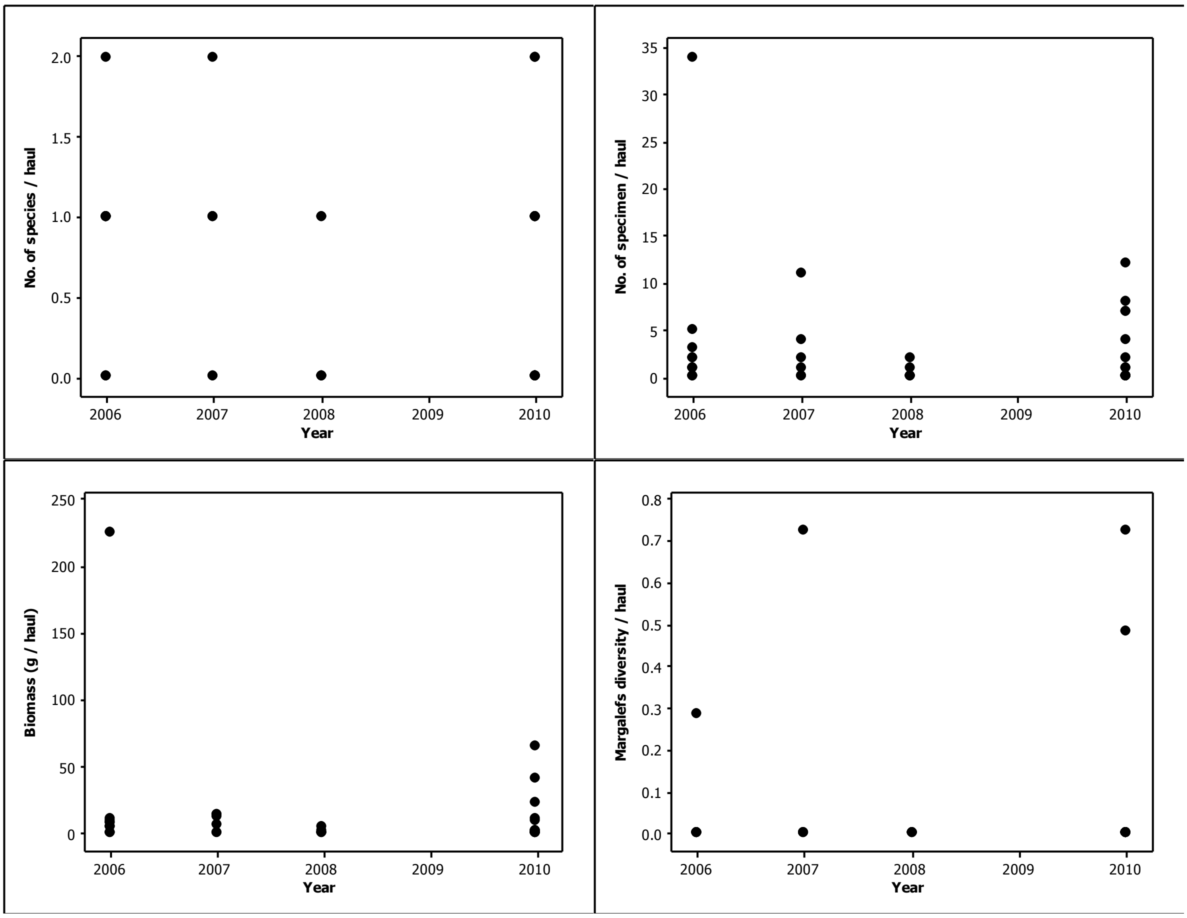


Figure 0-12 Number of species, Margalef's diversity, number and biomass of prawn in beach seine sampling at Baia between 2006 and 2010.

Conclusions

In the upper catchment there was no evidence of a possible mine related impact for species richness, prawn number and biomass in rank correlation assessments from catches for the sampling period 2000 to 2010. Rank correlations indicated a decreasing trend at Wasiba for prawn abundance and biomass, although catches are variable at this site depending on river levels for access to suitable sandbars for standardised seining. In the upper catchment no evidence supporting a mine-related impact to the species richness, diversity, abundance or biomass of fish was found for any of the other sites for the year 2010, nor in rank correlation assessments of trends over the sampling period 2000 to 2010.

In the lower Strickland region gill netting did not detect any significant differences between sites during 2010 and significant downwards trends in fish abundance, biomass and number of species at downstream of mine sites over the 2000 to 2010 time period were not observed. Seine netting did not detect any significant differences between sites during 2010, but significant negative correlations were detected for fish species richness, biomass and abundance at Tiumsinawam for the 2000 to 2010 time period.

Lower Strickland Off River Water Bodies

Hydroacoustic sampling was undertaken at the Strickland River off river water bodies, Kukufionga, Avu, Levame and Zongamange in May 2010. Results for the hydroacoustic surveys of the off river water bodies undertaken during 2010 are presented in Figure 0-13.

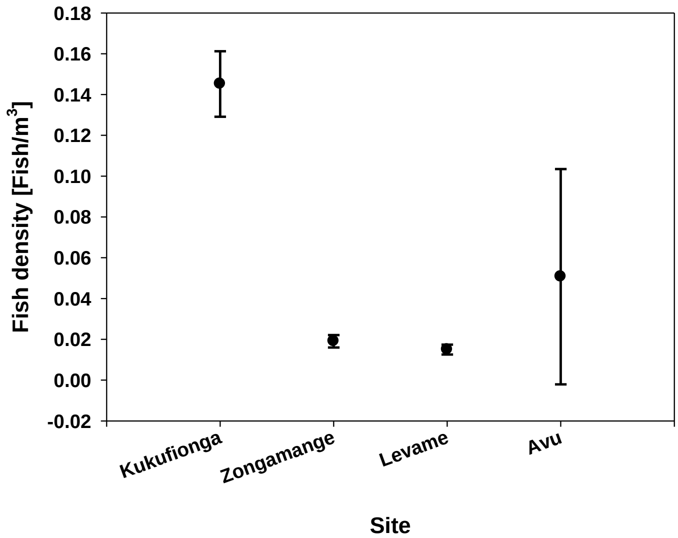


Figure 0-13 Average fish density (fish/m^3) with 95% confidence intervals for off river water body sites surveyed during 2010

Between site differences were detected for the fish density recorded at the off river water bodies during 2010. Fish density was found to be significantly greater ($p<0.001$) at Kukufionga than that observed at all the other off river water bodies surveyed. This result indicates that the potentially impacted site upstream of the Herbert River confluence at Kukufionga showed significantly higher fish density indicating no mine derived effects.

Fish Condition

Upper Catchment

Figure 0-14 presents box plots of the condition index (K) for specimens of mountain tandan, *N. equinus* and fresh water prawn, *M. handschini* from the upper catchment during 2010. By ANOVA, the average condition index for mountain tandan *N. equinus* was lower at Wasiba and Wankipe, when compared with data from Kuru ($p<0.05$) indicating that the mine may be having an effect on the condition of these fish. There were no significant differences in the mean condition index of *M. handschini* between sites.

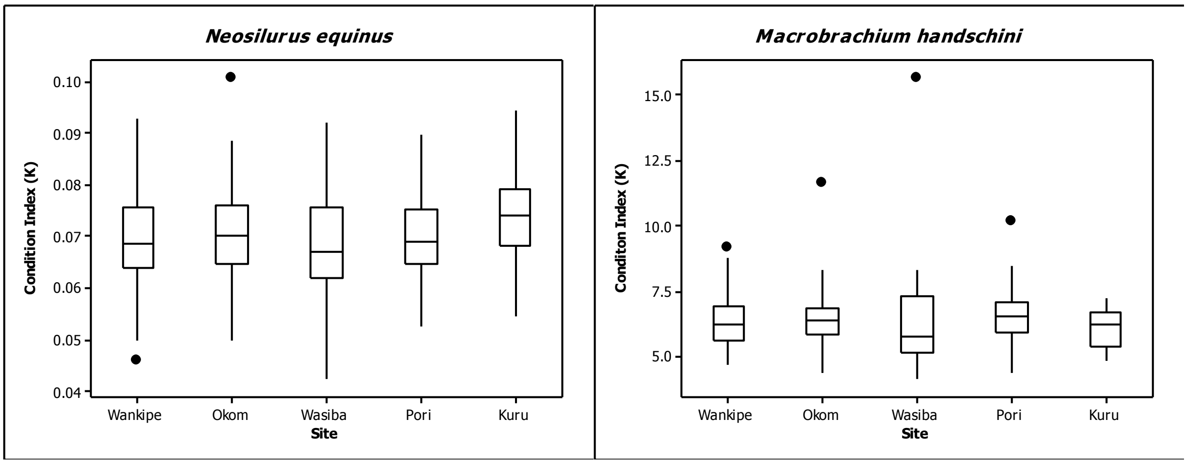


Figure 0-14 Box-plots of condition index (K) values for *N. equinus*, and *M. handschini*, from upper catchment sites in 2010.

Circles indicate outlier values while the horizontal lines in the boxes indicate median values.

Table 0-8 presents the significant Spearman's rank correlation results for mountain tandans and freshwater prawn condition for the period 2000 to 2010. Figure 0-15 shows dot plots of condition index by year for mountain tandans and freshwater prawns. An unmatched significant downward trend in condition was detected for *N. equinus* at Wasiba for the period 2000 to 2010. No significant negative correlations were detected for prawns at any downstream of mine sites.

Table 0-8 Spearman's rank correlation coefficients for significant ($p<0.05$) tests of fish and prawn condition for period 2000 to 2010 (or where data was available) in the upper catchment sites.

Species	Wankipe	Wasiba	Ok Om	Kuru River	Pori River
Neosilurus equinus	-	-0.197	-	0.297	-
Macrobrachium handschini	-	0.086	-0.145	-0.253	-

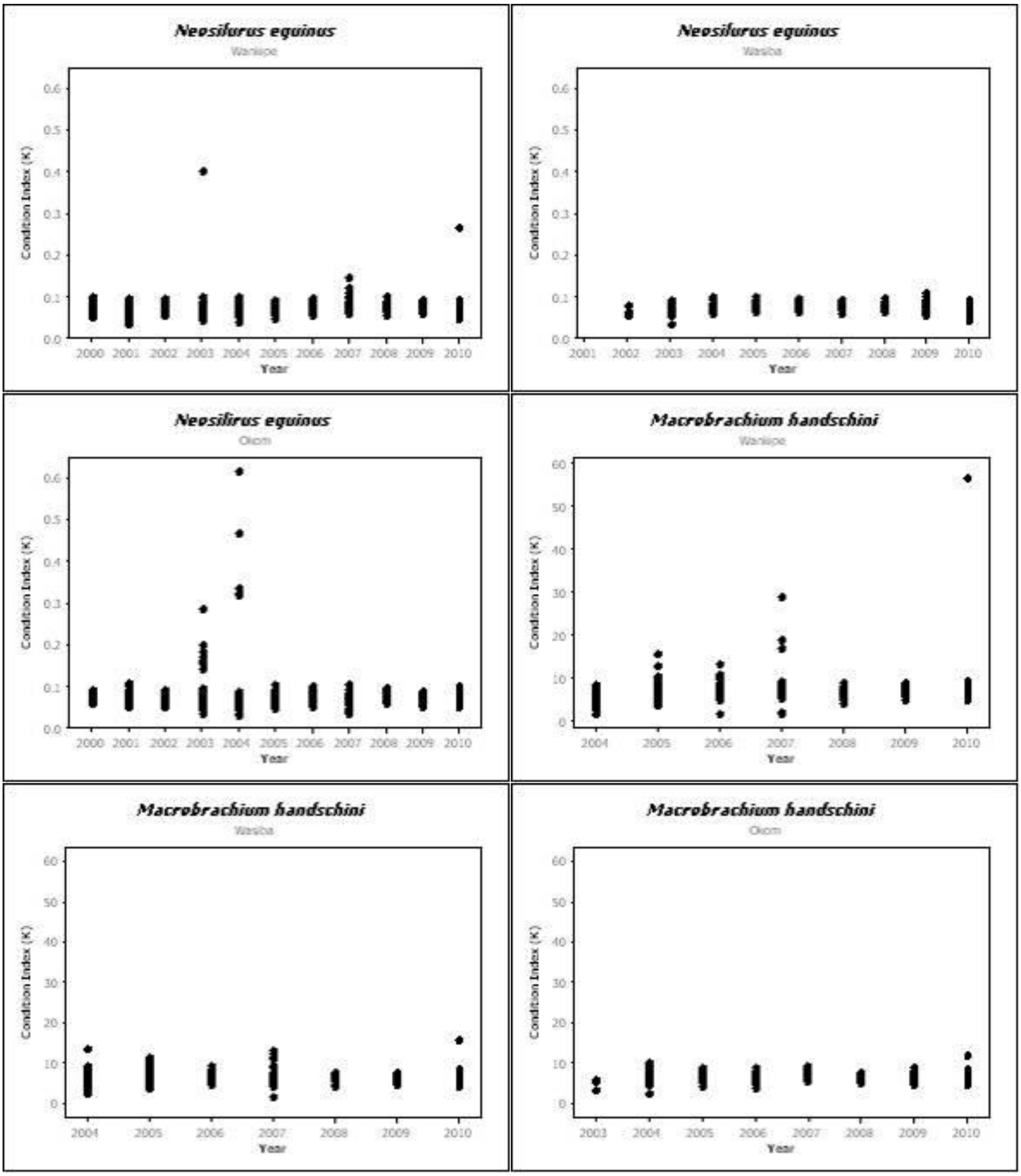


Figure 0-15 Dot plots of condition index (K) values for *N. equinus*, and *M. handschini*, over the period of 2000 to 2010 (or where data were available) at Wankipe, Wasiba and Ok Om.

Lower Strickland

Figure 0-16 and Figure 0-17 show box plots of the condition index for sharp-snouted catfish, *P. macrorhynchus*, broad-snouted catfish, *P. latirostris*, thick-lipped catfish, *Pa. crassilabrus*, giant freshwater prawns, *M. rosenbergii*, and cross-fingered prawns, *M. latidactylus*, from the Strickland River at Tiumsinawam and Bebelubi, and the reference sites in the Tomu and Baia Rivers. By ANOVA by site and species, the average condition index for all species analysed from Strickland River sites indicated no significant mine related impact for specimens collected in 2010.

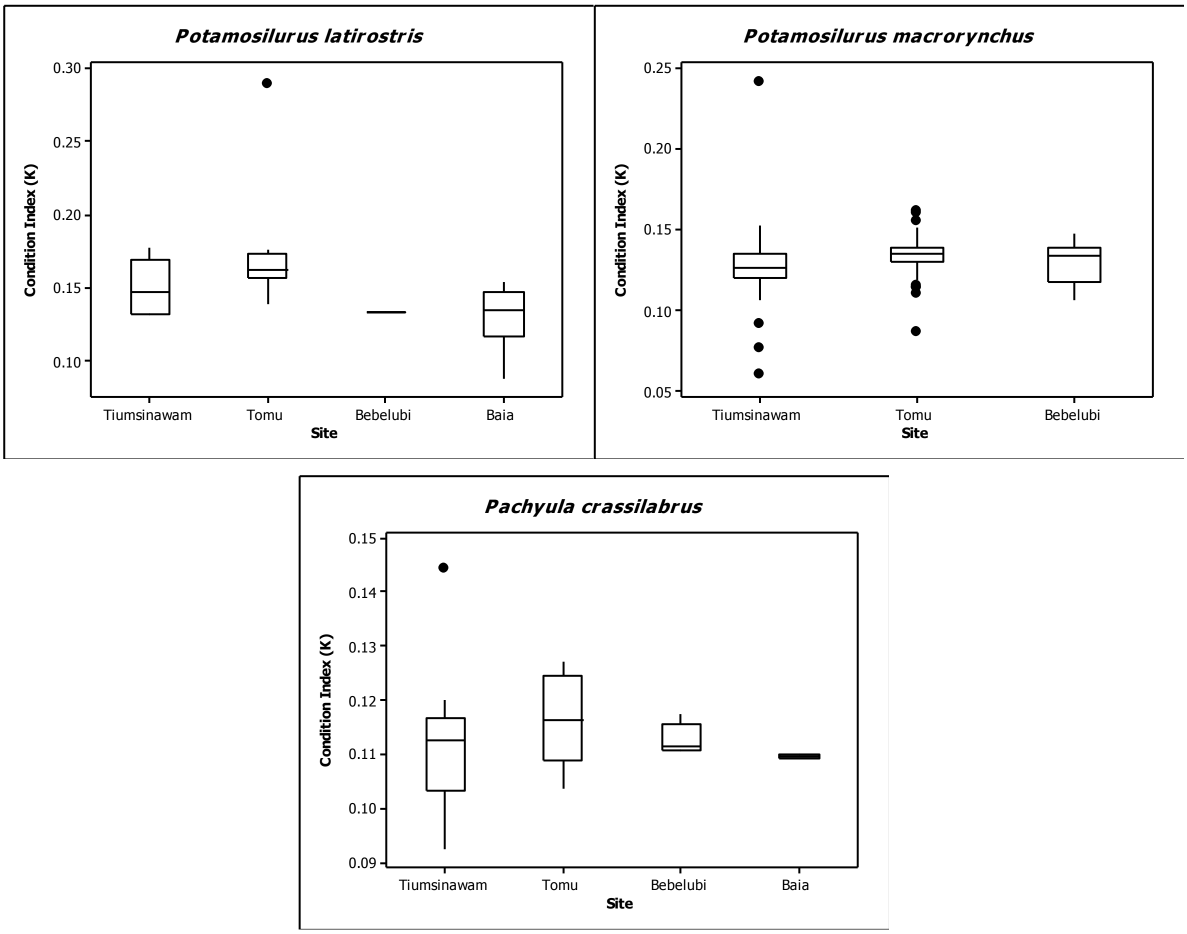


Figure 0-16 Box plots of condition index (K) for *P. macrorhynchus*, *P. latirostris* and *P. crassilabrus* from the Strickland River at Tiumsinawam and Bebelubi, and reference sites Tomu and Baia Rivers in 2010.

Circles indicate outlier values while the horizontal lines in the boxes indicate median values.

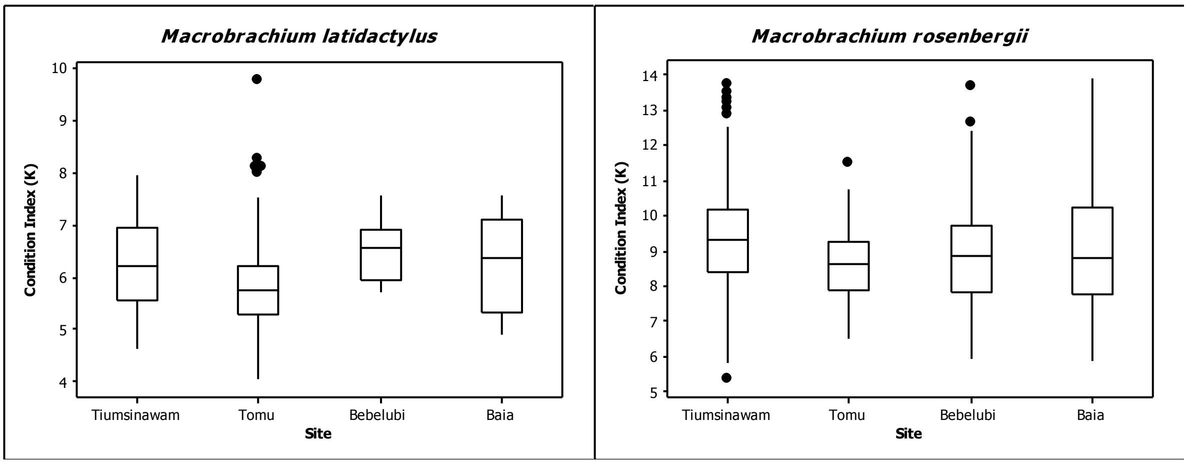


Figure 0-17 Box plots of condition index (K) for, *M. rosenbergii*, *M. latidactylus*, from the Strickland River at Tiumsinawam and Bebelubi, and reference sites Tomu and Baia rivers in 2010.
Circles indicate outlier values while the horizontal lines in the boxes indicate median values.

Figure 0-18 and Figure 0-19 shows dot plots of condition index for fish and prawns in the period 2000 to 2010. Table 0-9 presents the significant Spearman's rank correlation results for fish and prawns in the lower catchment sites. Significant decreasing trends were detected at Tiumsinawam for *P. macrorhynchus* condition that was not matched at the reference site at Tomu although, upon removal of outliers from earlier years, no negative correlation was detected. A decreasing trend was also detected for *P. crassilabrus* condition at Tiumsinawam, but was matched by a decreasing trend at Tomu therefore is not considered a mine related impact.

Table 0-9 Spearman's rank correlation analysis results of significant correlations in fish and prawn conditions for period 2000 to 2010 (or where data was available) at lower Strickland sites at Tiumsinawam and Tomu River.

Specimen	Tiumsinawam	Tomu
Potamosilurus latirostris	-	-0.157
Potamosilurus macrorhynchus	-0.190	-
Pachyula crassilabrus	-0.149	-0.157
Macrobrachium latidactylus	0.131	-0.082
Macrobrachium rosenbergii	-	-

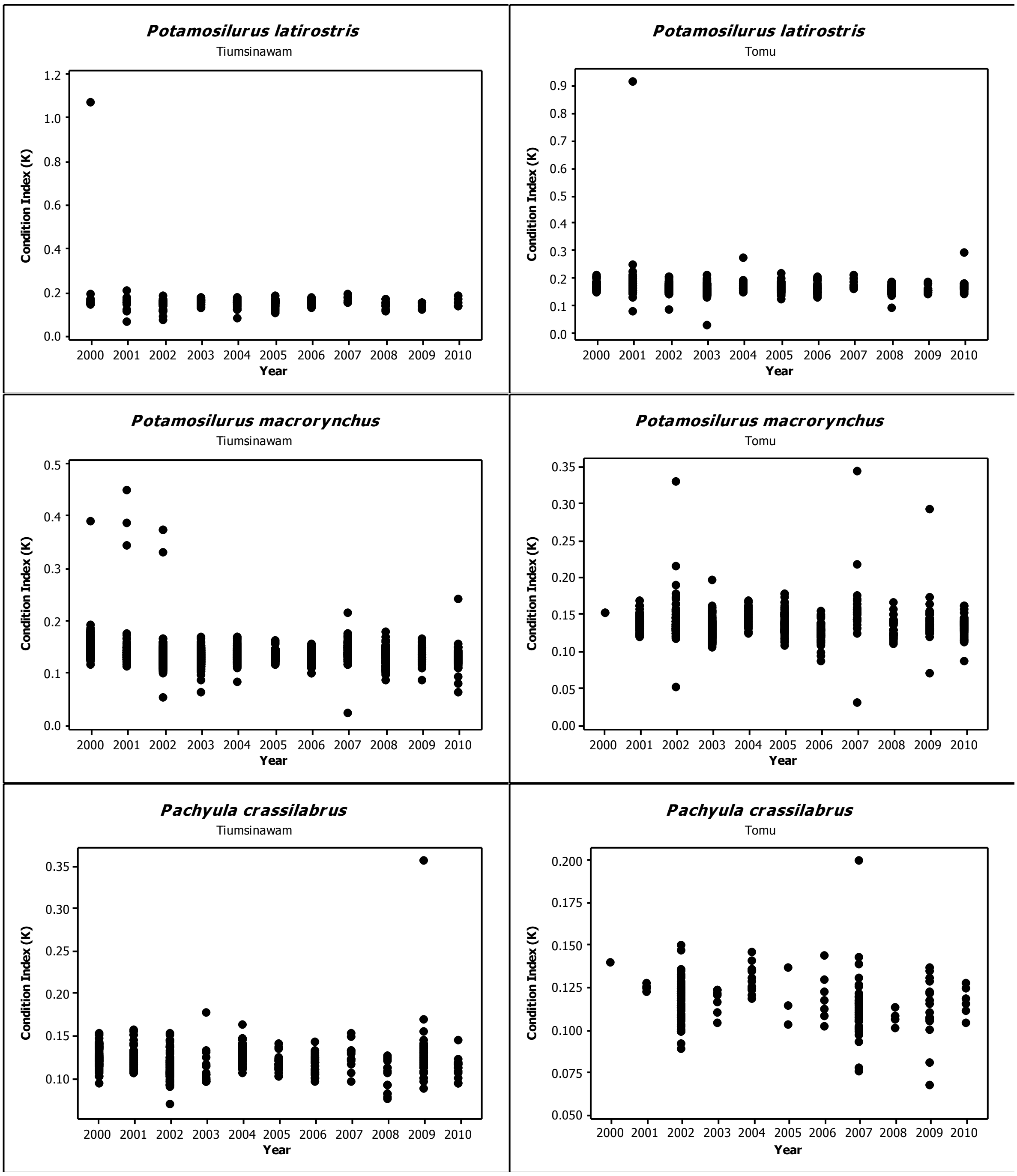


Figure 0-18 Dot plots for between year differences in condition index (K) for *P. macrorhynchus*, *P. latirostris* and *P. crassilabrus* in the Strickland River at Tiumsinawam and Tomu River over the period 2000 to 2010.

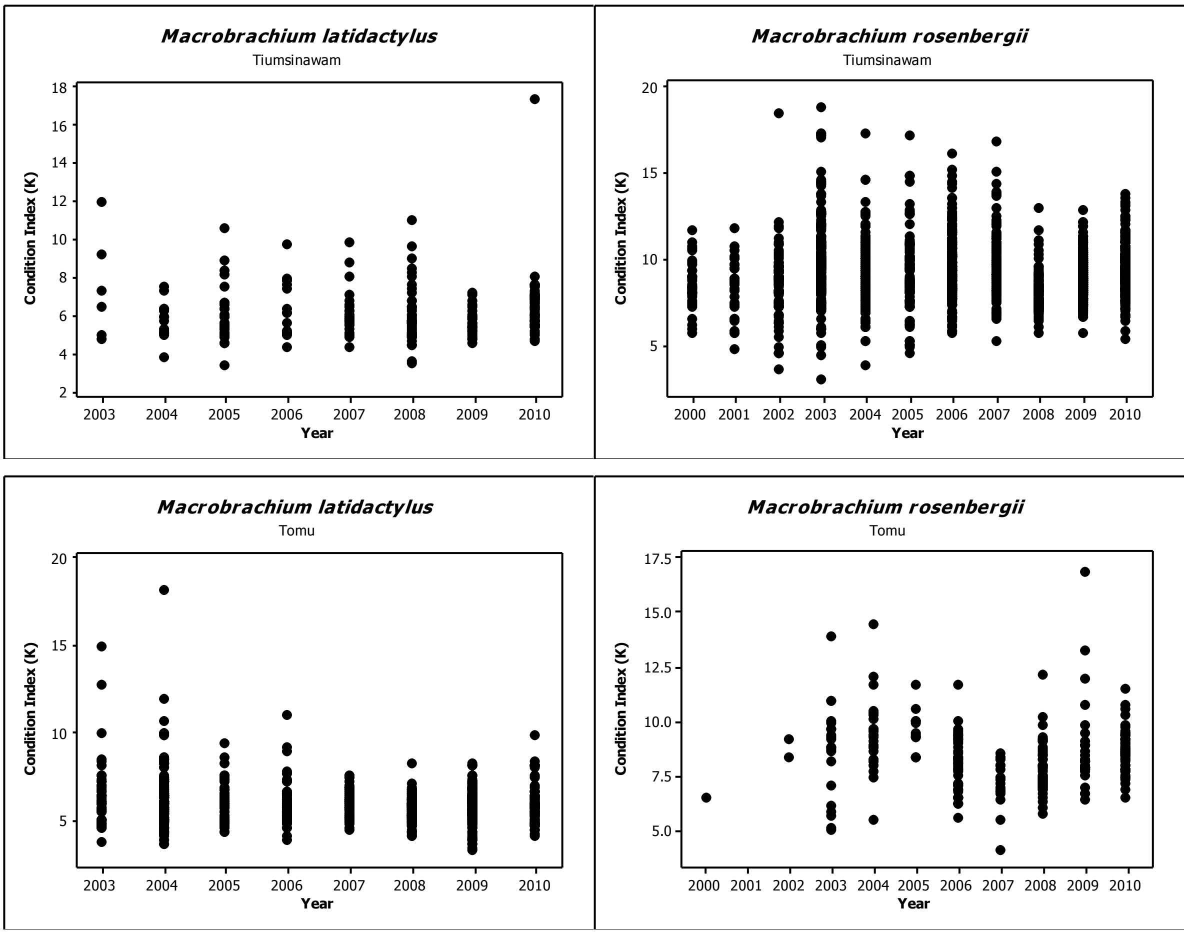


Figure 0-19 Dot plots for between year differences in condition index (K) for *M. rosenbergii*, and *M. latidactylus* at Tiumsinawam and Tomu River for the period 2000 to 2010.

Figure 0-20 and Figure 0-21 show dot plots of condition index for fish and prawns at Baia River and Bebelubi for the period 2006 to 2010. There were no significant correlations for condition index at Bebelubi from 2006 to 2010.

