



TropWATER

Centre for Tropical Water and Aquatic Ecosystem Research

CENTURY MINE SEDIMENT QUALITY MONITORING PROGRAM (SQMP) REVIEW 2017

A Report for New Century Resources

Report No. 18/07 Vol 1

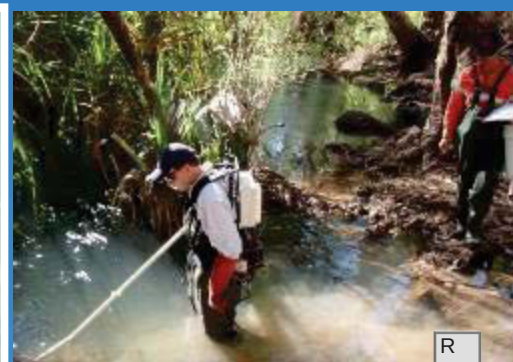
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**CENTURY MINE SEDIMENT QUALITY MONITORING PROGRAM (SQMP)
REVIEW, 2017**

A REPORT FOR NEW CENTURY RESOURCES

Report No. 18/07

March 2018

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TABLE OF CONTENTS

1. INTRODUCTION	4
1.1 Site Description	5
1.1.1 Climate.....	5
1.1.2 Surface Hydrology	5
1.1.3 Rainfall and Stream Flow	6
1.2 Relevant EA Conditions	8
1.3 Century REMP.....	10
1.3.1 Historical Background.....	10
1.3.2 REMP Site Network	10
1.4 Sediment Quality Assessment methods.....	13
1.4.1 Sampling	13
1.4.2 Analysis.....	14
2.1 Historical background	16
2.2 Current Status of Page Creek Sediments	25
2.3 Protocols for Future Monitoring	31
3. LAWN HILL CREEK.....	34
3.1 Historical background	34
3.2 Current Status.....	35
3.3 Protocols for Future Monitoring	37
4. NORTH MITTON CREEK.....	38
4.1 Historical background	38
4.2 Current Status	42
4.3 Protocols for Future Monitoring	45
5. COGLAN CREEK	47
5.1 Historical background	47
5.2 Current Status	48
5.3 Protocols for Future Monitoring	49
6. LITTLE ARCHIE CREEK	50
6.1 Historical background	50
6.2 Current Status	51
6.3 Protocols for Future Monitoring	52
7. BULLRIDGE CREEK	53
7.1 Historical background	53
7.2 Current Status	54
7.3 Protocols for Future Monitoring	56
8. REFERENCES	58

1. INTRODUCTION

A sediment quality monitoring program (SQMP) involving annual dry season sampling of the bottom sediments in receiving streams potentially impacted by Century mine has been in place since 2009. The program originally stemmed from the recommendations of an environmental evaluation report addressing a non-compliant water release during the 2008-2009 wet season and was initially designed to monitor the fate of contaminated sediments deposited in Page Creek. Since then the program has evolved in an *ad hoc* manner pursuant to recommendations made in numerous reports generated by other environmental evaluations, investigations triggered by EA trigger level (TL) exceedances, the receiving environment monitoring program (REMP) and the SQMP. As a consequence the SQMP site network now includes sites in all of the creeks in the immediate receiving environment surrounding the mine (namely Page, North Mitton, Coglan, Bullridge and Little Archie Creeks), as well as Lawn Hill Creek (the receiving environment for water and sediment discharged from Page Creek) .

This evolutionary process has required the adoption of a variety of different sampling tactics, site networks and assessment methods, and has yielded numerous *ad hoc* reports each dealing with separate issues and different individual streams. This has made it extremely difficult for managers, regulators and investigators to maintain an overview of the current status of the receiving environments or to accurately gauge existing and emerging management priorities.

The purpose of this review is to provide a single document that:

- assesses the current status of stream sediments throughout the study area in the context of historical events and findings; and,
- details the monitoring methods that will be employed in future SQMP sampling campaigns until circumstances change.

Subject to agreement from the administering authority, it is proposed that this document will be updated each year to incorporate new data, findings and recommendations, and record any proposed changes to the existing monitoring protocols. These revisions will generate a report that serves a dual role as an annual SQMP results report and an SQMP monitoring design document.

The objectives of the SQMP are as follows:

- Evaluate temporal trends in the extent and magnitude of non-compliant metal residues in the stream sediments of receiving waters potentially influenced by Century Mine.
- Notify managers if there is any evidence of fresh contamination entering the receiving waters, and assist in identifying their source.
- Assess the potential environmental risks associated with the existing contaminant residues in each receiving stream (this will include reference to the biological effect data provided in annual REMP reports).
- Inform managers of any existing or emerging remediation requirements and recommend potential mitigation measures for consideration.
- Where relevant, assist in identifying sections of stream where contaminated sediment removal works could be carried out with the greatest effect and least harm to the integrity of the stream.
- Evaluate the effectiveness of remediation works.
- Generate a statistically strong database which the REMP can use to examine correlations between sediment quality and biological condition, as an aid for devising local site-specific sediment quality guidelines.
- Revise the program as necessary to ensure that methodology remains appropriate to existing circumstances and addresses any recommendations stemming from other investigations such as the REMP.

Because the existing SQMP largely stems from the recommendations of previous investigations triggered by TL exceedances and EE notices, the scope of works of the current program comfortably meets all the monitoring and assessment requirements specified in relevant EA conditions (C15 to C16, see Figure 1.2.4). In fact, now that the SQMP encompasses all of the receiving streams in this study area, the existing program is effectively an ongoing extension of the trigger investigations required under EA condition C16 (d). Moreover, it is apparent from the data presented in this report that, due to the heterogeneity of sediments in this study area and the irrelevance of existing “reference” sites (all of which are located in inherently unsuitable mineralogical settings), the compliance assessment methods specified in the EA are far less reliable than the methods being employed in the SQMP.

It is particularly evident from the results obtained using the statistically strong reach-based composite SQMP sampling techniques, that the site-based sampling methods stipulated in the EA are subject to such high levels of random error and effects from localised influences, that the EA compliance results are rendered virtually meaningless. There are therefore sound scientific grounds to suggest that the EA conditions in question have now effectively been superseded and should be amended accordingly.

The required amendment could potentially be accomplished by simply amending the footnote on condition C16 (d) to include an exemption for sites which are under investigation in the SQMP, with the caveat that the SQMP design (presented in this document) and any subsequent alterations to that design, have been sanctioned by the administering authority.

1.1 Site Description

1.1.1 Climate

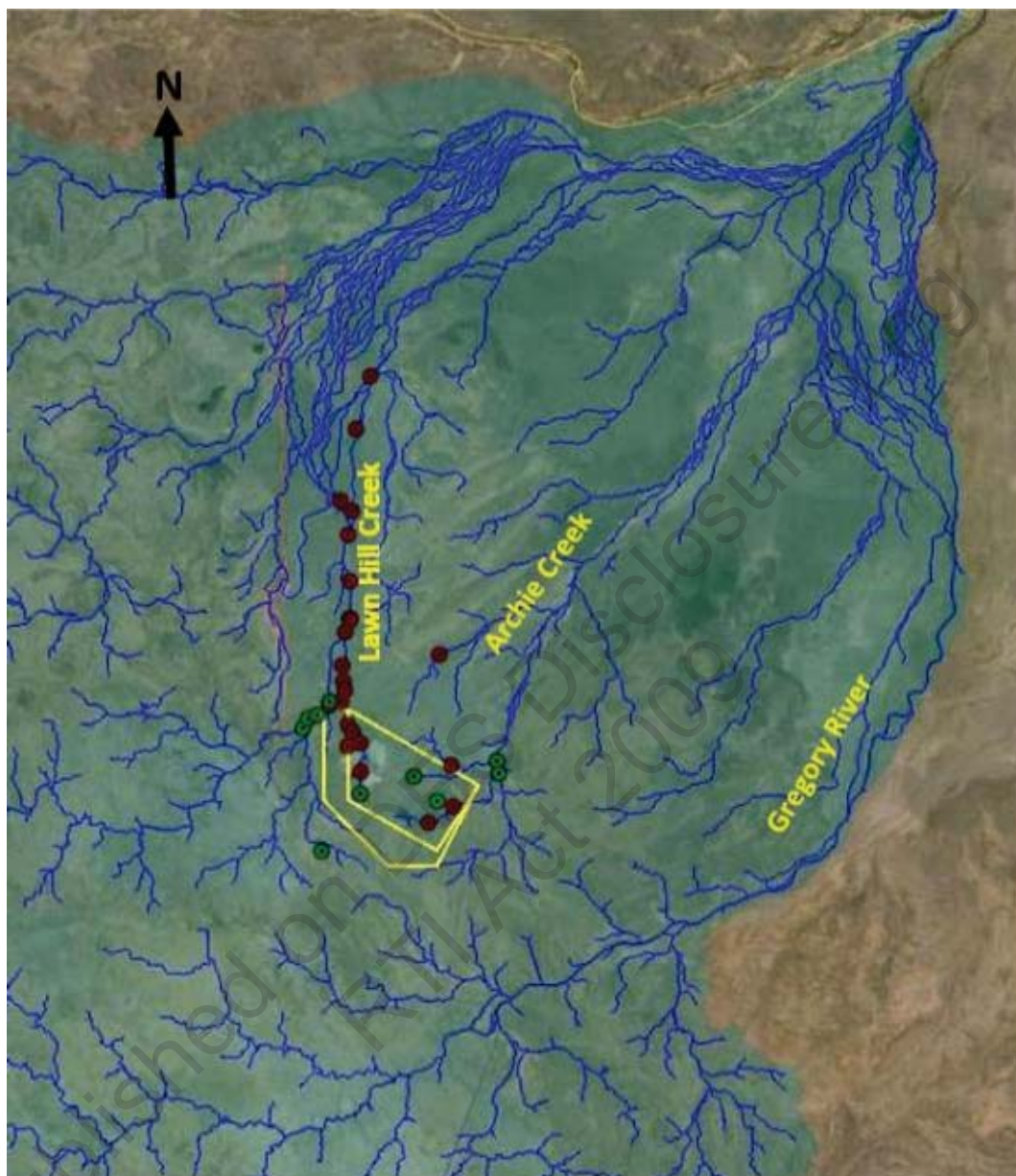
The New Century Resources Mine deposit is located in the Gulf of Carpentaria region of north-western Queensland approximately 250 km north-north-west of Mount Isa. The climate of the Gulf of Carpentaria region as a whole has been routinely described as dry tropical, yet monsoonal. There is a defined wet season occurring between December and March with minimal rainfall occurring over the remainder of the year. Average rainfall decreases with increasing distance from the coast and accordingly the climate of some of the more inland areas such as the Century Mine site are more aptly described as semi-arid with monsoonal influences (Dames & Moore 1994). The complex and unpredictable El Niño – La Niña Southern Oscillation (ENSO) phenomena exert significant influence on weather variability through time. Yearly weather patterns can range from effectively failed wet seasons through average years to strong wet seasons with pronounced monsoonal or often cyclonic activity. The long-term rainfall record for the Century area demonstrates considerable variability with Dames & Moore (1994) emphasising the uncertainty of typical climatic descriptors such as annual rainfall averages for this environment.

1.1.2 Surface Hydrology

The creek systems that drain the Century Mine are all ephemeral streams. Page Creek rises to the south of the mine site and flows in a northerly direction over the northern block of the Century Mine deposit to its confluence with Lawn Hill Creek. In order to accommodate the mine workings, the upper reaches of Page Creek underwent a substantial diversion in 1997, and again in 2001, to re-route stream-flow around the western margin of the mine pit. The diversion channel, identified in TropWATER reports as Reach A of Page Creek, was subject to a minor realignment in 2013 and 2014.

Other notable ephemeral systems including Cogan, Bullridge, Mitton, Little Archie and Archie Creeks arise to the west and south-west of the mine site. Most of these highly ephemeral systems share similar land and drainage characteristics, arising from the Argylla land system (Dames & Moore 1994). The exceptions are Mitton Creek and Little Archie Creek, which drain part of the Thornton land system to the north-west of the mine site.

Figure 1.1.1. Location of New Century Resources REMP sites (test sites in red, control sites in green) in relation to Gulf Rivers Strategic Environmental Area shown as green shaded area (Queensland Government 2014). Yellow lines denote New Century Resources mining leases. Map base - Google Earth

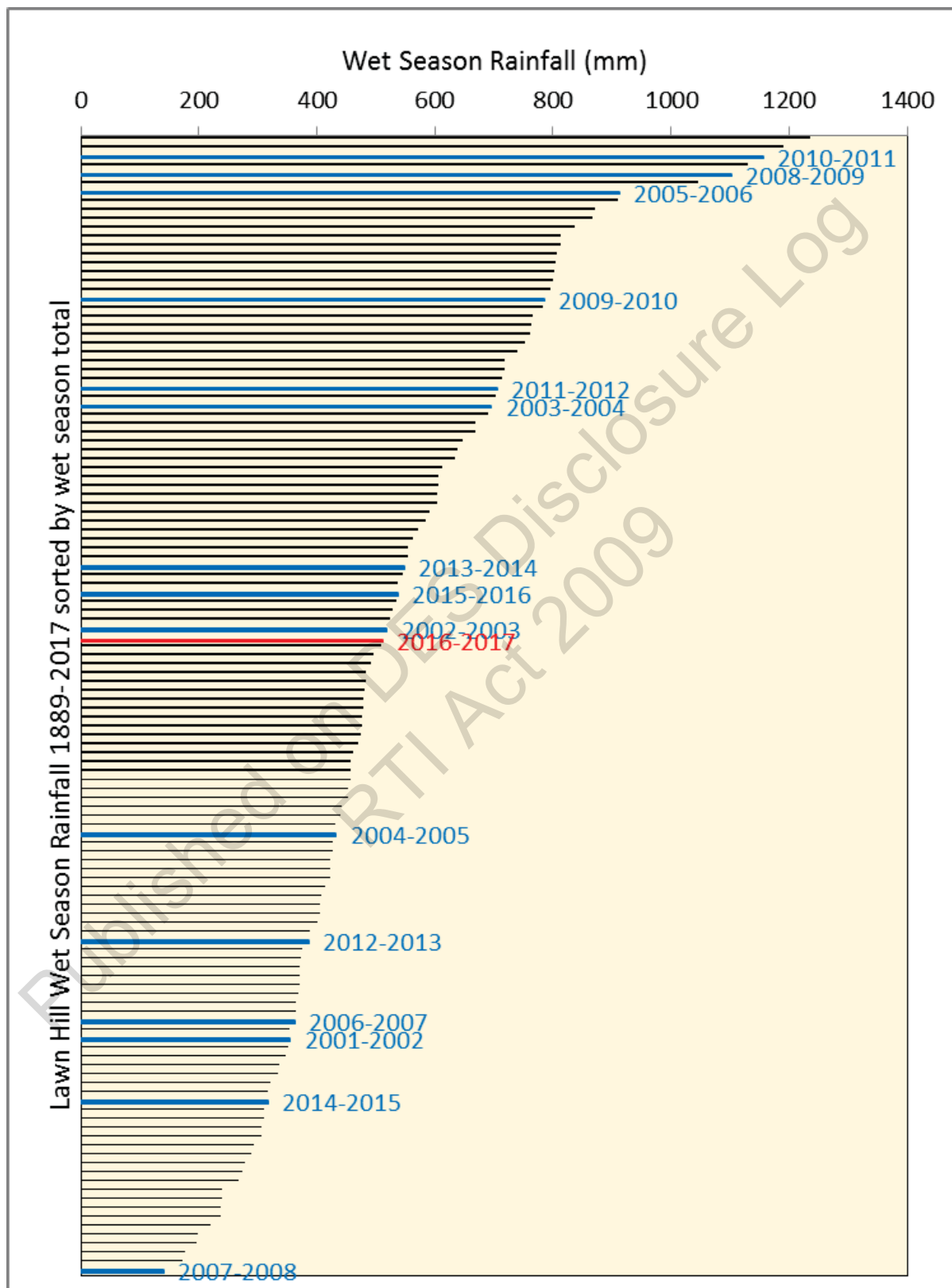


Spring Creek (which flows into Louie Creek) and Bullridge Creek flow in a northerly direction and ultimately discharge into Lawn Hill Creek, while Mitton and Coglan Creeks flow in an easterly path and discharge into Archie Creek (Figure 1.1). Lawn Hill Creek itself arises in the limestone and sandstone hills of Lawn Hill National Park to the west of Century Mine. Spring fed and perennial, it eventually flows into the Gulf of Carpentaria via the Gregory and Nicholson Rivers.

1.1.3 Rainfall and Stream Flow

Long term records for Lawn Hill (Figure 1.1.2) indicate that annual rainfall has consistently been less than or equal to the long term average since 2012. Conditions were particularly dry in the 2012-2013 and 2014-2015 wet seasons and the effects of that (low groundwater levels and parched soils) carried through into the intervening years resulting in lower than normal streamflow even in the average rainfall years. Consequently it is now more than five years since any of the ephemeral creeks in the Century Mine receiving environment have experienced any swiftflow events with sufficient energy to mobilise significant quantities of streambed sediments.

Figure 1.1.2 Annual wet-season rainfall at Lawn Hill 1889-2017 ranked in order of decreasing total rainfall (mm). Data from Climate Data Online, Bureau of Meteorology. <http://www.bom.gov.au/climate/data>. Bureau of Meteorology station number: 29031, Station name: LAWN HILL (note that 2016-17 data was derived in part from Century Mine rainfall data due to missing records in the Lawn Hill BOM data).



1.2 Relevant EA Conditions

Figure 1.2.1 Excerpt from Environmental Authority EPML00888813 (October 31, 2017) – Schedule C – Table 4.