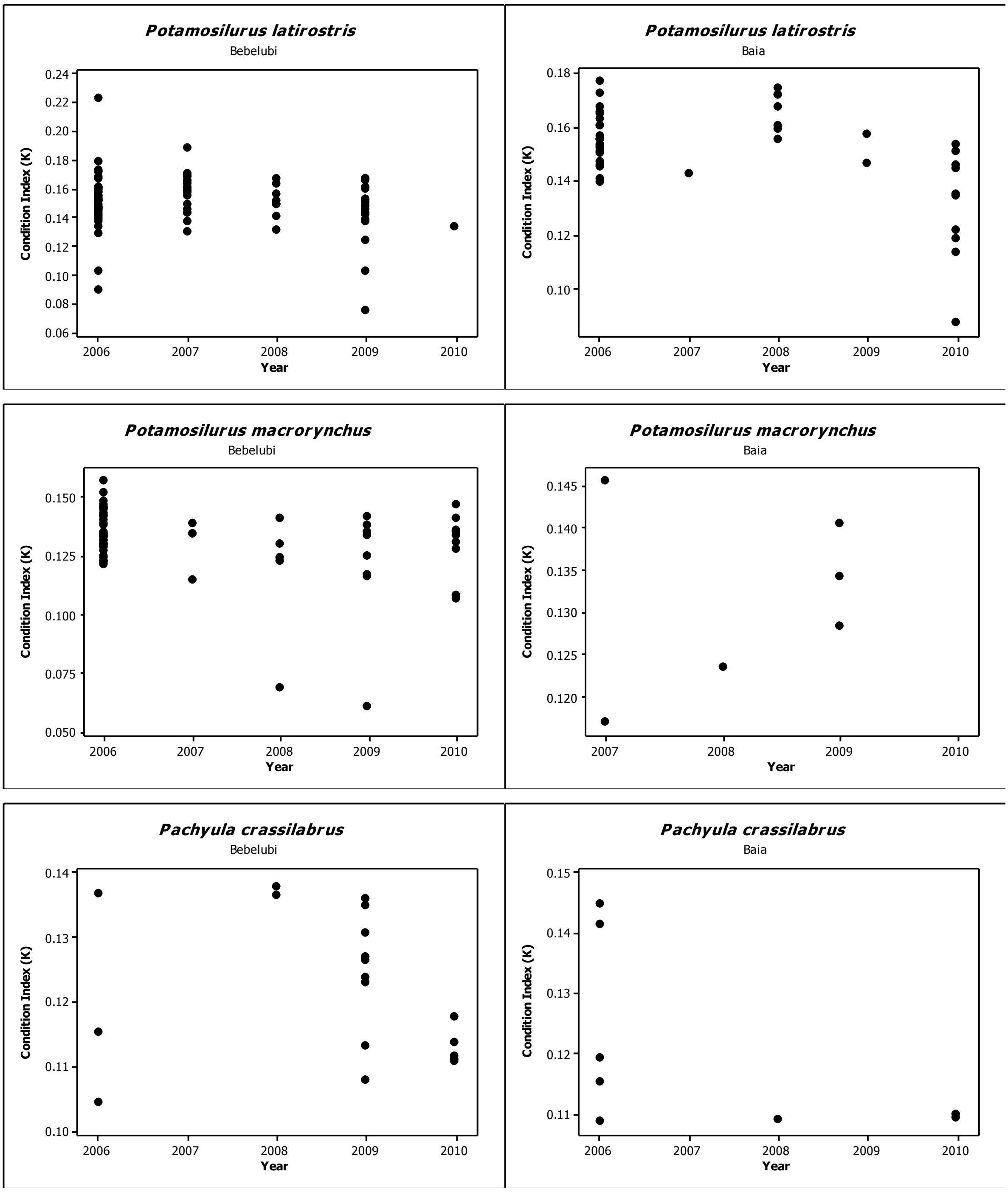


Figure 0-20 Dot plots for between year differences in condition index (K) for *P. macrorhynchus*, *P. latirostris* and *P. crassilabrus* in the Strickland River at Bebelubi and Baia River (or where data was available) over the period 2006 to 2010.

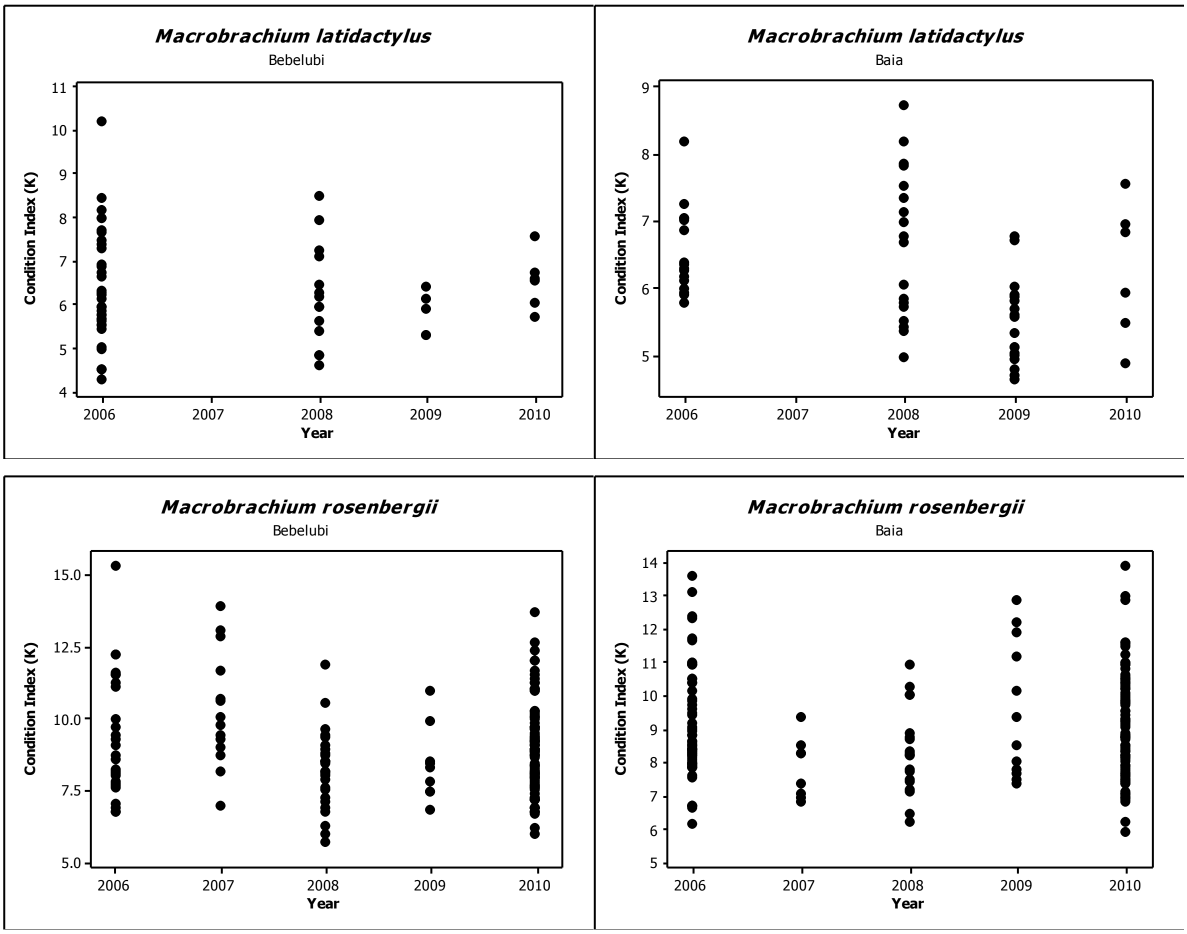


Figure 0-21 Dot plots for between year differences in condition index (K) for giant freshwater prawn, *M. rosenbergii*, and cross-fingered prawn *M. latidactylus* at Bebelubi and Baia River for the period 2006 to 2010

Conclusions

In the upper catchment, there was a significant decline observed for fish condition at Wasiba when compared with fish from Kuru River in 2010, but no difference was detected when compared with the other two reference sites. Prawn condition was not found to be different between reference and impact sites in 2010 and the period 2000 to 2010. A decreasing trend in fish condition at Wasiba was observed but not matched at the other further downstream impact site at Wankipe.

In the lower Strickland, there were no significant differences detected between sites indicating no reduction in condition of fish and prawns at Strickland River sites. A decreasing trend in condition was observed for *P. macrorhynchus* at Tiumsinawam that were not matched at the reference site at Tomu River for the 2000 to 2010 period.

Tissue Analysis Quality Assurance

Tissue samples collected during 2010 were sent to NMI in four separate batches, covering samples collected from each quarter of the calendar year respectively. Laboratory quality control sample results were provided separately for each batch.

For Quarter 1, the laboratory analysis included four blank samples, four laboratory control samples, six duplicate samples and eight matrix spike recoveries. All duplicate analyses were within the acceptable RPD limits. All matrix spike analyses, conducted on the same samples as the duplicate analyses, had recoveries within the acceptable range. Overall, the laboratory quality control for this batch was acceptable according to the criteria specified in Section 2.3.

For Quarter 2, the laboratory analysis included four blank samples, four laboratory control samples, six duplicate samples and eight matrix samples were analysed. All duplicate samples except one were within acceptable RPD limits. The RPD for zinc was found to be 40.4% for a duplicate undertaken for the prawn flesh sample matrix. All matrix spike analyses on these duplicate samples had recoveries within the acceptable range. Overall, the laboratory quality control for the quarter 2 batch of samples was acceptable according to the criteria specified in Section 2.3.

For Quarter 3, the laboratory analysis included four blank samples, four laboratory control samples, five duplicate samples and seven matrix spike recoveries. All duplicate analyses were within the acceptable RPD limits. All matrix spike analyses, conducted on the same samples as the duplicate analyses, had recoveries within the acceptable range. Overall, the laboratory quality control for the quarter 3 batch of samples was acceptable according to the criteria specified in Section 2.3.

For Quarter 4, the laboratory analysis included four blank samples, four laboratory control samples, five duplicate samples and six matrix spike recoveries. All duplicate analyses were within the acceptable RPD limits. All matrix spike analyses, conducted on the same samples as the duplicate analyses, had recoveries within the acceptable range. Overall, the laboratory quality control for the quarter 3 batch of samples was acceptable according to the criteria specified in Section 2.3.

During 2010, 46 samples were submitted for laboratory analysis as field blanks. The continued improvement of the use of field blanks should be commended as only 7 total field blanks were used in 2008, 31 during 2009 and during 2010 the aim of submitting at least 10 field blank samples per quarter was achieved. The use of a sample of *L. calcarifer* that was collected from Miwa during 2009 was continued during 2010, with six samples initially submitted to establish a range for comparison with field blanks throughout 2010.

Field blank results for 2010 were variable with indications of possible contamination during sample processing, analysis laboratory sample handling and/or analysis instrumentation variation, but in the general analysis results were within the range established. The complete field blank data set are presented in Appendix 5.

While contamination has been detected in the field blanks used in 2010, the effort to use field blanks improved again compared with previous years and should be maintained at this level. The contamination seen in samples at low levels may be due to the repeated thawing and freezing of the fish flesh used for field blanks. Future tissue sampling will need to be done with extra care to avoid this type of contamination and the introduction of an interlaboratory sample being used may help to identify the source of the variance seen in field blanks during the 2009 and 2010 monitoring programs.

Tissue Concentration Analysis

Graphs of tissue metal concentrations for all species, metals and tissue types sampled and analysed in 2010 are presented in Appendix 2. The following sections present the findings of the analysis of the tissue metal concentrations for the upper catchment and the lower Strickland River sites.

Upper Catchment

The sites used for collection of samples from the upper catchment during 2010 were those used since 2004 (PJV 2005, 2006, 2007, 2008, 2009, 2010) being, the reference sites, Ok Om, Pori River and Kuru River and the Lagaip River sites downstream of the mine, Wasiba and Wankipe.

Macrobrachium handschini cephalothorax and abdomen flesh

Cephalothorax samples of the prawn, *M. handschini*, collected from the downstream-of-mine sites of Wankipe and Wasiba were found to have significantly elevated average concentrations of arsenic, cadmium and lead compared with samples collected from the reference sites at Ok Om, Pori River and Kuru River (Figure 0-22). Average copper concentrations in cephalothorax samples collected from Wasiba were found to be significantly elevated when compared with samples collected from Pori River while samples collected from Wankipe and Wasiba were found to have significantly elevated average levels of zinc when compared with samples from Pori River (Figure 0-22). Average concentrations of chromium in samples collected from Wankipe were found to be significantly elevated compared with samples collected from Ok Om, the average concentration of nickel in samples collected from Wankipe was found to be significantly elevated when compared with samples collected from Pori River (Figure 0-22) and significant differences were detected between sites for average selenium concentrations but a multi comparison test could not detect which sites differed. The results of stepwise between-site ANCOVA analyses of metal concentrations in purged prawn cephalothorax samples are provided in Appendix 3

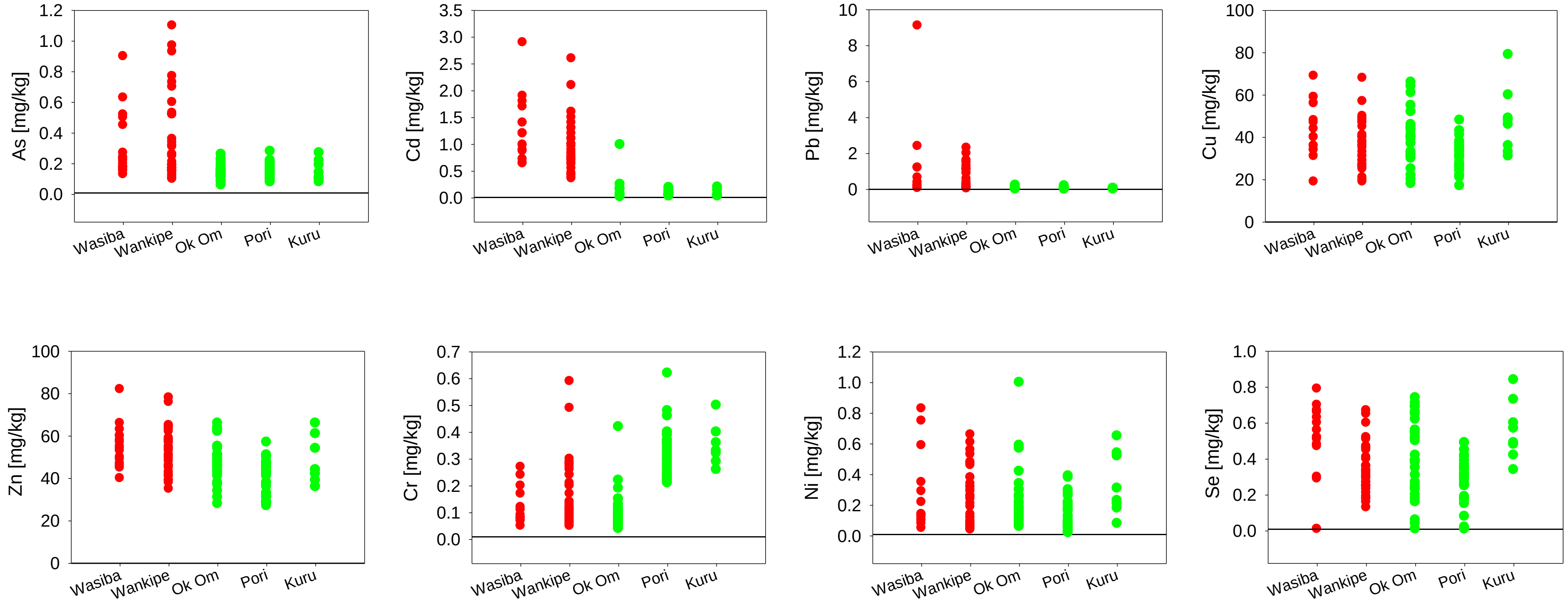


Figure 0-22 Concentrations in *M. handschini* cephalothorax samples collected during 2010 for metals discussed in the text.
Black line in single panel plots – detection limits

The average concentrations of cadmium for abdomen flesh samples collected from Wankipe and Wasiba during the year were significantly greater than for any of the reference sites (Figure 0-23). For lead, average concentrations at Wankipe were found to be significantly greater than those at all reference sites and samples from Wasiba were found to be significantly elevated compared with samples collected from Ok Om and Pori River. Average zinc concentrations in samples collected from Wankipe were found to be significantly elevated compared with samples from Pori River and average selenium concentrations in samples collected from both Wankipe and Wasiba were found to be significantly higher than those detected in samples from Pori River (Figure 0-23). Between-site differences were detected for average arsenic concentrations but a multiple comparison between the sites was not able to determine which sites these were (Figure 0-23). The results of stepwise between-site ANCOVA analyses of metal concentrations in purged prawn abdomen flesh samples are provided in Appendix 3.

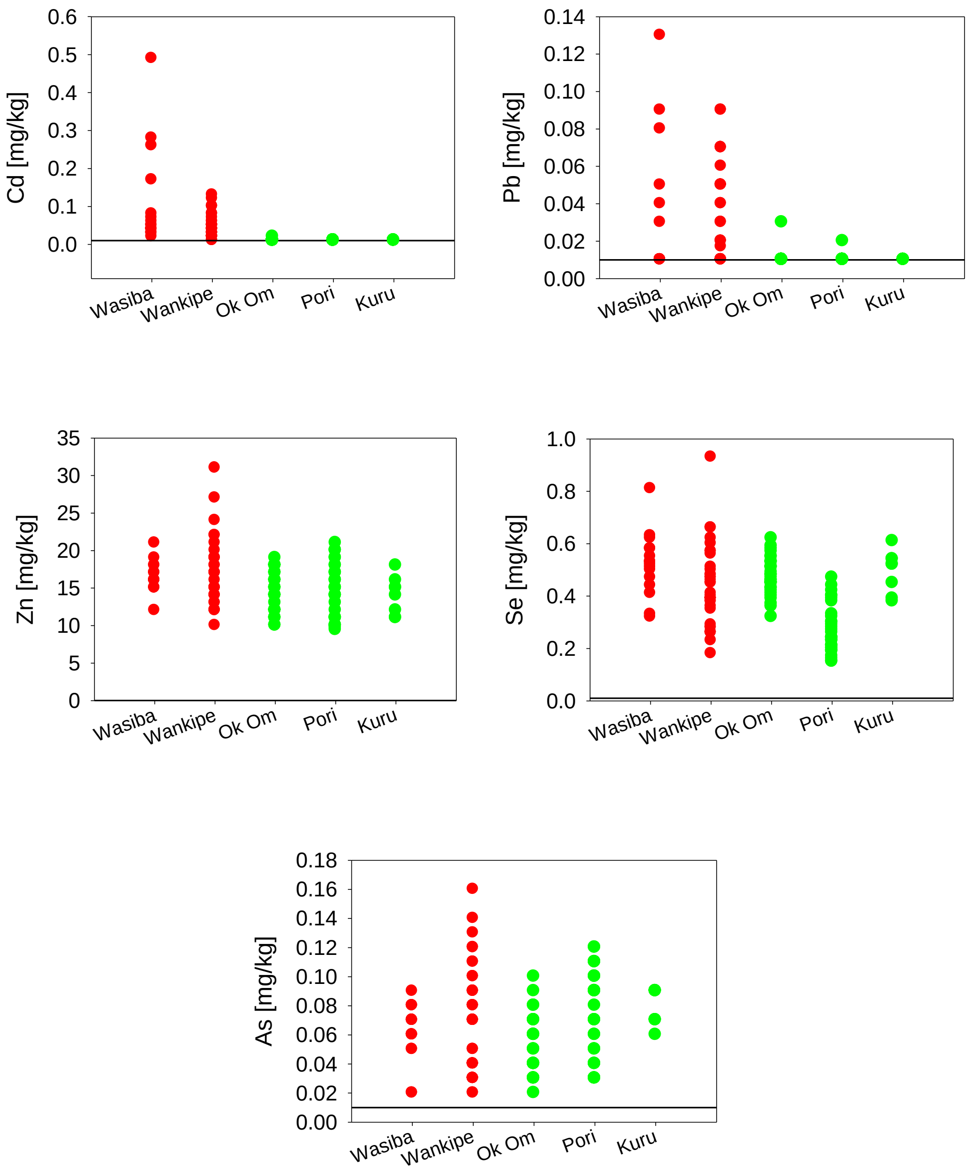


Figure 0-23 Concentrations in *M. handschini* abdomen flesh samples collected during 2010 for metals discussed in the text.
Black line in single panel plots – detection limits

Trends in prawn tissue metal concentrations were examined by use of Spearman's rank correlation for data bracketed in the time periods 2006 to 2010 (data sets of known quality) and for the last two years of sampling, (2009 and 2010). This tests for overall monotonic (that is, consistent in terms of direction) trends without any assumption of linearity of that trend. The results are summarised in Table 0-10.

Significant trends at sites downstream of the mine that were not matched by similar trends at reference sites for cephalothorax tissue included:

- Copper concentrations at both Wankipe and Wasiba decreased over the longer time period; and,
- Copper concentrations at both Wankipe and Wasiba decreased over the shorter time period.

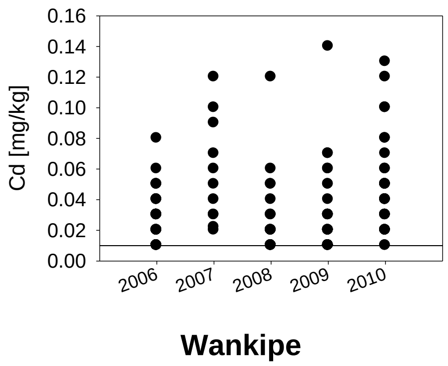
And for abdomen flesh:

- Cadmium concentrations at both Wankipe and Wasiba have increased over the longer time period (Figure 0-24);
- Lead concentrations at Wankipe has increased over the longer time period (Figure 0-25);
- Nickel concentrations at Wankipe have decreased over the longer time period;
- Cadmium and lead concentrations have increased at Wankipe over the shorter time period; and,
- Copper and zinc concentrations have increased at Wasiba over the shorter time period.

Table 0-10 Direction of Spearman's rank correlation coefficients for average metal concentrations in *M. handschini* cephalothorax and abdomen flesh samples over the full period of collection of purged samples and for the last two years of sampling.

D indicates declining trend. U indicates upward trend. 0 indicates no significant trend. – indicates insufficient variance for analysis.

Cephalothorax										
	2006-2010					2009-2010				
	Reference			Impact		Reference			Impact	
Metal	Ok Om	Pori	Kuru	Wankipe	Wasiba	Ok Om	Pori	Kuru	Wankipe	Wasiba
Cu	U	0	0	D	D	0	0	0	D	D
Cd	0	U	0	U	U	0	D	0	0	D
Pb	D	D	D	0	0	U	0	0	U	0
Zn	0	D	0	0	0	D	0	0	D	0
Cr	D	D	D	D	D	D	0	D	0	0
Ni	0	D	U	U	0	0	0	0	0	0
Se	0	D	U	0	U	D	D	D	D	D
As	D	D	0	0	0	0	0	0	0	0
Hg	0	D	U	D	0	0	D	0	D	D
Abdomen Flesh										
	2006-2010					2009-2010				
	Reference			Impact		Reference			Impact	
Metal	Ok Om	Pori	Kuru	Wankipe	Wasiba	Ok Om	Pori	Kuru	Wankipe	Wasiba
Cu	0	U	U	0	0	0	0	0	0	U
Cd	0	0	0	U	U	0	D	0	U	0
Pb	0	0	0	U	0	0	0	0	U	0
Zn	0	0	0	0	0	0	0	0	0	U
Cr	0	0	0	0	0	0	U	0	U	0
Ni	0	U	0	D	0	D	U	0	0	U
Se	D	D	0	D	0	D	0	0	0	0
As	0	U	U	0	U	0	U	U	U	U
Hg	-	-	-	-	-	-	-	-	-	-



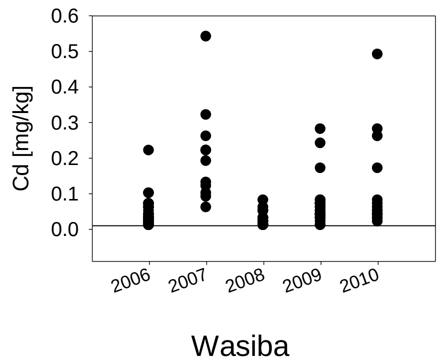


Figure 0-24 Concentrations of Cd in *M. handschini* abdomen flesh collected from Wankipe and Wasiba over the time period 2006 to 2010

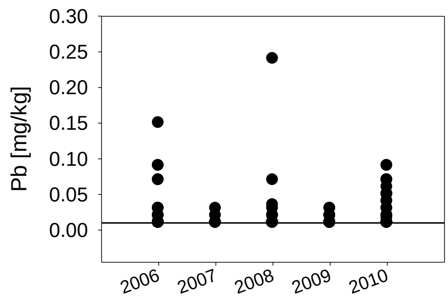


Figure 0-25 Concentrations of Pb in *M. handschini* abdomen flesh collected from Wankipe over the time period 2006 to 2010

Neosilurus equinus liver and flesh

For *N. equinus* liver samples significant differences between sites downstream of the mine and reference sites were detected for average cadmium and lead concentrations. Average cadmium concentrations were significantly elevated at Wankipe when compared with Pori River, Kuru River and Ok Om, and samples collected from Wasiba were significantly elevated compared with samples from Kuru River and Pori River (Figure 0-26). After the removal of outliers from the reference sites, average cadmium concentrations in samples from Wasiba were also significantly elevated compared with samples from Ok Om. Average concentrations of lead detected in samples collected from both Wankipe and Wasiba were found to be significantly greater than concentrations detected in samples collected at Kuru River and Pori River (Figure 0-26). The results of stepwise between-site ANCOVA analyses of average metal concentrations in mountain tandan liver samples are provided in Appendix 3.

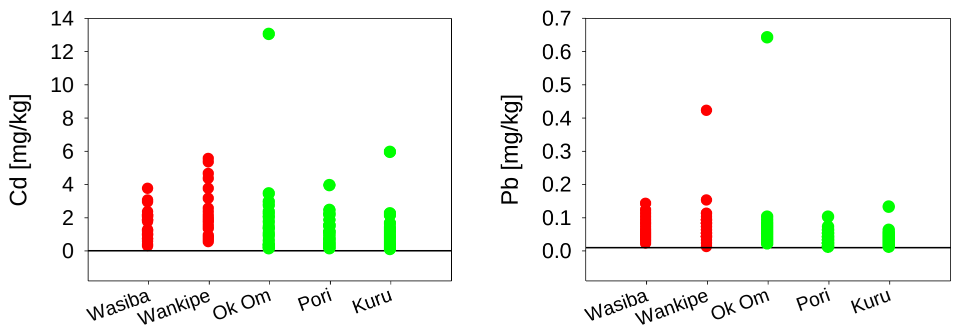


Figure 0-26 Concentrations in *N. equinus* liver samples collected during 2010 for metals discussed in the text.

Black line in single panel plots – detection limits

For *N. equinus* flesh samples, significant differences between Wasiba and all three reference sites were detected for length-adjusted average concentrations of selenium (Figure 0-27). The results of stepwise between-site ANCOVA analyses of metal concentrations in mountain tandan flesh samples are provided in Appendix 3.

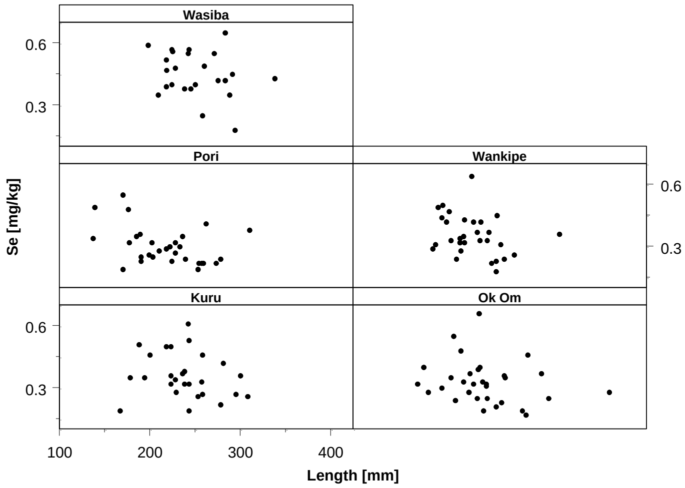


Figure 0-27 Concentrations in mountain tandan flesh samples during 2010 for selenium.

Trends in *N. equinus* tissue metal concentrations were examined by use of Spearman's rank correlation over the time periods 2000 to 2010 and for the last two years of sampling, (2009 and 2010). The results are summarised in Table 0-11.

Significant trends at sites downstream of the mine that were not matched by similar trends at reference sites for liver tissue included:

- Cadmium and arsenic concentrations at Wankipe have decreased over the longer time period; and,
- Arsenic concentrations at both Wankipe and Wasiba decreased over the shorter time period;

And for dorsal flesh:

- Cadmium and arsenic concentrations decreased at Wankipe over the longer time period;
- Arsenic concentrations at Wasiba decreased over the longer time period
- Selenium concentrations increased at Wankipe over the longer time period (Figure 0-28);
- Selenium concentrations at Wankipe have decreased over the shorter time period; and,
- Arsenic concentrations at Wasiba have decreased over the shorter time period.

Table 0-11 Direction of Spearman rank correlation coefficients for metal concentrations in *N. equinus* liver and flesh samples between 2000 and 2010 and for the last two years of sampling.
D indicates declining trend. U indicates upward trend. 0 indicates no significant trend. – indicates insufficient variance for analysis.

Liver										
	2000-2010					2009-2010				
	Reference		Impact			Reference		Impact		
Metal	Ok Om	Pori	Kuru	Wankipe	Wasiba	Ok Om	Pori	Kuru	Wankipe	Wasiba
Cu	0	D	0	D	D	D	0	0	0	0
Cd	0	0	0	D	0	0	0	0	0	0
Pb	D	0	0	D	0	0	U	0	U	0
Zn	0	D	D	D	D	0	0	0	0	0
Cr	D	0	D	D	0	U	0	0	0	0
Ni	0	0	0	0	0	0	0	0	0	0
Se	0	D	D	D	D	0	0	0	0	0
As	0	0	U	D	U	0	0	0	D	D
Hg	U	D	D	D	0	0	0	0	0	0
Flesh										
	2000-2010					2009-2010				
	Reference		Impact			Reference		Impact		
Metal	Ok Om	Pori	Kuru	Wankipe	Wasiba	Ok Om	Pori	Kuru	Wankipe	Wasiba
Cu	D	0	0	0	0	0	0	D	D	D
Cd	0	0	0	D	0	0	U	0	0	0
Pb	D	0	0	D	0	-	0	0	0	0
Zn	D	0	D	U	0	D	0	D	0	0
Cr	D	U	D	D	0	U	U	0	0	0
Ni	0	0	0	0	0	D	D	D	D	D
Se	0	0	0	U	0	0	0	0	D	0
As	0	0	0	D	D	0	0	0	U	D
Hg	D	0	0	0	0	0	D	D	0	0

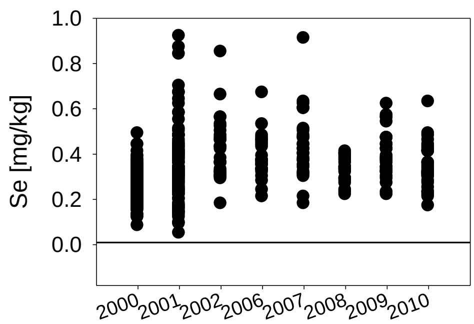


Figure 0-28 Concentrations of Se in *N. equinus* dorsal flesh collected from Wankipe during the time period 2000 to 2010
Black line in single panel plot – detection limits

Prawn sorbitol dehydrogenase analysis

It has been recommended on several occasions (PJV 2003, 2004, 2005, 2006; Bunn *et al* 2006) that in light of continued evidence for enhanced bioavailability of some metals in the Lagaip River that effort should be made to look for any evidence of detrimental effects to the resident biota resulting from that elevation. The measurement of increased bioaccumulation of metals is merely a measurement of exposure to increased bioavailability of metals, and does not necessarily imply that there were any adverse consequences. The primary effects monitoring tool for the Biological Monitoring Programs is assessment of diversity and abundance of fish and prawns, but power analyses of this sampling program by PJV (2005) demonstrated that as implemented that program had little statistical power to detect effects short of catastrophic changes to the resident populations although it should be noted the current report does provide evidence of impacts at Wasiba.

In 2006 SDH analysis was undertaken on prawns collected from the upper Lagiap River sites, Wasiba and Wankipe and the reference sites, Ok Om and the Kuru River. It was found that the prawns collected from the impacted sites had elevated levels of SDH in abdomen flesh, which is an indicator of hepatocellular death.

During 2009 a dedicated effort was made to collect prawns from the upper catchment sites for use in SDH analysis. Prawns were collected from Wasiba, Wankipe, Ok Om and Pori River and were sent to Curtin University in Western Australia where they underwent analysis. The results indicated that the prawns at the impacted sites, Wasiba and Wankipe were found to have significantly higher levels of SDH in their blood serum than those collected from the reference sites, Pori and Ok Om.

During 2010, prawns were collected in the Lower Strickland region at, Strickland River at Oxbow 3 entrance, SG5 and Fly River at Ogwa during May, and in the Upper Catchment at, Wasiba, Wankipe, Pori River and Ok Om, were sampled in November. The results of the analysis of the samples collected from the Lower Strickland in May 2010 are presented in Figure 0-29 and the results of the analysis of the samples collected from the Upper Catchment in November 2010 are presented in Figure 0-30.

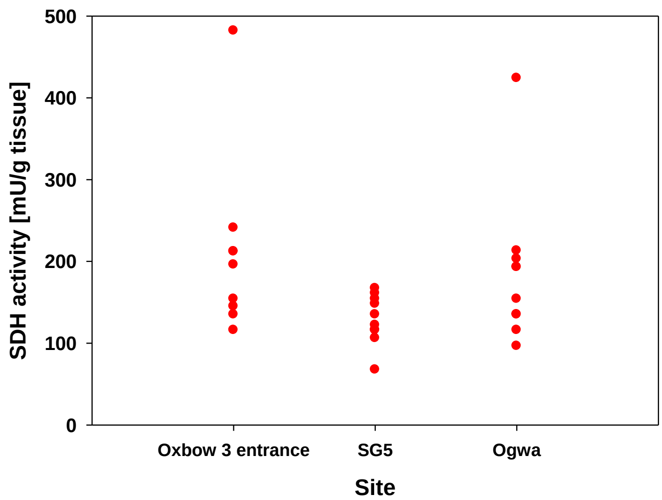


Figure 0-29 Results of SDH analysis of prawns (*M. rosenbergii*) collected from sites in the Lower Strickland in 2010

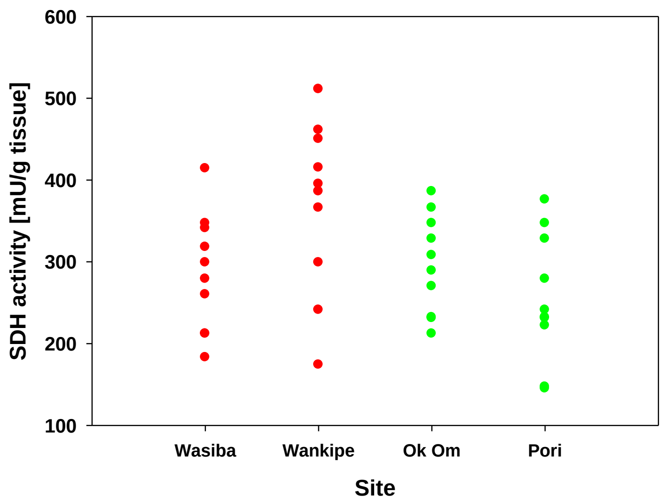


Figure 0-30 Results of SDH analysis of prawns (*M. handschini*) collected from sites in the Upper Catchment in 2010

In the Lower Strickland, SDH analysis of prawn abdomen indicated that samples collected from Oxbow 3 entrance had significantly higher levels of SDH activity on average than those collected from SG5, while samples from Ogwa were statistically similar to those collected from both Oxbow 3 entrance and SG5. This indicates that the prawns at Oxbow 3 entrance were under more duress causing greater hepatocellular death than those prawns collected from SG5. The site at Oxbow 3 entrance is upstream of the confluence with the Herbert River, a major source of dilution water to the Strickland River, while the site at SG5 is downstream of the confluence. The site at Ogwa is downstream of the confluence with the Fly River and therefore is also downstream of the Ok Tedi Copper Mine, a further source of metals contamination.

The results of the analysis of SDH levels in prawns collected from the Upper Catchment indicated that the prawns from the site downstream of the mine at Wankipe had significantly greater levels of SDH in abdomen flesh than prawns collected from both the reference sites. Prawns collected from Wasiba were not found to be significantly elevated when compared with reference site samples. Therefore, the prawns at Wankipe are considered to be incurring a greater rate of hepatocellular death than those at Ok Om and Pori River. The influence of the cyanide destruct circuit may be reducing the hepatocellular damage caused by available metals at Wasiba but has not had any influence on the prawns at Wankipe. Samples collected in 2011 will give an indication if this is the case.

At this stage it is not known if the level of hepatocellular damage observed is tolerable by the prawns, but the results do demonstrate that the elevated tissue metal concentrations found at the sites downstream of the mine are associated with an increased rate of hepatocellular death. A report of the investigation can be seen in Appendix 4, where the procedures for methods and analysis are given.

Conclusions

The tissue metal concentration analyses for samples from the upper catchment during 2010 demonstrated continued elevation of metal bioaccumulation in samples from the Lagaip River compared with the reference sites.

Average cadmium was significantly elevated at both Wankipe and Wasiba in prawn cephalothorax and flesh samples and in mountain tandan liver samples as was found in the 2007, 2008 and 2009 Annual Biology Reports. Average lead was also significantly elevated at both Wankipe and Wasiba in prawn cephalothorax and flesh samples and in mountain tandan liver samples during 2010. This observation is an increase in the relative elevation of lead to that seen in 2009. Average arsenic concentrations in prawn cephalothorax and flesh were also found to be significantly elevated at Wankipe and Wasiba. Other metals that were found to be significantly elevated in prawn cephalothorax samples included copper, chromium, nickel zinc and selenium in prawn flesh samples at impact sites.

An analysis of significant trends in the data collected from 2000 for *N. equinus* and 2006 for *M. handschini* to 2010 and for the last two years indicated a number of decreases in metal concentrations in fish and prawn tissue types. Downward trends in average copper concentrations in prawn cephalothorax samples from Wankipe and Wasiba were observed for the long term and short term analysis. For prawn abdomen flesh trend analysis indicated that nickel concentrations in samples from Wankipe had decreased over the longer term analysis. This may be an effect of the cyanide destruct circuit removing greater amounts of metals from the discharge effluent reducing the amount of available metals to the organisms downstream. Collection and analysis of samples in 2011 will allow for continued observation of these decreasing trends.

For *N. equinus*, decreasing trends were observed for liver tissue over the longer term for average concentrations of cadmium and arsenic at Wankipe and over the shorter term concentrations of arsenic at both Wankipe and Wasiba decreased. For dorsal flesh, decreasing trends over the longer term were observed for average concentrations of cadmium and arsenic samples collected from Wankipe and arsenic concentrations in samples collected from Wasiba, while over the shorter period decreasing trends were observed for selenium concentrations in samples from Wankipe and arsenic samples collected from Wasiba. Again, this may be a result of the cyanide destruct circuit reducing the available metals to organisms downstream and will be further investigated in 2011.

Increasing trends for prawn tissue were only detected in abdomen flesh samples collected from both Wankipe and Wasiba for average copper concentrations over the longer term, and for lead concentrations for samples collected from Wankipe. For the shorter time period, cadmium and lead were seen to increase in samples collected from Wankipe while copper and zinc were seen to have increased in samples collected from Wasiba.

Increasing trends for the fish, *N. equinus*, were observed in flesh samples collected from Wankipe for average zinc and selenium concentrations over the longer time period and for average arsenic concentrations at Wankipe in the shorter term data. No increasing trends were observed for fish liver samples.

Overall, these results demonstrate a continued persistence of mine-related elevation of bioavailability of cadmium, copper, lead, zinc, selenium and arsenic in the Lagaip River for certain tissue types, but the decreasing trends observed also indicate that the cyanide destruct circuit may well be having an effect on reducing the availability of the metals to organisms downstream of the mine. Continued bio-monitoring in 2011 should give a clearer picture in terms of these trends.
The question of relevance of this to the status of the populations of aquatic biota was partially addressed for the first time during 2006 (PJV 2007) and followed up in 2009 (PJV 2010), via the use of the SDH enzyme marker of hepatic cell damage. This demonstrated elevated rates of hepatopancreas cell damage in prawns from both the Lagaip sites compared with specimens from the reference sites, particularly the Ok Om. The SDH analysis program was undertaken again in 2010 with prawn samples collected from the Lower Strickland and the Upper Catchment sites and analysed for SDH activity. The results were similar to those observed in 2006 and 2009 for prawns collected from the upper catchment although only samples from Wankipe were observed to have significantly elevated levels of SDH activity compared with those detected in prawns from both reference sites. This indicates elevated rates of hepatocellular damage and therefore potentially inhibition of metabolic activities at Wankipe compared with the reference sites. At Wasiba, hepatocellular damage decreased in 2010 which may be a result of the cyanide destruct circuit reducing the available metals at this site. Wankipe prawns were found to still be experiencing greater rates of hepatocellular damage compared to the reference sites which may indicate that metals are still available at levels that are detrimental to the health of these organisms. The continuation of this program in 2011 will allow for further investigation into this finding.

Results of SDH analysis of prawns collected from sites in the Lower Strickland region indicated that hepatocellular damage was significantly greater at site Oxbow 3 entrance when compared with samples from SG5 and that Ogwa prawns were found to have similar levels of SDH activity when compared with samples from both Oxbow 3 entrance and SG5. The site at Oxbow 3 entrance is upstream of the confluence with the Herbert River, a major source of dilution water to the Strickland River, while the site at SG5 is downstream of the confluence. The site at Ogwa is downstream of the confluence with the Fly River and therefore is also downstream of the Ok Tedi Copper Mine, a further source of metals contamination.

Lower Strickland

Strickland River sites at Tiumsinawam, Bebelubi and SG5 were sampled in 2010 along with reference sites in the Tomu and Baia Rivers.

Macrobrachium rosenbergii cephalothorax and abdomen flesh

During 2010 giant freshwater prawns, *M. rosenbergii,* were collected from the usual monitoring sites in the Lower Strickland region, including Strickland River at Bebelubi, the Baia River, the Strickland River at Tiumsinawam, the Tomu River and the Strickland River at SG5 along with sites that have been added to the Biology program to better assess the distribution of elevated cadmium that has been seen in previous years results. These sites included Kukufionga, an oxbow upstream of Baker junction, the Strickland River at Oxbow 3 entrance, a site on the Strickland River upstream of Baker junction, Levame , an oxbow at the midpoint between the Baker and Everill junctions, Strickland River above Everill junction, a site downstream of the Baker junction but upstream of the confluence of the Fly River and the Fly River at Ogwa, downstream of the confluence of the Strickland and Fly rivers. These added sites allow for an investigation of the extent of the metals that have been detected in organisms as far down stream as SG5 in previous years. The results of stepwise between-site ANCOVA analyses of metal concentrations in giant freshwater prawn cephalothorax and flesh samples are provided in Appendix 3.

Average cadmium and lead concentrations in *M. rosenbergii* cephalothorax samples were found to be significantly higher at Tiumsinawam, Bebelubi, Kukufionga and SG5, when compared with both reference sites, Tomu River and Baia River. Ogwa samples were found to be significantly elevated in cadmium when compared with samples from Baia River and for lead in comparison with samples from the Tomu River (Figure 0-31). Samples from Levame were found to have significantly elevated levels of cadmium when compared with both reference sites. The average concentrations of arsenic that were detected at Bebelubi, Oxbow 3 entrance, SG5, Levame and Ogwa were found to be significantly elevated compared with those samples collected from Baia River and Tomu River and samples from Kukufionga were found to be significantly elevated when compared with samples from Tomu (Figure 0-31). Average nickel concentrations in samples from Bebelubi and Kukufionga were significantly greater than samples from Tomu River (Figure 0-31). Samples collected at SG5 were also found to be significantly elevated in average selenium concentrations compared with samples from Baia River and Tomu River (Figure 0-31). Average copper concentrations detected in samples collected from Levame and Ogwa were found to be significantly elevated when compared with samples collected from Baia River. Average zinc concentrations were found to be elevated in samples collected from Kukufionga when compared with samples from both Baia River and Tomu River (Figure 0-31). Average concentrations of selenium were found to be significantly elevated in samples collected from Levame when compared with both reference sites (Figure 0-31)

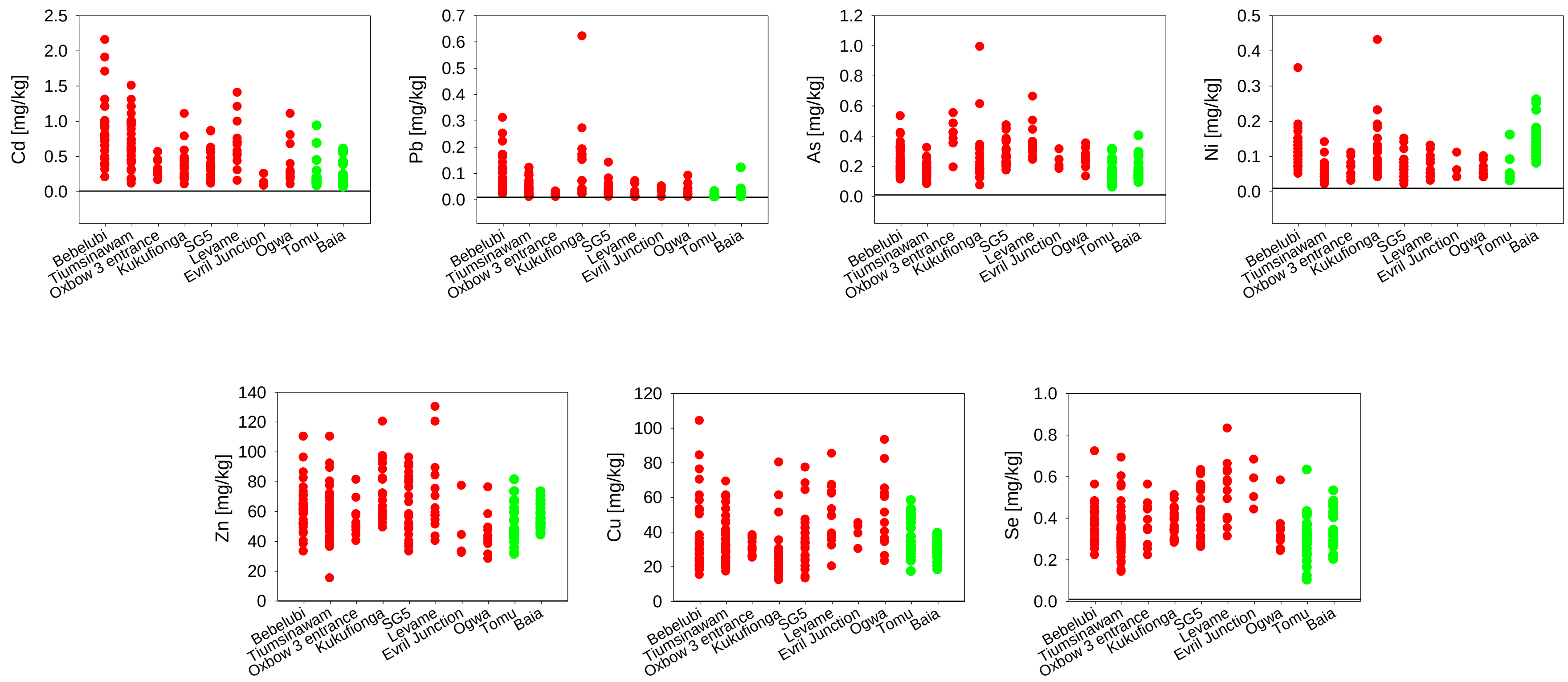


Figure 0-31 Metal concentrations in *M. rosenbergii* cephalothorax samples collected during 2010, as discussed in the text.
Black line in single panel plots – detection limits

The results of stepwise between-site ANCOVA analyses of average metal concentrations in giant freshwater prawn abdomen flesh samples indicated that there were significant differences between reference and impact sites for the metals cadmium, selenium and arsenic. Average cadmium concentrations were detected at elevated levels at Bebelubi and Levame when compared with both the reference sites (Figure 0-32). Significant differences were detected between sites for average selenium concentrations with samples from Everill junction significantly elevated compared with both Baia River and Tomu River and for samples collected from Levame when compared with samples from Baia (Figure 0-32). Average arsenic concentrations observed in samples collected from impact sites Kukufionga, Oxbow 3 entrance, SG5, Levame and Ogwa were all significantly elevated when compared with both reference sites, and samples from Tiumsinawam were significantly elevated when compared with samples from Tomu River (Figure 0-32).

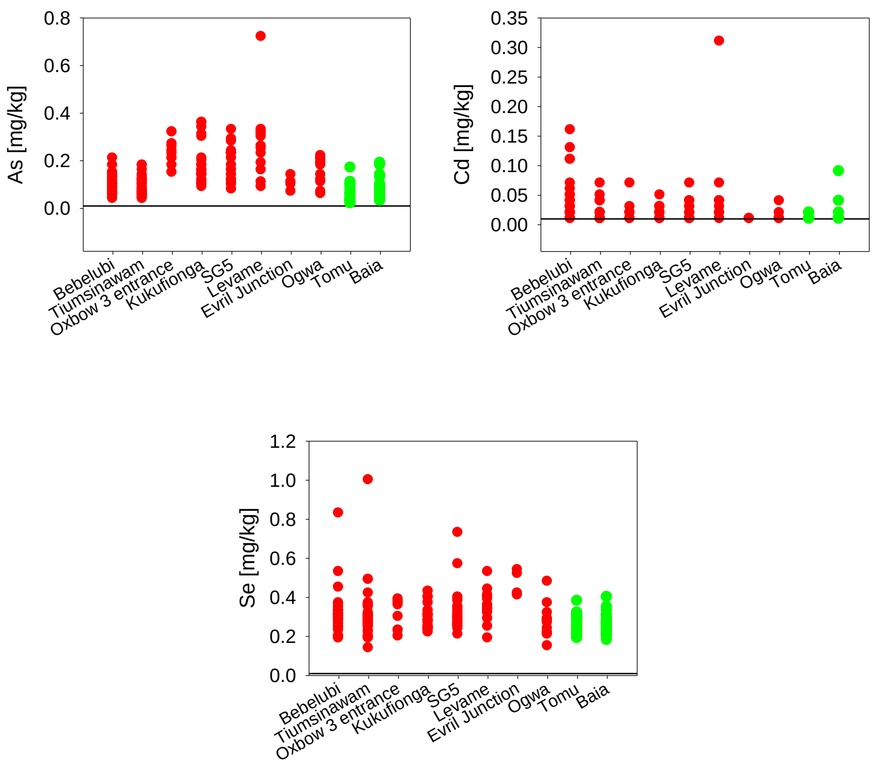


Figure 0-32 Concentrations in *M. rosenbergii* abdomen flesh samples collected during 2010 for metals discussed in the text.
Black line in single panel plots – detection limits

Spearman's rank correlation was used to identify trends in average metal concentrations in *M. rosenbergii* tissues collected from the Lower Strickland region over the time periods 2006 to 2010 and 2009 to 2010. The results are summarised in Table 0-12.

Significant trends at sites downstream of the mine that were not matched by similar trends at reference sites for cephalothorax tissue included:

- Mercury concentrations have decreased at Tiumsinawam and SG5 over the longer period;
- Copper and nickel concentrations have decreased at Tiumsinawam over the shorter time period;
- Cadmium concentrations have increased at Tiumsinawam over the longer time period;
- Cadmium concentrations at Tiumsinawam and Bebelubi have increased over the shorter time period; and,

- Nickel concentrations at Bebelubi have increased over the shorter time period.

And for abdomen flesh:

- Lead concentrations at Tiumsinawam decreased over the longer time period;
- Zinc and mercury concentrations at SG5 decreased over the longer time period;
- Copper and selenium concentrations at Tiumsinawam decreased over the shorter time period;
- Zinc concentrations at SG5 have decreased over the shorter time period; and,
- Cadmium concentrations at Bebelubi increased over the longer time period;
- Cadmium concentrations at Bebelubi increased over the shorter time period;
- Chromium and nickel concentrations at SG5 have increased over the shorter time period.

Table 0-12 Direction of Spearman rank correlation coefficients for metal concentrations in *M. rosenbergii* cephalothorax and abdomen flesh samples between 2006 and 2010 and for the last two years of sampling.
D indicates declining trend. U indicates upward trend. 0 indicates no significant trend. – indicates insufficient variance for analysis.

Cephalothorax										
	2006-2010					**2009-2010**				
	Reference		**Impact**			**Reference**		**Impact**		
Metal	**Tomu**	**Baia**	**Tiumsinawam**	**Bebelubi**	**SG5**	**Tomu**	**Baia**	**Tiumsinawam**	**Bebelubi**	**SG5**
Cu	D	0	D	0	0	0	0	D	D	0
Cd	U	U	U	U	0	0	0	U	U	0
Pb	D	0	0	U	0	0	0	0	U	0
Zn	0	U	0	0	0	D	0	D	0	D
Cr	D	D	D	0	D	D	D	D	0	0
Ni	D	U	D	U	D	0	0	D	U	D
Se	D	0	D	0	0	D	D	D	D	D
As	D	D	D	0	0	D	D	D	0	D
Hg	0	0	D	0	D	D	0	0	0	D
Abdomen Flesh										
	2006-2010					**2009-2010**				
	Reference		**Impact**			**Reference**		**Impact**		
Metal	**Tomu**	**Baia**	**Tiumsinawam**	**Bebelubi**	**SG5**	**Tomu**	**Baia**	**Tiumsinawam**	**Bebelubi**	**SG5**
Cu	0	U	0	U	0	0	0	D	0	0
Cd	0	0	0	U	0	0	0	0	U	0
Pb	0	0	D	0	0	0	0	0	0	0
Zn	0	0	0	0	D	0	0	0	0	D
Cr	D	U	0	U	U	0	0	0	0	U
Ni	D	U	0	0	0	D	0	0	0	U
Se	D	D	D	0	D	0	0	D	0	0
As	0	0	0	0	0	D	0	0	0	0
Hg	0	-	-	-	D	-	-	-	-	0

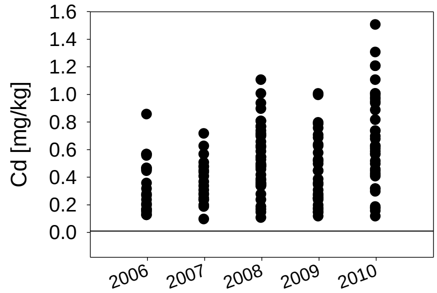


Figure 0-33 Concentrations of Cd in *M. rosenbergii* cephalothorax collected from Tiumsinawam during the time period 2006 to 2010.
Black line in single panel plot – detection limits

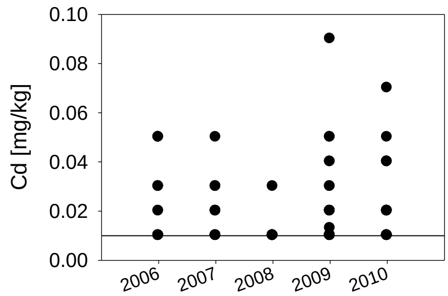


Figure 0-34 Concentrations of Cd in *M. rosenbergii* abdomen flesh collected from Tiumsinawam during the time period 2006 to 2010.
Black line in single panel plot – detection limits

Macrobrachium latidactylus cephalothorax and abdomen flesh

Cross-fingered prawns, *M. latidactylus*, were collected from the Strickland River at Tiumsinawam, the Strickland River at Bebelubi, the Baia River and the Tomu River during 2010. The results of stepwise between-site ANCOVA analyses of metal concentrations in *M. latidactylus* cephalothorax and flesh samples are provided in Appendix 3.

Average cadmium concentrations in *M. latidactylus* cephalothorax samples collected from both Tiumsinawam and Bebelubi were significantly elevated when compared with samples from both Tomu River and Baia River (Figure 0-35). Average lead concentrations in samples collected from Bebelubi were significantly elevated when compared with samples collected from both reference sites while samples from Tiumsinawam were significantly elevated when compared with samples from Tomu River (Figure 0-35). Average nickel concentrations in samples collected from Bebelubi were significantly elevated when compared with samples collected from the reference site at Tomu River and samples collected from Bebelubi and Tiumsinawam were found to have significantly elevated average concentrations of arsenic when compared with samples collected from Tomu River (Figure 0-35).

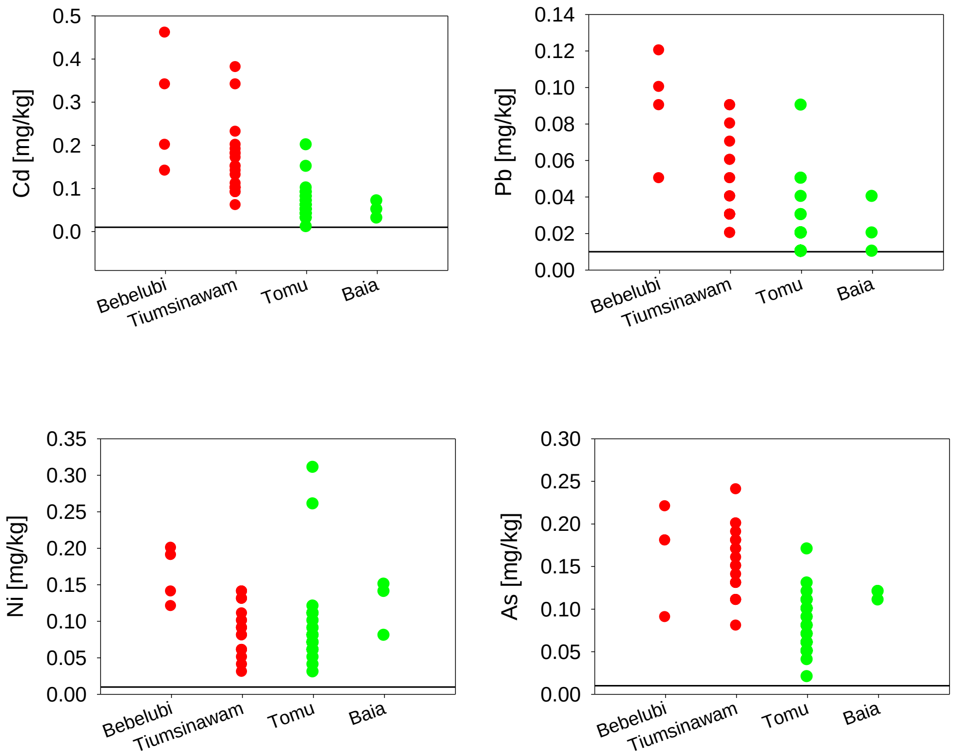


Figure 0-35 Concentrations in *M. latidactylus* cephalothorax samples collected during 2010 for metals discussed in the text.
Black line in single panel plots – detection limits

Average copper concentrations in *M. latidactylus* flesh samples collected from Bebelubi were found to be significantly elevated when compared with samples from both reference sites, and samples from Tiumsinawam were found to be significantly elevated when compared with samples collected from the Tomu River (Figure 0-36). Average chromium and selenium concentrations in samples collected from Bebelubi were found to be significantly elevated when compared with samples collected from the Tomu River, and average zinc concentrations in samples from Tiumsinawam were found to be significantly elevated when compared with samples from the Tomu River (Figure 0-36).