Schedule C - Table 4 (Receiving water reference sites and downstream compliance monitoring points)

Monitoring Points	Receiving Waters Location Description	GDA 94 MGA zone 54	
		Easting	Northing
Receiving Water Reference Sites			
P_SW17_REF	Page Creek upstream	246 864	7 925 109
C_SW14_REF	Coglan Creek upstream	256 260	7 923 258
SM_SW05_REF	South Mitton Creek upstream	253 265	7 926 237
Downstream Compliance Monitoring Points			
B_SW01_REC	Bull Ridge Creek	242 739	7 934 568
P_SW03_REC	Page Creek	246 684	7 930 113
NM_SW04_REC	North Mitton Creek	253 031	7 927 828
C_SW08_REC	Coglan Creek	260 217	7 923 065
SM_SW04_REC	South Mitton Creek	258 044	7 926 163

1. Reference sites must:

- be from the same bio-geographic and climatic region;
- have similar geology, soil types and topography;
- contain a range of habitats similar to those at the test sites;
- have a similar flow regime; and
- not be on rivers in the test sites that are tributaries of the test sites, also provide in a riverine at the reference site.

Figure 1.2.2 Satellite image showing Century Mine Lease boundaries and the location of the EA receiving water monitoring sites specified in EA EPML00888813.

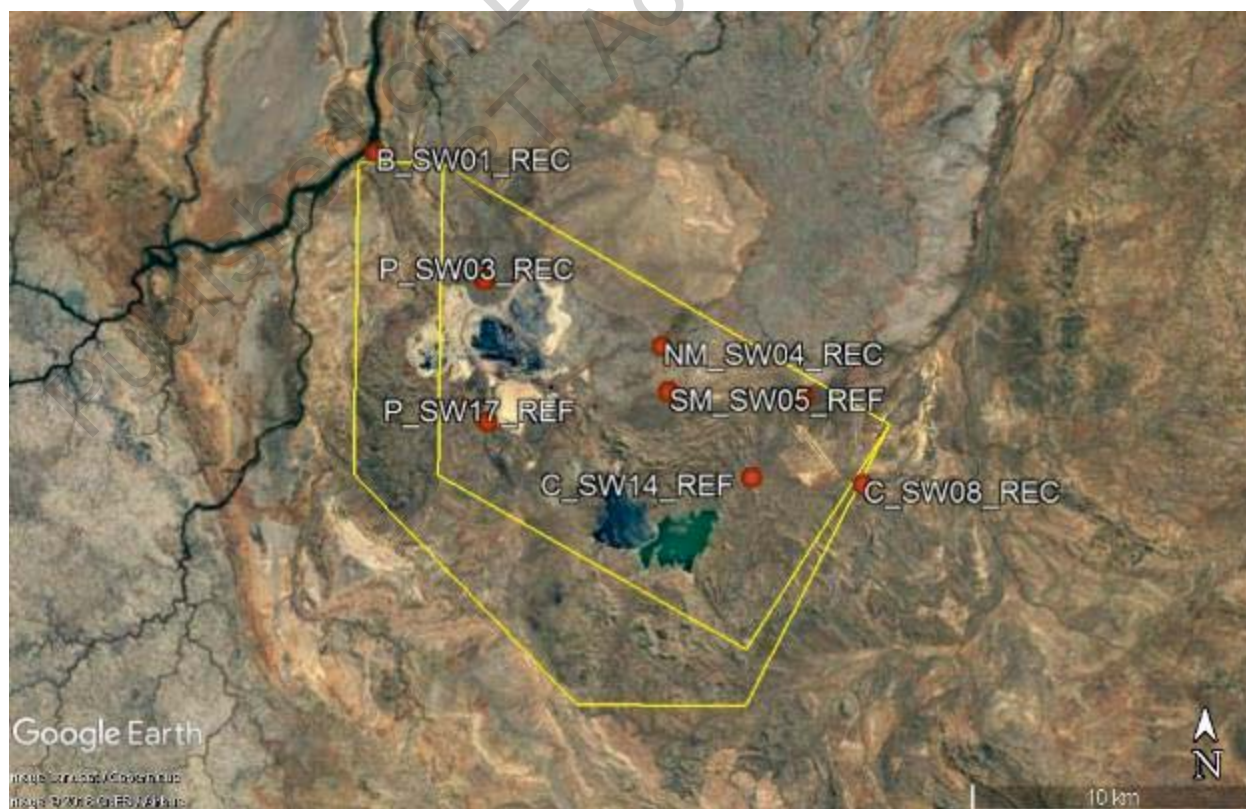


Figure 1.2.3 Excerpt from Environmental Authority EPML00888813 (October 31, 2017) – Conditions C13 and C14

Stream sediment																					
C13	<p>Sediment quality of receiving waters and reference waters must be monitored annually (after the wet season) at the monitoring locations defined in Schedule C - Table 4 (Receiving water reference sites and downstream compliance monitoring points) and identified on Schedule J - Figure 2 (Receiving water monitoring points and reference sites) and for the parameters defined in Schedule C - Table 7 (Stream sediment trigger levels).</p> <table border="1"> <caption>Schedule C - Table 7 (Stream sediment trigger levels)</caption> <thead> <tr> <th>Parameter¹</th><th>Trigger Level</th></tr> </thead> <tbody> <tr> <td>Arsenic (mg/kg)</td><td>70²</td></tr> <tr> <td>Cadmium (mg/kg)</td><td>10²</td></tr> <tr> <td>Copper (mg/kg)</td><td>270²</td></tr> <tr> <td>Lead (mg/kg)</td><td>220²</td></tr> <tr> <td>Manganese (mg/kg)</td><td>For interpretation purposes</td></tr> <tr> <td>Nickel (mg/kg)</td><td>52²</td></tr> <tr> <td>Selenium (mg/kg)</td><td>3 times greater than reference site³</td></tr> <tr> <td>Zinc (mg/kg)</td><td>410²</td></tr> <tr> <td>Particle size distribution</td><td>For interpretation purposes</td></tr> </tbody> </table> <p>1. All samples must be sieved to remove the >2 mm sediment fraction prior to analysis 2. Trigger level derived from ANZECC (2000) Interim Sediment Quality Guidelines - High 3. Reference sites as specified in Schedule C - Table 4 (Receiving water reference sites and downstream compliance monitoring points)</p>	Parameter ¹	Trigger Level	Arsenic (mg/kg)	70 ²	Cadmium (mg/kg)	10 ²	Copper (mg/kg)	270 ²	Lead (mg/kg)	220 ²	Manganese (mg/kg)	For interpretation purposes	Nickel (mg/kg)	52 ²	Selenium (mg/kg)	3 times greater than reference site ³	Zinc (mg/kg)	410 ²	Particle size distribution	For interpretation purposes
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Selenium (mg/kg)	3 times greater than reference site ³																				
Zinc (mg/kg)	410 ²																				
Particle size distribution	For interpretation purposes																				
C14	<p>All stream sediment sampling must be undertaken in accordance with the most recent version of Australian Standard AS 5667.12 <i>Guidance on Sampling of Bottom Sediment</i>.</p>																				

Figure 1.2.4 Excerpt from Environmental Authority EPML00888813 (October 31, 2017) – Conditions C15 to C17.

Sediment quality monitoring program (SQMP)	
C15	<p>The holder of the environmental authority must develop and implement a SQMP.</p> <p>The SQMP must incorporate the following:</p> <ul style="list-style-type: none"> (a) compare reference site sediment quality data to downstream compliance monitoring point data; (b) propose appropriate locally-derived sediment quality trigger values for downstream compliance monitoring points once a sufficient body of data has been collected; and (c) identify if downstream compliance monitoring point data trends indicate that contaminants are accumulating at the site(s).
C16	<p>If the quality characteristics of sediments at the downstream compliance monitoring points defined in Schedule C - Table 4 (Receiving water reference sites and downstream compliance monitoring points) exceed any of the trigger levels specified in Schedule C - Table 7 (Stream sediment trigger levels), the holder of this environmental authority must compare results of the downstream site to the data from reference monitoring sites and:</p> <ul style="list-style-type: none"> (a) where the downstream result is the same or a lower value than the reference site value for the quality characteristic during the same sampling event then no action is to be taken; (b) where the downstream results exceed the reference site, undertake an investigation as to whether the exceedance is attributable to the mining activity; (c) if the exceedance is not attributable to the mining activity then no further action is required; (d) if the exceedance is attributable to the mining activity, complete the investigation in accordance with the ANZECC & ARM CANZ 2000 methodology, into the potential for environmental harm and provide a written report to the administering authority within three (3) months, outlining: <ul style="list-style-type: none"> (i) details of the investigations carried out; and (ii) actions taken or to be taken to minimise environmental harm including measures to remediate the receiving environment to the extent of the contamination. <p><i>Note: Where an exceedance of a trigger level has occurred and is being investigated, in accordance with C16(d) of this condition, no further reporting is required for subsequent trigger events of an equal-to or lesser extent for that quality characteristic.</i></p>
C17	<p>The holder of this environmental authority must implement the measures proposed under condition C16 to remediate the receiving environment to the extent of the contamination.</p>

1.3 Century REMP

1.3.1 Historical Background

Since 2005, TropWATER (formerly the Australian Centre for Tropical Freshwater Research - ACTFR) has been engaged annually by Century Mine (currently Century Mining Ltd) to carry out limnological assessments in receiving environments associated with the mine. This entailed assessment of ambient water and sediment quality, ecological condition, macroinvertebrate and fish communities.

In 2009 it proved necessary to significantly expand the scope of monitoring activities and alter some of the established methodology in order to meet the requirements of a DEHP (then DERM) Environmental Evaluation (EE) order issued to Century Mine in connection with a wet season discharge incident. This included the introduction of sediment pore water sampling, the establishment of three upstream control sites and three downstream impact sites on Lawn Hill Creek, and the implementation of annual dry season sediment surveys to assess the distribution of sediment metals residues within the streambed of Page Creek and Lawn Hill Creek. In 2010 two additional limnological impact monitoring sites were established on Lawn Hill Creek, and in 2011 the site network on Lawn Hill Creek was further expanded by including four additional sites downstream of the Page Creek confluence and another which is situated between the entry points of Bullridge and Page Creeks.

The original program was established on behalf of Century as a voluntary program. However, in 2015 implementation of the Receiving Environment Monitoring Program (REMP) became a mandatory requirement under Environmental Authority (EA) EPML0088813. The site network and monitoring parameter suites have been subject to ongoing review since that time in order to ensure that the program meets the requirements set out in EA conditions C18 to C20.

Mining operations at Century ceased in August 2015 (with all ore processing completed in January 2016) and the mine is now subject to closure planning and management. It is anticipated that the nature, location and extent of potential contaminant sources will change over time and this may necessitate further ongoing alterations to the design of the REMP.

1.3.2 REMP Site Network

The REMP site network currently comprises nine impact sites and four controls in Lawn Hill Creek, eight impact sites and two controls in Page Creek, eleven impact sites located on other ephemeral/intermittent streams and five ephemeral/intermittent reference sites (Table 1.3.1 and Figure 1.3.1). A concerted effort has been made to include sites that correspond to the EA compliance locations listed in Figure 1.2.1. However, since most of those sites do not retain water long enough to be suitable candidates for biological assessment, it has been necessary to instead establish the REMP sites in the closest existing waterholes, and in some cases that is a significant distance away. Where relevant, Table 1.3.1 lists the closest applicable EA compliance site.

Even though the monitoring sites have been established in the locations with the greatest potential to retain water, some of the streams under investigation are so ephemeral that they dry out too quickly to be sampled in all but the wettest years. When there is water present each site is sampled for water quality, sediment pore water quality, macroinvertebrates and fish. Sediment samples are collected at all sites regardless of whether or not water is present.

Table 1.3.1. Current Century Mine REMP Sites. *indicates the EA reference or compliance site that is most closely located with the REMP site. Sites L1a, L1b and L1c are situated within three separate braids of Lawn Hill Creek. The L1c braid has not been sampled since 2013 as it became hydraulically inactive. However, the site will be sampled in the future if that braid ever becomes active again.

Site	Old Site ID	EA Compliance Site Equivalent*	Status	Km upstream of Site L5	WGS84 Latitude Longitude (S) (E)		Stream order	Water regime
Lawn Hill Creek								
RL3	LH ref3	N/A	Reference	47	18°41.37'	138°31.83'	4	perennial
RL2	LH ref2	N/A	Reference	45.5	18°40.61'	138°32.22'	4	perennial
RL1	LH ref1	N/A	Reference	44.3	18°40.35'	138°32.89'	5	perennial
RL0		N/A	Reference	41.7	18°39.48'	138°33.73'	5	perennial
L1a		N/A	Impact	31	18°34.00'	138°35.11'	5	perennial
L1b	LH1	N/A	Impact	31	18°34.05'	138°35.15'	5	perennial
L1c		N/A	Impact	31	18°34.02'	138°35.21'	5	perennial
L2a		N/A	Impact	26.3	18°31.52'	138°35.16'	5	perennial
L02	LH2	N/A	Impact	20.1	18°28.46'	138°35.04'	5	perennial
L3a		N/A	Impact	17.1	18°26.88'	138°35.30'	5	perennial
L03	LH3	N/A	Impact	18.9	18°26.19'	138°34.49'	5	perennial
L04	L4	N/A	Impact	6.8	18°21.44'	138°35.58'	5	perennial
L05	L5	N/A	Impact	0	18°17.96'	138°36.57'	5	perennial
Page Creek								
R01	Page ref1	P_SW17_REF	Control	55.5	18°45.58'	138°35.88'	2	ephemeral
R02								
A01	Page1	N/A	Impact	52.7	18°44.12'	138°35.91'	3	ephemeral
C01	Page2	P_SW03_REC	Impact	48.5	18°42.23'	138°35.90'	3	ephemeral
D01	Page3	N/A	Impact	46.5	18°41.49'	138°35.34'	3	ephemeral
E01	Page4	N/A	Impact	45.4	18°41.02'	138°35.02'	3	ephemeral
F01	Page5	N/A	Impact	42.4	18°39.51'	138°34.52'	4	ephemeral
F04	F04	N/A	Impact	41.2	18°38.89'	138°34.72'	4	intermittent
F09	F09	N/A	Impact	39	18°38.15'	138°34.71'	4	intermittent
G07	Page7	N/A	Impact	32.7	18°34.88'	138°34.84'	4	ephemeral
Other ephemeral and intermittent creeks								
Bul1	Bullridge1	N/A	Impact	48.75	18°42.43'	138°35.00'	1	ephemeral
Bul2	Bullridge2	B_SW01_REC	Impact	42.5	18°39.86'	138°33.66'	3	ephemeral
Cog1	Coglan1	N/A	Impact	N/A	18°47.45'	138°40.44'	3	semi-permanent
Cog2	Coglan2	C_SW08_REC	Impact	N/A	18°46.32'	138°42.49'	4	intermittent
Cog1b	Coglan	N/A	Impact	N/A	18°47.22'	138°41.31'		ephemeral
Cog1d	Coglan	N/A	Impact	N/A	18°46.89'	138°42.04'		ephemeral
RCog1	Coglan ref1	C_SW14_REF	Control	N/A	18°46.06'	138°41.25'	2	ephemeral
RM1	Mitton Ck	SM_SW05_REF	Control	N/A	18°44.43'	138°39.63'	3	ephemeral
MS	Mitton Spring	NM_SW04_REC	Impact	N/A	18°43.53'	138°42.12'	2	permanent/spring
RAr1	Archie ref1	N/A	Control	N/A	18°44.24'	138°45.55'	5	permanent
RAr2	Archie1	N/A	Control	N/A	18°43.41'	138°45.41'	5	permanent
LAr1	Little Archie	A_SW01_REC	Impact	N/A	18°36.27'	138°41.94'	4	semi-permanent
PH99	Little Archie	A_SW01_REC	Impact	N/A	18°39.29'	138°39.54'		ephemeral
PH387	Little Archie	A_SW01_REC	Impact	N/A	18°37.18'	138°40.68'		ephemeral
RSpr1	RSpr1	N/A	Control	64.3	18°49.37'	138°33.18'	3	ephemeral
NM24	North Mitton	N/A	Impact	N/A	18°43.54'	138°39.13'		ephemeral

Figure 3.1.1. Location of Century Mine REMP Sites. Control sites are shown in green and potential impact sites in red. The Century Mining Limited leases are outlined in yellow with access road in red.



1.4 Sediment Quality Assessment methods

1.4.1 Sampling

REMP Sampling Protocols

REMP sediment sampling is conducted by using a plastic or stainless steel hand trowel to collect a minimum of six random subsamples of benthic sediment from different locations at each site. The subsamples are collected in a plastic bag to yield a single composite sample. Subsamples are taken with the aim of representing the general composition of the near-surface sediment layer at each site, as it contains the most recently deposited material and is also the microhabitat most heavily utilised by benthic and demersal biota. This is the most appropriate material to sample in order to assess the potential for impacts on the biota inhabiting each waterhole, but it is not optimal for evaluating sediment contaminant loads and/or the potential for future impacts on downstream receiving waters. These latter issues are addressed in the SQMP.

When present, sediment pore water is extracted from a depth of 10 to 20 cm below the surface of the benthic sediment using a stiff plastic tube attached to a plastic syringe. A clean unused disposable plastic tube and syringe is used at each site. A hollow slotted re-usable stainless steel spear is used as an outer casing for the plastic tube at sites where the bottom is too hard for the plastic to penetrate. The outer casing is thoroughly washed with phosphate-free detergent and Milli-Q super high purity water, and dried after each use. In order to ensure that surface water is not drawn into the syringe, pore water samples are collected from the exposed edges of the bottom sediment at each water body. In most cases this is still well within the main streambed. Samples are centrifuged and filtered (at 0.45 µm) and are then submitted to a NATA registered commercial laboratory for analysis of filterable Ca, Cd, Mg, Pb and Zn by ICP-MS.

SQMP Sampling Protocols

SQMP sampling is always conducted in the dry season in order to maximise accessibility to all sections of the stream and streambed. SQMP sampling methods are tailored to suit the different geomorphological conditions at each site (which range from small bedrock constrained low order streams with sparse/rocky substratum, to large sandy higher order streams). Methods have also varied over time in order to meet different monitoring objectives.

Sediments at some of the key sites in Lawn Hill Creek, which is by far the largest stream in the SQMP site network, have proven to be particularly heterogeneous. This linked, with the fact that it is the only perennial waterway in the SQMP, has necessitated the adoption of specialised approaches which are detailed where relevant later in this report.

At all other sites, in cases where a slug of contaminated sediment has been detected the initial response has typically been to conduct intensive and extensive sampling aimed at accurately determining the full extent of the contamination and precisely identifying locations where removal works should be carried out. In cases where sediment depth exceeds 15 cm this entails the collection of numerous depth profile samples representative of the 0-15cm, 15-35cm and 35-50cm horizons. In cases where the sediment is shallow this generally entails the collection of large numbers of subsamples representative of defined stream reaches (typically ≤100 m in length). Further intensive sampling is then conducted to assess the effectiveness of removal works and identify key sites for ongoing monitoring to assess any potential movement of residual contaminants and/or any additional contaminant inputs.

Ongoing routine monitoring typically employs similar tactics to those used for the detailed assessments but the number of sites employed are reduced. In small streams this is done by collecting composite samples representative of longer reaches. For example four 60 m reaches would be replaced by a single 240 m reach.

High resolution monitoring is typically reinstated if there are non-compliant sediments present and there is a large wet season swift flow event with the potential to have significantly altered the streambed, or if routine monitoring detects any potentially adverse trends.

1.4.2 Analysis

REMP

In years when there has been sufficient stream flow to potentially alter the texture and mobility of stream sediments, the <2 mm and <63 µm sediment fractions of REMP samples are subjected to dilute (1M HCl) acid extraction and analysed for metals listed in Table 1.4.1. If there have been no flow events during the preceding wet season large enough to trigger that requirement, only the <2 mm fraction is analysed. That is the appropriate fraction to use for assessing compliance with ANZECC sediment quality guidelines (SQGs) and evaluating the potential relevance to benthic fauna.

(Historically the dilute acid extraction, which targets bioavailable metals, has been referred to as weak acid extraction or WAE, in line with the convention established by ANZECC 2000. This was a misnomer which was corrected in a 2013 review of the ANZECC sediment quality guidelines).

Table 1.4.1. Physical and chemical analyses performed on benthic stream sediment samples collected in annual REMP surveys.

<ul style="list-style-type: none">• Sieving to reject the plus 2mm fraction• Sieving to determine the mass percentage passing 63µm• Weak acid extractions of the <2 mm (and where necessary) <63 µm sediment fraction, and ICP analysis of the extracts to determine arsenic, cadmium, copper, lead, manganese, nickel, selenium and zinc concentrations.

SQMP

As exemplified by the 2017 REMP sediment analysis results shown in Table 1.4.2, none of the REMP sites have reported any anomalous results for metals other than zinc, cadmium and lead. The other REMP metals will not be included in the SQMP analysis suite unless this situation changes (i.e. unless anomalies are detected in the REMP samples). Hence SQMP samples are currently only analysed for <2 mm zinc, cadmium and lead.

During the early stages of the SQMP elevated phosphorus levels were reported at many sites. However, phosphorus monitoring has been discontinued based on the following findings:

- Natural phosphorus inputs from the Phantom Hills and Mt Jennifer phosphate deposits are the principle source of elevated concentrations in the receiving streams.
- There is no correlation between metal and phosphorus concentrations at mine-contaminated sites demonstrating that the phosphorus derives from a source other than the mine (close correlation between zinc and cadmium has proven to be a diagnostic feature of mine-sourced contamination in this study area).
- Aqueous phosphorus levels have been consistently low at all sites and there have been no indications of any adverse biological effects even at sites with highly elevated sediment phosphorus concentrations, indicating that the sedimentary phosphorus has low solubility and limited bioavailability.

Table 1.4.2 <2 mm WAE metal results for surficial sediment samples collected in connection with the 2017 REMP. Results that exceed the ANZECC SQG-high are shown in blue, while those that exceed the SQG-low are green.

Site	<2 mm WAE metal (mg/kg)							
	Cadmium	Copper	Lead	Nickel	Zinc	Arsenic	Manganese	Selenium
<i>Page Creek</i>								
R01	<0.1	1	4.5	<0.5	5.2	2	200	<1
R02	0.5	3	20	1.4	130	2	480	<1
A01	0.3	3	18	2.3	110	5	330	<1
C01	1.9	8	60	0.7	620	6	680	<1
D01	3	9	69	0.6	960	3	800	<1
E01	1.2	4	26	3.6	370	1	490	<1
F01	0.5	2	12	1.7	160	1	320	<1
F04	0.5	2	11	<0.5	190	2	320	<1
F09	1.1	2	12	3	430	7	530	<1
G07	1.7	5	18	6	460	3	700	<1
<i>Spring Creek</i>								
RSpr1	<0.1	2	5.2	1.2	7.4	2	190	<1
<i>Bullridge Creek</i>								
Bul1	3.5	10	110	1.8	2700	6	2400	<1
Bul2	0.1	3	10	1.7	36	1	320	<1
<i>Coglan Creek</i>								
RCog1	<0.1	1	2	<0.5	5.1	1	57	<1
Cog1	0.2	3	6	5.7	1200	3	1100	<1
Cog1b	0.2	5	9.8	3.8	45	6	370	<1
Cog1d	<0.1	1	1.9	0.8	7.8	6	22	<1
Cog2	<0.1	4	6.4	2.1	30	5	230	<1
<i>N. Mitton-Mitton</i>								
RM1	<0.1	4	55	1.3	51	<0.5	98	<1
NM24	0.9	12	43	<0.5	620	<0.5	840	<1
MS	0.2	8	16	3.7	44	3	650	<1
<i>L. Archie-Archie</i>								
RAr1	<0.1	4	5.8	1.9	15	2	250	<1
RAr2	0.4	3	150	1.9	60	6	780	<1
PH99	0.1	8	19	9.5	7.6	4	1200	<1
PH387	0.2	4	14	1.6	14	3	750	<1
LAr1	<0.1	3	8	1.7	4	5	270	<1

2. PAGE CREEK

2.1 Historical background

Limnological monitoring of receiving streams, comprising sampling of water, sediment and biological indicators, has been carried out at Century by TropWATER (previously known as ACTFR) since 2005. Prior to 2009, monitoring of Page Creek focused on a few sites located within the small highly ephemeral stream reaches immediately downstream of the mine-site and within the boundaries of the mine lease. However, in order to address the requirements of an Environmental Evaluation (EE) Order issued by DERM (now DES) in connection with a non-compliant release event in 2009, exploratory surveys were conducted along the length of Page Creek and downstream into Lawn Hill Creek. There had already been evidence of contaminant accumulation and ecological impairment in Page Creek in previous years prior to any non-compliant releases having been reported, it is therefore uncertain how much of the impact observed in 2009 was actually attributable to the non-compliant discharge event referred to in the EE Order.

This uncertainty notwithstanding, the study showed that:

- benthic sediments throughout most of Page Creek contained high enough residues of mine-derived contaminants, and especially zinc, to potentially be ecologically harmful;
- contaminant concentrations at the sites closest to the mine, where ongoing zinc and cadmium accretion had previously been detected, had increased disproportionately in 2009; and;
- zinc and phosphorus levels in the benthic sediments of Lawn Hill Creek sites located immediately downstream of Page Creek were measurably higher than the levels at upstream reference sites.

Later in 2009 MMG Century engaged TropWATER to conduct a detailed survey of sediments and aquatic habitats in Page Creek as a precursor to remediation works. This entailed collecting sediment profile samples down to a maximum depth of 500 mm, as well as recording stream morphology data and habitat descriptions, at 109 sampling stations located at regular intervals along the length of the creek (see Figures 3.1 and 3.2). For the purposes of these investigations the creek was divided into seven reaches designated as A to G, and sites were identified using the reach ID as a prefix followed by a two digit number indicative of the site's position in the reach (e.g. C02 is the second site in reach C). Note that the first site in each reach corresponds to a REMP biological monitoring site, though these cannot always be sampled each year as they sometimes dry out during the wet season.

The 2009 study showed that the intrinsic habitat values of the creek were not particularly high. There were two sites that received higher potential value scores than the rest of the creek because during wet years they held semi-permanent water and/or saturated bed sands. However, these were in very poor condition due to impacts from anthropogenic pressures unrelated to mining activities, especially cane toads, feral pigs, cattle and horses. Sediment contamination was discovered in all sections of Page Creek downstream of the mine, and although the most significant deposits were concentrated in the surficial sediment layers in close proximity to the mine-site, the vertical distribution in downstream reaches was quite heterogeneous.

Notably there were a number of sites on Page Creek where elevated zinc levels extended to sediment depths in excess of the maximum sampling depth of 500 mm. This could potentially have been caused by vertical leaching of contaminants previously deposited on the surface sediment. However, subsequent investigations (TropWATER 2013) suggest that metal had very limited solubility so it is more likely that basal sands had mixed during high flow events, which would in turn suggest that a significant proportion of the contaminated sediment is potentially mobile under high flow conditions. Accordingly an annual Sediment Quality Monitoring Program (SQMP) was established to track any subsequent contaminant movements and this has been ongoing since 2009.

Figure 2.1.1 Page Creek SQMP sites located in stream reaches A to D, and Silver King tributary sites T01-1 and T01-2. Upstream control site R01 is sampled in the post-wet season REMP survey each year but it is no longer-sampled in the dry season [Google Earth].

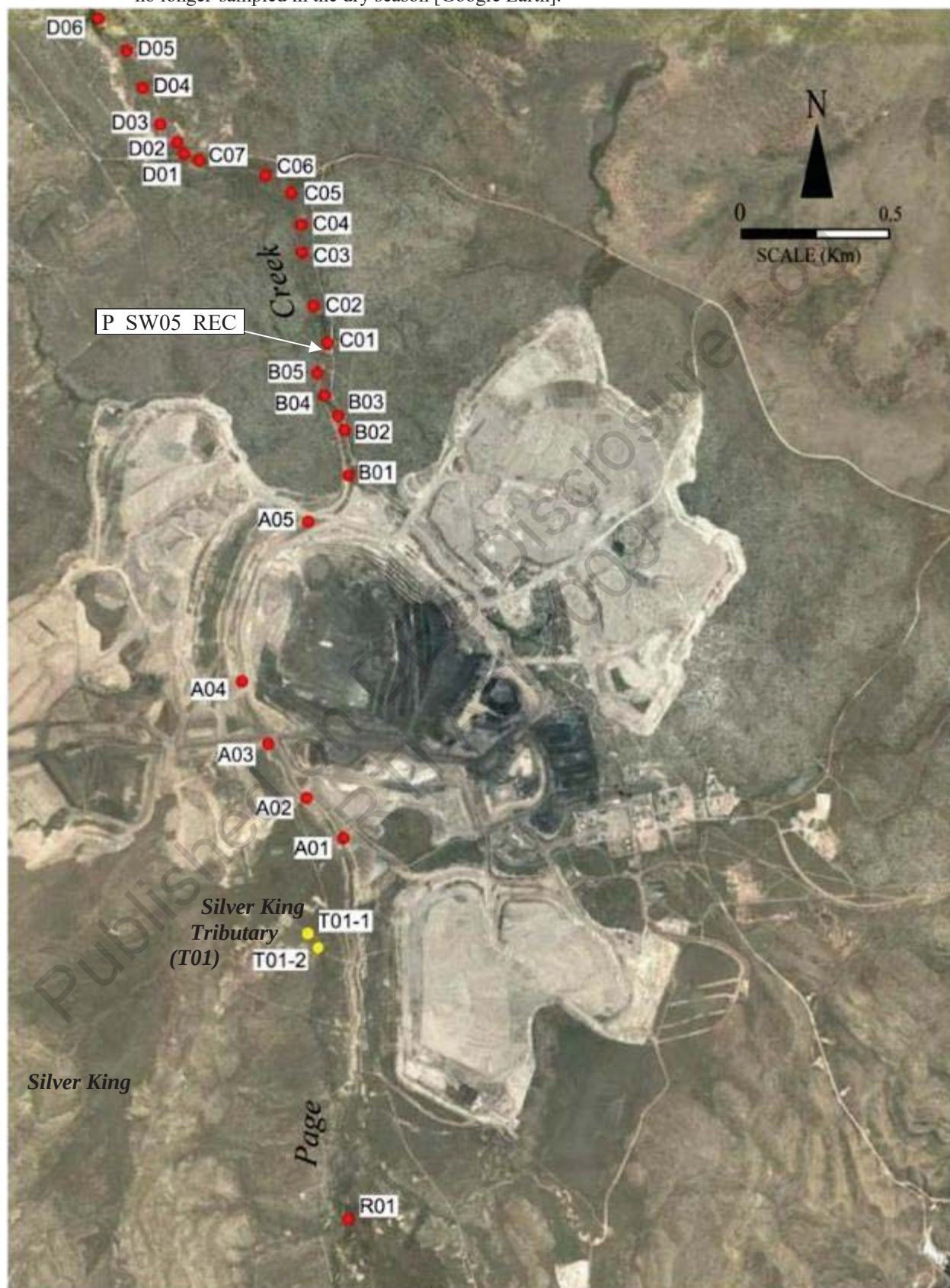


Figure 2.1.2 Page Creek sites located in stream reaches E to G. [Google Earth]. Tributary sites (prefixed T) were sampled in 2010 but have not been sampled since.



Table 2.1.1 Historical Page Creek SQMP site locations. (Datum: Australian Geodetic 1984 – UTM 54).

SITE NAME	East	North	Distance downstream from A01 (km)	SITE NAME	East	North	Distance downstream from A01 (km)
A01	246608	7926551	0.0	E07	244331	7933324	8.3
A02	246512	7927056	0.4	E08	244411	7933554	8.5
A03	246146	7927274	0.9	E09	244252	7934000	9.0
A04	245950	7927707	1.3	E10	244075	7934277	9.3
A05	246562	7929023	2.6	E11	244019	7934462	9.5
B01	246739	7929195	3.0	E12	243964	7934647	9.7
B02	246718	7929355	3.2	E13	243998	7934798	9.9
B03	246693	7929535	3.4	E14	244018	7934829	10.0
B04	246575	7929704	3.6	E15	244054	7934947	10.4
B05	246539	7929879	3.8	F01	244077	7935163	10.6
C01	246603	7930120	4.0	F02	244247	7935533	11.0
C02	246505	7930344	4.3	F03	244348	7936028	11.5
C03	246442	7930738	4.7	F04	244433	7936208	11.7
C04	246426	7930917	4.8	F05	243987	7936726	12.4
C05	246365	7931134	5.1	F06	243979	7936916	12.6
C06	246175	7931270	5.3	F07	244140	7937307	13.0
C07	245691	7931390	5.8	F08	244238	7937551	13.3
D01	245566	7931460	5.9	F09	244412	7937568	13.4
D02	245468	7931571	6.1	F10	244603	7937801	13.7
D03	245272	7931862	6.4	F11	244271	7938165	14.2
D04	245248	7932041	6.6	F12	244043	7938651	14.8
D05	245116	7932136	6.8	G01	244248	7939478	15.6
D06	245032	7932256	6.9	G02	244269	7939540	15.7
E01	245004	7932321	6.99	G03	244717	7941203	16.6
E02	244995	7932458	7.1	G04	244785	7940492	17.3
E03	245014	7932611	7.3	G05	244460	7942940	19.0
E04	244837	7932718	7.5	G06	244490	7943442	19.6
E05	244632	7932941	7.8	G07	244554	7943603	19.8
E06	244510	7933120	8.0				

Table 2.1.2 Tributary sites surveyed in 2010 (Datum: Australian Geodetic 1984-UTM 54)

Basis for Tributary Selection	Site Name	East	North	Distance of site from Page Creek (km)	Distance of confluence from Site A01 (km)
Drains Silver King base metal deposit	T01-1	246686	7925918	0.58	-0.5
	T01-2	246600	7925948	0.52	-0.5
Drains Phantom Hills phosphate deposit	T02-1	246610	7933277	1.71	7.6
	T02-2	246420	7933256	1.49	7.6
	T02-3	246233	7933115	1.27	7.6
	T02-4	245681	7932972	0.68	7.6
	T02-5	245417	7932791	0.33	7.6
	T02-6	245223	7932731	0.10	7.6
Drains Mt Jennifer phosphate deposit	T04-1	245251	7941000	1.30	19.0
	T04-2	245169	7941069	1.18	19.0
	T04-3	245027	7941308	0.90	19.0
	T05-4	244855	7941662	0.48	19.0
	T05-5	244766	7941779	0.31	19.0
	T05-6	244589	7941937	0.10	19.0

In 2010 sediment profile sampling was also carried out at the REMP control site situated in the upper reach of Page Creek (Site R01) and at the REMP reference sites (RSpr1 and RSpr2) located on Spring Creek (which was added to the routine sampling site network in 2010 because, morphologically and hydrologically, it is more similar to the middle reaches of Page Creek than any other potential reference stream in the region). However, as can be seen from the results in Table 2.1.3 these sites do not drain naturally mineralised sections of the catchment area, so although they are useful reference sites for biological monitoring purposes, they do not provide a valid basis for gauging the sedimentary metals status of Page Creek, the catchment of which is a naturally mineralised geological anomaly. Accordingly, the REMP reference sites have not been included in the SQMP.