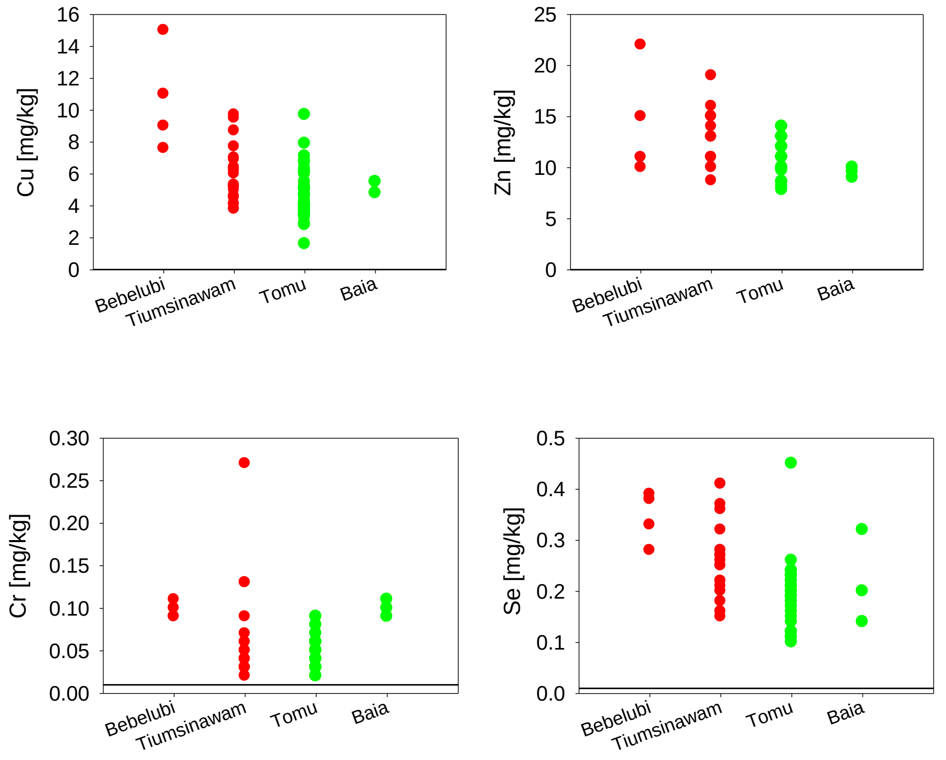


Figure 0-36 Concentrations in *M. latidactylus* prawn abdomen flesh samples collected during 2010 for metals discussed in the text.
Black line in single panel plot – detection limits

Spearman's rank correlation was used to identify trends in average metal concentrations in *M. latidactylus* tissues collected from the Lower Strickland region over the time periods 2006 to 2010 and 2009 to 2010. The results are summarised in Table 0-13.

Significant trends at sites downstream of the mine that were not matched by similar trends at reference sites for cephalothorax tissue included:

- Mercury concentrations at Tiumsinawam decreased over the shorter time period;
- Cadmium and selenium concentrations at Tiumsinawam decreased over the longer time period;
- Selenium concentrations at Bebelubi increased over the longer time period;
- Lead concentrations at Tiumsinawam increased over the shorter time period; and,
- Copper concentrations at Bebelubi increased over the shorter time period.

And for abdomen flesh:

- Cadmium and lead concentrations at Tiumsinawam have decreased over the longer time period;
- Copper, cadmium, chromium and selenium concentrations have increased at Bebelubi over the longer time periods;
- Nickel and arsenic concentrations at Tiumsinawam have increased over the shorter time period; and,

- Copper, cadmium, chromium and nickel at Bebelubi have increased over the shorter time period.

Table 0-13 Direction of Spearman rank correlation coefficients for metal concentrations in *M. latydactylus* cephalothorax and abdomen flesh samples between 2006 and 2010 and for the last two years of sampling.

D indicates declining trend. U indicates upward trend. 0 indicates no significant trend. – indicates insufficient variance for analysis.

Cephalothorax								
	2006-2010				2009-2010			
	Reference		Impact		Reference		Impact	
Metal	**Tomu**	**Baia**	**Tiumsinawam**	**Bebelubi**	**Tomu**	**Baia**	**Tiumsinawam**	**Bebelubi**
Cu	0	0	0	0	D	0	D	U
Cd	U	0	D	0	0	U	0	0
Pb	D	0	D	D	0	0	U	0
Zn	D	D	0	0	D	0	D	0
Cr	D	0	0	0	D	0	D	0
Ni	D	D	D	0	D	0	D	0
Se	0	0	D	U	D	D	D	0
As	D	0	D	0	D	0	0	0
Hg	D	0	0	0	0	0	D	0

Abdomen Flesh								
	2006-2010				2009-2010			
	Reference		Impact		Reference		Impact	
Metal	**Tomu**	**Baia**	**Tiumsinawam**	**Bebelubi**	**Tomu**	**Baia**	**Tiumsinawam**	**Bebelubi**
Cu	0	0	0	U	D	0	0	U
Cd	0	-	D	U	D	-	0	U
Pb	0	0	D	0	0	D	0	0
Zn	D	D	0	0	D	0	0	0
Cr	0	0	0	U	D	0	0	U
Ni	D	U	0	0	0	0	U	U
Se	D	D	D	U	D	0	D	0
As	0	U	0	U	D	0	U	0
Hg	0	-	-	-	-	-	-	-

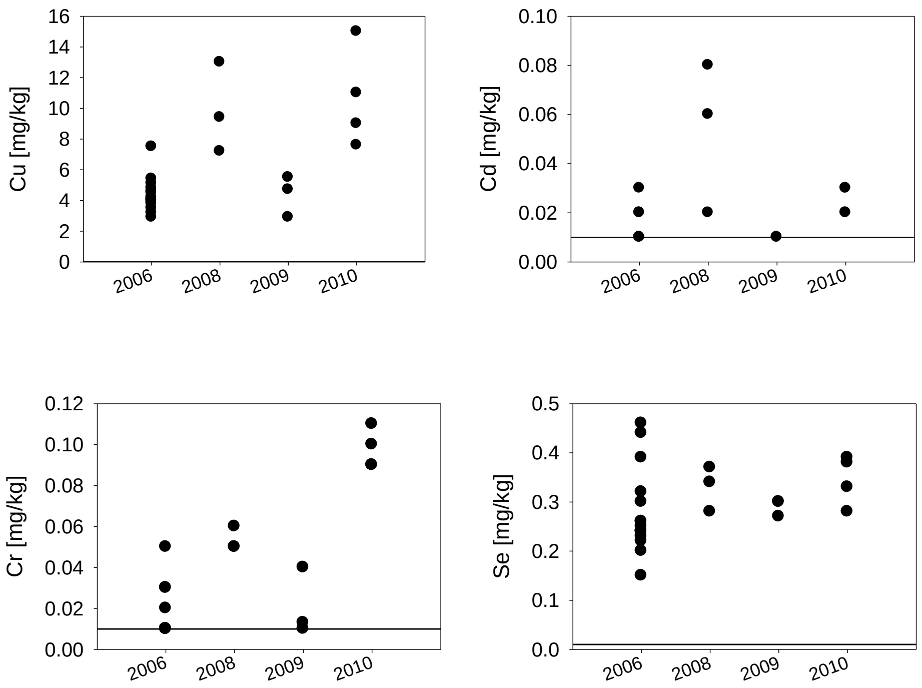


Figure 0-37 Concentrations of Cu, Cd, Cr, Se in *M. latidactylus* abdomen flesh collected from Bebelubi during the time period 2006 to 2010.
Black line in single panel plot – detection limits

Potamosilurus macrorhynchus liver and flesh

Sharp-snouted catfish, *P. macrorhynchus*, samples were collected from the Strickland River at Bebelubi, the Strickland River at Tiumsinawam, Tomu River and Baia River in 2010. The results of stepwise ANCOVA analysis of between-site comparisons are provided in Appendix 3 for liver and flesh samples.

Liver samples taken from *P. macrorhynchus* collected from Bebelubi were found to be significantly elevated in average concentrations of cadmium when compared with samples collected from the reference site at Tomu River (Figure 0-38).

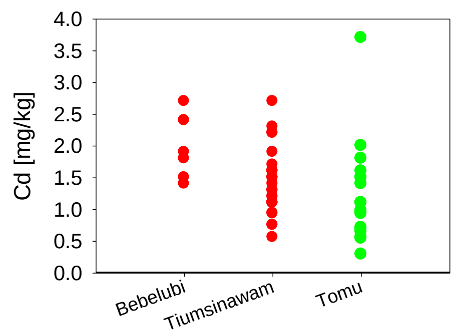


Figure 0-38 Concentrations in *P. macrorhynchus* liver samples collected during 2010 for metals discussed in the text.
Black line in single panel plot – detection limits

No significant between-site differences were detected for metal concentrations in flesh samples of *P. macrorhynchus* collected during 2010.

Spearman's rank correlation was used to identify trends in average metal concentrations in *P. macrorhynchus* tissues collected from the Lower Strickland region over the time periods 2000 to 2010 and 2009 to 2010. The results are summarised in Table 0-14.

Significant trends at sites downstream of the mine that were not matched by similar trends at reference sites for liver tissue included:

- Chromium concentrations at Tiumsinawam have decreased over the longer time period;
- Cadmium, zinc, nickel and mercury concentrations at Bebelubi have decreased over the shorter time period; and,
- Copper, cadmium, zinc and selenium concentrations at Tiumsinawam have increased over the longer time period.

And for dorsal flesh:

- Lead, chromium and arsenic concentrations at Tiumsinawam have decreased over the longer time period;
- Selenium and arsenic concentrations at Tiumsinawam have decreased over the shorter time period;
- Mercury and selenium concentrations at Bebelubi have decreased over the shorter time period;
- Selenium concentrations at Tiumsinawam have increased over the longer time period; and,
- Chromium concentrations at Tiumsinawam have increased over the shorter time period.

Table 0-14 Direction of Spearman's rank correlation coefficients for metal concentrations in *P. macrorhynchus* liver and flesh samples between 2000 and 2010 and for the last two years of sampling.

D indicates declining trend. U indicates upward trend. 0 indicates no significant trend. – indicates insufficient variance for analysis.

Liver								
	2000-2010				2009-2010			
	Reference		Impact		Reference		Impact	
Metal	**Tomu**	**Baia**	**Tiumsinawam**	**Bebelubi**	**Tomu**	**Baia**	**Tiumsinawam**	**Bebelubi**
Cu	0	0	U	0	0	-	0	0
Cd	0	0	U	0	0	-	0	D
Pb	D	0	0	0	0	-	0	0
Zn	0	0	U	0	0	-	0	D
Cr	U	-	D	0	0	-	0	0
Ni	0	0	0	0	0	-	0	D
Se	0	0	U	0	0	-	0	0
As	0	0	0	0	D	-	D	0
Hg	U	0	U	0	0	-	0	D
Flesh								
	2000-2010				2009-2010			
	Reference		Impact		Reference		Impact	
Metal	**Tomu**	**Baia**	**Tiumsinawam**	**Bebelubi**	**Tomu**	**Baia**	**Tiumsinawam**	**Bebelubi**
Cu	D	0	D	0	D	-	D	D
Cd	-	-	-	0	-	-	-	0
Pb	0	-	D	-	-	-	0	-
Zn	D	0	0	0	D	-	0	0
Cr	0	-	D	0	0	-	U	0
Ni	0	-	0	0	D	-	0	0
Se	0	0	U	0	0	-	D	D
As	0	0	D	0	0	-	D	0
Hg	0	0	0	0	0	-	0	D

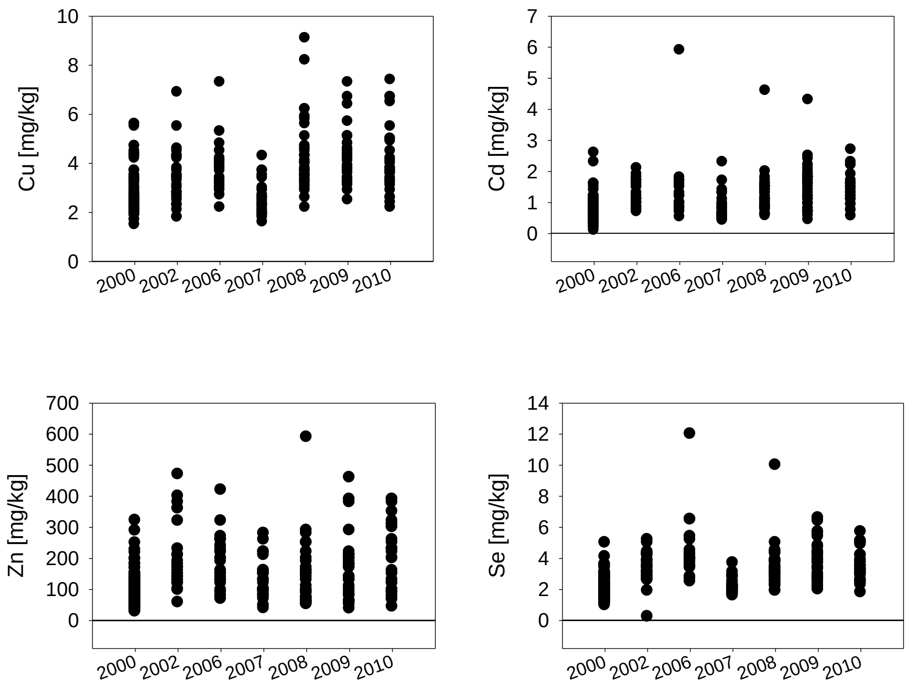


Figure 0-39 Concentrations of Cu, Cd, Zn, Se in *P. macrorhynchus* liver collected from Tiumsinawam during the time period 2000 to 2010.
Black line in single panel plot – detection limits

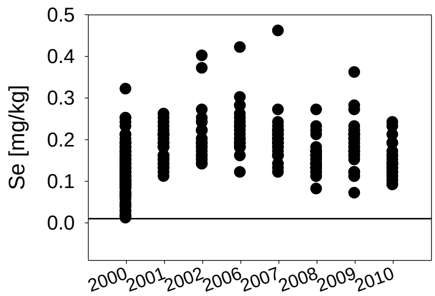


Figure 0-40 Concentrations of Cu, Cd, Zn, Se in *P. macrorhynchus* dorsal flesh collected from Tiumsinawam during the time period 2000 to 2010.
Black line in single panel plot – detection limits

Conclusions

The trend of bioaccumulation of cadmium in freshwater prawns in samples collected from sites downstream of the mine continued during 2010. Since 2006 samples collected from sites downstream of the mine in the Lower Strickland region have consistently had significantly higher levels of cadmium, lead, arsenic and selenium than those collected from reference sites.

During 2010, cadmium and lead concentrations were found to be elevated in *M. rosenbergii* and *M. latydactylus* cephalothorax samples collected from all impacted sites when compared with samples from both reference sites. Average cadmium concentrations were also found to be elevated in *M. rosenbergii* abdomen samples collected from Bebelubi compared with both reference sites. Liver samples of *P. macrorhynchus* collected from Bebelubi were also found to have significantly elevated concentrations of cadmium when compared with samples from the reference site at Tomu River. As has been observed in previous editions of the annual biology report, the bioaccumulation of cadmium and lead in prawns and fish liver indicates that the mine-related alteration of cadmium and lead bioavailability continued in 2010.

Samples of *M. rosenbergii* and *M. latidactylus* cephalothorax were also found to contain elevated concentrations of lead, selenium, arsenic and nickel collected from at least one of the impact sites when compared with reference site samples, and *M. rosenbergii* abdomen flesh samples collected from impact sites were found to have significantly elevated concentrations of selenium and arsenic.

Between-site analysis of *P. macrorhynchus* liver and flesh indicated that only cadmium concentrations in liver samples collected from Bebelubi where significantly higher than those detected at Tomu River, but rank correlations indicated that over the last decade average concentrations of copper, cadmium, zinc and selenium in liver samples and average concentrations of selenium in flesh samples collected from Tiumsinawam have generally been increasing. While not true for each site and species and tissue type (indeed, some have shown decreasing trends), the accumulation of metals in the tissues of *P. macrorhynchus* should be noted and continually monitored each year.

Lake Murray

Sites at Lake Murray were not sampled during 2010 due to landowner intervention. It is unknown whether this sampling will be allowed to occur in the future.

Comparisons with Effects Levels

The measured tissue metal concentrations for 2010 were compared against the lowest observed concentration co-occurring with an effect (LOEC) for each tissue type and organism type (fish or prawn) for each metal in the effects database of Jarvinen and Ankley (1999) (Table 0-15). Table 0-16 gives the results of non-reference sites where the proportion of samples found to have metal concentrations above the corresponding LOEC was greater than that found for all reference sites.

Table 0-15 Lowest observed effect concentration for each tissue type and organism collated from Jarvinen and Ankley (1999)

	Fish (post-larval)				Prawn
Metal (mg/L)	Flesh	Liver	Gill	Whole	Whole
Cadmium	0.16	1.6	0.92	0.14	1.8
Mercury	0.7	3	51	1.31	
Copper	0.5	4.3	0.64		
Selenium	3.8	8.84		1.08	
Zinc	13.6	48.5	76.9	40	
Arsenic	6	47		2.24	
Nickel	118.1	82.2	202.8		

The screening of tissue metal concentrations against the LOEC values of Jarvinen and Ankley (1999) cannot be used to prove increased adverse ecological effects of metal bioaccumulation, rather it is unlikely that concentrations below the LOEC would result in detrimental effects. The patterns of increased proportions of samples above the corresponding LOECs described in this section suggest an increased potential for there being some additional risk of detrimental impact, but determining whether or not any actual detriment has occurred would require measurement of effects.

Table 0-16 Sites where the ratio of above:below LOEC for impact sites was greater than for any reference site using the LOEC values of Jarvinen and Ankley (1999).

Species	Tissue Type	Metal	Sites Recorded
Macrobrachium handschini	Cephalothorax	Cd	Wasiba, Wankipe
Macrobrachium rosenbergii	Cephalothorax	Cd	Bebelubi
Neosilurus equinus	Liver	Cd	Wankipe, Wasiba
Potomosiluris macrorhynchus	Flesh	Cu	Tiumsinawam
	Liver	Cu	Bebelubi
	Liver	Cd	Bebelubi, Tiumsinawam
	Liver	Zn	Bebelubi, Tiumsinawam
	Liver	Hg	Bebelubi

Comparison with Human Health Standards

The metal concentrations were compared with existing and proposed international health guidelines or standards, including the Food Standards Australia New Zealand (FSANZ) Food Standards Code (FSANZ 2009) and Generally Expected Level (GEL) 90th percentile (ANZFA 2001), the World Health Organization (WHO)/Food and Agriculture Organization (FAO) current and proposed CODEX standards[2] and the United States Food and Drug Administration guidance levels (USFDA 2001). These values are presented as an indication of what metal concentrations may be expected or tolerable in a tissue type but should only be interpreted with respect to human health in conjunction with detailed local dietary data. However, where metal concentrations in edible tissues were below the food standards, it is a good indication of low risk of adverse human health impacts to occur from consumption of these tissues.

A screening of the samples of fish and prawns collected in 2010 using appropriate human health standards and guidelines indicated that none of the samples collected had concentrations of metals above the standards and guidelines. It can be stated that there is a low likelihood of human health impacts from the consumption of the edible portion of the fish and prawns in the upper catchment and the lower Strickland region.

General Conclusions

Species Richness, Abundance and Condition

In the upper catchment, there was no evidence to suggest any mine-related impacts to the species richness, diversity, abundance or biomass of fish or prawns between sites for the year 2010. Rank correlations did detect some significant decreases in number of species, abundance and biomass for prawns. At Wankipe, for the period 2000 to 2010, a negative trend was observed for species richness, abundance and biomass of prawns that was not matched at the reference site at Tomu. At Wasiba a negative trend in prawn abundance and biomass was observed for the period 2000 to 2010 that was not matched at the reference site at Ok Om. Standardised sampling is not currently undertaken at the reference sites at Kuru River and Pori River due to the lack of suitable sandbank to perform seine netting. It is planned that during 2011 backpack electrofishing will be implemented at all upper catchment sites to increase the likelihood of achieving sample numbers for tissue collection and to give another standardised method to measure species richness, abundance, diversity and biomass.

At lower Strickland River sites standardised gill and seine netting did not suggest any mine-related impacts to the species richness, diversity, abundance or biomass of fish or prawns for the year

[2] WHO/FAO Food guidelines are developed by the Codex Alimentarius Commission that publishes the standards in a series of conference sessions. Guideline values were collated from a variety of online and literature sources. http://www.codexalimentarius.net/web/standard_list.jsp

2010. Negative trends were detected for species richness, biomass and abundance for fish caught at Tiumsinawam that were not matched at the reference site at Tomu over the 2000 to 2010 period.

Hydroacoustic sampling was undertaken at the Strickland River off river water bodies, Kukufionga, Avu, Levame and Zongamange in May 2010. Between site differences were detected for the fish density recorded at the off river water bodies during 2010. Fish density was found to be significantly greater ($p<0.001$) at Kukufionga than that observed at all the other off river water bodies surveyed. This result indicates that the potentially impacted site upstream of the Herbert River confluence at Kukufionga showed significantly higher fish density than downstream of the dilution of the Strickland River by the Herbert River, indicating no measurable mine derived effects.

Specimen condition in the upper catchment indicated a significant difference for the fish *N. equinus* at Wasiba when compared with fish collected at Kuru River, indicating a possible mine-related effect. This trend was not observed between Wasiba and the other reference sites at Ok Om or Pori River but should continue to be monitored keeping in mind that the differences may be an artefact of the difficulties of sampling at these sites. Spearman's rank correlations indicated that *N. equinus* condition was significantly decreasing at Wasiba which was not observed at any of the reference sites.

The condition of fish and prawns at lower Strickland River sites was not found to be significantly different between downstream-of-mine sites and reference sites during 2010. However, a significant decreasing trend in the condition of *P. macrorhynchus* collected at Tiumsinawam was detected over the time period 2000 to 2010 which was not matched at the reference site at Tomu. Which was found to be the result of a number of outliers in the earlier years of the data set. Upon removal of these outliers, there was not a negative correlation.

Overall the catch and abundance recorded at downstream of mine sites during 2010 did not indicate any direct impact due to mining activities. Unfortunately, standardised catch methods in the upper catchment can be somewhat compromised by environmental conditions at the time of sampling. This will hopefully be rectified by the use of electrofishing methods in 2011. At sites in the lower Strickland region, during 2010 there were no significant differences detected between sites indicating no mine related impact.

Fish condition investigations indicated that most of the species caught during 2010 were in good health. The exception to this was *N. equinus* collected at Wasiba and Wankipe when compared with fish caught at the reference site at Kuru River where the average condition at the downstream-of-mine sites was found to be significantly lower.

Tissue Metal Concentrations

Quality Assurance

Laboratory based quality assurance was acceptable for samples analysed in Quarters 1, 2, 3 and 4.

The use of field blanks was a great improvement over recent years and the biological team should be commended for this effort. A total of 46 field blanks were used in 2010, a major improvement on 2008, where only seven field blanks were used, and over 2009, where 31 field blanks were used. The level of field blanks used in 2010 should be maintained. The analysis of the field blanks indicated that some contamination of samples was occurring during sample processing and/or possibly during sample preparation and analysis at the analytical laboratory. A continued effort to ensure that the laboratory is as clean as possible and dissection of samples both in the laboratory and the field is done using clean techniques is needed.

Temporal and Spatial Variation

Tissue sampling of target organisms was undertaken at all planned sites in 2010, except at Lake Murray, where sampling was not attempted. Prawns were sampled from a number of extra sites in the lower Strickland. Samples were collected from sites, Kukufionga, Strickland River at Oxbow 3 entrance, Levame oxbow, Strickland River above Everill Junction and Fly River at Ogwa.
The extent of mine-related (and in some cases anomalous) elevation of metal bioaccumulation is summarised for each metal in turn below:

Cadmium: Average concentrations of cadmium has continued to be found at significantly elevated levels in tissues of both fish and prawns sampled from sites downstream of the mine during 2010. Prawn cephalothorax samples from downstream-of-the-mine sites in both the upper catchment and lower Strickland indicated continued persistence of cadmium at elevated levels when compared with reference sites. Wasiba, Wankipe, Bebelubi, Tiumsinawam, Kukufionga, SG5, Levame and Ogwa prawn cephalothorax samples were all found to have significantly elevated levels of cadmium when compared with samples collected from both reference sites. Other tissue types that were found to be elevated at impact sites when compared with reference sites included prawn flesh at Wankipe, Wasiba, Bebelubi and Levame, and fish liver samples at Wankipe, Wasiba and Bebelubi. Increasing trends in cadmium concentrations at impact sites that were not matched at reference sites were also detected for a number of tissues, including prawn cephalothorax at Bebelubi and Tiumsinawam over the shorter term, prawn flesh at Wankipe over the shorter term, at Bebelubi over the shorter and longer term and fish liver at Tiumsinawam over the longer period.

Copper: Average copper concentrations were found to be significantly elevated at impact sites compared with reference sites for prawn cephalothorax and flesh during 2010. Prawn cephalothorax samples were found to be significantly elevated at Wasiba, Levame and Ogwa when compared with samples from at least one reference site and prawn flesh at Bebelubi samples were significantly elevated when compared with samples from all reference sites. Increasing copper concentration trends were identified at downstream-of-mine sites that were not matched at reference sites for a number of tissues, including prawn flesh at Wankipe and Wasiba over the longer term and at Bebelubi over both the shorter and longer term, prawn cephalothorax at Bebelubi over the shorter term and fish liver at Tiumsinawam over the longer time period.

Lead: Average concentrations of lead were found to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax and flesh and fish liver during 2010. Prawn cephalothorax samples collected from downstream-of-mine sites from both the upper catchment and lower Strickland region were found to have significantly elevated levels of lead when compared with samples from reference sites. Prawn flesh collected from Wankipe and Wasiba were found to have elevated levels of lead relative to samples collected from at least one of the reference sites, and fish liver at both Wankipe and Wasiba were found to be significantly elevated in lead concentrations when compared with samples from both Pori River and Kuru River. Increasing trends were detected at downstream-of-mine sites that were not matched at reference sites. Increasing trends were detected for prawn cephalothorax at Tiumsinawam over both the short and long time period and prawn flesh at Wankipe over the long time period.

Zinc: Zinc average concentrations were found to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax and flesh. Prawn cephalothorax samples collected from Wankipe, Wasiba, Kukufionga and Tiumsinawam were found to be significantly elevated in average zinc concentrations when compared with at least one reference sites. Prawn flesh was found to have elevated average concentrations of zinc in samples collected from Wankipe when compared with samples collected from Pori River. Increasing trends were observed at downstream-of-mine sites that were not matched by reference sites for prawn flesh at Wasiba over the short term, fish flesh at Wankipe over the longer term and fish liver at Tiumsinawam over the longer period.

Selenium: Average selenium concentrations were found to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax, prawn flesh, fish liver and fish flesh. Prawn cephalothorax was found to be significantly elevated at downstream-of-mine sites, Wankipe, Wasiba, SG5 and Levame when compared with at least one reference site and prawn flesh was found to have significantly elevated levels of average selenium at site Wankipe, Wasiba, Levame, Everill junction and Bebelubi when compared with at least one reference site. Fish flesh samples collected from Wasiba were found to have elevated levels of average selenium when compared with samples collected from both reference sites. Increasing trends in average selenium concentrations were observed for prawn cephalothorax at Bebelubi over the longer time period and fish flesh and liver collected from Tiumsinawam were seen to be increasing at Tiumsinawam over the longer time period.

Arsenic: Average arsenic concentrations were observed to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax and flesh. Prawn cephalothorax was found to be significantly elevated at downstream-of-mine sites Wankipe, Wasiba, Bebelubi, Tiumsinawam, Oxbow 3 entrance, Kukufionga, SG5, Levame and Ogwa when compared with at least one of the reference sites. Prawn flesh was found to be significantly elevated at downstream-of-mine sites Wankipe, Wasiba, Bebelubi, Oxbow 3 entrance, Kukufionga, SG5, Levame and Ogwa when compared with samples from at least one reference site. Increasing trends were detected for fish flesh at Wankipe over the shorter period and prawn flesh at Tiumsinawam over the shorter period.

Nickel: Average concentrations of nickel were observed to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax. Prawn cephalothorax was found to be significantly elevated at sites Wankipe, Bebelubi and Kukufionga when compared with samples from at least one of the reference sites. Increasing trends of average concentrations of nickel were observed at downstream-of-mine sites that were not matched at reference sites for prawn cephalothorax and flesh at Bebelubi over the shorter period.

Chromium:`Average chromium concentrations were observed to be significantly elevated at downstream-of-mine sites when compared with reference sites for prawn cephalothorax and flesh. Prawn cephalothorax was found to be significantly elevated at downstream-of-mine site, Wankipe, when compared with samples from the reference site, Ok Om, while prawn flesh from the downstream-of-mine site, Bebelubi, was found to have significantly elevated concentrations of average chromium when compared with the reference site at Tomu River. Increasing trends in average chromium concentrations were observed for prawn flesh at Bebelubi over both the short and long term and samples from SG5 over the short term, while samples of fish flesh at Tiumsinawam were observed to be increasing over the short term.

Mercury: Average mercury concentrations were seen to decrease in samples collected during 2010. No significant elevations in mercury concentrations were detected for samples collected from downstream-of-mine sites when compared with samples from reference sites. Increasing trends in average mercury concentrations were also not observed for any of the tissue types and time periods. Decreasing trends were observed at the downstream-of-mine sites Bebelubi, Tiumsinawam and SG5 for fish flesh, prawn cephalothorax and prawn flesh.

The elevated levels of metals in tissues from impact sites in the upper catchment and the lower Strickland region observed in previous years annual reports continued in 2010. Concentrations of cadmium and lead have continued to be detected at significantly elevated levels in prawn cephalothorax tissues collected from established downstream-of-mine sites as far down river as SG5. Overall, these results indicated that the pattern of bioaccumulation of metals at downstream-of-mine sites in the Lagaip River and the lower Strickland region has continued with small alterations to the difference seen in the uptake of some metals, for example, mercury was not detected at significantly elevated levels at impact sites compared with reference sites and was also seen to have decreased in some tissues over both long and short time periods. There was also a correlation that the cyanide destruct circuit is reducing the availability of some metals downstream of the mine.

The results of the tissue metal concentrations for each tissue type and organism type were screened against the lowest observed concentration co-occurring with an effect (LOEC) from the effects database of Jarvinen and Ankley (1999). Sites where the ratio of results above:below the corresponding effects threshold for downstream-of-mine sites was found to be greater than for any of the corresponding reference sites were found at all downstream-of-mine sites down to Bebelubi for cadmium in prawn cephalothorax and to Tiumsinawam for fish liver. Other sites where the ratio found the results above the corresponding effects threshold were Tiumsinawam for copper in fish flesh, Bebelubi for copper in fish liver, Tiumsinawam and Bebelubi for zinc in fish liver and Bebelubi for mercury in fish liver.

The collection of prawn samples for SDH analysis from the upper catchment continued in 2010 and was also expanded to sites in the lower Strickland region, with samples collected from Strickland River at Oxbow 3 entrance, SG5 and Fly River at Ogwa. Results for SDH analysis in 2010 indicated that prawns collected from Wankipe in the upper catchment had significantly elevated hepatic cell damage when compared with samples collected from the reference sites at Ok Om and Pori River. This result differed from that seen in analysis undertaken in 2006 and 2009, where Wasiba was seen to also have elevated levels of hepatic cell damage indicating that prawns at Wasiba during 2010 were under less stress than seen in previous surveys most likely due to the cyanide destruct circuit reducing the amount of available metals to the prawns. Results for samples collected at sites in the lower Strickland region indicated that prawns from site Oxbow 3 entrance had significantly elevated hepatic cell damage when compared with samples collected from SG5, while samples from Ogwa were statistically similar to samples collected from both Oxbow 3 entrance and SG5. As prawns were not collected from any reference sites in the lower Strickland region in 2010, it is not known whether the levels of hepatic cell damage observed are at levels of concern at the downstream of mine sites. This will hopefully be rectified during the 2011 program with the collection of prawns from an appropriate reference site. It is not known whether the amount of hepatic cell damage reflected by these increased levels of SDH are tolerable by the prawn species sampled. Investigations into the relationship between these levels of SDH in the prawn abdomen and organism health would allow for a better understanding of the state of the populations in the upper catchment and lower Strickland region.

A screening of the samples of fish and prawns collected in 2010 using appropriate human health standards and guidelines indicated that none of the samples collected had concentrations of metals above the standards and guidelines. It can be stated that there is a low likelihood of human health impacts from the consumption of the edible portion of the fish and prawns in the upper catchment and the lower Strickland region.

Recommendations

- Implement electrofishing sampling at upper catchment and lower Strickland region sites to enhance the current methods used to monitor catch and to ensure adequate prawn samples are collected for tissue and SDH analysis;
- Continue to investigate and negotiate with landowners in the Nomad and Rentoul River systems to establish at least one more reference site in the lower Strickland region;
- Continue the level of use of field blank samples and ensure the cleanliness of the biology laboratory when processing samples to limit the chance of contamination;
- Introduce the use of a second laboratory as a further QA/QC procedure to help determine the source of contamination that has been seen in field blanks during 2009 and 2010;
- Remove the analysis of Ni and Cr from the program as suggested in the PJV optimisation review as there is no enrichment of these metals in the ore body;
- Continue SDH analysis of upper catchment and lower Strickland prawns to further investigate the possible effect the cyanide destruct circuit is having on the reduction in hepatocellular damage detected in prawns collected from Wasiba in 2010;
- Implement a program to benchmark the effect levels of the elevated bioavailability of metals to the prawns in the upper catchment in terms of the observed SDH and the impacts this may be having on the biological processes of the organisms;
- Consider other sub-organism and organisms level effect markers in areas where SDH analyses demonstrate increased hepatic cell loss rates. Such markers could include histopathological examination of selected tissues and markers of fecundity, such as the gonado-somatic index. Development of this approach could be done in collaboration with the existing research being conducted jointly with CSIRO and Hydrobiology; and,
- Implement seine netting at SG5 and continue to trial fyke nets in an effort to increase prawn catches.

References

ANZECC/ARMCANZ (Australia and New Zealand Environment and Conservation Council)/(Agriculture and Resource Management Council of Australia and New Zealand) (2000a). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. (Agriculture and Resource Management Council of Australia and New Zealand: Canberra).

Australia New Zealand Food Authority (2001). Generally Expected Levels (GELs) for Metal Contaminants. Additional Guidelines to maximum levels in Standard 1.4.1 - Contaminants and Natural Toxicants, Canberra: Commonwealth of Australia. Available at: http://www.foodstandards.gov.au/_srcfiles/GELs_0801.pdf [Accessed September 9, 2009].

Bunn, S.E., Apte, S.C., Bentley, K., Hart, B.T. and Smith, R.E.W. 2006 "Porgera Riverine Monitoring Program Review and Optimisation." Porgera Joint Venture.

Food Standards Australia New Zealand, (2009). *Australia New Zealand Food Standards Code*, Canberra: Commonwealth of Australia.

Fujino et al. 1980 Bulletin of the Japanese Society of Scientific Fisheries 46:543-548.

Hydrobiology (2003). "An ecological assessment of the aquatic and terrestrial habitats of the Willawong remediation site." Hydrobiology Pty Ltd, Brisbane.

Hydrobiology (2005a). "Lane Xang Minerals Limited Aquatic Biomonitoring Report. Wet Season 2004." Hydrobiology Pty Ltd, Brisbane.

Hydrobiology (2005b). "Lane Xang Minerals Limited Aquatic Biomonitoring Report. Dry Season 2004." Hydrobiology Pty Ltd, Brisbane.

Hydrobiology (2005c). "A biological assessment of Oxley and Blunder Creeks." Hydrobiology Pty Ltd, Brisbane.

Insightful Inc. 2003 "S-Plus 6.2 for Windows" Insightful Inc, Seattle.

Jarvinen A. W. and Ankley G. T. 1999 "Linkage of Effects to Tissue Residues: Development of a Comprehensive Database for Aquatic Organisms Exposed to Inorganic and Organic Chemicals." SETAC Press, Pensacola.

Lang, R. 1971 "Enzyme der Monosaccharidumwandlung bei dem Flußkrebs *Orconectes limosus*." J. Comparat. Physiol. A. 73(3):285-304

Porgera Joint Venture 2003 "PJV Environmental Monitoring 2002 Annual Report January-December 2002." PJV/ENV-1/03.

Porgera Joint Venture 2004 "Porgera Joint Venture Biological Monitoring Technical Report 1 January – 31 December 2003." PJV/ENV-2/04.

Porgera Joint Venture 2004b "Sustainable Development Dept Environment Section Biology Procedures Manual." Controlled document, Version 1.1, Release Date Feb 2004.

Porgera Joint Venture 2005 "Biological Monitoring Technical Report. 01 January – 31 December 2004." PJV/ENV-2/05

Porgera Joint Venture 2006 "Biological Monitoring Technical Report. 01 January – 31 December 2005." PJV/ENV-2/06

Porgera Joint Venture 2007 'Biological Monitoring Technical Report. 01 January – 31 December 2006." PJV/ENV2/07

Porgera Joint Venture 2008 "Biological Monitoring Technical Report. 01 January – 31 December 2007. PJV/ENV-2/08

Porgera Joint Venture 2009 "Biological Monitoring Technical Report. 01 January – 31 December 2008. PJV/ENV-2/08

Porgera Joint Venture 2010 "Biological Monitoring Technical Report. 01 January – 31 December 2009. PJV/ENV-2/08

Travlos GS, Morris RW, Elwell MR, Duke A, Rosenblum S & Thompson MB. 1996. "Frequency and relationships of clinical chemistry and liver and kidney histopathology findings in 13-week toxicity studies in rats." Toxicol 107: 17-29.

United States Food and Drug Administration (2001). Centre for Food Safety and Applied Nutrition. *Fish and Fisheries Products, Hazards and Control Guidance*. Third Edition.

WHO (2010). Joint FAO/WHO Food Standards Programme (Codex Alimentarius). Website accessed 19 February 2011: http://www.who.int/foodsafety/codex/en/

Appendix 1 Fish and Prawn Catch Statistics

Upper Catchment

Results of ANOVA analyses of prawn, abundance and biomass for samples collected using Seine net for the upper catchment sites at Wasiba and Wankipe (or where data were available) between 2000 - 2010.

Site	Parameter	Factor	Multiple comparisons (best.fast method)
Wankipe (15)	Abundance	Source DF SS MS F P Year 10 1405.1 140.5 3.75 0.000 Error 212 7935.9 37.4 Total 222 9341.0 S = 6.118 R-Sq = 15.04% R-Sq(adj) = 11.03%	Individual 95% CIs For Mean Based on Pooled StDev Level N Mean StDev ----+---------+---------+---------+----- 2000 18 1.556 2.175 (------*------) 2001 16 1.625 1.025 (------*-------) 2002 24 2.250 2.848 (------*-----) 2003 23 5.000 6.230 (------*-----) 2004 21 3.381 3.369 (-----*------) 2005 18 10.389 17.480 (------*------) 2006 19 3.158 4.694 (------*------) 2007 9 4.000 5.315 (---------*---------) 2008 18 3.444 5.447 (------*------) 2009 30 1.233 2.725 (----*-----) 2010 27 0.704 1.171 (-----*-----) ----+---------+---------+---------+----- 0.0 4.0 8.0 12.0 Pooled StDev = 6.118
Wankipe (15)	Biomass (g / haul)	Source DF SS MS F P Year 10 13994 1399 3.91 0.000 Error 212 75837 358 Total 222 89832 S = 18.91 R-Sq = 15.58% R-Sq(adj) = 11.60%	Individual 95% CIs For Mean Based on Pooled StDev Level N Mean StDev ----+---------+---------+---------+----- 2000 18 7.67 11.30 (------*-------) 2001 16 8.56 7.04 (-------*-------) 2002 24 13.08 15.70 (-----*-----) 2003 23 22.59 23.19 (------*-----) 2004 21 10.71 11.52 (------*------) 2005 18 31.11 43.90 (------*------) 2006 19 14.40 20.83 (------*------) 2007 9 16.84 20.68 (---------*---------) 2008 18 10.97 18.17 (------*------) 2009 30 5.34 9.87 (----*-----) 2010 27 2.19 3.64 (-----*-----) ----+---------+---------+---------+----- 0 12 24 36 Pooled StDev = 18.91

Site	Parameter	Factor	Multiple comparisons
Wasiba (124)	Abundance	Source DF SS MS F P Year 10 1088.8 108.9 3.68 0.000 Error 172 5082.1 29.5 Total 182 6170.9 S = 5.436 R-Sq = 17.64% R-Sq(adj) = 12.86%	Individual 95% CIs For Mean Based on Pooled StDev Level N Mean StDev ---------+---------+---------+---------+ 2000 5 2.800 1.304 (-----------*-----------) 2001 23 3.217 4.327 (-----*-----) 2002 13 1.462 2.537 (-------*------) 2003 19 4.895 5.010 (-----*-----) 2004 21 9.524 8.818 (-----*-----) 2005 24 3.000 4.934 (-----*----) 2006 21 2.667 4.004 (-----*-----) 2007 10 4.500 3.951 (-------*--------) 2008 6 0.833 0.753 (----------*----------) 2009 18 0.500 0.707 (-----*------) 2010 23 3.870 8.385 (-----*----) ---------+---------+---------+---------+ 0.0 4.0 8.0 12.0 Pooled StDev = 5.436
Wasiba (124)	Biomass (g / haul)	Source DF SS MS F P Year 10 5157 516 2.07 0.029 Error 172 42777 249 Total 182 47934 S = 15.77 R-Sq = 10.76% R-Sq(adj) = 5.57%	Individual 95% CIs For Mean Based on Pooled StDev Level N Mean StDev -------+---------+---------+---------+-- 2000 5 18.40 11.52 (----------*-----------) 2001 23 15.22 22.49 (-----*----) 2002 13 6.69 10.41 (-------*------) 2003 19 11.13 11.08 (-----*-----) 2004 21 20.94 20.12 (----*-----) 2005 24 8.00 12.21 (-----*----) 2006 21 11.96 15.61 (-----*-----) 2007 10 10.11 9.33 (-------*--------) 2008 6 3.88 4.61 (---------*----------) 2009 18 1.54 2.68 (-----*-----) 2010 23 11.35 21.54 (----*-----) -------+---------+---------+---------+-- 0 12 24 36 Pooled StDev = 15.77

Lower Strickland

Results of ANOVA analyses on fish, abundance and biomass for samples collected using Gill nets for the lower Strickland sites at Tiumsinawam and Tomu between 2000 - 2010.

Site	Parameter	Factor	Multiple comparisons
Tiumsinawam (19)	Abundance	Source DF SS MS F P Years 10 4868 487 4.59 0.000 Error 292 30998 106 Total 302 35866 S = 10.30 R-Sq = 13.57% R-Sq(adj) = 10.61%	Individual 95% CIs For Mean Based on Pooled StDev Level N Mean StDev +---------+---------+---------+--------- 2000 28 12.54 10.42 (-------*-------) 2001 26 9.77 12.41 (-------*------) 2002 36 15.17 12.55 (-----*------) 2003 33 14.94 12.83 (------*------) 2004 35 10.63 11.60 (------*------) 2005 32 7.50 7.38 (------*------) 2006 16 14.81 14.27 (----------*---------) 2007 18 13.22 9.91 (--------*---------) 2008 18 4.83 4.79 (---------*--------) 2009 37 5.08 6.58 (------*------) 2010 24 4.25 4.62 (--------*-------) +---------+---------+---------+--------- 0.0 5.0 10.0 15.0 Pooled StDev = 10.30
Tiumsinawam (19)	Biomass (g / haul)	Source DF SS MS F P Years 10 1849844940 184984494 3.15 0.001 Error 292 17151104614 58736660 Total 302 19000949554 S = 7664 R-Sq = 9.74% R-Sq(adj) = 6.64%	Individual 95% CIs For Mean Based on Pooled StDev Level N Mean StDev ---+---------+---------+---------+------ 2000 28 8016 6817 (-------*-------) 2001 26 6220 9770 (--------*-------) 2002 36 8621 10058 (-------*------) 2003 33 8787 7139 (------*-------) 2004 35 7851 12190 (------*-------) 2005 32 4782 5869 (-------*------) 2006 16 6854 5800 (----------*---------) 2007 18 7132 7318 (---------*----------) 2008 18 2519 2756 (---------*---------) 2009 37 2681 4020 (------*------) 2010 24 1890 2010 (-------*--------) ---+---------+---------+---------+------ 0 3500 7000 10500 Pooled StDev = 7664

Site	Parameter	Factor	Multiple comparisons
Tomu (121)	Abundance	Source DF SS MS F P Years 10 2679.6 268.0 4.56 0.000 Error 246 14447.4 58.7 Total 256 17127.0 S = 7.663 R-Sq = 15.65% R-Sq(adj) = 12.22%	Individual 95% CIs For Mean Based on Pooled StDev Level N Mean StDev --+---------+---------+--------- +------- 2000 8 10.375 10.141 (----------*---------) 2001 25 9.480 7.573 (-----*-----) 2002 36 13.417 11.488 (----*----) 2003 35 7.400 7.441 (----*----) 2004 25 7.080 6.244 (-----*-----) 2005 25 11.640 7.319 (-----*-----) 2006 16 8.063 5.721 (------*-------) 2007 15 7.000 9.710 (-------*-------) 2008 15 2.933 3.535 (-------*-------) 2009 34 4.088 4.528 (----*----) 2010 23 4.783 6.626 (------*-----) --+---------+---------+---------+------- 0.0 5.0 10.0 15.0 Pooled StDev = 7.663
Tomu (121)	Biomass (g / haul)	Source DF SS MS F P Years 10 2976475448 297647545 3.91 0.000 Error 246 18730602386 76140660 Total 256 21707077834 S = 8726 R-Sq = 13.71% R-Sq(adj) = 10.20%	Individual 95% CIs For Mean Based on Pooled StDev Level N Mean StDev ---+---------+---------+--------- +------ 2000 8 13031 13286 (---------*---------) 2001 25 9023 10113 (-----*-----) 2002 36 11900 13381 (----*----) 2003 35 8216 10448 (----*----) 2004 25 7588 7347 (-----*----) 2005 25 11281 8068 (-----*-----) 2006 16 6908 6431 (-------*------) 2007 15 5169 6516 (-------*------) 2008 15 2527 3470 (------*-------) 2009 34 2852 3294 (----*----) 2010 23 3282 4588 (-----*-----) ---+---------+---------+---------+------ 0 6000 12000 18000 Pooled StDev = 8726

Lower Strickland

Results of ANOVA analyses on prawn for the number of species for collected using Seine net for the lower Strickland sites at Tiumsinawam, Bebelubi, and Baia River in 2010.

Site	Parameter	Factor	Multiple comparisons
Tiumsinawam (19) Bebelubi (213) Baia (214)	No. of species	Source DF SS MS F P Site_code 2 4.431 2.215 3.98 0.025 Error 51 28.403 0.557 Total 53 32.833 S = 0.7463 R-Sq = 13.49% R-Sq(adj) = 10.10%	Individual 95% CIs For Mean Based on Pooled StDev Level N Mean StDev ----+---------+---------+---------+----- 19 24 1.2083 0.8330 (--------*-------) 213 12 1.0000 0.6030 (------------*-----------) 214 18 0.5556 0.7048 (---------*---------) ----+---------+---------+---------+----- 0.35 0.70 1.05 1.40 Pooled StDev = 0.7463

Lower Strickland

Results of ANOVA analyses on fish, biomass, species richness and number of samples collected using Seine net at Tiumsinawam, between 2000 and 2010.

Site	Parameter	Factor	Multiple comparisons
Tiumsinawam (19)	No. of species	Source DF SS MS F P Year 10 34.791 3.479 5.70 0.000 Error 182 111.084 0.610 Total 192 145.876 S = 0.7813 R-Sq = 23.85% R-Sq(adj) = 19.67%	Individual 95% CIs For Mean Based on Pooled StDev Level N Mean StDev --------+---------+---------+---------+- 2000 12 0.6667 0.9847 (------*-------) 2001 20 0.2000 0.6156 (----*-----) 2002 31 0.5161 0.9263 (----*---) 2003 19 0.8947 1.1002 (-----*-----) 2004 20 1.4000 1.1877 (----*-----) 2005 6 0.1667 0.4082 (----------*---------) 2006 10 0.6000 0.6992 (-------*-------) 2007 16 0.3750 0.8851 (-----*------) 2008 17 0.0000 0.0000 (-----*-----) 2009 18 0.0556 0.2357 (-----*-----) 2010 24 0.0417 0.2041 (-----*----) --------+---------+---------+---------+- 0.00 0.60 1.20 1.80 Pooled StDev = 0.7813

Site	Parameter	Factor	Multiple comparisons
Tiumsinawam (19)	Abundance	Source DF SS MS F P	Individual 95% CIs For Mean Based on

		Year 10 199.24 19.92 3.55 0.000 Error 182 1020.24 5.61 Total 192 1219.48 S = 2.368 R-Sq = 16.34% R-Sq(adj) = 11.74%	Pooled StDev Level N Mean StDev --------+---------+---------+---- -----+- 2000 12 0.833 1.337 (--------*--------) 2001 20 0.200 0.616 (------*------) 2002 31 1.774 4.349 (-----*----) 2003 19 2.263 3.347 (------*------) 2004 20 3.000 2.734 (------*------) 2005 6 0.833 2.041 (------------*-----------) 2006 10 1.300 1.567 (---------*---------) 2007 16 0.688 1.580 (-------*------) 2008 17 0.000 0.000 (-------*-------) 2009 18 0.056 0.236 (------*-------) 2010 24 0.042 0.204 (-----*------) --------+---------+---------+---------+- 0.0 1.5 3.0 4.5 Pooled StDev = 2.368
Tiumsinawam (19)	Biomass (g / haul)	Source DF SS MS F P Year 10 27707 2771 2.37 0.012 Error 182 212859 1170 Total 192 240566 S = 34.20 R-Sq = 11.52% R-Sq(adj) = 6.66%	Individual 95% CIs For Mean Based on Pooled StDev Level N Mean StDev --------+---------+---------+---- -----+- 2000 12 10.83 21.55 (--------*---------) 2001 20 3.00 9.59 (-------*------) 2002 31 12.13 32.80 (-----*-----) 2003 19 36.79 87.36 (------*-------) 2004 20 17.20 20.23 (-------*------) 2005 6 13.00 31.84 (-------------*------------) 2006 10 35.45 45.79 (----------*---------) 2007 16 1.85 4.69 (--------*-------) 2008 17 0.00 0.00 (-------*-------) 2009 18 0.57 2.44 (-------*-------) 2010 24 2.76 13.52 (------*------) --------+---------+---------+---------+- 0 20 40 60 Pooled StDev = 34.20

Upper Catchment

Results of ANOVA analyses on mountain tandans, *Neosilurus equinus* condition index (K) values from upper catchment sites (site code) in 2010.

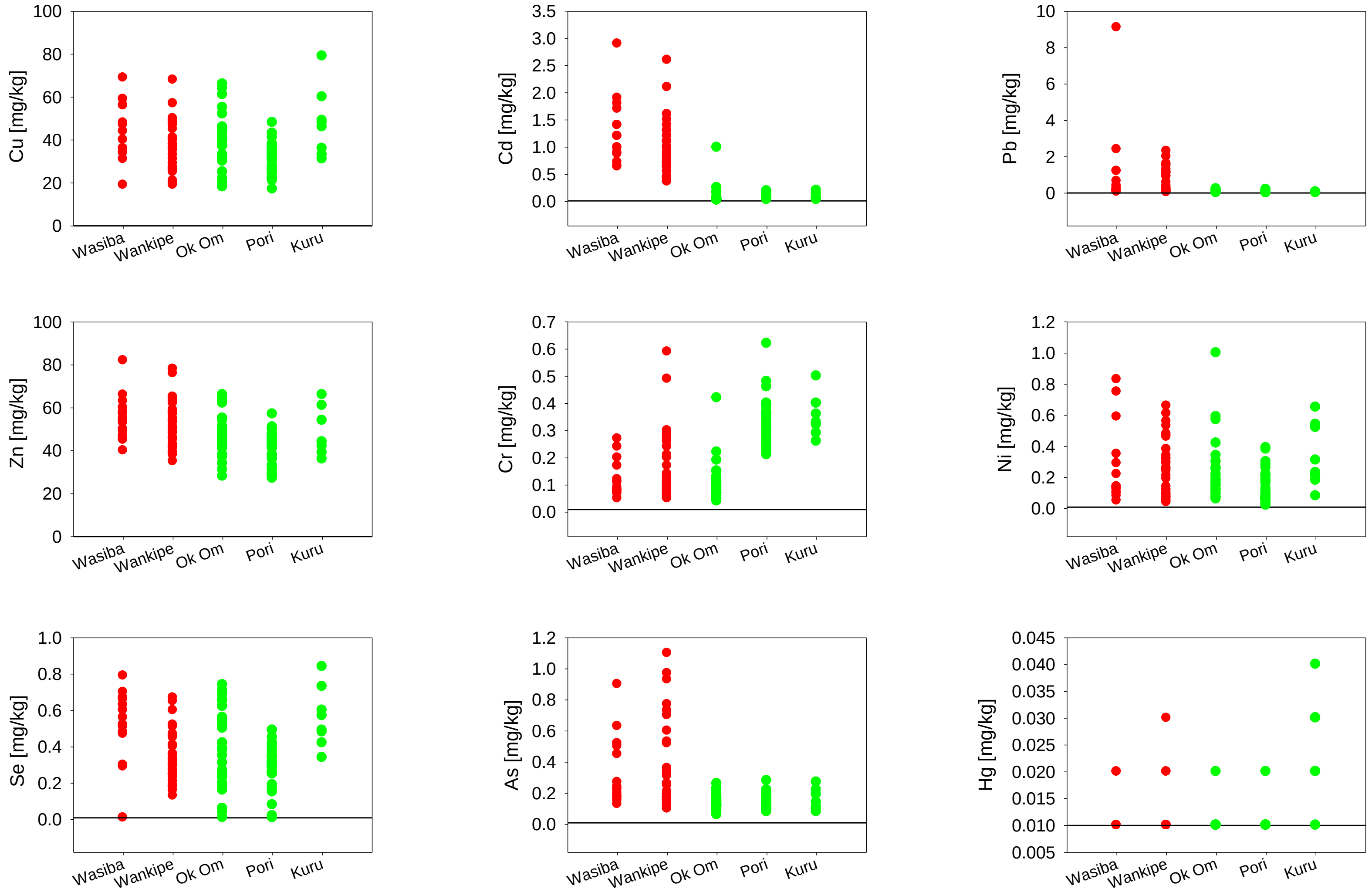
Site	Parameter	Factor	Multiple comparisons
Wankipe (15) Ok Om (80) Wasiba (124) Pori (210) Kuru (211))	Condition Index (K)	Source DF SS MS F P Site_code 4 0.0015803 0.0003951 5.28 0.000 Error 486 0.0363828 0.0000749 Total 490 0.0379631 S = 0.008652 R-Sq = 4.16% R-Sq(adj) = 3.37%	Individual 95% CIs For Mean Based on Pooled StDev Level ---------+---------+---------+---------+ 15 (----*----) 80 (-----*----) 124 (------*-----) 210 (-----*-----) 211 (-------*------) ---------+---------+---------+---------+ 0.0690 0.0720 0.0750 0.0780 Pooled StDev = 0.008652

Upper Catchment

Results of ANOVA analyses for mountain tandans, *Neosilurus equinus*, condition index (K) between 2000 and 2010 (or where data were available) at Wasiba.