Table 2.1.3 Minus 2 mm WAE metals results obtained at reference sites in 2010 (ACTFR 2010b)

Location	Sample Depth (cm)	Zinc (mg/kg)	Cadmium (mg/kg)	Phosphorus (mg/kg)	Lead (mg/kg)	Arsenic (mg/kg)
R01-11	5	15	< 0.1	< 10	15	< 0.5
R01-21	5	8.5	< 0.1	< 10	25	0.6
R01-22	25	13	< 0.1	< 10	22	0.6
R01-23	50	12	< 0.1	< 10	23	< 0.5
RSpr1-11	5	15	< 0.1	150	4.1	0.8
RSpr1-12	25	51.5	0.1	130	11.5	< 0.5
RSpr1-13	50	11	< 0.1	140	4.1	0.5
RSpr1-21	5	9.6	< 0.1	140	3.7	0.5
RSpr1-22	25	8.4	< 0.1	140	4.6	< 0.5
RSpr1-23	50	8.1	< 0.1	130	3.6	0.7
RSpr2-11	5	22	< 0.1	140	3.8	0.5
RSpr2-12	25	7.3	< 0.1	120	4	< 0.5
RSpr2-13	50	7.4	< 0.1	130	3.7	< 0.5
RSpr2-21	5	1.4	< 0.1	140	6.4	1.1
RSpr2-22	25	13	< 0.1	93	6.3	0.5
RSpr2-23	50	21	< 0.1	100	6.25	< 0.5

The phosphorus (P) results obtained from tributaries draining the Phantom Hills and Mount Jennifer phosphate deposits in 2010 (Table 2.1.4) and subsequent analysis of the spatial distribution of P concentrations in the main Creek relative to the tributaries, led to conclusion that the majority of the P in the middle to lower reaches of Page Creek, and further downstream in Lawn Hill Creek, was a consequence of runoff from the natural P mineral deposits (ACTFR 2012). It was particularly apparent that P is not a reliable indicator of mine-related influences in this catchment area and it was also evident from REMP monitoring results that the sedimentary P had limited solubility and bioavailability, and therefore presented little risk to the aquatic ecosystem. Subsequent annual monitoring results strongly supported those initial conclusions and accordingly in 2017 a decision was made to discontinue routine monitoring of P concentrations. This was under the proviso that P may be reintroduced to the analysis suite in the future if there were any indications of potential changes to the existing situation.

The elevated Zn, Cd and Pb levels reported from the Silver King tributary led to the establishment of new diversion drain sites to better discriminate between potential input sources to the diversion channel. Major clean up works involving removal and/or stabilisation of metal-enriched materials were subsequently conducted in the Silver King catchment area. Since then minor quantities of metal-enriched sediment from Silver King have remained present in the upper reaches of the creek but there have been no indications of any further sedimentary metal releases from Silver King. However, there have been no major rainfall events during that period and it will not be possible to test the effectiveness of the remediation works until there has been a rainfall runoff event large enough to potentially mobilise any residual sedimentary materials.

Table 2.1.4 Minus 2 mm WAE metals results for tributary sites sampled in 2010. Metals values greater than the ISQG-high are shown in red and those that lie between the ISQG-low and ISQG-high are shown in blue. Phosphorus values greater than the 80th and 95th percentiles of this dataset are shown in blue and red, respectively.

Tributary	Sample	Sample Depth (cm)	Distance of confluence from A01 (km)	Zinc (mg/kg)	Cadmium (mg/kg)	Phosphorus (mg/kg)	Lead (mg/kg)	Arsenic (mg/kg)
Silver King	T01-11	5	-0.5	2380	6.0	<50	475	0.5
	T01-12	25	-0.5	4820	14.0	<50	627	0.5
	T01-13	50	-0.5	2440	6.0	830	41	2.0
	T01-21	5	-0.5	6730	20.0	<50	1420	2.0
	T01-22	25	-0.5	1630	4.0	1960	32	2.0
	T01-23	50	-0.5	2610	6.0	1620	35	2.0
Phantom Hills	T02-11	5	7.6	110	<0.5	2370	-	<0.5
	T02-12	25	7.6	46.8	<0.5	1750	-	1.0
	T02-13	50	7.6	5.07	<0.5	<50	-	<0.5
	T02-21	5	7.6	3.88	<0.5	<50	-	<0.5
	T02-31	5	7.6	11.1	<0.5	<50	-	<0.5
	T02-32	25	7.6	10.1	<0.5	90	-	<0.5
	T02-33	50	7.6	23.4	<0.5	60	-	<0.5
	T02-41	5	7.6	6.05	<0.5	80	-	<0.5
	T02-42	25	7.6	5.36	<0.5	130	-	<0.5
	T02-43	50	7.6	1.88	<0.5	<50	-	<0.5
	T02-51	5	7.6	21	<0.5	<50	-	0.6
	T02-61	5	7.6	2.7	<0.5	<50	-	<0.5
	T02-62	25	7.6	30.1	<0.5	4510	-	<0.5
	T02-63	50	7.6	39.9	<0.5	6290	-	0.6
Mt Jennifer	T04-11	5	19.0	32	0.5	13200	17	2.0
	T04-21	5	19.0	877	3.0	1310	22	1.0
	T04-31	5	19.0	14	0.5	90	19	1.0
	T04-32	25	19.0	1260	3.0	3080	28	2.0
	T04-41	5	19.0	325	1.0	810	13	0.5
	T04-42	25	19.0	1770	5.0	670	41	2.0
	T04-51	5	19.0	1260	4.0	320	43	2.0
	T04-61	5	19.0	1580	4.0	420	40	2.0

The new sites established in the diversion included control sites located upstream of site A01. That upper section of the diversion has been designated as “Reach 1A”. In 2014 a minor realignment of the diversion resulted in site A04 being bypassed and four new sites were established in order to obtain baseline data for the new section of channel. The current diversion site network, which has not changed since 2014, is shown in Figure 2.1.3.

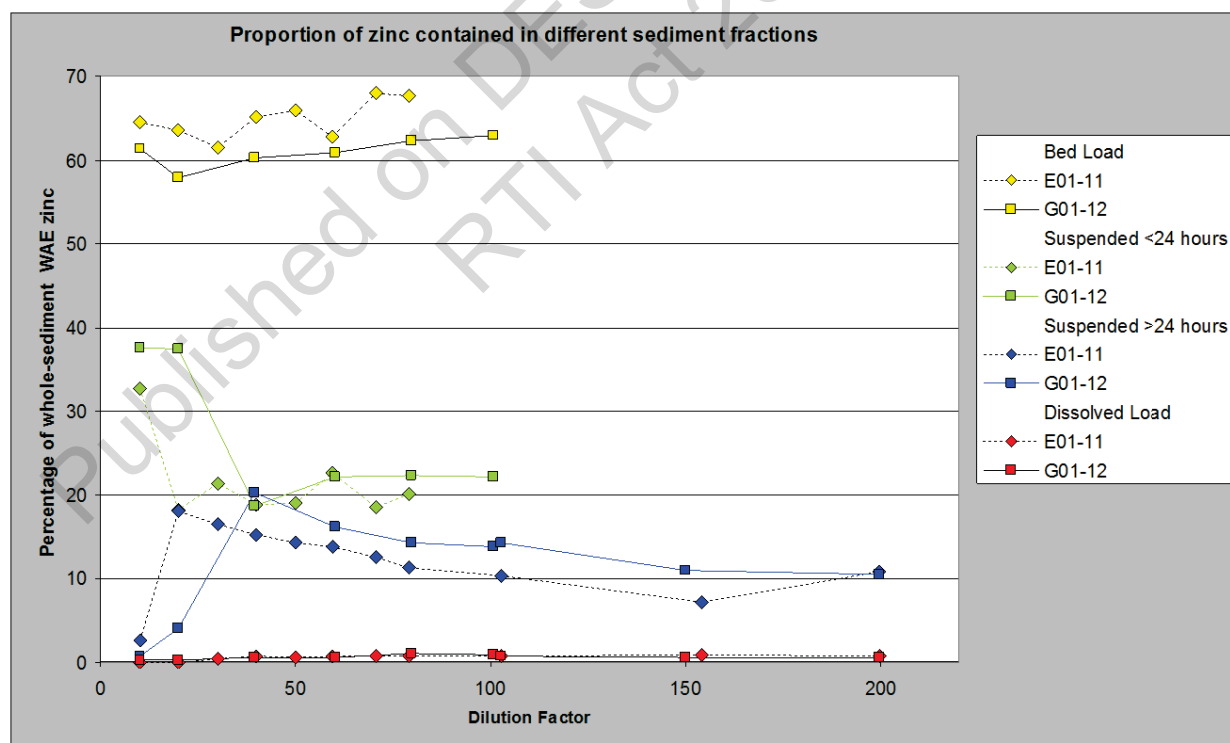
Figure 2.1.3 Page Creek Diversion channel sites sampled in 2014. [Google Earth 2017].



An analytical quality control issue emerged prior to the implementation of the 2014 sampling program when it became apparent that there was a matrix-dependent bias between different analytical laboratories (i.e. the size of the bias varied depending on the mineral composition of the sample). Subsequent QC failures were experienced in 2014 and 2015, and accordingly those samples were temporarily withheld until the issue had been resolved. This was accomplished by preparing matrix-matched QC standards which are now included with each new batch of samples, and by conducting numerous interlaboratory comparison tests to identify the best performing laboratory. It has become evident that none of the commercial laboratories involved in the comparison tests provide consistently reliable results over time-frames of several years. Accordingly, in order to be able to reliably detect trends it will be important to ensure that the existing QC procedures are maintained and to accept that it may prove necessary to periodically change laboratories. The 2014 and 2015 results were eventually analysed and are compared to the 2016 and 2017 results in subsequent sections of this report.

Analysis of the concentration changes that have occurred over time, and visual observations on site, both suggest that much of the metal-enriched sediment in Page Creek is being transported in the form of small discrete slugs which move *en masse* during the peak of flow events. This is a common occurrence when dealing with coarse-grained sediments which are too heavy to become suspended in the water column and instead move downstream by saltation (i.e. rolling/bouncing along the bottom). This observation is consistent with expectations based on laboratory testing (ACTFR 2012) which found that the majority of the contaminated sediment comprised sands which were not readily suspendable (see Figure 2.1.4).

Figure 2.1.4 Results of laboratory tests involving the agitation of sediment samples at varying water:sediment dilution ratios to determine the potential instream mobility of the sediment under simulated turbulent high flow conditions (ACTFR 2012).



The contaminated sediments were therefore considered to be readily amenable to capture in sediment traps. In response to that finding a sediment trap was installed in the lower reaches of Page Creek in 2014 (location shown in Figure 2.1.2) in order to prevent the sediment from reaching Lawn Hill Creek. It is planned that sediment trapped by this structure will be removed on a routine annual basis.

In 2014 it was also evident that even though there had been average rainfall during the preceding wet season, stream flow had been insufficient to significantly alter the spatial distribution of sedimentary contaminants in the creek. It was therefore decided to reduce sampling intensity until there were any indications of potentially significant changes, in which case the more intensive sampling employed in 2014 would be re-employed. The tactic employed in 2015 was to collect 58 composite samples each representative of a stream reach of nominally 500 m. An attempt was also made to quantify the contaminant load within each reach, by employing a variety of techniques, including ground penetrating radar, to obtain estimates of sediment volume. Unfortunately the streambed proved to be too rough and too heterogeneous for that tactic to be feasible.

The reach compositing approach proved to be excessively laborious, so an alternative tactic was employed in 2016 and 2017. This entailed sampling at 50 of the discrete depth profiling locations that had been sampled each year between 2010 and 2014. Site selections were done by statistically analysing selected subsets of the 2014 data to ensure that the mean Zn concentrations in each reach were the same as the mean values generated by the full dataset. That statistical analysis suggests that 50 is the minimum number of samples required to accomplish that objective. The results obtained from these different sampling approaches are compared in the next section of this report.

Historically there has always been a strong correlation between Zn and Cd in Page Creek ($R^2 \geq 0.89$) indicating that these two metals originate from a common source (the mine) and are currently exhibiting similar mobility properties. This is very strong correlation given that a significant proportion of the Cd results are at or below the reporting limit and therefore less clearly defined than the higher Zn results. Since the existing Zn concentrations are much higher than Cd (in terms of both absolute concentration and potential risk) the Zn data are more relevant for risk assessment and more amenable to accurate analysis and graphical displays. This report therefore focuses heavily on the trends exhibited by Zn, on the understanding that they also accurately reflect Cd trends. Each year the correlation is checked to ensure that this assumption is still supported.

The Silver King catchment appears to be the only potentially significant source of anthropogenic Pb enrichment in Page Creek. There are a few isolated slugs of such sediment in the diversion channel and the upper reaches of Page Creek where Pb concentrations have historically exceeded the SQG-Low but to date Pb has not emerged as a significant issue compared to Zn (which has consistently exceeded the SQG-High along the full length of Page Creek) and Cd (which has regularly exceeded the SQG-Low at most receiving sites). Pb has been retained in the analysis suite primarily to serve as an indicator to identify sediments sourced from Silver King. Recent Pb results are tabulated in this report but to date occurrences of elevated levels have not been sufficiently frequent or widespread to warrant detailed analysis.

Manganese (Mn) has not historically been included in the SQMP monitoring but it was added to the analytical suite on a one off basis in 2016 as part of an investigation triggered by an EA TL exceedance at P_SW03_REC. That investigation recommended that the Mn TL be removed from the EA on the grounds that high values were not a reliable indicator of risks to the ecosystem or effects from the mine. That recommendation was accepted by the administering authority and Mn is now monitored at compliance sites for interpretation purposes only. Accordingly Mn has not been included in the routine SQMP analytical suite.

2.2 Current Status of Page Creek Sediments

Annual REMP reports indicate that instream biological conditions have improved measurably since 2012. As is usually the case when dealing with stagnant retracting waterholes in ephemeral creeks, there has on occasion been evidence of ecological impairment at both reference and impact sites, but in recent years all such instances appear to have been attributable to natural deterioration processes and/or livestock impacts. Notably, since 2013 there has been no evidence of any correlation between sediment metal residue concentrations and ecological condition, some of the highest diversity and abundances having often been reported at the sites with the highest contaminant levels.

As would be expected based on historical data, the Zn concentration at the sediment compliance site exceeded the EA TL (Table 2.2.1) in 2017. A trigger investigation report has been submitted to DES as required under EA condition C16. Stream sediments in this study area are so heterogeneous that the individual grab samples that are used to assess compliance carry very little statistical weight especially in comparison to the statistically strong datasets being collected in the SQMP. Ostensibly, and particularly in cases such as this where exceedances are to be expected each year, the compliance sampling required under the current EA has been rendered redundant by the SQMP investigations. TropWATER recommend negotiating with DES to include an EA clause that exempts a site from condition C16 if that site is currently subject to intensive investigation under the SQMP.

Table 2.2.1 Minus 2 mm WAE metals results for sediment compliance on Page Creek in 2017.

EA Stream sediment trigger levels (mg/kg)	Site	P_SW17_REF	P_SW03_REC
	Sample Date	30/06/2017	30/06/2017
10	Cadmium	<0.1	2
270	Copper	1.5	3.4
220	Lead	7.1	26
52	Nickel	1.4	5
410	Zinc	15	750
70	Arsenic	3.5	3.4
3 x greater than reference site	Selenium	<1	<1
For interpretation purposes	Manganese	220	640
For interpretation purposes	< 63µm Particle size (%)	16.5	3.3

Raw Data generated by SQMP sampling campaigns between 2014 and 2017 are presented in Tables A.1 to A.4 of Appendix A. Annual summary statistics for data collected since 2009 are shown in Table 2.2.2 and these are displayed in boxplots in Figures 2.2.1 (lead), 2.2.2 (phosphorus) and 2.2.3 (zinc).

It is apparent in these figures that Pb concentrations are generally low and there is no evidence of any statistically significant temporal trends in Pb or P concentrations. This contrasts with Zn and Cd (not plotted) both of which have shown significant declines in mean concentrations since 2009. Notably mean Zn values have decreased by more than 50%. This appears to be a consequence of dilution by natural sediment inputs rather export to downstream environments because Zn concentrations in Lawn Hill Creek have not changed significantly (see next section). Despite the substantial reduction in mean concentrations 74% of the Zn results reported in 2017 were still greater than the SQG-High. A further 50% reduction in Zn concentrations will be required in order for mean values fall below the SQG-High.

Table 2.2.1 Annual statistics for <2 mm WAE metal results obtained from SQMP sampling in Page Creek since 2009. Values that exceed the ANZECC SQG-high are shown in red, while those that exceed the SQG-low are blue.