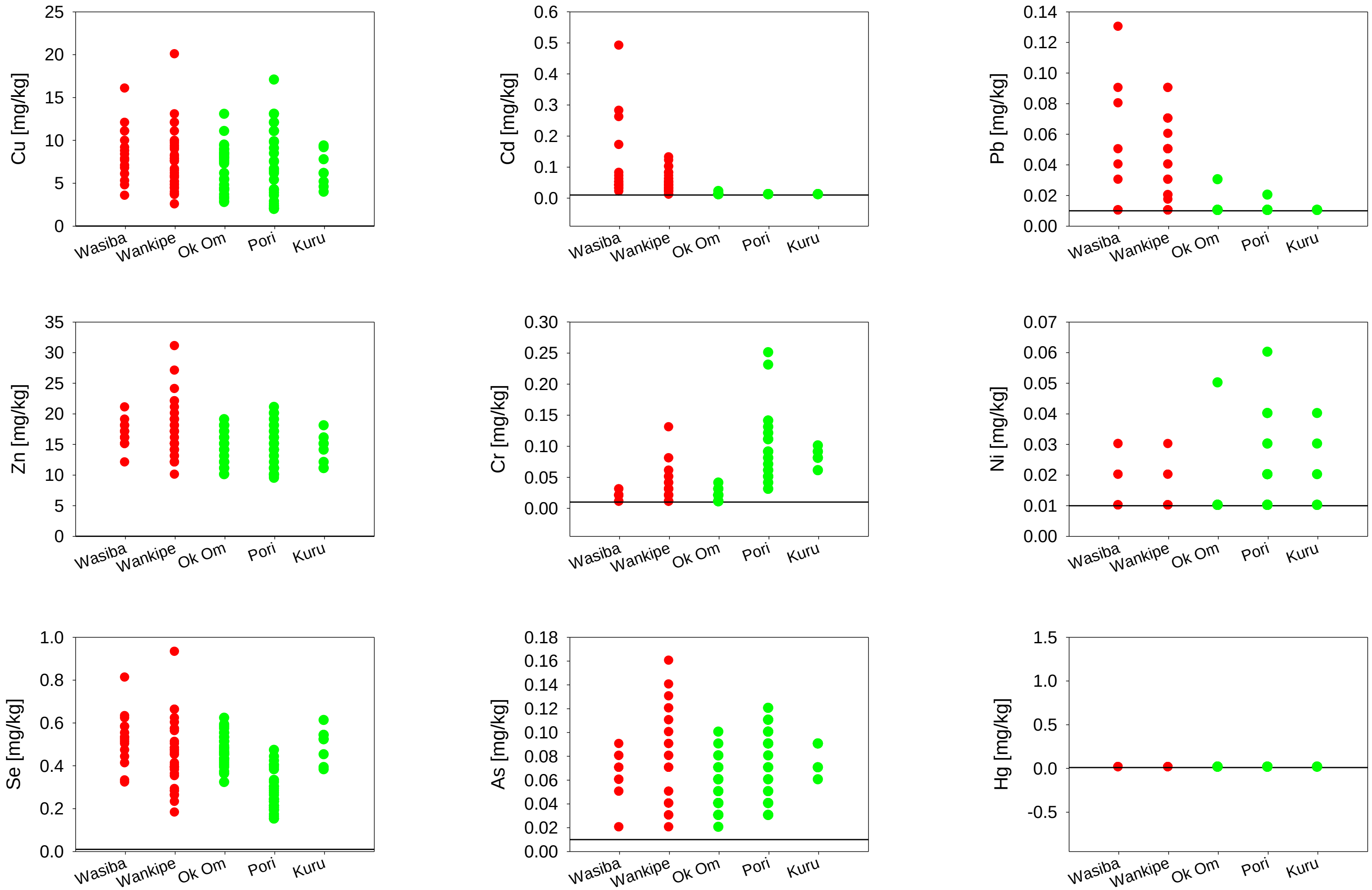
Site	Parameter	Factor	Multiple comparisons
Wasiba (124)	Condition Index (K)	Source DF SS MS F P Year 8 0.0068292 0.0008536 10.25 0.000 Error 358 0.0298192 0.0000833 Total 366 0.0366484 S = 0.009127 R-Sq = 18.63% R-Sq(adj) = 16.82%	Individual 95% CIs For Mean Based on Pooled StDev Level N Mean StDev --+---------+---------+---------+------- 2002 4 0.063020 0.011741 (----------*----------) 2003 46 0.073357 0.010814 (---*--) 2004 38 0.077264 0.008454 (---*--) 2005 60 0.077576 0.008060 (--*--) 2006 51 0.080020 0.007266 (--*--) 2007 24 0.073777 0.008264 (---*----) 2008 19 0.077091 0.008145 (----*-----) 2009 42 0.077943 0.010531 (--*---) 2010 83 0.068254 0.009700 (-*--) --+---------+---------+---------+------- 0.0560 0.0640 0.0720 0.0800 Pooled StDev = 0.009127

Appendix 2 Tissue Metal Concentration Graphs



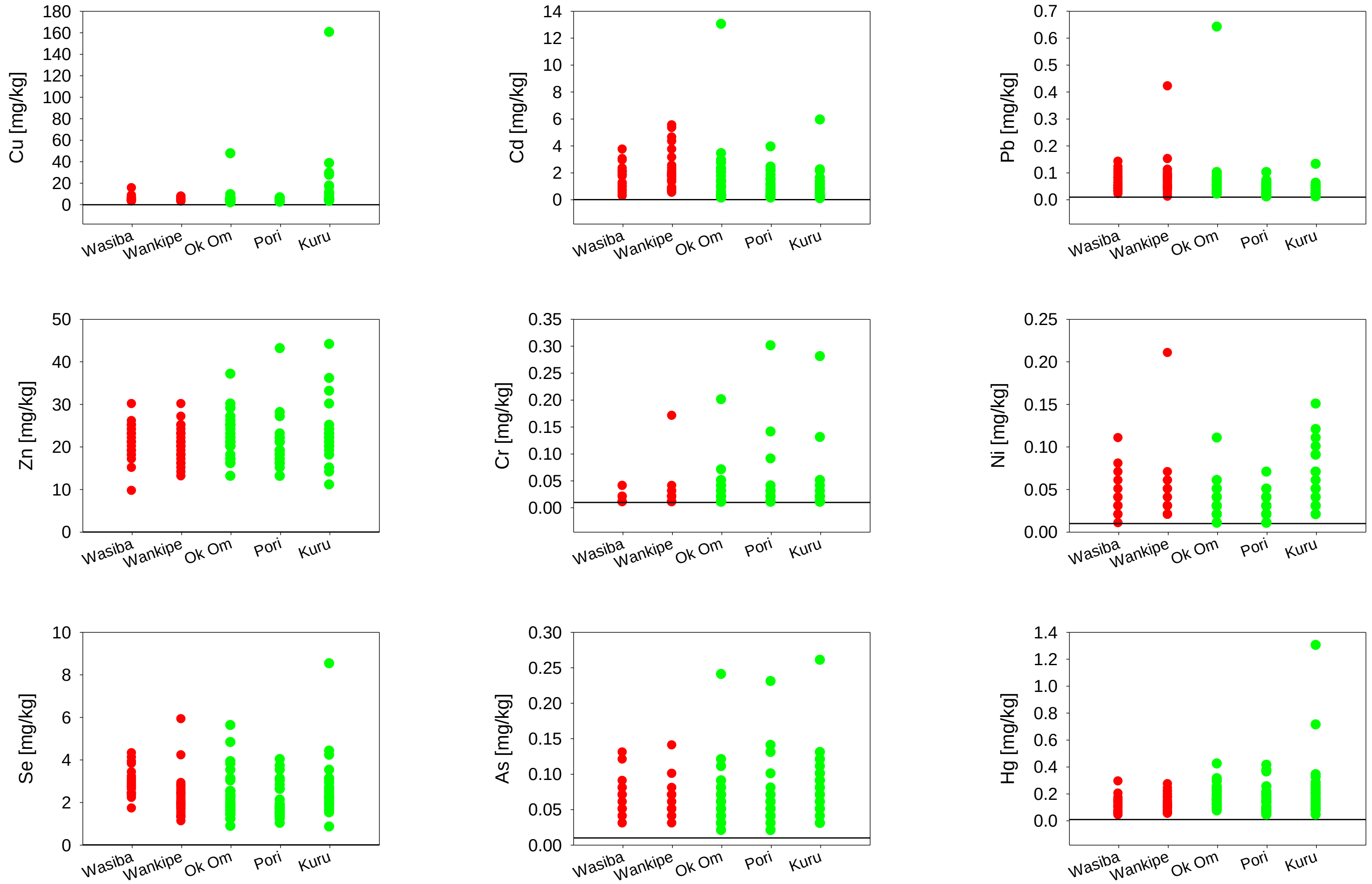
***Macrobrachium handschini* - cephalothorax**

Black line - detection limits



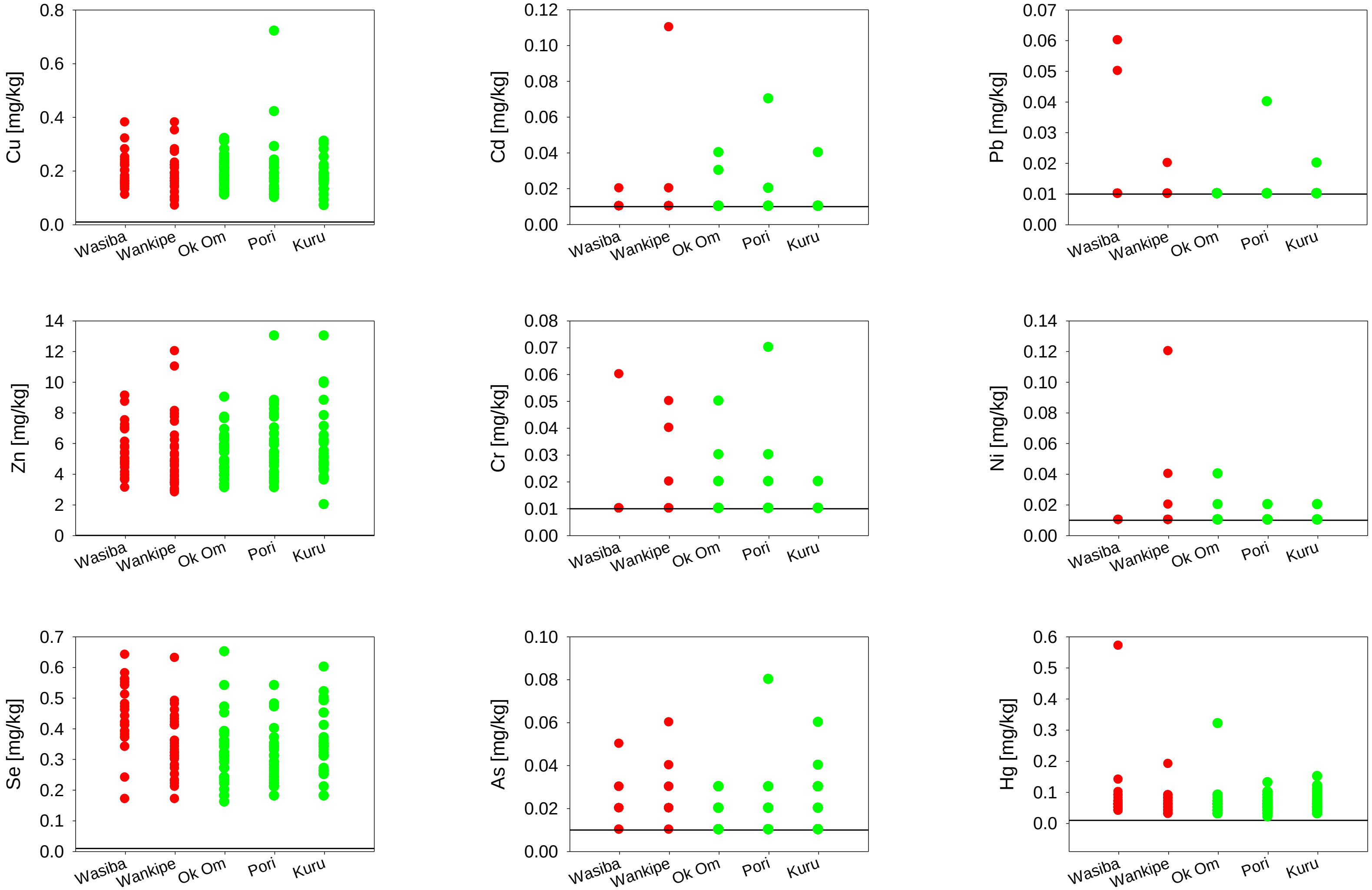
***Macrobrachium handschini* - flesh**

Black line - detection limits



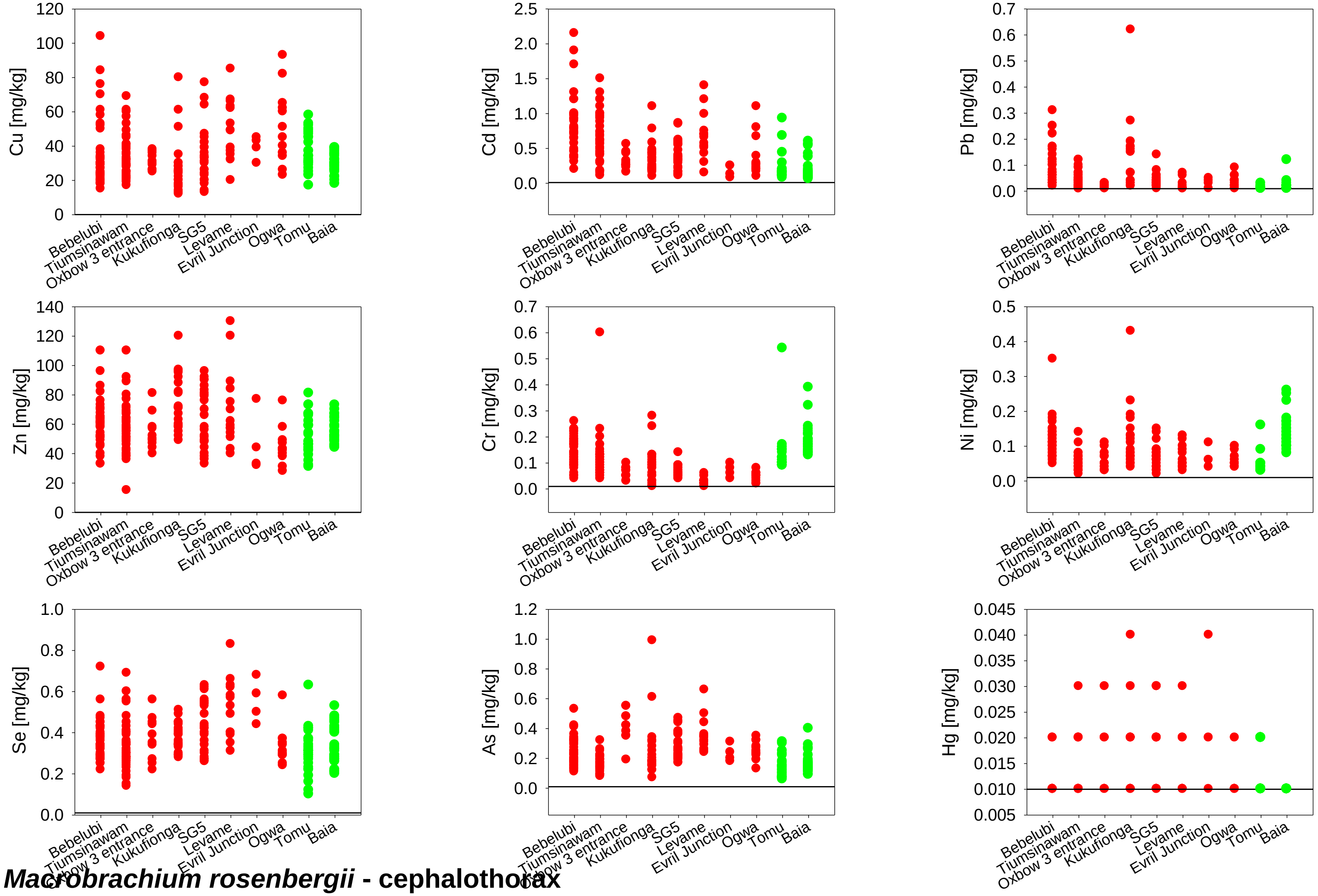
Neosilurus equinus **- liver**

Black line - detection limits



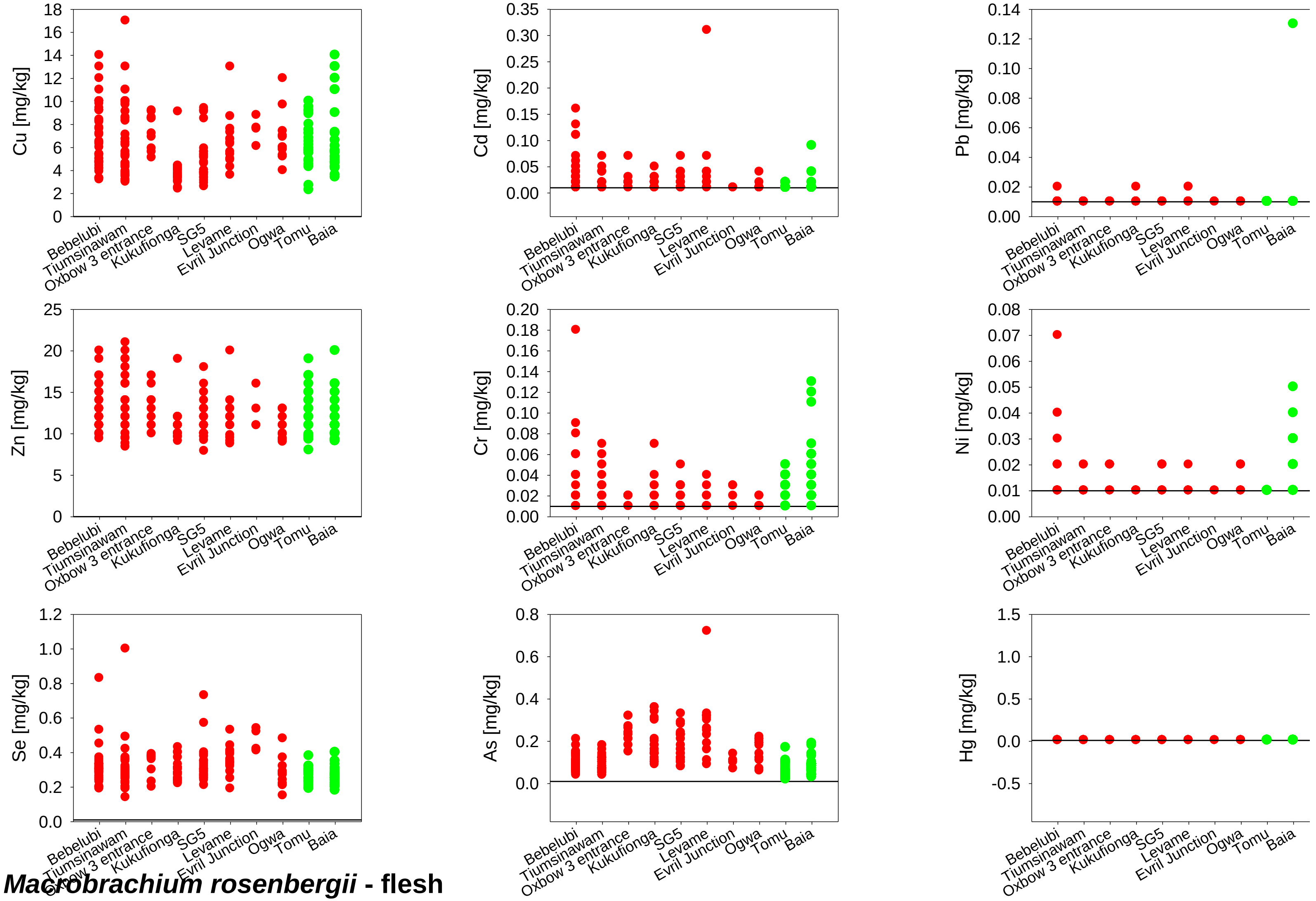
***Neosilurus equinus* - flesh**

Black line - detection limits



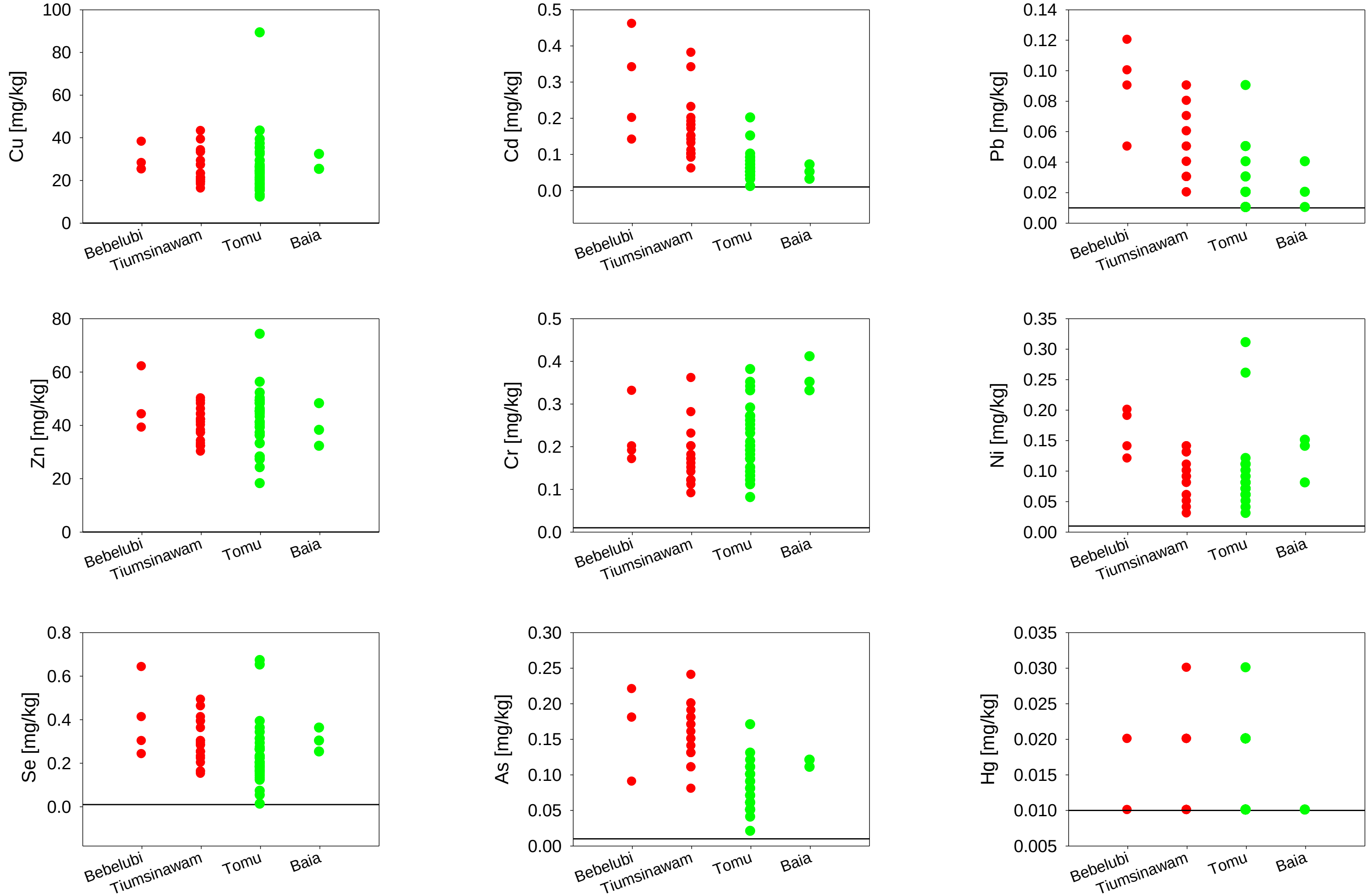
***Macrobrachium rosenbergii* - cephalothorax**

Black line - detection limits



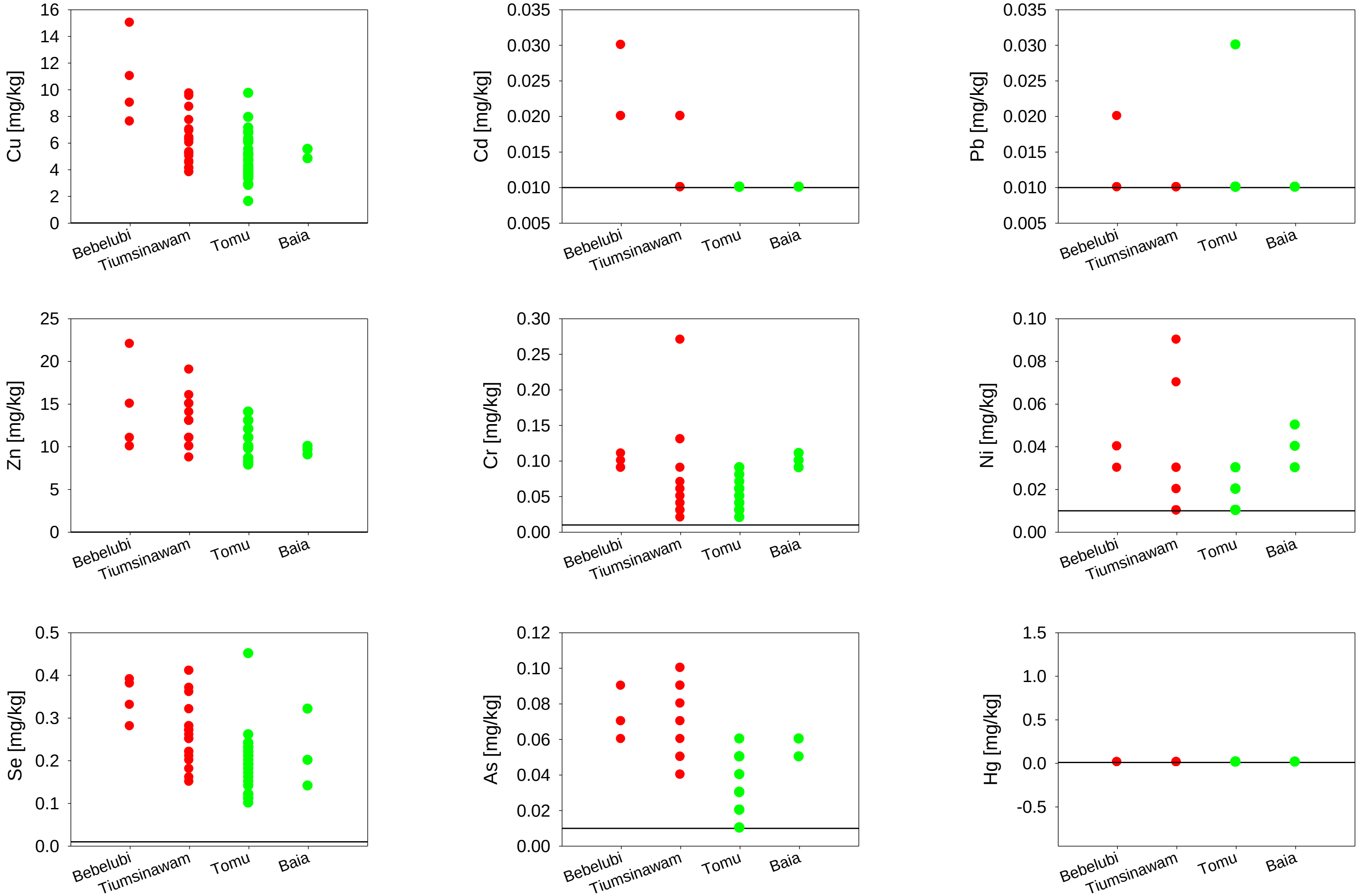
***Macrobrachium rosenbergii* - flesh**

Black line - detection limits



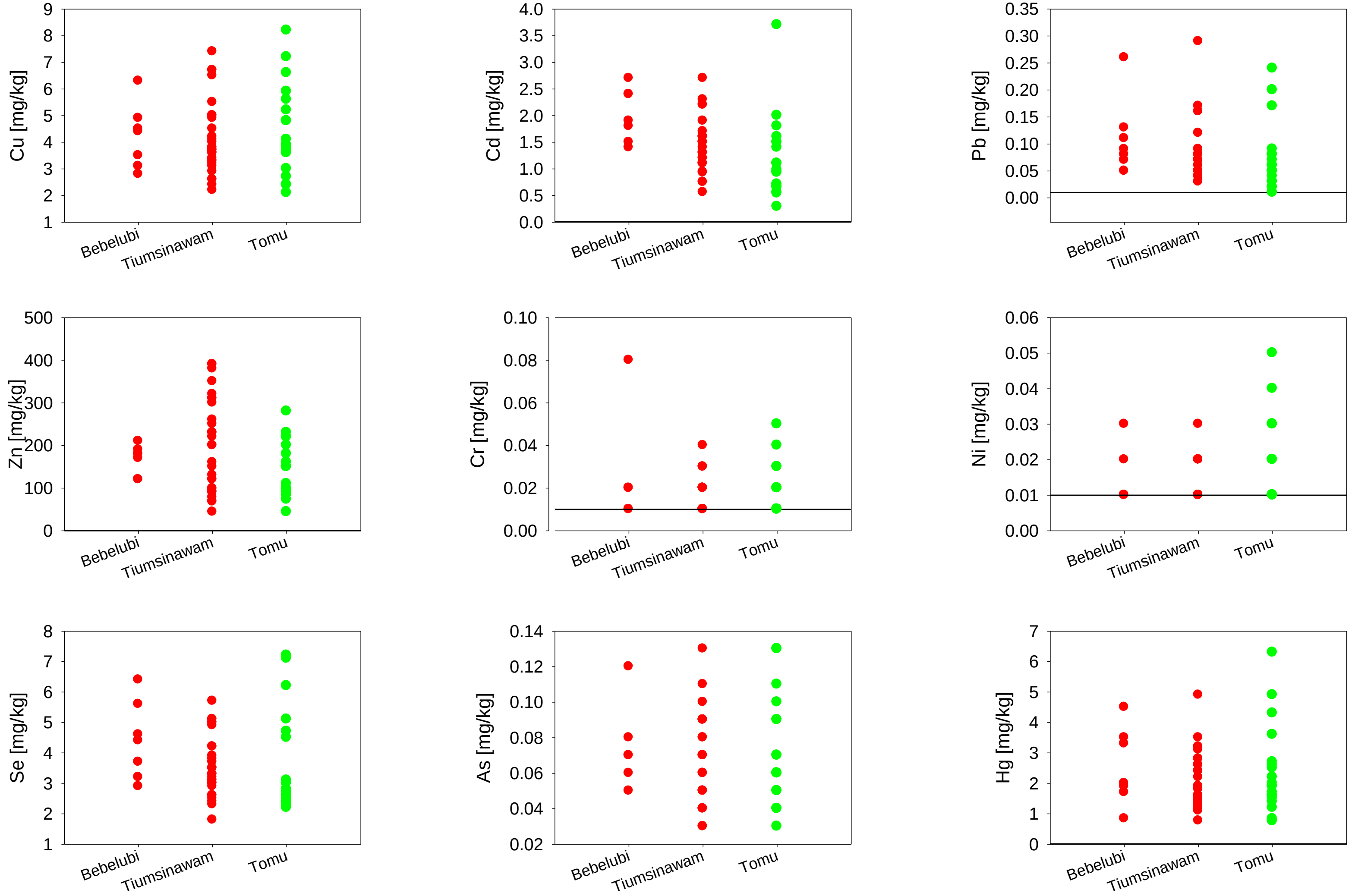
***Macrobrachium latidactylus* - cephalothorax**

Black line - detection limits



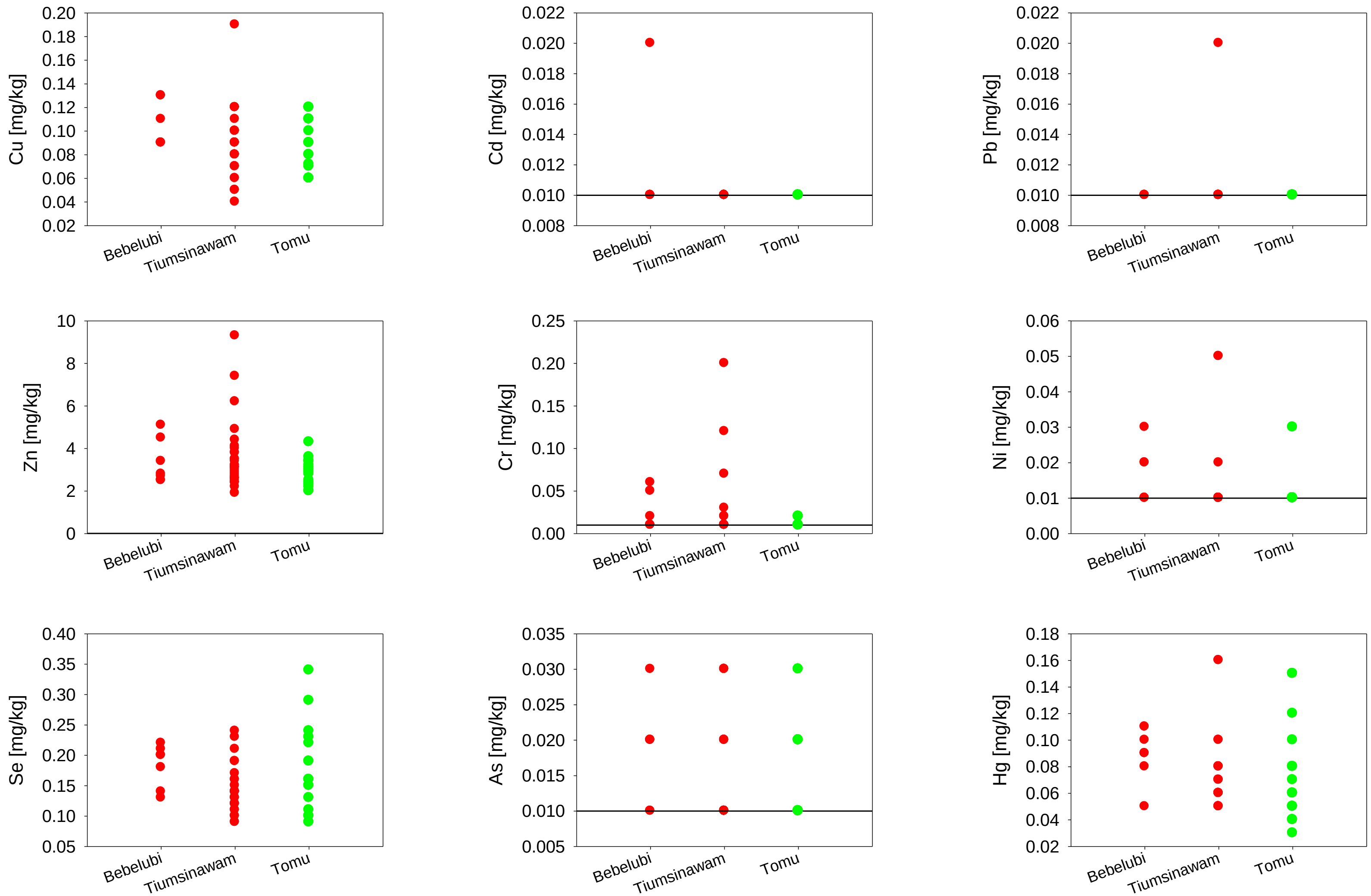
Macrobrachium latidactylus **- flesh**

Black line - detection limits



***Potamosilurus macrorhynchus* - liver**

Black line - detection limits



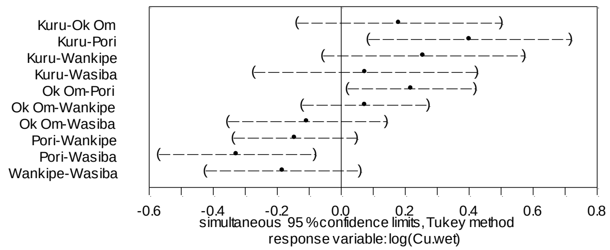
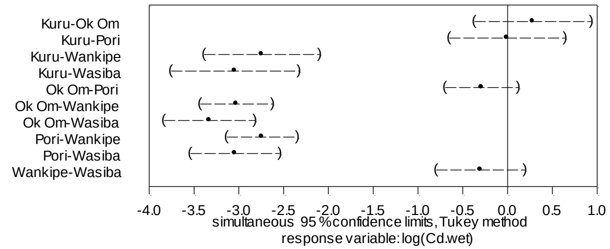
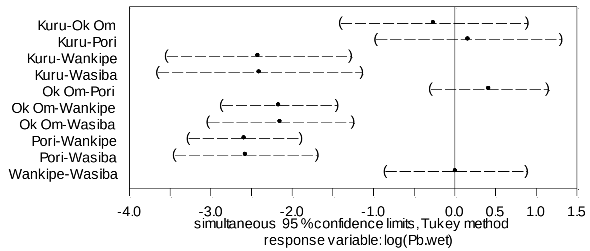
***Potamosilurus macrorhynchus* - flesh**

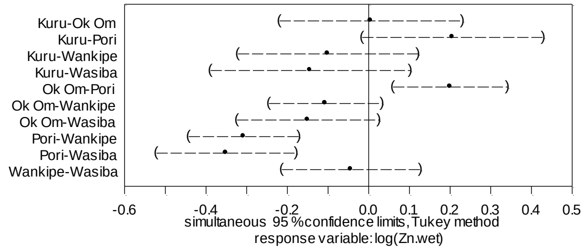
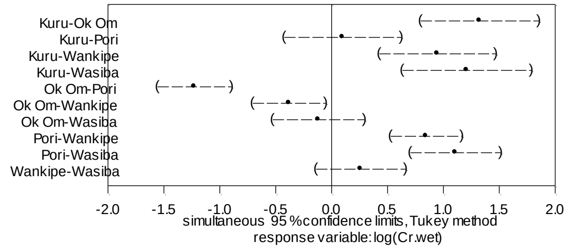
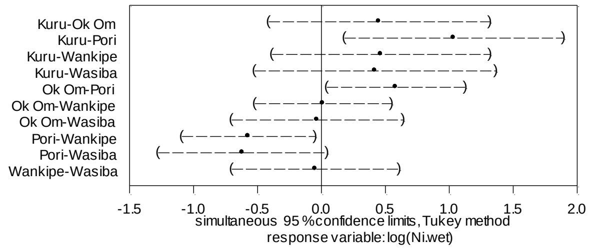
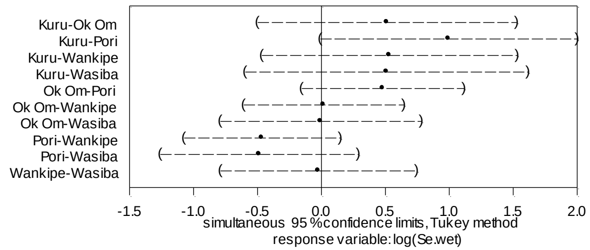
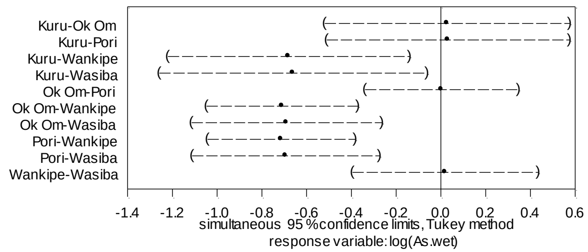
Black line - detection limits

Appendix 3 Tissue Metal Concentration Statistics

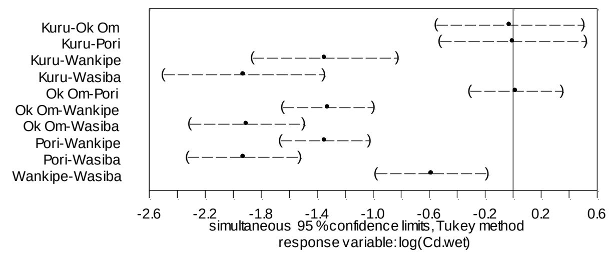
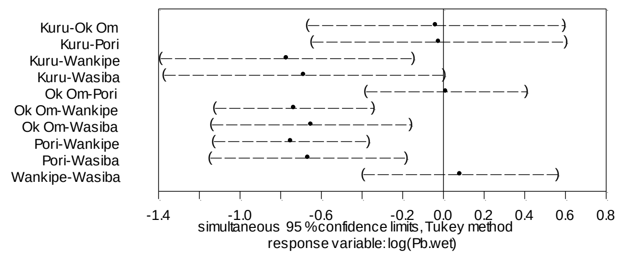
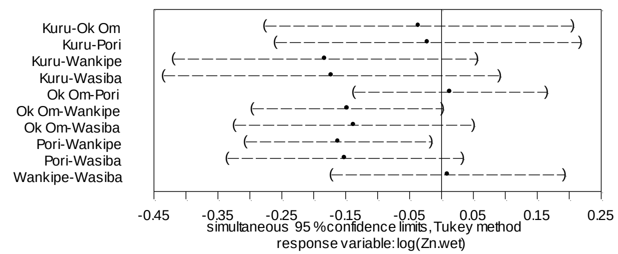
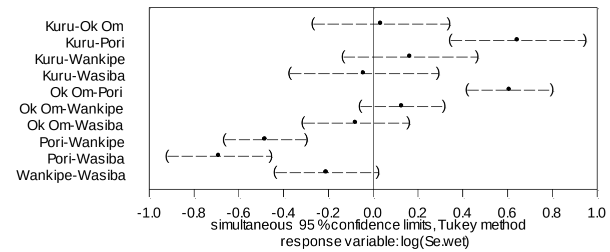
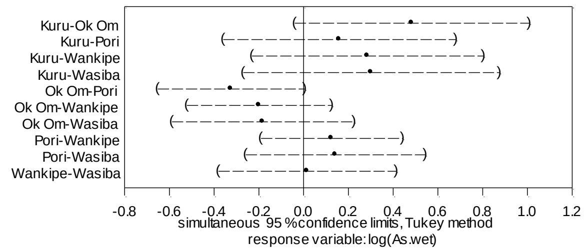
Upper Catchment

Results of ANCOVA analyses of prawn, *Macrobrachium handschini*, purged cephalothorax samples collected during 2010.

Metal	Factor	Multiple Comparisons
Cu	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 4 0.913393 0.228348 3.29822 0.01331688 Length 1 1.898021 1.898021 27.41469 0.00000072 Residuals 119 8.238812 0.069234	
Cd	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 4 267.417 66.85424 188.2203 0 Residuals 120 42.623 0.35519	
Pb	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 4 172.8522 43.21305 50.50142 0.000000e+000 Length 1 29.2542 29.25422 34.18828 4.480637e-008 Residuals 119 101.8259 0.85568	

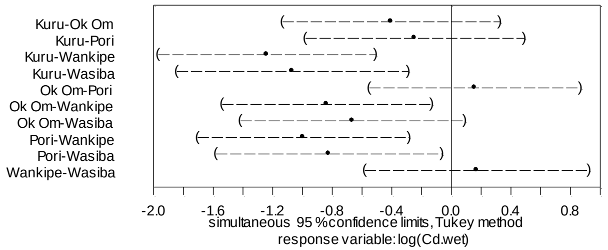
Metal	Factor	Multiple Comparisons
Zn	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 4 2.128140 0.5320349 12.69447 1.202418e-008 Residuals 120 5.029289 0.0419107	
Cr	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 4 31.58091 7.895227 40.81989 0.000000e+000 Length 1 4.81578 4.815775 24.89851 2.085199e-006 Residuals 119 23.01653 0.193416	
Ni	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 4 20.16356 5.04089 11.11996 1.069483e-007 Length 1 20.46145 20.46145 45.13695 6.681000e-010 Residuals 119 53.94498 0.45332	
Se	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 4 8.6851 2.171283 2.551495 0.04257184 Residuals 120 102.1182 0.850985	
As	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 4 14.95044 3.737609 15.0234 5.541519e-010 Residuals 120 29.85431 0.248786	

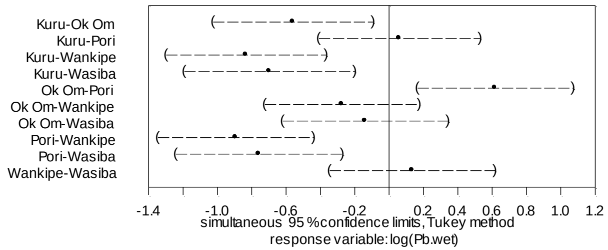
Results of ANCOVA analyses of prawn, *Macrobrachium handschini*, purged abdomen flesh samples collected during 2010.

Metal	Factor	Multiple Comparisons
Cd	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 4 72.57628 18.14407 82.07981 0.00000000 Length 1 1.10669 1.10669 5.00642 0.02711487 Residuals 119 26.30542 0.22105	
Pb	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 4 3.52402 0.881006 3.946745 0.004869949 Length 1 1.94689 1.946892 8.721722 0.003813468 Site:Length 4 6.14535 1.536337 6.882512 0.000052907 Residuals 115 25.67069 0.223223	
Zn	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 4 0.930717 0.2326793 5.71254 0.0003060867 Length 1 0.925849 0.9258486 22.73064 0.0000053274 Residuals 119 4.847025 0.0407313	
Se	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 4 8.812707 2.203177 28.88235 1.110223e-016 Residuals 120 9.153729 0.076281	
As	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 4 2.41492 0.6037303 2.648526 0.03663549 Residuals 120 27.35395 0.2279495	

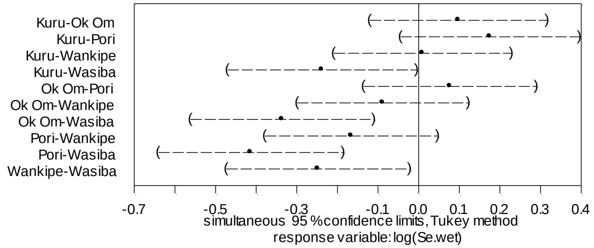
Results of ANCOVA analyses of mountain tandan, *Neosilurus equinus*, liver samples collected during 2010.

Metal	Factor	Multiple Comparisons

Cd	`Type III Sum of Squares`
	`Df Sum of Sq Mean Sq F Value Pr(F)`
	`Site 4 32.5504 8.137595 8.086043 6.90776e-006`
	`Residuals 138 138.8798 1.006375`
		

Pb	`Type III Sum of Squares`
	`Df Sum of Sq Mean Sq F Value Pr(F)`
	`Site 4 19.34511 4.836278 11.78988 2.88327e-008`
	`Residuals 138 56.60840 0.410206`
		

Results of ANCOVA analyses of mountain tandan, *Neosilurus equinus*, flesh samples collected during 2010.

<table>
<tr><th>Metal</th><th>Factor</th><th>Multiple Comparisons</th></tr>
<tr><td>Se</td><td>Type III Sum of Squares
Df Sum of Sq Mean Sq F Value Pr(F)
Site 4 3.10763 0.7769085 9.22426 0.000001249
Length 1 0.90263 0.9026267 10.71692 0.001344035
Residuals 137 11.53875 0.0842245</td><td>
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Lower Strickland

Results of ANCOVA analyses of giant freshwater prawn, *M. rosenbergii*, purged cephalothorax samples collected during 2010.

<table>
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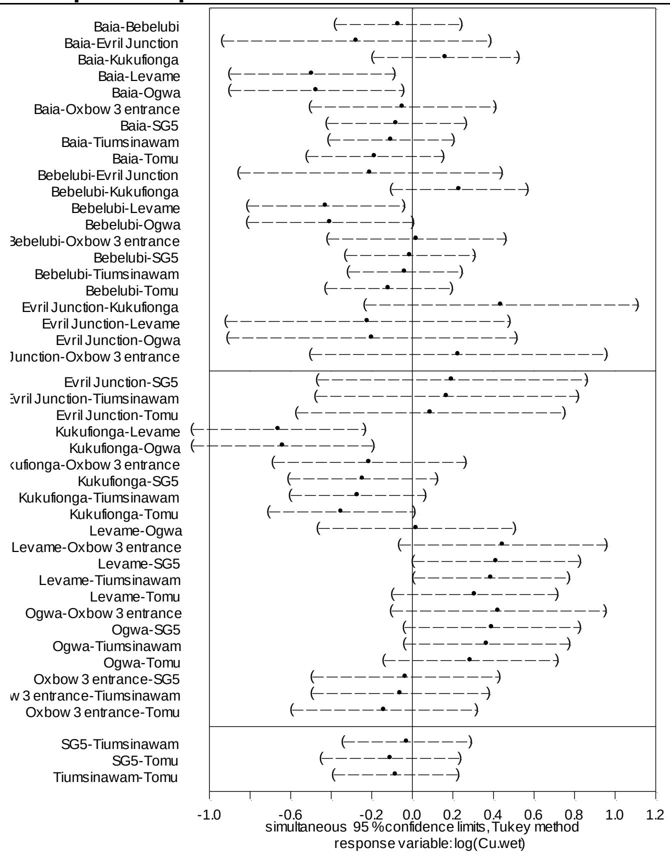
<tr><td>Cu</td><td><pre>Type III Sum of Squares
          Df Sum of Sq   Mean Sq F Value   Pr(F)
    Site   9   5.93487 0.6594296 4.452225 0.00002375849
Residuals 208 30.80737 0.1481124</pre></td><td>
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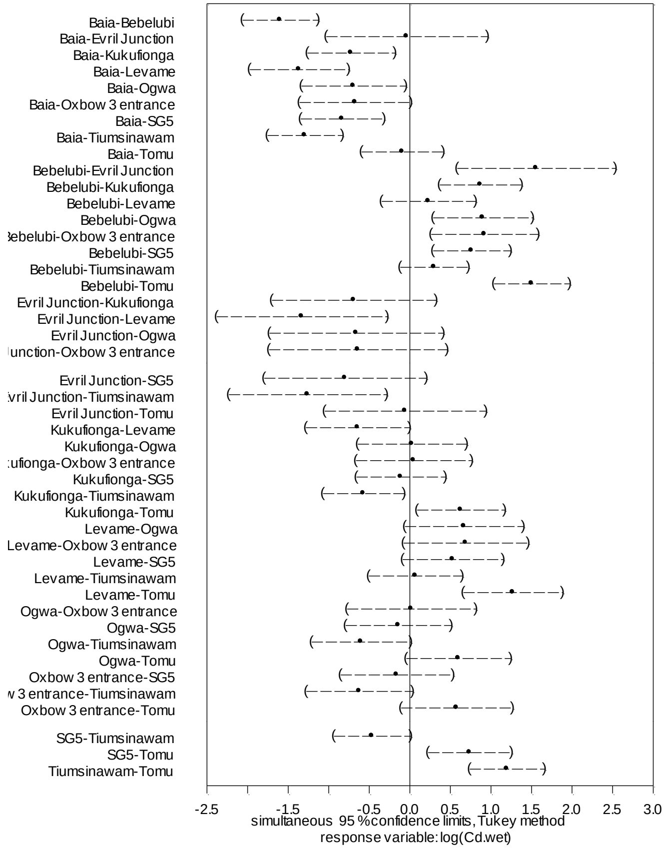
<table>
<tr><th>Metal</th><th>Factor</th><th>Multiple Comparisons</th></tr>
<tr><td>Cd</td><td>

```
Type III Sum of Squares
           Df Sum of Sq  Mean Sq  F Value Pr(F)
     Site   9  71.33879 7.926532 23.51708     0
Residuals 208  70.10729 0.337054
```

</td><td>



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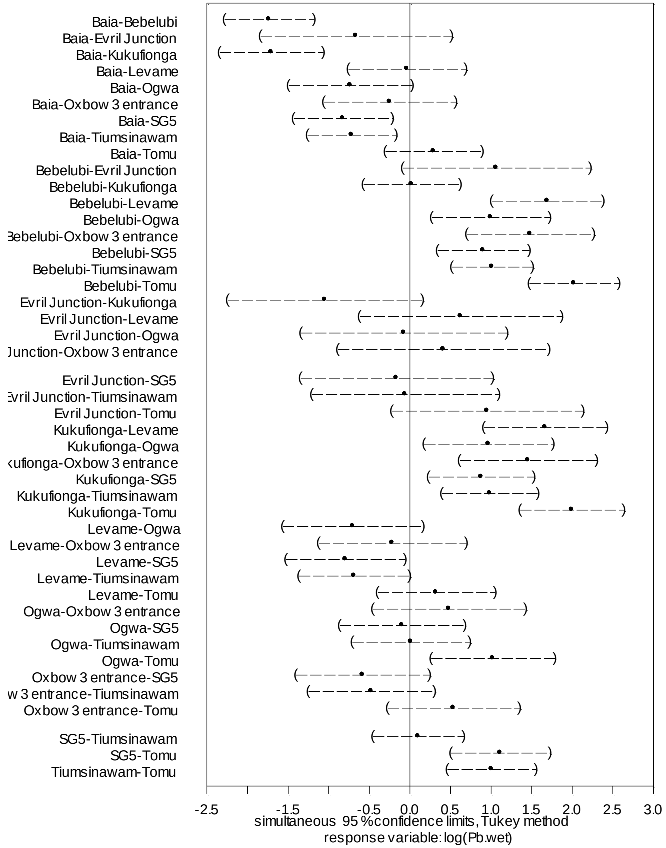
Metal	Factor	Multiple Comparisons
Pb	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 9 110.0944 12.23271 25.86241 0 Residuals 208 98.3823 0.47299	

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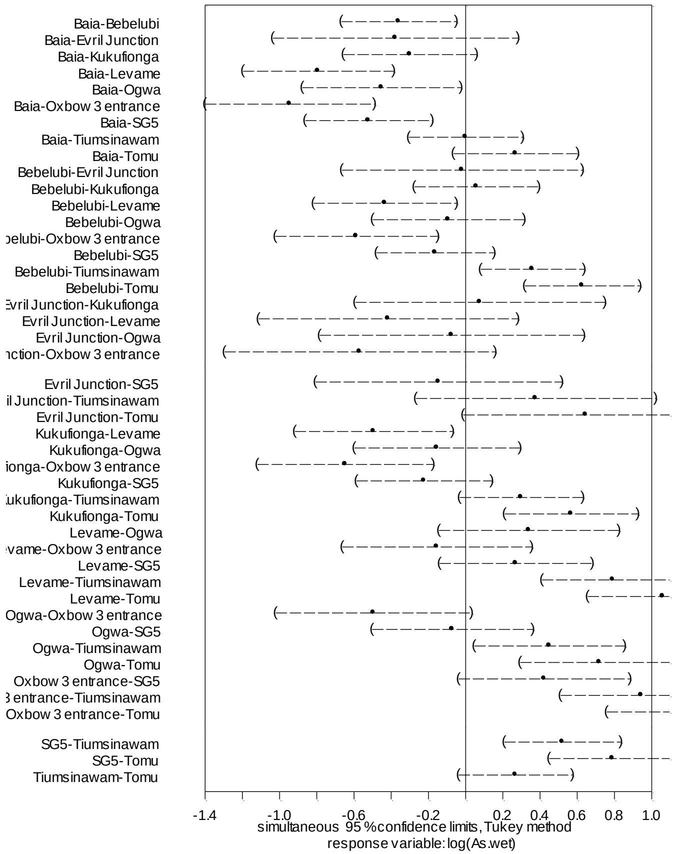
<tr><th>Metal</th><th>Factor</th><th>Multiple Comparisons</th></tr>
<tr><td>As</td><td>Type III Sum of Squares
Df Sum of Sq Mean Sq F Value Pr(F)
Site 9 23.30778 2.589753 17.49654 0
Residuals 208 30.78715 0.148015</td><td>
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<table>
<tr><th>Metal</th><th>Factor</th><th>Multiple Comparisons</th></tr>
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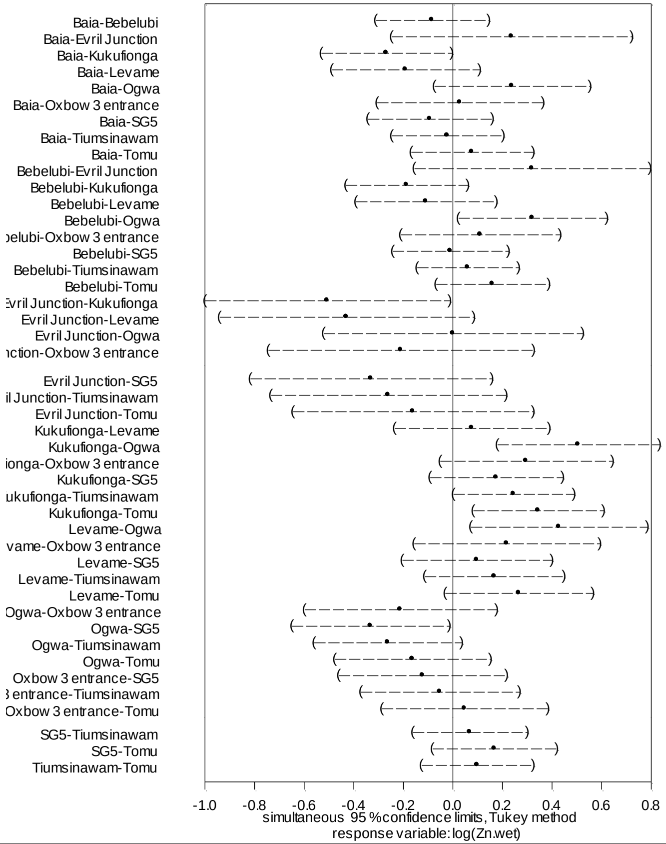
Df Sum of Sq Mean Sq F Value Pr(F)
Site 9 3.26557 0.3628414 4.531919 0.00001847524
Residuals 208 16.65321 0.0800635</td><td>
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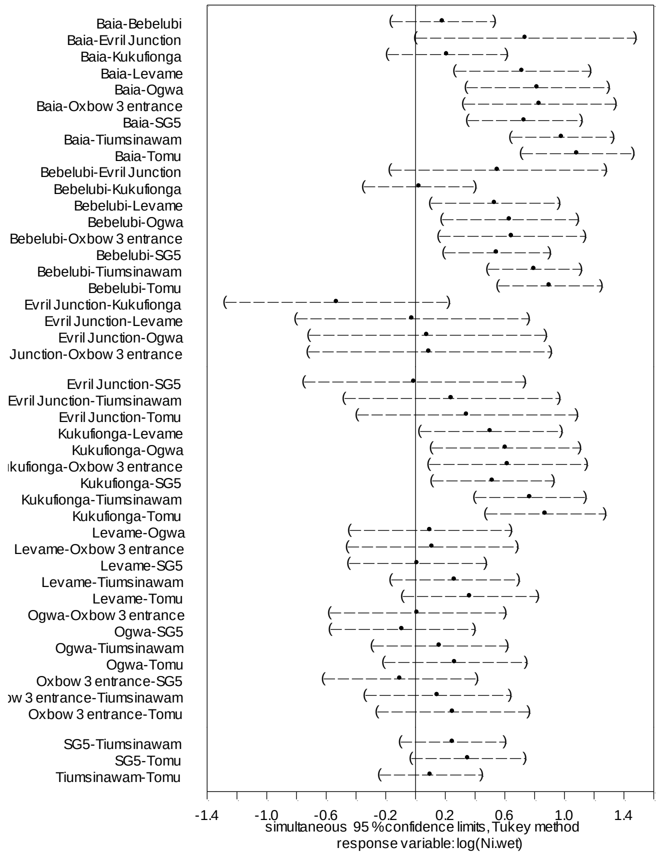
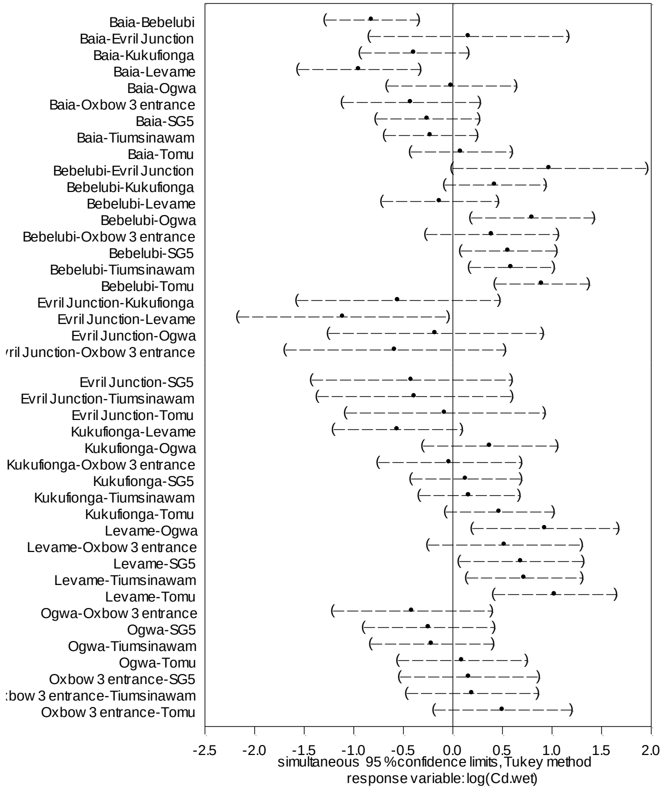
Metal	Factor	Multiple Comparisons
Ni	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 9 33.61584 3.735093 20.13904 0 Residuals 208 38.57679 0.185465	

Results of ANCOVA analyses of giant freshwater prawn, *M. rosenbergii*, purged abdomen flesh samples collected during 2010.