Metal	Year	Mean	95% Confidence Interval	Median	n	Minimum	Maximum	20th Percentile	80th Percentile	% greater than SQG-high	% greater than SQG-low
Zinc	2009	1805	408	980	195	95	23000	386	2200	78.5	92.8
	2010	1401	108	1400	183	65	4600	828	1900	91.8	97.8
	2011	1125	117	1000	168	19	3200	420	1700	80.4	88.7
	2012	1255	184	903	152	58	5320	443	1710	80.3	89.5
	2013	1126	137	1020	172	6	4470	211	1780	72.1	80.2
	2014	862	105	660	199	3	3600	226	1500	63.8	83.4
	2015	772	126	670	58	48	2200	374	1200	75.9	91.4
	2016	826	140	845	50	51	1700	354	1400	74.0	90.0
	2017	719	123	640	50	49	1800	306	1100	74.0	90.0
Cadmium	2009	3.8	1	2.8	195	0.0	23	0.0	6	5.1	67.7
	2010	4.3	1	3.5	183	0.0	53	1.9	6	2.7	85.2
	2011	3.3	0	2.9	168	0.0	14	1.0	5	1.8	72.0
	2012	3.4	1	2.0	152	0.0	17	1.0	5	7.2	73.0
	2013	2.9	0	3.0	172	0.0	14	0.0	5	1.7	68.6
	2014	2.3	0	1.9	199	0.0	10	0.0	4	0.0	57.3
	2015	2.9	0	2.3	49	1.1	8	1.5	4	0.0	71.4
	2016	2.5	1	2.3	50	0.0	7	0.0	4	0.0	64.0
	2017	2.0	0	1.8	50	0.0	6	0.0	3	0.0	54.0
Lead	2009	32	3	26	195	6	150	17	44	0.0	13.3
	2010	29	3	27	183	9	210	17	39	0.0	5.5
	2011	28	2	26	168	5	100	19	35	0.0	4.8
	2012	21	3	16	152	3	241	11	26	0.7	3.9
	2013	26	6	17	172	3	342	10	30	1.7	5.8
	2014	11	1	9	199	3	51	6	15	0.0	0.5
	2015	28	6	23	58	8	140	13	41	0.0	13.8
	2016	17	2	15	50	3	38	12	22	0.0	0.0
	2017	15	3	11	50	5	69	10	21	0.0	2.0
Phosphorus	2009	755	135	500	195	25	11000	260	982		
	2010	866	126	620	183	25	6100	334	1200		
	2011	466	64	370	168	25	3600	200	620		
	2012	970	305	475	152	25	20100	240	1096		
	2013	1028	191	720	172	25	9290	174	1490		
	2014	799	134	530	199	25	6400	200	1100		
	2015	1035	368	440	58	13	6300	274	1440		
	2016	823	223	550	50	25	3600	304	1420		

Figure 2.2.1 Boxplot showing interannual variations in the distribution of lead results obtained from SQMP sampling in Page Creek. Boxes display 20th, 50th and 80th percentiles. Error bars are maxima and minima.

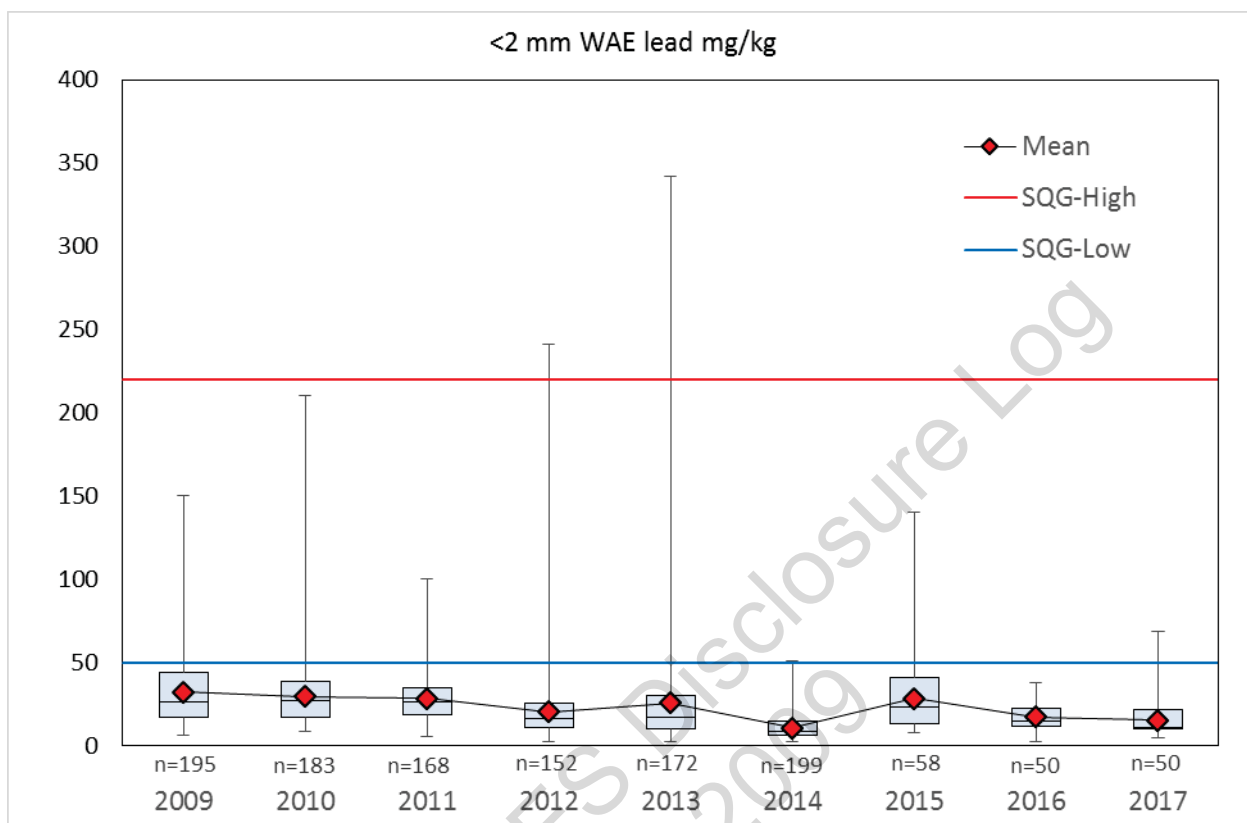


Figure 2.2.2 Boxplot showing interannual variations in the distribution of phosphorus results obtained from SQMP sampling in Page Creek. Boxes display 20th, 50th and 80th percentiles. Error bars are maxima and minima.

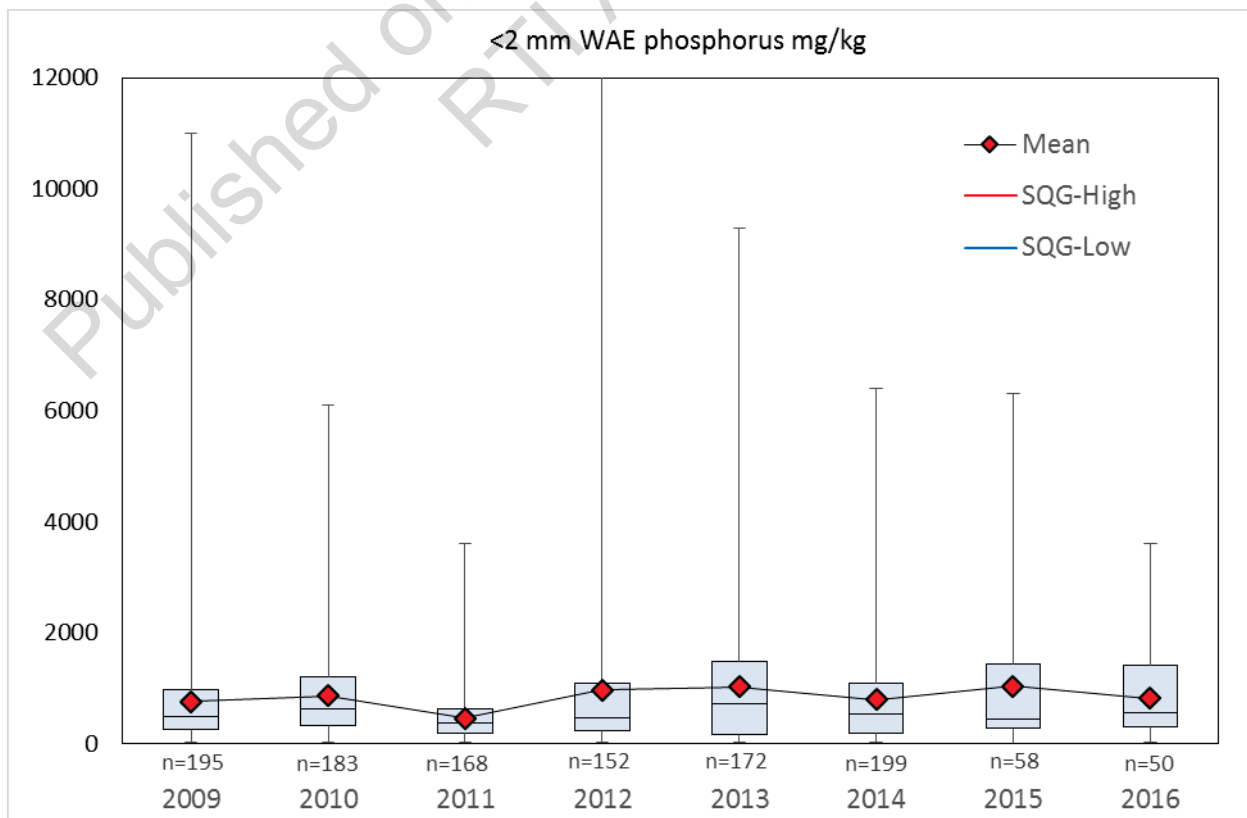
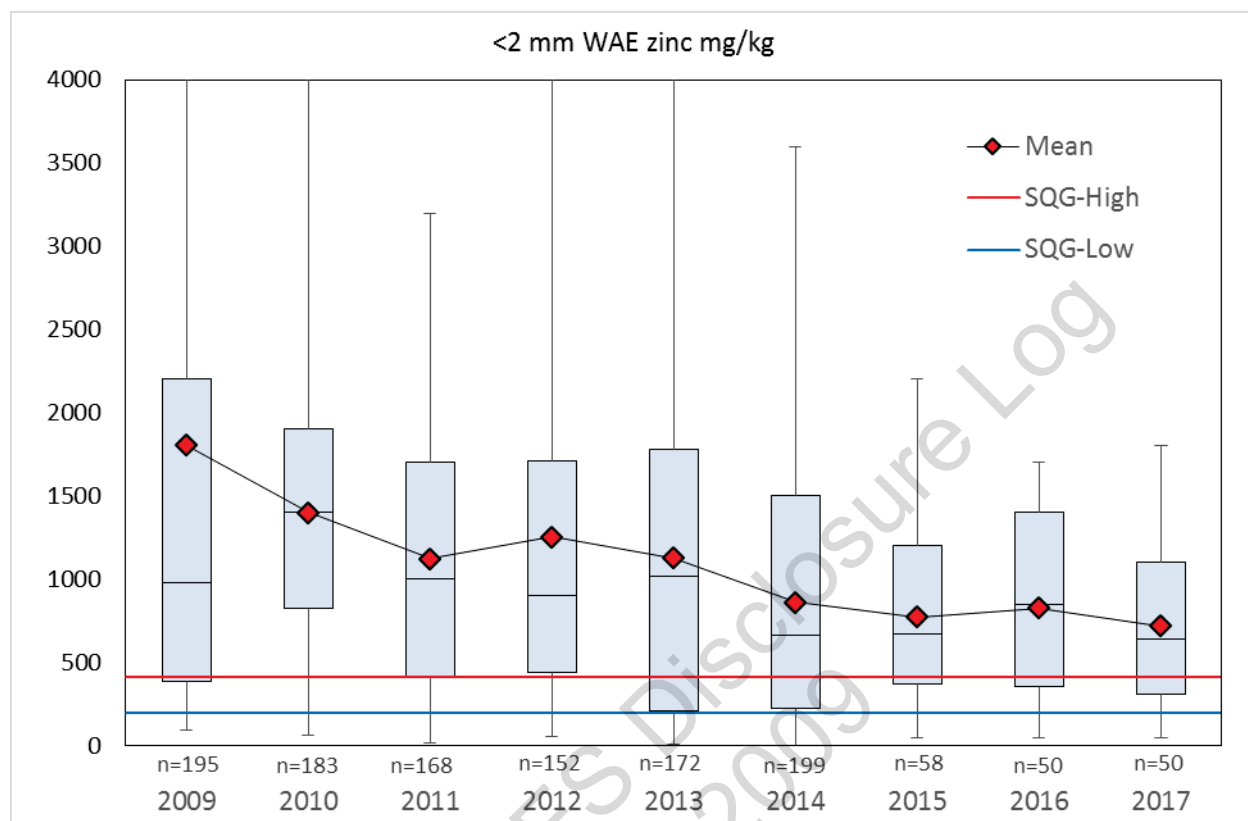


Figure 2.2.3. Boxplot showing interannual variations in the distribution of zinc results obtained from SQMP sampling in Page Creek. Boxes display 20th, 50th and 80th percentiles. Error bars are maxima and minima.



Temporal trends in Zn concentrations within each individual stream reach are plotted in Figure 2.2.4. Analysis of the SQMP datasets for 2009 to 2017 indicates that the mean zinc levels in most reaches have declined moderately since 2013 although Reach F is the only case where the apparent decline was statistically significant and Reach A (the diversion channel) is the only reach where mean zinc levels were below the ISQG-High (the Cd in that Reach was also below the ISQG-Low). On face value this appears to indicate that recent inputs to Page Creek from the mine have been low and that pre-existing sedimentary metal residues have been moderately diluted by natural sediment inputs. These effects could potentially be a temporary consequence of the lack of large flow events since 2012 (resulting in surface deposition of unenriched natural sediments from localised soil sources) and an absence of movement within the streambed.

The short term effects of this are evident in the depth profiling data shown in Figure 2.2.5. It can be seen that the decreasing trends in Reaches A to D have primarily been confined to the surface (0-15cm) layer of the streambed. In Reaches E and F the decreasing trend is evident through the sediment profile implying that flows in that section of the stream since 2013 have been sufficiently energetic to induce vertical mixing of the streambed and some downstream transportation of bed sediments to Reach G. During the wetter years prior to 2013 this resulted in an increase in concentrations in Reach G; however, since then there have been significant declines in Reach G especially within the surficial sediment layer. In fact G is the only reach where surface Zn concentrations have been significantly lower than the deeper underlying sediments for the past four years.

These trends have developed over a drought period. It will not be possible to confidently ascertain longer term trends until there has been a large-scale flow event with the potential to more fully mobilise the bed sediments.

Figure 2.2.4. Spatiotemporal variations in Page Creek sediment zinc concentrations since 2009 clustered by reach. Error bars are 95% confidence intervals for the mean. An outlier of 15000 mg/kg for Reach A in 2009 and a maximum value of 23000 mg/kg for Reach C in 2009 are not shown:

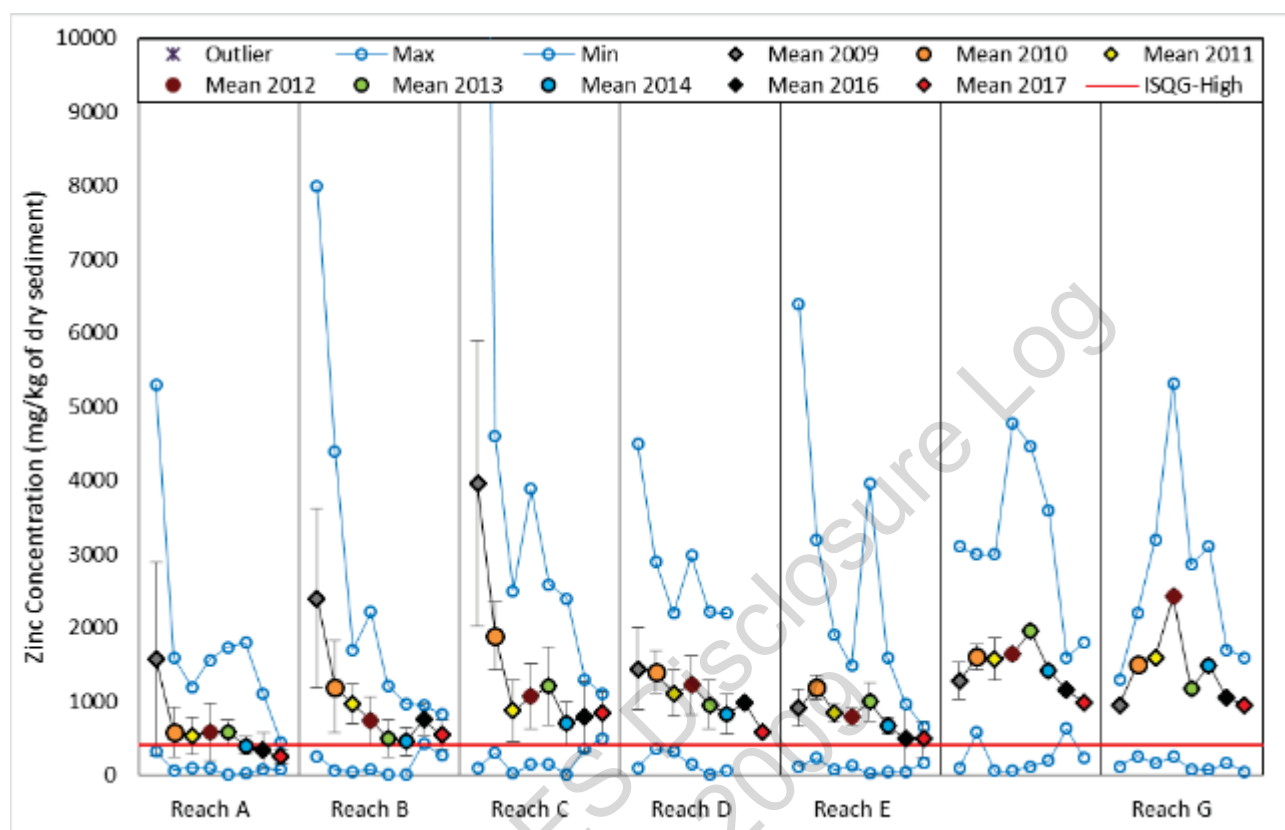
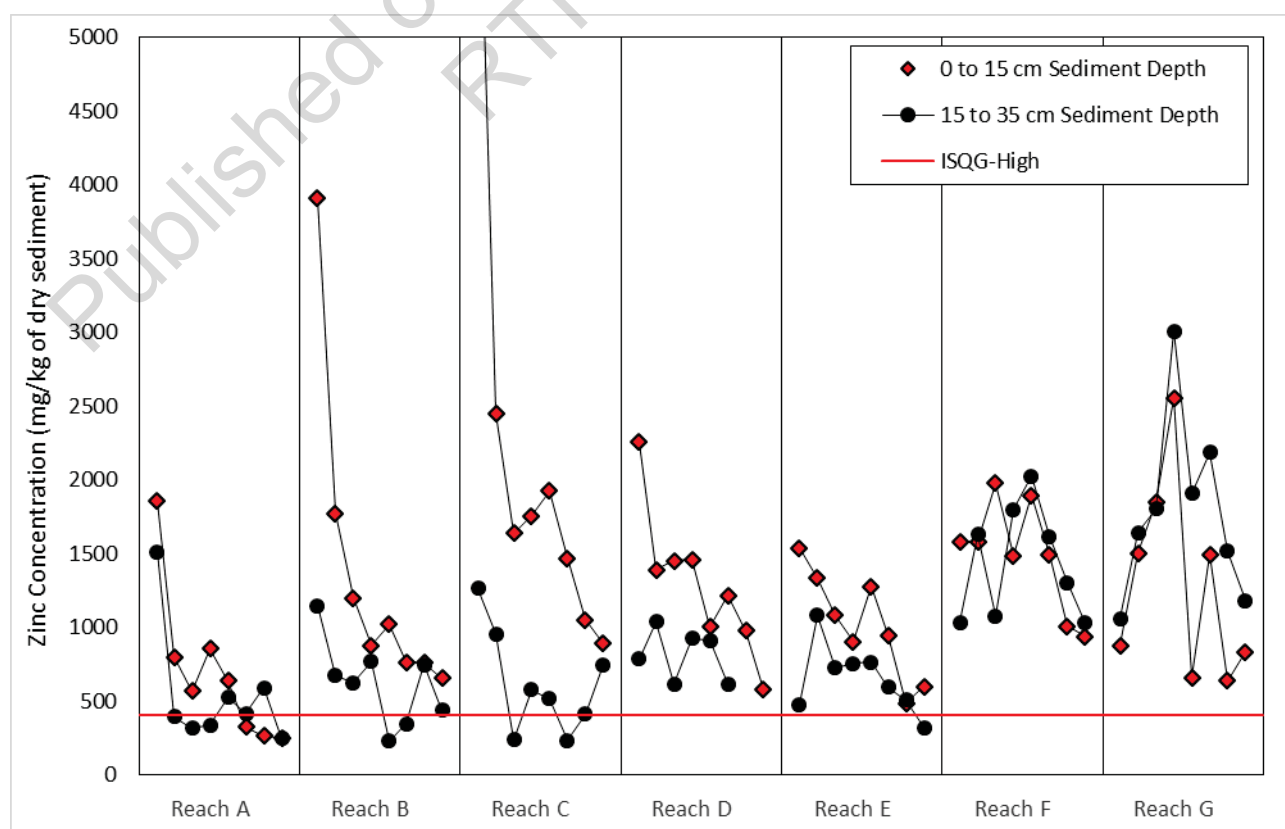