<table>
<tr><th>Metal</th><th>Factor</th><th>Multiple Comparisons</th></tr>
<tr><td>Cd</td><td>

```
Type III Sum of Squares
           Df Sum of Sq  Mean Sq  F Value         Pr(F)
     Site   9  24.74216 2.749128 8.025485 3.509946e-010
Residuals 208  71.25036 0.342550
```

</td><td>



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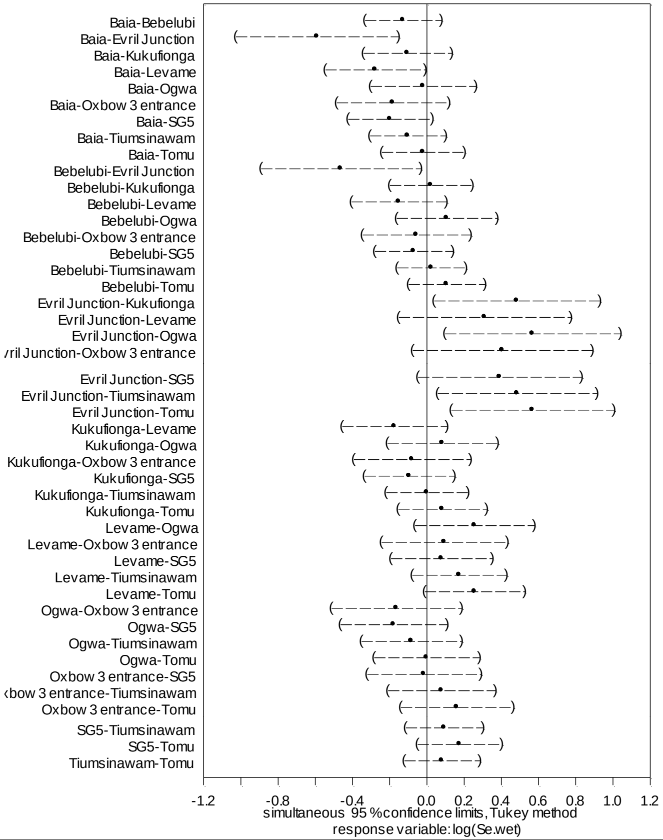
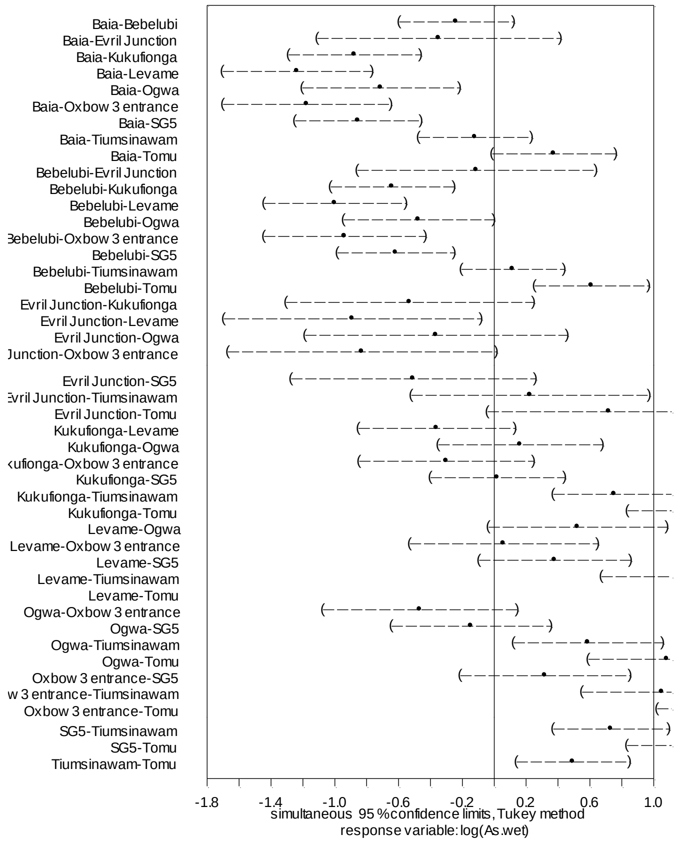
Metal	Factor	Multiple Comparisons
Se	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 9 2.20352 0.2448359 3.752286 0.0002146288 Residuals 208 13.57196 0.0652498	

<table>
<tr><th>Metal</th><th>Factor</th><th>Multiple Comparisons</th></tr>
<tr><td>As</td><td>

```
Type III Sum of Squares
           Df Sum of Sq  Mean Sq  F Value Pr(F)
     Site   9  51.36187 5.706875 28.81203     0
Residuals 208  41.19911 0.198073
```

</td><td>


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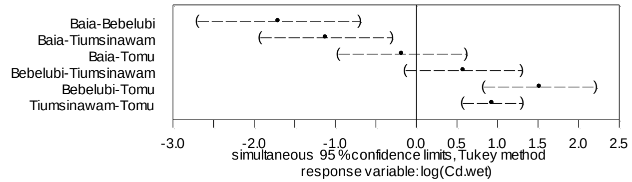
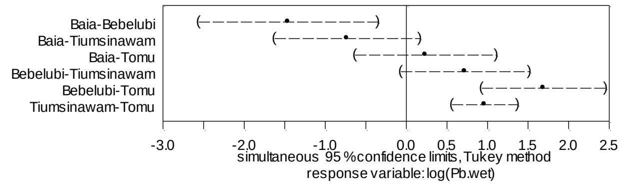
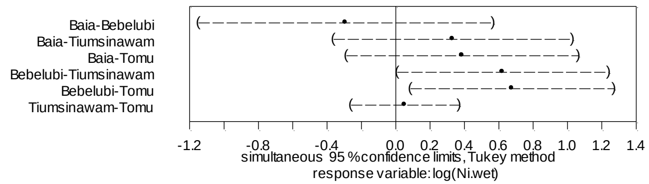
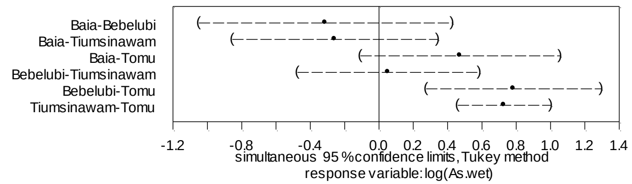
Results of ANCOVA analyses of cross-fingered prawn, *M. latidactylus*, purged cephalothorax samples collected during 2010.

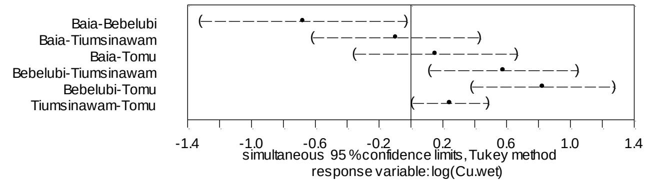
Metal	Factor	Multiple Comparisons
Cd	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 3 17.44449 5.814831 23.70611 3.857042e-010 Residuals 58 14.22672 0.245288	
Pb	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 3 18.74857 6.249523 20.90544 2.640958e-009 Residuals 58 17.33866 0.298942	
Ni	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 3 1.95606 0.6520184 3.614029 0.0183679 Residuals 58 10.46396 0.1804132	
As	Type III Sum of Squares Df Sum of Sq Mean Sq F Value Pr(F) Site 3 7.880454 2.626818 19.66461 6.459029e-009 Residuals 58 7.747698 0.133581	

Results of ANCOVA analyses of cross-fingered prawn, *M. latidactylus*, purged abdomen flesh samples collected during 2010.

<table>
<tr><th>Metal</th><th>Factor</th><th>Multiple Comparisons</th></tr>
<tr><td>Cu</td><td>

```
Type III Sum of Squares
          Df Sum of Sq   Mean Sq F Value          Pr(F)
     Site  3  2.822079 0.9406930 9.23028 0.00004392082
Residuals 58  5.911000 0.1019138
```

</td><td>



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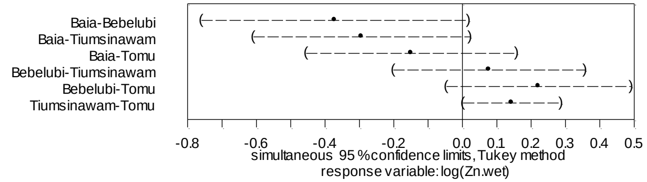
<tr><td>Zn</td><td>

```
Type III Sum of Squares
          Df Sum of Sq   Mean Sq  F Value        Pr(F)
     Site  3  0.502632 0.1675439 4.516897 0.006482244
Residuals 58  2.151376 0.0370927
```

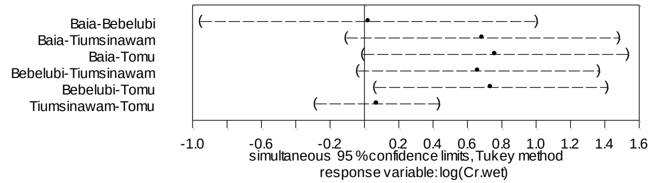
</td><td>



</td></tr>
<tr><td>Cr</td><td>

```
Type III Sum of Squares
          Df Sum of Sq  Mean Sq F Value       Pr(F)
     Site  3   3.30703 1.102343 4.69633 0.005286486
Residuals 58  13.61401 0.234724
```

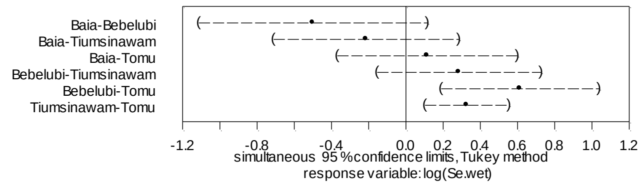
</td><td>



</td></tr>
<tr><td>Se</td><td>

```
Type III Sum of Squares
          Df Sum of Sq   Mean Sq  F Value         Pr(F)
     Site  3   2.28848 0.7628266 8.249096 0.0001168766
Residuals 58   5.36349 0.0924740
```

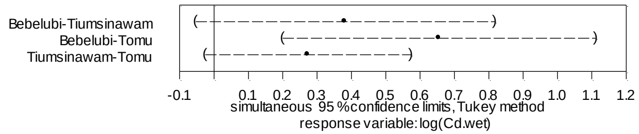
</td><td>



</td></tr>
</table>

Results of ANCOVA analyses of sharp-snouted catfish, *P. macrorhynchus*, liver samples collected during 2010.

Metal	Factor	Multiple Comparisons

Cd	`Type III Sum of Squares`
	`          Df Sum of Sq  Mean Sq  F Value       Pr(F)`
	`     Site  2   2.38282 1.191410 6.429301 0.003128849`
	`Residuals 54  10.00671 0.185309`
		

Appendix 4 Prawn SDH Analysis Report

Sorbitol Dehydrogenase (SDH) in Prawn Tails, 2010

Introduction

The enzyme sorbitol dehydrogenase (SDH) is primarily found in the liver of vertebrates and catalyses the reversible oxidation-reduction reaction between fructose and sorbitol. SDH is normally used as a diagnostic tool for liver injury in vertebrates however, past research has shown that the quantification of SDH activity in prawn tails correlates well with exposure to contamination. While the biological relevance of elevated SDH activity in prawn flesh has not been elucidated, this biomarker remains an excellent monitoring tool available to assess the exposure of prawns and possibly other aquatic biota, to effluent discharge in the PNG rivers.

Procedures

Two samplings have been conducted in 2010, a first one in May 2010 with thirty (30) prawns collected from 3 sites, and a second sampling in November 2010 with forty (40) prawns collected from four sites. All samples were received in excellent condition preserved on dry ice (May) or in liquid nitrogen (November).
The tissues were thawed slowly, and homogenized with Trizma / EDTA physiological buffer that was supplemented with phenylmethylsulfonyl fluoride (PMSF) as a protease inhibitor preventing the degradation of the enzymes. Following high speed centrifugation under refrigerated conditions, the supernatant was isolated and used immediately for the SDH assay.
SDH activity was measured by following the rate of decrease in absorbance (ΔA) over one minute at 340 nm on a spectrophotometer, using the kinetic (continuous) reading of the absorbance. The enzymatic activity is reported in milli-International Unit (mU) per gram of tissue. One International Unit (U) of an enzyme is defined as the amount which will convert 1µM of substrate into product per minute (in this case, fructose is converted to sorbitol).

Statistical analysis

The two sets of data were analyzed separately using SPSS version 18 at $\alpha = 0.05$. Details of statistical results are provided in Appendix 1.
The information provided for the May 2010 data was that there was no reference site amongst the three locations, and the samples provided were for experimental purposes only. Consequently, only descriptive statistics and an ANOVA were performed on the logged-data.
For the November 2010 sampling, two reference sites (Ok Om and Pori) and two exposed sites (Wankipe and Wasiba) were sampled. Initially, the two reference sites were compared using a t-test, which confirmed that the two reference sites were statistically similar. The data from the two sites were therefore pooled to compare to the two exposed sites. The pooling of the two reference sites provides a better statistical power to establish differences between reference and exposed locations.
A one-way ANOVA, with ‘origin’ as a classification factor, was performed on the log-transformed data using Dunnett as a post-hoc test. The advantage of using the Dunnett test is that is allows for the identification of a reference group to which all other groups are compared, providing a better discriminatory power.

Prawn SDH activity Results

May 2010

The SDH activity for the prawns collected in May 2010 is described in Table 1.

Table 1. Summary of organisms collected and SDH activity (mU / g flesh) determined in prawn tails.

Origin	Type	Number prawns collected	SDH activity (average ± SEM)
Strox3	N/A	10	280 ± 77
OGWA	N/A	10	186 ± 29
SG5	N/A	10	129 ± 9.5

No reference site was identified for the May 2010 prawns however, results from the ANOVA confirm that the prawns collected at Strox3 had a significantly higher SDH activity in their flesh than those originating from SG5. Prawns collected at OGWA had similar enzymatic activity than those at Strox3 and SG5.

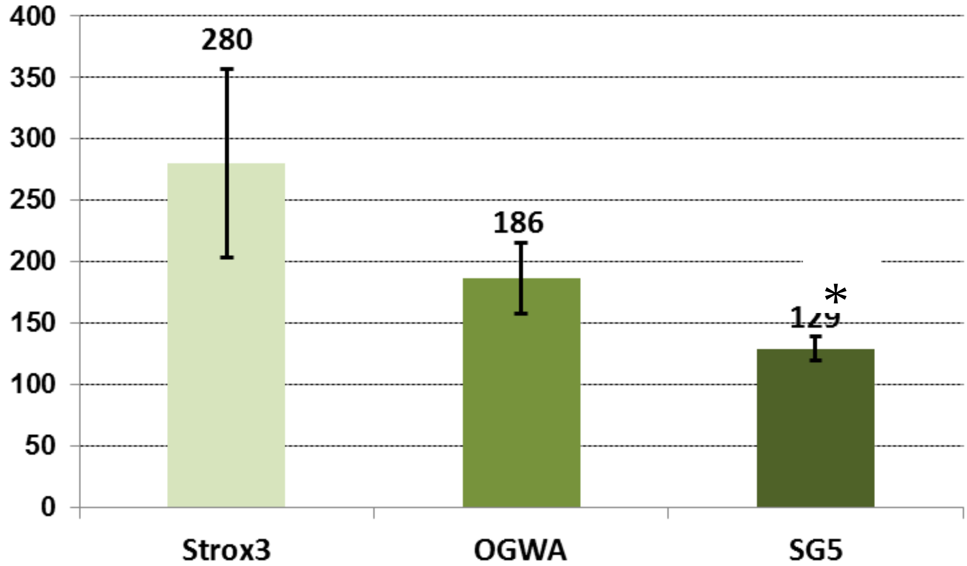


Figure 1. SDH activity atStrox3, OGWA and SG5 locations in May 2010. SDH activity in prawns collected at Strox3 was significantly (α = 0.031) higher than the SDH activity in prawns originating from SG5.

November 2010

The prawns sampled at Ok Om and at Pori had statistically similar SDH activity in their tissue (p = 0.160). The data from these two sites were combined into a single reference group in order to compare the reference SDH activity to the SDH activity at the exposed sites of Wankipe and Wasiba. The results of SDH quantification in the November 2010 prawns are listed in Table 2.

Table 2. Summary of SDH activity (mU/g flesh) determined in prawn collected at four locations in November 2010..

Origin	Type	Number prawns	SDH activity

		collected	(average ± SEM)
Ok Om	Reference	10	297 ± 19.1
Pori	Reference	10	254 ± 24.8
Wankipe	Exposed	10	370 ± 32.9
Wasiba	Exposed	10	286 ± 22.8

SDH activity observed at Wankipe was found to be statistically higher (*p* = 0.030) than the SDH activity observed at the reference sites. However, the SDH activity in prawn collected at Wasiba was statistically similar to that of the reference sites (*p* = 0.902).

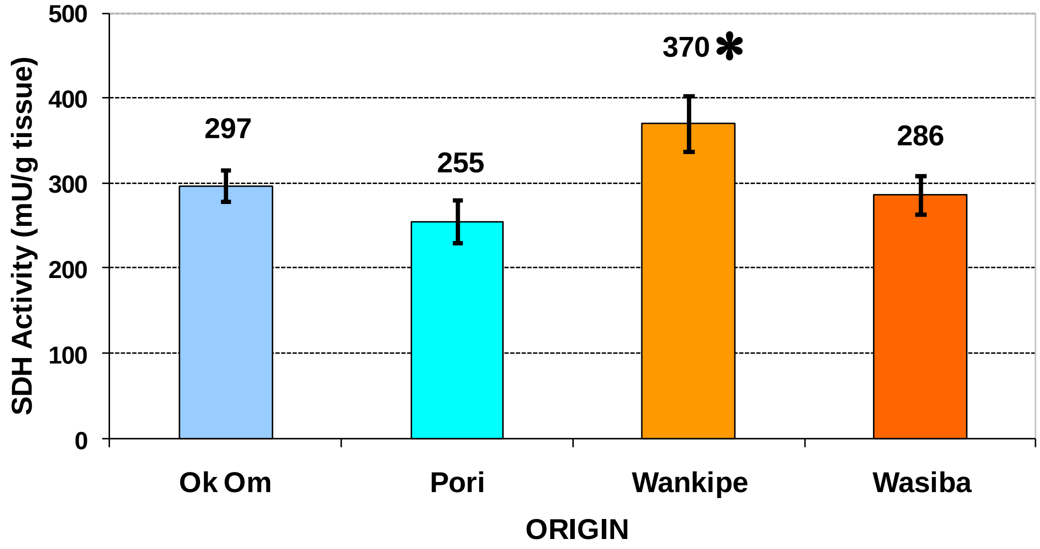


Figure 2. SDH activity levels (mU / g flesh) in prawn tails at various sites in November 2010. Bars represent standard errors of the mean. * indicates a statistical difference from the (combined) reference sites.

The observed SDH activity in the prawns collected in 2010 at Ok Om, Pori, Wankipe and Wasiba follows similar trends to the SDH activity observed in prawn flesh from these locations in previous samplings. While the absolute value of the SDH activity in the reference prawns varies between years, the trends remain the same from year to year. In 2010, only the prawns collected at Wankipe were showing statistically higher levels than the reference prawns, while the organisms collected in Wasiba had similar SDH enzymatic activity relative to the reference prawns.

Appendix 1. Statistical Results.

Prawn Tails SDH activity (May 2010)

SDH **Descriptives – Raw Data**

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Strox3	10	280.0000	243.53416	77.01226	105.7862	454.2138	116.00	907.00
OGWA	10	186.2500	92.43353	29.23005	120.1270	252.3730	96.50	424.00
SG5	10	129.2500	30.16183	9.53801	107.6735	150.8265	67.50	167.00
Total	30	198.5000	159.17265	29.06082	139.0640	257.9360	67.50	907.00

LogSDH **ANOVA**

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.318	2	.159	3.950	.031
Within Groups	1.088	27	.040		
Total	1.406	29			

Tukey B[a] **LogSDH**

group	N	Subset for alpha = 0.05: 1	2
SG5	10	2.0988	
OGWA	10	2.2332	2.2332
Strox3	10		2.3509

Prawn Tails SDH activity (Nov 2010)

Descriptives – Raw Data

SDH

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Ok Om	10	296.9000	60.42709	19.10872	253.6731	340.1269	212.00	386.00
Pori	10	254.8000	78.28978	24.75740	198.7949	310.8051	145.00	376.00
Wankipe	10	369.8000	104.12685	32.92780	295.3121	444.2879	174.00	511.00
Wasiba	10	286.5000	71.96180	22.75632	235.0216	337.9784	183.00	414.00
Total	40	302.0000	88.16127	13.93952	273.8047	330.1953	145.00	511.00

T-Test – Comparing SDH activity at Ok Om and at Pori, Nov 2010

Group Statistics

	site#	N	Mean	Std. Deviation	Std. Error Mean
LogSDH	Ok Om	10	2.4643	.09059	.02865
	Pori	10	2.3863	.14174	.04482

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LogSDH	Equal variances assumed	1.050	.319	1.465	18	**.160**	.07794	.05319	-.03382	.18970
	Equal variances not assumed			1.465	15.301	.163	.07794	.05319	-.03525	.19113

Conclusion: SDH activity at Ok Om and at Pori are statistically similar (*p* = 0.160).

Oneway ANOVA – Comparing Combined Reference sites to Wankipe and Wasiba, Nov 2010.

Descriptives

LogSDH

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Ok Om + Pori	20	2.4253	.12248	.02739	2.3680	2.4826	2.16	2.59
Wankipe	10	2.5488	.14395	.04552	2.4459	2.6518	2.24	2.71
Wasiba	10	2.4444	.11205	.03543	2.3642	2.5245	2.26	2.62
Total	40	2.4609	.13301	.02103	2.4184	2.5035	2.16	2.71

Test of Homogeneity of Variances

LogSDH

Levene Statistic	df1	df2	Sig.
.199	2	37	.820

ANOVA

LogSDH

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.105	2	.053	3.336	**.047**
Within Groups	.585	37	.016		
Total	.690	39			

Multiple Comparisons

LogSDH

Dunnett t (2-sided)[a]

(I) site#	(J) site#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Wankipe	Ok Om + Pori	.12355*	.04868	**.030**	.0108	.2363
Wasiba	Ok Om + Pori	.01910	.04868	**.902**	-.0936	.1319

a. Dunnett t-tests treat one group as a control, and compare all other groups against it.

*. The mean difference is significant at the 0.05 level.

Conclusion: Combined reference sites have statistically lower SDH activity than the activity observed at Wankipe (*p* = 0.030). However Wasiba is similar to the reference sites (p = 0.902).

Appendix 5 Field Blank Analysis Results

Field blank QA/QC limits establishment data.

Year	Date	Blank Code	Field_code	Site_code	Cu_wet	Cd_wet	Pb_wet	Zn_wet	Cr_wet	Ni_wet	Se_wet	As_wet	Hg_wet
2010	13/03/2010	236	116	70	0.11	0.01	0.01	3.8	0.01	0.01	0.16	0.01	0.54
2010	13/03/2010	236	117	70	0.14	0.01	0.01	4.8	0.01	0.03	0.16	0.01	0.58
2010	13/03/2010	236	114	70	0.21	0.01	0.01	5.2	0.02	0.01	0.16	0.02	0.48
2010	13/03/2010	236	118	70	0.17	0.01	0.01	6.5	0.01	0.01	0.19	0.01	0.65
2010	13/03/2010	236	113	70	0.12	0.01	0.01	3.5	0.01	0.01	0.17	0.01	0.57

Quarter 1 field blank analysis results.

Year	Date	Blank Code	Field_code	Site_code	Cu_wet	Cd_wet	Pb_wet	Zn_wet	Cr_wet	Ni_wet	Se_wet	As_wet	Hg_wet
2010	25/01/2010	236	4	19	0.12	0.01	0.01	3.4	0.02	0.01	0.35	0.01	0.21
2010	26/01/2010	236	13	121	0.11	0.01	0.01	2.7	0.01	0.01	0.27	0.01	0.22
2010	18/02/2010	236	72	80	0.11	0.01	0.48	2.7	0.01	0.01	0.28	0.01	0.24
2010	20/02/2010	236	80	211	0.27	0.01	0.01	3.2	0.01	0.01	0.27	0.01	0.22
2010	23/03/2010	236	134	124	0.23	0.01	0.01	5.1	0.01	0.01	0.47	0.03	0.06
2010	7/03/2010	236	100	15	0.14	0.01	0.01	4.1	0.01	0.01	0.19	0.01	0.64
2010	7/03/2010	236	97	15	0.16	0.01	0.01	4.2	0.01	0.01	0.19	0.01	0.63
2010	8/03/2010	236	108	210	0.22	0.01	0.01	5.1	0.03	0.01	0.16	0.01	0.65
2010	9/03/2010	236	110	210	0.14	0.01	0.01	3.5	0.03	0.01	0.14	0.01	0.51

Quarter 2 field blank analysis results.

Site_code	Year	Date	Blank Code	Field_code	Cu_wet	Cd_wet	Pb_wet	Zn_wet	Cr_wet	Ni_wet	Se_wet	As_wet	Hg_wet
213	2010	6/04/2010	236	142	0.16	0.01	0.01	4.50	0.05	0.01	0.15	0.01	0.75
121	2010	8/04/2010	236	150	0.09	0.01	0.01	2.60	0.02	0.01	0.17	0.02	0.65
19	2010	9/04/2010	236	158	0.09	0.01	0.01	2.60	0.44	0.01	0.16	0.03	0.71
211	2010	28/05/2010	236	280	0.13	0.01	0.01	4.20	0.01	0.01	0.17	0.03	0.74
211	2010	28/05/2010	236	283	0.09	0.01	0.01	2.40	0.01	0.01	0.15	0.02	0.67
80	2010	29/05/2010	236	289	0.08	0.01	0.01	2.60	0.02	0.01	0.17	0.03	0.70
80	2010	29/05/2010	236	293	0.16	0.01	0.03	5.00	0.01	0.01	0.17	0.01	0.78
210	2010	16/06/2010	236	300	0.09	0.01	0.01	3.00	0.02	0.01	0.14	0.02	0.69
210	2010	16/06/2010	236	303	0.09	0.01	0.01	2.50	0.02	0.01	0.15	0.02	0.64
15	2010	18/06/2010	236	310	0.08	0.01	0.02	2.70	0.07	0.01	0.18	0.03	0.68
15	2010	18/06/2010	236	314	0.08	0.01	0.01	2.20	0.06	0.02	0.13	0.03	0.65

Quarter 3 field blank analysis results.

Site_code	Year	Date	Blank Code	Field_code	Cu_wet	Cd_wet	Pb_wet	Zn_wet	Cr_wet	Ni_wet	Se_wet	As_wet	Hg_wet
19	2010	30/07/10	236	340	0.07	0.01	0.01	2.3	0.01	0.01	0.11	0.01	0.42
19	2010	30/07/10	236	344	0.07	0.01	0.01	2.3	0.01	0.01	0.13	0.01	0.48
121	2010	31/07/10	236	349	0.09	0.01	0.01	3.2	0.01	0.01	0.18	0.01	0.65
124	2010	18/08/10	236	393	0.11	0.01	0.01	3	0.01	0.01	0.15	0.01	0.55
124	2010	18/08/10	236	397	0.16	0.01	0.01	4.5	0.01	0.01	0.15	0.02	0.5
15	2010	25/09/10	236	454	0.1	0.01	0.02	4.1	0.03	0.01	0.15	0.01	0.58
15	2010	25/09/10	236	458	0.1	0.01	0.01	3	0.01	0.01	0.18	0.02	0.57
210	2010	27/09/10	236	474	0.12	0.01	0.01	4.8	0.03	0.01	0.13	0.02	0.55
210	2010	27/09/10	236	478	0.1	0.01	0.01	4.4	0.01	0.01	0.15	0.02	0.57
211	2010	27/09/10	236	494	0.1	0.01	0.01	3.3	0.01	0.01	0.13	0.01	0.54
211	2010	27/09/10	236	497	0.08	0.01	0.01	3.3	0.02	0.01	0.12	0.01	0.45
80	2010	29/09/10	236	501	0.23	0.01	0.01	6.3	0.08	0.01	0.16	0.02	0.54
80	2010	29/09/10	236	504	0.1	0.01	0.01	3.3	0.01	0.01	0.14	0.01	0.55

Quarter 4 field blank analysis results.

Year	Date	Field Code	Site_code	Cu_wet	Cd_wet	Pb_wet	Zn_wet	Cr_wet	Ni_wet	Se_wet	As_wet	Hg_wet
2010	23/10/2010	236	211	0.13	0.01	0.01	3.7	0.05	0.01	0.17	0.01	0.59
2010	23/10/2010	236	211	0.12	0.01	0.01	4	0.01	0.01	0.2	0.01	0.65
2010	26/10/2010	236	80	0.09	0.01	0.01	3.3	0.01	0.01	0.16	0.01	0.44
2010	26/10/2010	236	80	0.15	0.01	0.01	4.7	0.01	0.01	0.17	0.01	0.56
2010	4/11/2010	236	210	0.17	0.01	0.01	4.1	0.01	0.01	0.18	0.02	0.47
2010	4/11/2010	236	210	0.13	0.01	0.02	4	0.03	0.01	0.18	0.01	0.51
2010	6/11/2010	236	15	0.13	0.01	0.01	4.6	0.01	0.01	0.19	0.01	0.64
2010	6/11/2010	236	15	0.13	0.01	0.01	4.3	0.01	0.01	0.17	0.01	0.59
2010	13/11/2010	236	19	0.13	0.01	0.01	4.3	0.01	0.01	0.14	0.01	0.48
2010	13/11/2010	236	19	0.12	0.01	0.01	5.1	0.01	0.01	0.16	0.01	0.56
2010	14/11/2010	236	121	0.19	0.01	0.01	3.3	0.01	0.01	0.15	0.01	0.47
2010	11/11/2010	236	124	0.18	0.01	0.01	5.1	0.02	0.01	0.22	0.01	0.58
2010	11/11/2010	236	124	0.1	0.01	0.01	4	0.03	0.01	0.17	0.01	0.51