Figure 2.2.5 Variations in Page Creek zinc concentrations with sediment depth since 2009 clustered by stream reach. Points are mean values and are arranged chronologically as in Figure 2.2.4.



Laboratory-based investigations conducted in 2010 demonstrated that the sedimentary metal residues in Page Creek have low water solubility, and hence relatively low bioavailability and toxicity. Historical REMP data support that contention, as do the 2016 and 2017 results; zinc and cadmium levels in the water samples were low and in most cases undetectable, and sediment pore-water metal concentrations were consistent with a maximum solubility of 0.03 to 0.04 % (cf 0.1 to 2.7 % at regional reference sites). Notably there was no correlation between the metal concentrations in the solid and aqueous phases of the bottom sediment suggesting that the pore water metal mostly originated from sources other than the sediment.

The water quality conditions encountered at most Page Creek sites during the 2016 and 2017 REMP sampling campaigns were generally good by regional standards and this was reflected in the biological monitoring results. Notably the only water quality anomalies observed were clearly a result of natural deterioration, exacerbated by livestock pressures. In fact with respect to mine-related water quality parameters recent results have ranked amongst the best that have been recorded to date and there have been no indications of any potential impacts that could potentially be attributed to mine-sourced contaminant residues.

These findings strongly support the assertion that the metal residues in Page Creek have had minimal impact on the creek's ecosystem. Nevertheless, the quantities of Zn and Cd contained in the streambed present a potential risk to the more valuable, diverse and potentially more sensitive, biological communities downstream in Lawn Hill Creek. Accordingly ongoing monitoring and maintenance of the Page Creek sediment trap and, if necessary structural improvements, will remain a management priority well into the foreseeable future. Continued monitoring of zinc concentrations in the sediments of Lawn Hill Creek will also be essential in order to confirm the effectiveness of existing management measures (see Section 3).

Note that since the sediment trap was installed in 2014 there have been no flow events large enough to substantially mobilise the bed sediments, and hence no opportunity to fully test the structures effectiveness. Due to a lack of any significant flow events very little sediment was captured in the trap in 2017, but a total of 45 tonnes of sediment was removed from the trap in 2016. The average grade of the material (1223 mg/kg) was very close to the mean value for that stream reach, so the effects of the removal will not be immediately detected by monitoring the metal concentrations in Page Creek. However, the reduced load means that less natural sediment will be necessary to achieve effective dilution, so it is expected that this will eventually result in reduced concentrations over a number of years.

2.3 Protocols for Future Monitoring

Each year during the postwet season REMP sampling campaign the condition and composition of the Page Creek streambed of each REMP site will be assessed to determine if there is any evidence of potentially significant changes or emerging water quality issues that require investigation under the SQMP. The previous year's SQMP results will also be reviewed in order to determine if any new issues were identified.

Routine Sampling

If there is no evidence of circumstances having changed, routine SQMP sampling will be conducted during the dry season employing the same approaches that were used in 2016 and 2017. This will entail collection of the 50 depth profile samples listed in Table 2.3.1, the locations of which are listed and mapped in the preceding sections of this report. Samples will be sieved to remove material >2mm, analysed for dilute acid extractable Zn, Cd and Pb, and wet sieved to determine percent passing 63 µm.

Table 2.3.1 Samples to be collected during routine SQMP sampling campaigns. Site locations are listed in Table 2.1.1 and mapped in Figures 2.1.1 to 2.1.3.

Reach	Sample	Sample Depth (cm)	Thread Distance from A01 (km)	Reach	Sample	Sample Depth (cm)	Thread Distance from A01 (km)
A	A01-11	0-15	0.0	F	F07-11	0-15	13.0
	A01-13	15-35	0.0		F07-12	15-35	13.0
	A02-11	0-15	0.4		F08-11	0-15	13.3
	A03-11	0-15	0.9		F08-12	15-35	13.3
	P09-11	0-15	1.0		F09-11	0-15	13.4
	N02-11	0-15	1.4		F09-12	15-35	13.4
	N04-11	0-15	1.6		F10-11	0-15	13.7
	A05-11	0-15	2.6		F10-12	15-35	13.7
	A05-12	15-35	2.6		F11-11	0-15	14.2
B	B01-11	0-15	3.0		F11-12	15-35	14.2
	B01-12	15-35	3.0	G	G02-11	0-15	15.7
	B03-11	0-15	3.4		G02-12	15-35	15.7
	B03-12	15-35	3.4		G03-11	0-15	16.6
	B05-11	0-15	3.8		G03-12	15-35	16.6
	B05-12	15-35	3.8		G04-11	0-15	17.3
C	C01-11	0-15	4.0		G04-12	15-35	17.3
	C01-13	15-35	4.0		G04-13	35-50	17.3
	C02-11	0-15	4.3		G05-11	0-15	19.0
	C02-12	15-35	4.3		G05-12	15-35	19.0
	C05-11	0-15	5.1		G05-13	35-50	19.0
D	D04-11	0-15	6.6		G06-11	0-15	19.6
E	E05-11	0-15	7.8		G06-12	15-35	19.6
	E10-11	0-15	9.3		G07-11	0-15	19.8
	E10-13	15-35	9.3		G07-12	15-35	19.8
	E10-21	0-15	9.3				
	E10-23	15-35	9.3				

Post Event Sampling

If the REMP determines that during the preceding wet season there has been an event with the potential to have altered the condition and/or composition of the Page Creek (for example a major flood or a potentially significant non-compliant release from the mine) monitoring will be intensified to include all of the sites sampled in 2014 (as listed in Table 2.3.2). Depth profile samples encompassing the 0-15cm, 15-35cm and 35-50cm sediment horizons will be collected at all sites where sediments are deep enough to do so. Samples will be sieved to remove material >2mm, analysed for dilute acid extractable Zn, Cd and Pb, and wet sieved to determine percent passing 63 µm.

Table 2.3.2 Samples to be collected during post-event SQMP sampling campaigns. Site locations are mapped in Figures 2.1.1 to 2.1.3.

Reach	Site	Station	Longitude	Latitude	Distance from A01 (km)	Reach	Site	Station	Longitude	Latitude	Distance from A01 (km)
R01	R01	R01	138.5980	-18.7596	-2.6	D	D03	D03-1	138.5862	-18.6874	6.43
1A	A00	A00	138.5991	-18.7512	-2.40	D	D03	D03-2	138.5863	-18.6877	6.43
1A	O01	001-1	138.5989	-18.7500	-1.65	D	D04	D04-1	138.5858	-18.6858	6.61
1A	O02	002-1	138.5990	-18.7451	-1.09	D	D05	D05-1	138.5853	-18.6849	6.77
1A	O03	003-1	138.5991	-18.7421	-0.76	D	D06	D06-1	138.5838	-18.6839	6.92
1A	T01-1	T01-1	138.5978	-18.7411	-0.50	E	E01	E01-1	138.5835	-18.6833	6.99
1A	T01-2	T01-2	138.5981	-18.7415	-0.50	E	E01	E01-2	138.5835	-18.6832	6.99
1A	O04	004-1	138.5987	-18.7390	-0.42	E	E02	E02-1	138.5834	-18.6820	7.12
1A	P02	P02	138.5984	-18.7362	-0.10	E	E03	E03-2	138.5837	-18.6806	7.28
1A	P01	P01	138.5981	-18.7358	-0.04	E	E04	E04-1	138.5820	-18.6795	7.48
A	A01	A01-1	138.5979	-18.7355	0.00	E	E05	E05-1	138.5801	-18.6776	7.78
A	P03	P03	138.5961	-18.7327	0.36	E	E06	E06-1	138.5790	-18.6761	8.00
A	A02	A02-1	138.5956	-18.7323	0.40	E	E07	E07-1	138.5773	-18.6742	8.27
A	P04	P04	138.5949	-18.7313	0.57	E	E07	E07-2	138.5773	-18.6739	8.27
A	P05	P05	138.5945	-18.7303	0.69	E	E08	E08-1	138.5775	-18.6727	8.51
A	A03	A03-1	138.5937	-18.7290	0.86	E	E09	E09-1	138.5766	-18.6680	8.98
A	P09	P09	138.5929	-18.7279	1.00	E	E10	E10-1	138.5754	-18.6658	9.32
A	P10	P10	138.5928	-18.7277	1.03	E	E10	E10-2	138.5752	-18.6658	9.32
A	N01	N01	138.5919	-18.7260	1.28	E	E11	E11-1	138.5745	-18.6636	9.51
A	N02	N02	138.5913	-18.7246	1.38	E	E12	E12-1	138.5743	-18.6619	9.66
A	N03	N03	138.5913	-18.7239	1.45	E	E13	E13-1	138.5747	-18.6604	9.85
A	N04	N04	138.5913	-18.7224	1.58	E	E14	E14-1	138.5748	-18.6595	10.05
A	O05	005-1	138.5920	-18.7194	2.00	E	E14	E14-2	138.5748	-18.6594	10.05
A	A05	A05-1	138.5964	-18.7151	2.57	E	E14	E14-3	138.5749	-18.6592	10.05
A	P08	P08	138.5979	-18.7143	2.87	F	F01	F01-1	138.5751	-18.6577	10.59
A	O06	006-1	138.5991	-18.7139	3.00	F	F02	F02-1	138.5767	-18.6544	11.00
B	B01	B01-1	138.5996	-18.7126	3.03	F	F03	F03-1	138.5774	-18.6503	11.50
B	B02	B02-1	138.5994	-18.7100	3.19	F	F04	F04-1	138.5786	-18.6481	11.70
B	B03	B03-1	138.5992	-18.7087	3.37	F	F04	F04-2	138.5792	-18.6477	11.70
B	B04	B04-1	138.5981	-18.7071	3.58	F	F04	F04-3	138.5803	-18.6471	11.70
B	B05	B05-1	138.5977	-18.7059	3.76	F	F05	F05-1	138.5764	-18.6445	12.38
C	C01	C01-1	138.5983	-18.7037	4.01	F	F06	F06-1	138.5745	-18.6417	12.57
C	C02	C02-1	138.5976	-18.7013	4.25	F	F07	F07-1	138.5754	-18.6389	13.00
C	C02	C02-2	138.5981	-18.7011	4.25	F	F08	F08-1	138.5775	-18.6360	13.26
C	C03	C03-1	138.5970	-18.6977	4.65	F	F09	F09-1	138.5789	-18.6357	13.43
C	C04	C04-1	138.5970	-18.6964	4.83	F	F10	F10-1	138.5798	-18.6330	13.73
C	C05	C05-1	138.5962	-18.6941	5.06	F	F11	F11-1	138.5769	-18.6298	14.23
C	C06	C06-1	138.5945	-18.6927	5.29	F	F12	F12-1	138.5752	-18.6260	14.76
C	C07	C07-1	138.5899	-18.6919	5.79	G	G01	G01-1	138.5769	-18.6191	15.61
D	D01	D01-1	138.5893	-18.6916	5.93	G	G02	G02-1	138.5780	-18.6171	15.68
D	D01	D01-2	138.5888	-18.6912	5.93	G	G03	G03-1	138.5803	-18.6077	16.57
D	D02	D02-1	138.5883	-18.6905	6.08	G	G04	G04-1	138.5803	-18.6016	17.30
D	D02	D02-2	138.5881	-18.6902	6.08	G	G05	G05-1	138.5783	-18.5896	19.04
						G	G06	G06-1	138.5802	-18.5826	19.58
						G	G07	G07-1	138.5807	-18.5814	19.75

Investigative Monitoring Contingency

Each year the annual REMP and SQMP reports will recommend any additional *ad hoc* monitoring components which may need to be temporarily added to the SQMP in order to address emerging issues or assist sediment management activities. This could for example include the incorporation of additional sites to assess the effectiveness of a new remediation measure or the addition of new analytes to assess the potential significance of an anomaly detected by the REMP.

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3. LAWN HILL CREEK

3.1 Historical background

Since 2009 moderately elevated concentrations of sedimentary zinc and phosphorus in the stream reaches immediately downstream of the Page Creek confluence have provided the only evidence of potential mine-related influences on Lawn Hill Creek. Previous SQMP investigations have demonstrated that most of the phosphorus almost certainly originates naturally from the Mt Jennifer phosphate deposit which is immediately adjacent to Reach G of Page Creek and to Lawn Hill Creek itself, with some potential additional contributions (via Page Creek) from the Phantom Hills Phosphate deposits.

Most of the Zn in this section of Lawn Hill clearly originates from Page Creek. However, Zn concentrations similar to those in the middle reaches of Page Creek (up to 1770 mg/kg) have been recorded in the Mt Jennifer tributary which enters Page Creek prior to its intersection with Lawn Hill. Moreover, the natural mineralisation associated with the Century ore body was probably always a source of measurable Zn enrichment to both Page and Lawn Hill Creeks. Accordingly, it is possible that a significant proportion of the Zn currently contained in the Lawn Hill Creek sediments is naturally occurring, but in the absence of pre-mine baseline data and until proven otherwise, it is conservative to assume that most of the Zn could potentially have originated from the mine. Certainly it is clear that a proportion of the current Zn residues in Page Creek originated from the mine.

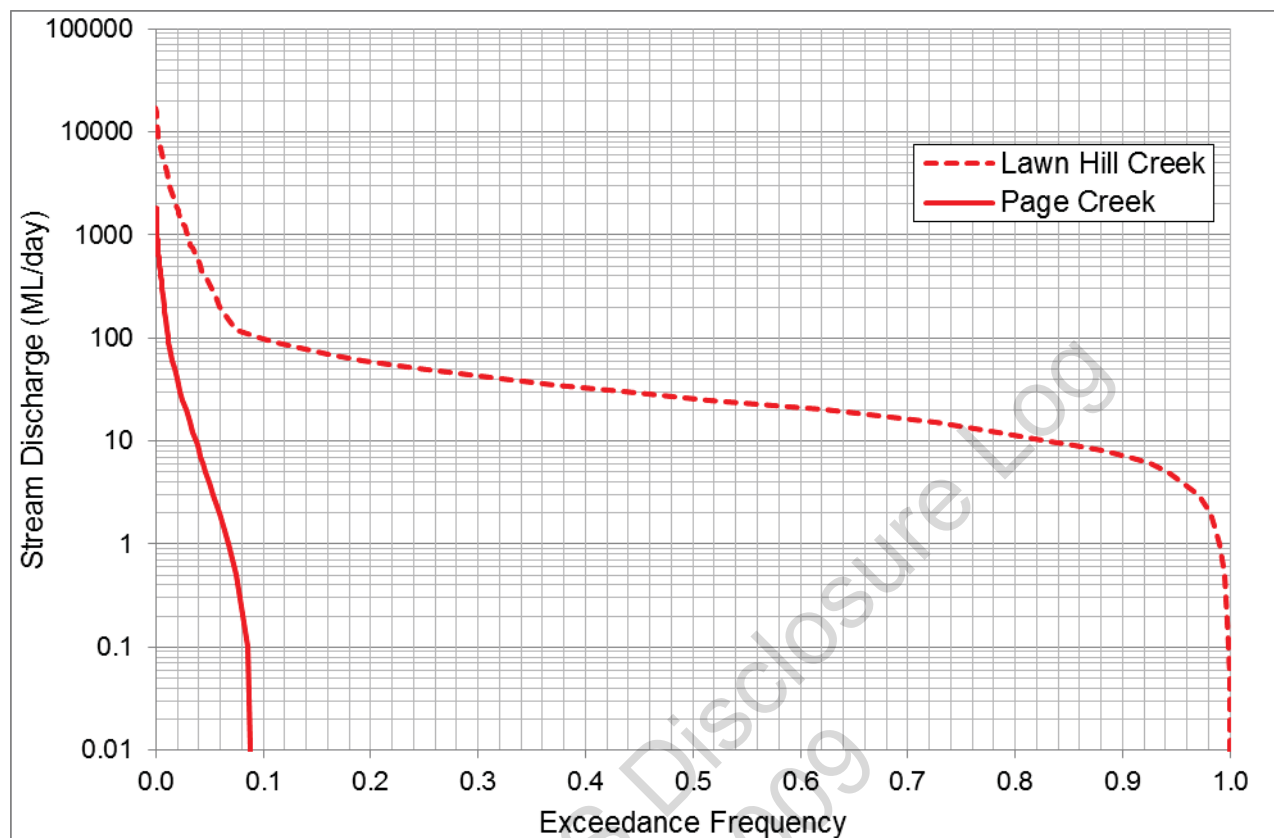
Currently risks of impact from the Page Creek metal residues appear to be relatively low. Lawn Hill Creek is much larger than Page Creek and has substantially greater dilution capacity (by more than an order of magnitude) as illustrated by the flow exceedance curves in Figure 3.1.1. This naturally mitigates the potential for impacts from Page Creek, and to date annual REMP monitoring has found no evidence of any adverse effects on the ecology, water quality or macroinvertebrate communities in Lawn Hill Creek. Sediment pore water samples have also yielded low values, and there has been no evidence of a potential correlation to sediment contamination levels (in fact the highest pore water Zn results have often been reported at the sites with the lowest sediment concentration).

However, Zn concentrations in the section of Lawn Hill Creek immediately downstream of Page Creek have remained elevated since 2009 and there is very little margin for even minor increases without exceeding the ANZECC SQGs. Moreover, Lawn Hill Creek is a high value ecosystem which supports biological communities that are more diverse and therefore potentially more sensitive, than those in Page Creek. Therefore, until proven otherwise, it would not be conservative to assume that the Lawn Hill Creek ecosystem has the same capacity to tolerate SQG exceedances. Accordingly it has been concluded that the Zn residues in Page Creek present sufficient potential risk to Lawn Hill Creek to warrant ongoing monitoring.

Sediments at the Lawn Hill Creek sites immediately downstream of Page Creek have proven to be highly heterogeneous, and in order to investigate the nature of the existing spatio-temporal variability it proved necessary to alter sampling methods between trips during the early stages of the SQMP. Initially composite surface samples were collected in triplicate to ascertain whether the composites were representative. The results indicated that variability between samples was unacceptably high, so during the 2012 REMP trip sites were sampled intensively with multiple replicates of both surface and depth profile samples being collected. The results showed that, although contamination was distributed through the sediment profile in a few places near the mouth of Page Creek, the metal residues at most sites were concentrated in the near-surface layer, suggesting that surface sampling is an adequate method of detecting any emerging impacts.

A routine sampling methodology (detailed in Section 3.3) was finally developed in 2013 and is still in use at this time.

Figure 3.1.1 Flow Exceedance curves for Lawn Hill and Page Creeks



3.2 Current Status

The SQMP Zn results for 2017 are presented in Table 3.2.1. These are compared to previous years in Figure 3.2.1. It can be seen that the sediments proximal to Page Creek are highly heterogeneous and this limits our capacity to resolve subtle temporal variations. That caveat notwithstanding, there have been no statistically significant variations over the course of the monitoring program to date, suggesting that there have been no significant inputs from Page Creek during that time. It is possible that Zn levels at the L1 sites may have declined slightly since 2009. However, the composite samples collected during the early stages of the SQMP do not carry sufficient statistical weight to test that assertion.

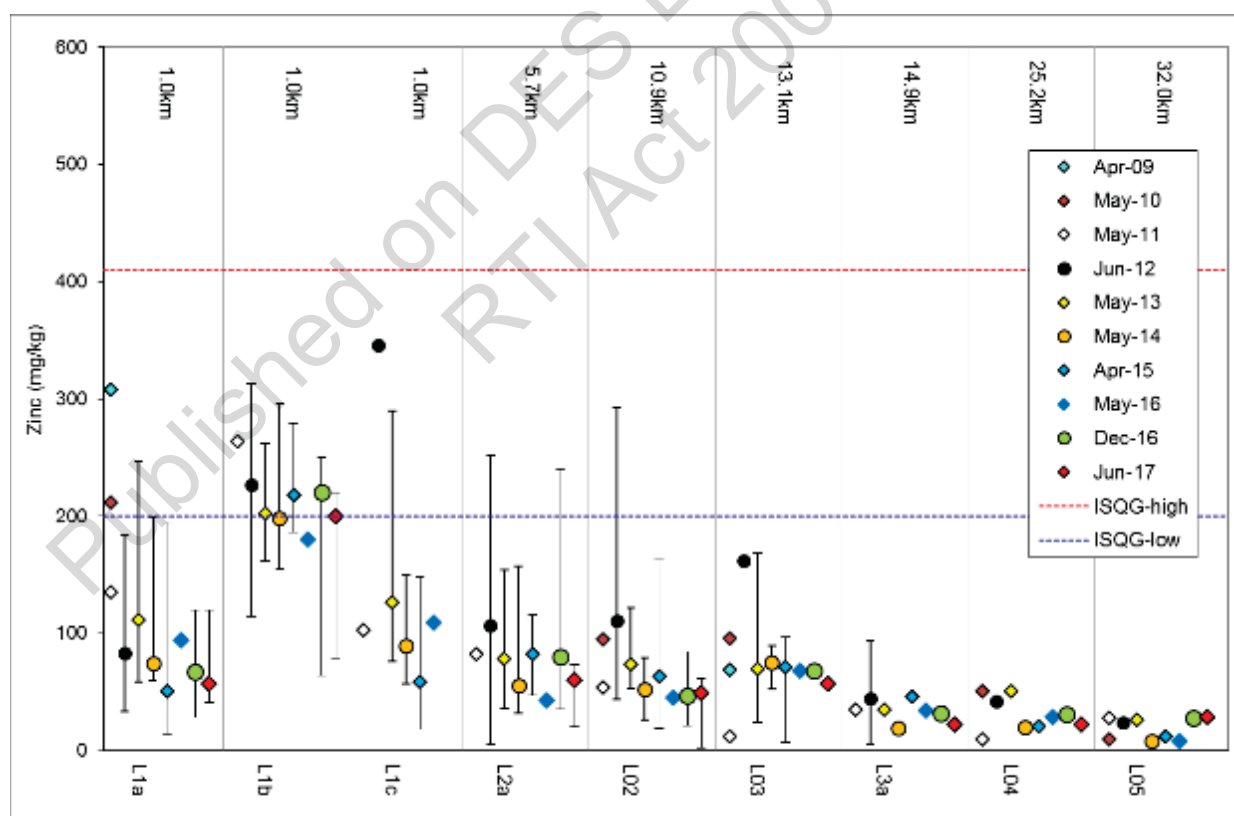
The obvious attenuation of concentrations with increasing distance from Page Creek provides an opportunity for the REMP to test for any potential correlations between sediment quality, water quality and ecological condition. To date no such correlations have been found and in fact on a number of occasions the poorest biological results have been reported at the sites with the lowest metal residues and vice versa. Notably the 2016 and 2017 REMP reports found that L1b, the site with the highest sedimentary zinc levels was within reference with respect to all key metrics, and all sites with zinc levels significantly above background reported in AUSRIVAS Band-A (i.e., meeting reference condition for macroinvertebrate communities).

Accordingly, as in previous years, the moderately elevated concentrations of sedimentary zinc proximal to the page Creek confluence provide the only evidence of potential mine-related influences on Lawn Hill Creek, and to date there have been no indications of any ecological impacts that could potentially be attributable to the mine.

Table 3.2.1. Summary of sediment Zinc results for Lawn Hill Creek monitoring sites in June 2017. Values highlighted in blue font are greater than the ISQG-Low.

<2mm WAE Zinc (mg/kg)						
Site	Random Composite	Site Mean ($\pm$ 95% C.I.)	Upper limit of mean	Min	Median	Max
L1a	130	72 $\pm$ 24	95	41	57	120
L1b	230	171 $\pm$ 45	216	79	200	220
L2a	-	55 $\pm$ 15	69	20	60	73
L02	-	42 $\pm$ 16	58	3	50	61
L03	57	-	-	-	-	-
L3a	22	-	-	-	-	-
L04	22	-	-	-	-	-
L05	29	-	-	-	-	-

Figure 3.2.1. Spatiotemporal variations in Lawn Hill Creek sediment zinc concentrations since 2009. Points without error bars are obtained from composite samples. Points with error bars indicative of minimum and maximum values are medians obtained from 8 transect samples. Points are arranged chronologically within each site group. Data for upstream reference sites RL0 to RL3 (n=28; mean=10 mg/kg; maximum=25 mg/kg) are not shown.



3.3 Protocols for Future Monitoring

REMP sampling

The four upstream reference sites and eight of the nine test sites listed in Table 1.3.1 are sampled in the post wet season REMP surveys each year by collecting a single random composite from each site. The ninth test site, L1c, has been discontinued because it is situated in a separate braid of the stream which became disconnected from the creek. It will be reinstated as a monitoring site if it ever re-establishes hydraulic connectivity with Lawn Hill Creek. (Note that sites L1a, L1b and L1c are situated on three different braids of the creek and are equidistant from Page Creek.)

SQMP Sampling

The REMP test sites listed in Table 3.3.1 are resampled during the annual dry season SQMP sampling campaign but the reference sites, which have consistently reported low values, are not resampled. SQMP sampling methods vary between sites.

At sites with elevated Zn levels (currently comprising L1a, L1b, L2a and L2) separate samples for analysis are taken at eight stations located at regular intervals along a lateral (cross-sectional) transect crossing the full width of the stream. Each of the transect samples are composites prepared by collecting subsamples from a number of random points located immediately up and downstream of (i.e. at 90° to) the transect line. This yields 32 composite sediment samples comprising 8 replicates from each of the four sites.

The remaining four sites (L03 to L05), which have to date reported low to moderate Zn values, are sampled by collecting a single random composite at each site.

All samples are sieved to remove material >2 mm and analysed for dilute acid (1M HCl) extractable Zn, Cd and Pb. One low level and one high level QC standard are included in each batch of samples submitted for analysis.

Table 1.3.1. Current Lawn Hill Creek SQMP sampling schedule

Site	Thread Distance from Page Ck (km)	Longitude	Latitude	Samples
L1a	1.0	138.5853580	-18.5671070	8 Transect Samples
L1b	1.0	138.5858730	-18.5671320	8 Transect Samples
L2a	5.7	138.5858420	-18.5256830	8 Transect Samples
L02	10.9	138.5838240	-18.4742920	8 Transect Samples
L03	13.1	138.5743598	-18.4377008	One Composite
L3a	14.9	138.5884460	-18.4473870	One Composite
L04	25.2	138.5928455	-18.3578529	One Composite
L05	32.0	138.6086590	-18.2986730	One Composite

4. NORTH MITTON CREEK

4.1 Historical background

The upper reaches of North Mitton Creek were first surveyed by TropWATER in August 2014 as part of a broad one-off study to characterise waterways in the vicinity of the mine site as an aid to closure planning. That survey indicated that North Mitton creek and its associated vegetation communities were in reasonably intact condition, but bottom sediments in the creek were found to be enriched with mine-related metals, especially zinc. In response to that initial finding Century immediately contracted TropWATER to conduct a detailed study to quantify the source, nature and extent of the sedimentary contaminant residues, assess ecological risks, recommend remedial measures and target locations for potential sediment removal. Sampling was conducted at 42 locations established at gradually increasing intervals between the Sediment Dam One spillway and Mitton Springs site MS1 (which was already known to contain low metal concentrations based on REMP sampling results); a thread distance of approximately 10 km from the Sediment Dam Spillway (Figure 4.1.1).

Figure 4.1.1: Map showing the location of sites sampled during the initial survey of North Mitton Creek in 2014.

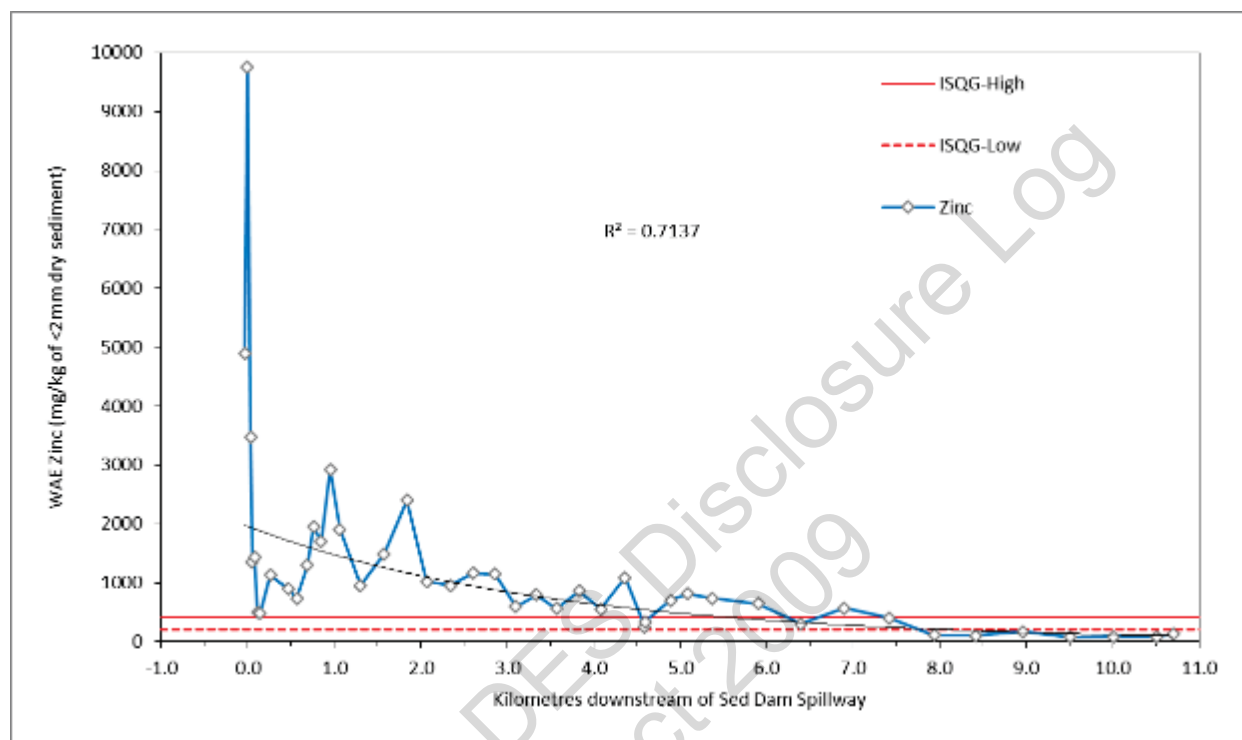


The results of that sediment sampling survey, completed in October 2014, indicated that sediments within a 7.4 km section of North Mitton Creek, between Sediment Dam One and the entry point of Gum Hole Plains tributary, contained elevated concentrations of mine-sourced zinc (plus minor quantities of cadmium and lead). Zinc concentrations within that stream-reach attenuated significantly with distance downstream (see Figure 4.1.2), but only three of the 42 sites sampled reported results that did not exceed the ANZECC 2000 ISQG-High, indicating that immediate remedial action was warranted. Zinc loads in the contaminated section of the creek totalled approximately 1400 kg, 540 kg of which was contained within a 1.32 km length of stream situated within 2 km of the sediment dam.

Pursuant to these findings Century commissioned excavation works to remove as much of the contaminated sediment as possible prior to the impending wet season. This work, which was completed in December 2014, primarily targeted accessible stream reaches that contained zinc loads in excess of 0.22 kg per lineal metre of streambed, but included removal of sediments from some other readily accessible stream locations situated within 3.5 km of the dam. In total 1260 m³ of bed material predicted to contain an estimated zinc

load of 440 kg was excavated from a 710 m length of the streambed. A total of 7,650 m³ of contaminated sediment was also removed from the base of the sediment dam itself, and the dam release valve was sealed to ensure that future releases will occur only during overflows.

Figure 4.1.2 Spatial distribution of Zn concentrations in North Mitton Creek sites prior to removal works in December 2014.



A follow-up survey in 2015 entailed the collection of 32 samples composited from 89 reaches along the creek between the toe of the Sediment Dam One (SD1) spillway and the Compliance Sediment site NM_SW04_REC (3.7 km thread distance), in order to quantify the effects of removal works on sediment loads and identify any remaining hot spots to target for further removal works. The results of this survey have previously been reported (TropWATER 2015) and will not be reproduced in this report as the data have been superseded by the findings of more recent surveys.

One of the recommendations of the above investigations was to attempt to establish additional REMP monitoring sites in potentially impacted sections of North Mitton Creek. Surveys were subsequently conducted to locate prospective sites; however, due to the highly ephemeral nature of those upper creek reaches, very few potential candidates were identified. There were a few locations which appear to have retained water at some stage in the past and the REMP protocols have been revised to ensure that these sites will be routinely inspected in the future and sampled if they are ever found to be holding sufficient water. Accordingly, the pre-existing REMP site (MS1 - Mitton Springs), which has been sampled routinely since 2006, is the only impact site in the Mitton Creek section of the Century study area that regularly (though not always) retains sufficient water to be sampled for water quality and aquatic ecosystem condition indicators. During the 2016 REMP sampling campaign one of the prospective new sites (NM24) was holding sufficient water to be sampled; however, water levels were low and rapidly retracting, suggesting that regular sampling in the future is an unlikely proposition.

The lack of aquatic habitats in the affected section of the creek limits the potential for harm to aquatic ecosystems inhabiting that part of the creek. Accordingly, investigations to date have focussed on assessing

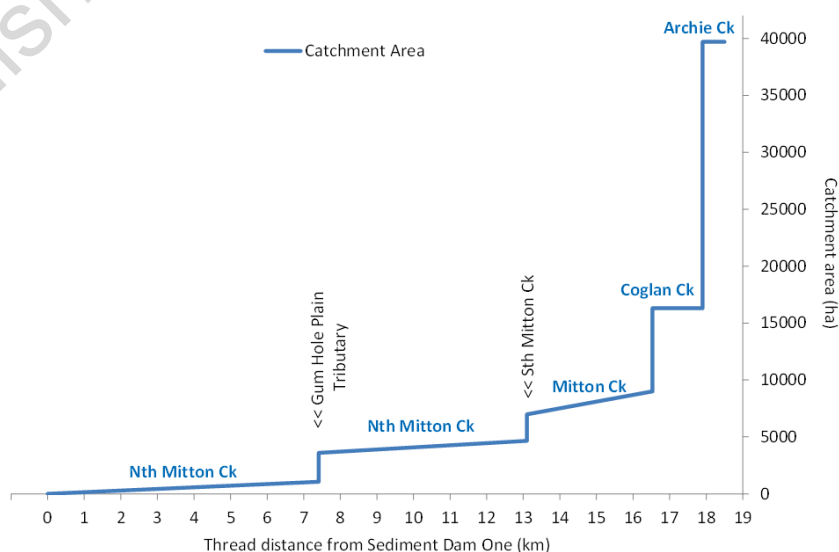
and minimising the potential for impacts on downstream environments that support more viable aquatic habitats. Risk assessments require increased consideration of Zn loads rather than concentrations. That is because the upper reaches of the creek are generally small and narrow with thin bottom sediments, so even though the Zn concentrations in the sediment are elevated, the total quantities of contaminated sediment present may be too low to present a risk to downstream receiving waters, especially those situated downstream of the Gum Hole Plains tributary (7.4 km from SD1) which receive substantial supplies of natural sediment. For this reason metal concentrations alone are not a useful indicator of risks to downstream environments.

This is a particular issue for North Mitton Creek because it rises at the spillway of Sediment Dam One and therefore the upper reaches have virtually no natural catchment area to provide dilution. In 2016 a dirty water diversion was constructed to reduce the spill risk of Sediment Dam One from a spill volume of 124.3 ML for a 1 in 20 year 2 month wet season event to a zero spill volume for the same wet season event. The control has been designed so successfully that the new sediment dam flood immunity is now great than a 1 in 100 year 2 month wet season event and accordingly the catchment area of the creek at the foot of the spillway is now effectively zero.

When conducting removal works it is necessary to maintain the geomorphological integrity of the stream and avoid damage to riparian communities (to do otherwise would potentially be more harmful than the contaminants being removed). Hence there will always be some residual Zn-enriched sediment remaining in the streambed, and given the limited supply of natural sediment it could take many years for that material to be diluted, if at all. It is therefore conceivable that Zn concentrations in North Mitton will remain in exceedance well into the foreseeable future even if the total quantities of Zn present are reduced to negligible levels.

Though the lithology of the catchments in this drainage system is diverse, the surface topography and edaphics are sufficiently uniform to suggest that cumulative catchment area will be a reasonably reliable first order indicator of relative sediment dilution capacity, and previous investigations have employed this as a method of assessing the capacity of the streams to safely assimilate metal loads. The catchment area breakdown for the stream reaches between SD1 and Archie Creek are shown in Figure 4.1.

Figure 4.1.3 Catchment areas of receiving streams between Sediment Dam One and Archie Creek.

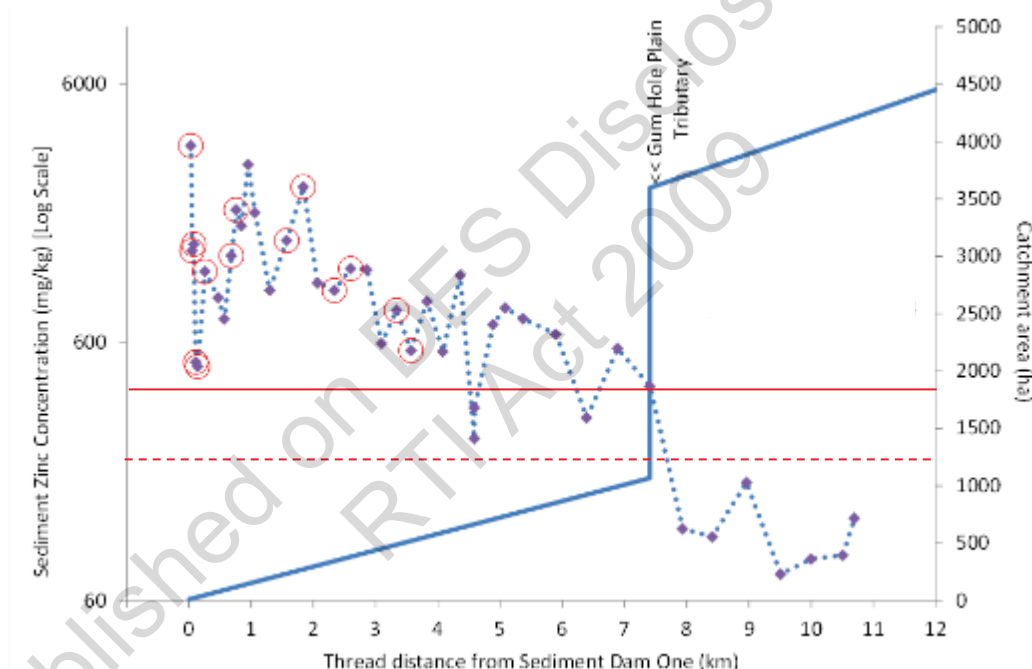


It can be seen that there is a quantum increase in effective catchment area about 7.4 km downstream from SD1 at the point where North Mitton Creek intersects an unnamed tributary which drains Gum Hole Plain

(situated to the north of the creek). The 2014 investigation suggested that natural sediment supplies to the receiving waters downstream of that point would be sufficient to ensure that the existing contaminant load could be safely assimilated if it were to ever be carried that far downstream. To date monitoring results support that contention, as the sediment zinc concentrations immediately downstream of the Gum Hole Plain tributary have consistently been below the ISQG-Low (see for example Figure 4.1.4), and REMP Site MS1 has never shown any signs of enrichment.

The 2015 report concluded that the risks presented by the existing post-removal Zn load was low enough to suggest that the physical impacts of any further removal works involving wholesale excavation of the creek bed could potentially present a greater threat to the environmental values of the stream. Accordingly it was recommended that any further removal works should be highly targeted and focussed on small defined hot spots. It was also suggested that some of the excavated sections could potentially act as sediment traps which could be periodically re-excavated after flow events in order to gradually remove sediment over a number of years with minimal impact to the majority of the stream.

Figure 4.1.4 Graph showing the effect of increasing catchment area on the sediment zinc concentrations in North Mitton Creek. The blue represents catchment area. The solid red line is the ISQG-High and the broken red line is the ISQG-Low. Red Circles denote sites where removal works were conducted in 2014.



A Zn TL exceedance was reported at the North Mitton Compliance site in 2016. This triggered follow-up monitoring at the sites shown in Figure 4.1.5 to identify any further opportunities for sediment removal. The results of that survey have previously been reported and are not reproduced in this report as they have been superseded by the 2017 survey results which are presented below.

Up until 2017 the primary monitoring objective in North Mitton Creek was to identify places where sediment removal works could be carried out with the greatest effect, and in order to accomplish that objective it was necessary to vary the location and length of the reaches being assessed to suit the different circumstances that were encountered each year. This was an effective means of obtaining the necessary management information, but the resulting dataset was not well suited for accurately tracking temporal trends.

During those early surveys a great deal of effort was expended attempting to quantify the sediment loads within each reach. It will probably always be possible to provide management with coarse estimates of the sediment loads at key/proposed removal locations so that they can gauge the approximate scope of the

required works. However, the process of evaluating the sediment volume in every part of every reach is excessively laborious for ongoing routine monitoring purposes. More significantly, the bottom sediments in many key sections of the creek are now so sparse (1 to 6 cm deep) that it is no longer feasible to obtain sediment load estimates that are sufficiently accurate to be used for trend assessment purposes. For example a sediment depth estimation error of only ± 2 cm (which is not easy to achieve) may now equate to an uncertainty level of $\pm 100\%$ or more.

Figure 4.1.5 North Mitton Creek SQMP stream reaches sampled in 2016 and 2017. Points mark the beginning of each reach (except for NS19 which marks the end of Reach NS18). The REMP and compliance sites are discrete sampling locations.



Accordingly, in 2017 an attempt was made to rationalise the program by establishing fixed site locations that could be resampled each year in order to assess temporal trends without undermining our capacity to identify sediment removal opportunities. The 2017 pilot trial entailed collecting composite samples representative of reaches nominally 250 to 500 m in length (actual reach lengths are recorded in the results tables). This procedure requires sampling personnel to traverse the entire length of each reach taking regular subsamples along the way in order to accumulate a representative composite sample.

4.2 Current Status

The North Mitton EA compliance site NM_SW04_REC is situated at the beginning of Reach NS16. The sediment Zn concentration reported at the compliance site in 2017 was 270 mg/kg which comfortably complied with the TL (see Table 4.2.1) even though the mean concentrations in the adjacent reaches (NS15 and NS16) were 780 and 750 mg/kg, respectively (see Table 4.2.2). This highlights the inadequacies of site-based sampling methods when dealing with highly heterogeneous sediments.

Table 4.2.1: North Mitton Creek sediment compliance analysis results (concentrations in mg/kg) for North and South Mitton Creeks in 2017. Red font indicates results greater than the EA TL and blue results are greater than the SQG-Low.

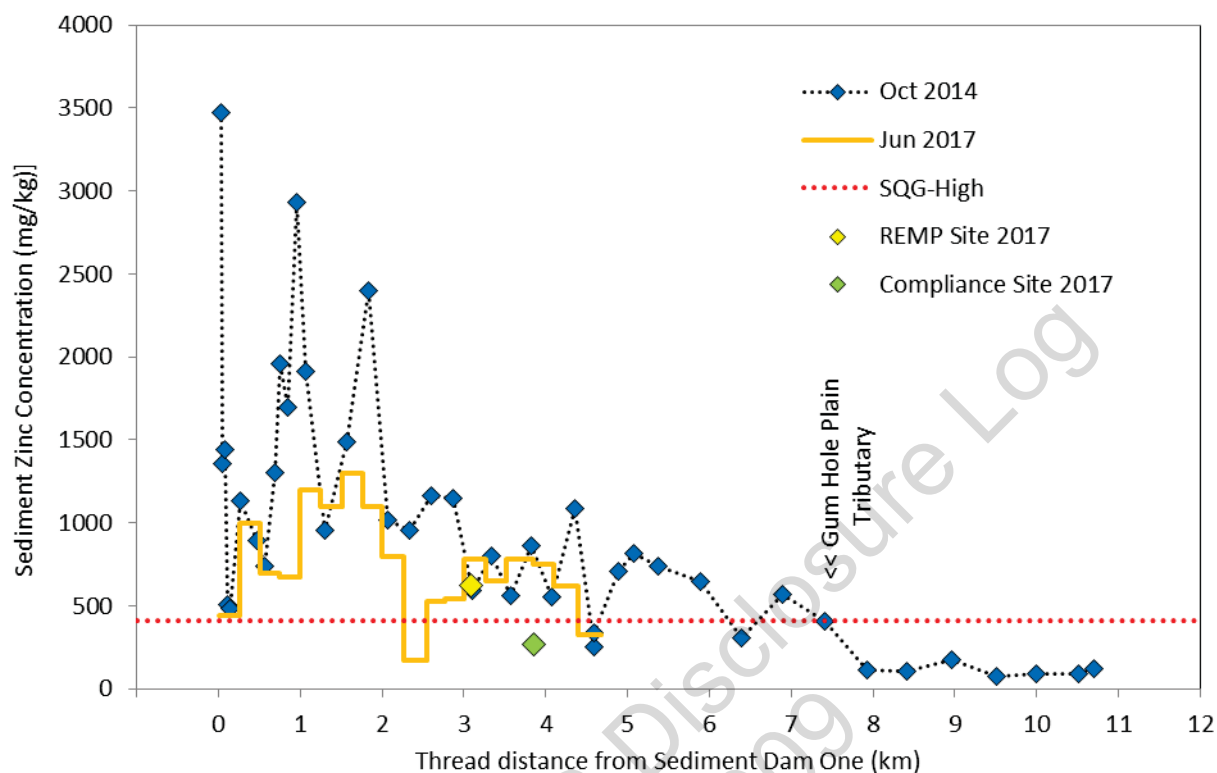
EA Stream sediment trigger levels (mg/kg)	Site	NM_SW04_REC	SM_SW05_REF	SM_SW04_REC
	Sample Date	30/06/2017	30/06/2017	30/06/2017
10	Cadmium	0.5	<0.1	<0.1
270	Copper	8.2	1.5	1.2
220	Lead	26	16	7.7
52	Nickel	5.8	<0.5	<0.5
410	Zinc	270	13	6.3
70	Arsenic	1.7	1.3	1.1
3 x greater than reference site	Selenium	<1	<1	<1
For interpretation purposes	Manganese	930	26	130
For interpretation purposes	< 63µm Particle size (%)	54.5	5.2	4.5

Table 4.2.2: North Mitton Creek SQMP analysis results (in mg/kg) for 2017. Red font indicates results greater than the SQG-High and blue results are greater than the SQG-Low.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb
17NS01	0	250	440	0.6	39
17NS02	250	260	1000	1.0	38
17NS03	510	240	700	0.7	26
17NS04	750	250	670	0.7	40
17NS05	1000	250	1200	1.1	34
17NS06	1250	260	1100	1.0	32
17NS07	1510	250	1300	1.3	36
17NS08	1760	240	1100	1.1	27
17NS09	2000	260	800	1.0	27
17NS10	2260	290	170	0.2	14
17NS11	2550	210	530	0.5	16
17NS12	2760	240	540	0.4	15
17NS13	3000	270	780	1.0	23
17NS14	3270	250	650	0.6	20
17NS15	3520	330	780	1.0	21
17NS16	3850	240	750	0.9	20
17NS17	4090	300	620	0.7	16
17NS18	4390	280	330	0.2	18

It is evident from the previous investigations discussed in 4.1 that removal works to date have effectively reduced the Zn load in upper reaches of the creek and hence the amount of dilution required for downstream waters to safely assimilate the contaminated sediment. This improvement is partially reflected in the Zn concentration data (see Figure 4.2.1) as there are no longer any extreme levels in excess of 1500 mg/kg. However, the relatively small amounts of residual sediment remaining within the upper 4 km of the creek contain Zn concentrations that are still above the SQG-High.

Figure 4.2.1 Zinc concentrations in 2017 compared to 2014 (prior to sediment removal works). The 2017 samples were composites indicative of the mean concentration within each stream reach.



As noted previously, due to the small size of North Mitton's upper catchment area and the consequent paucity of natural water and sediment supply, it may take a long time for these residual sediments to become diluted. In risk terms the lack of water supply is also an extenuating factor as it decreases the likelihood of the contaminated bedload being carried downstream to more valuable environments.

It may still be advisable to attempt to accelerate natural dilution processes by exploiting any opportunities to further reduce the bedload, but only under the proviso that the work can be done without excessively damaging the integrity of the stream. In that regard it is pertinent to note the extensive evidence (discussed in previous sections) that Century Mine-sourced Zn has low bioavailability, and there are many sites in this study area with sediment Zn concentrations similar to the existing levels in North Mitton which support healthy aquatic ecosystems. In short, as things stand, the damage caused by excessive excavation of the streambed and banks would very likely have greater impact on the aquatic ecosystem than would the existing sediment contamination. Accordingly, any further removal works should be highly targeted, low impact and conducted using light excavation equipment or suction methods.

To that end, during the 2017 survey each reach was divided into sub-reaches, the length of which was dictated by changes in the morphology of the streambed. An attempt was made to estimate the sediment load within each sub-reach. As explained previously, due to the heterogeneity and sparse nature of the bed sediments, this excessively laborious procedure yielded first order load estimates which, though not sufficiently accurate to be used for quantitative trend analysis, were adequate to provide an indication of the approximate scope of any removal works that might be considered. These data were then analysed to identify sub-reaches which contained sufficient Zn load to be potential candidates for sediment removal.

The identified sub-reaches are listed in Table 4.2.4. It must be stressed that these simply represent the locations where managers would achieve the best return on investment and disturb the smallest sections of stream, if removal works were to be carried out. Effectively these are sites which deserve closer examination by Century environmental managers to determine if it is feasible to conduct removal works without excessively impacting on the inherent values of the stream and associated riparian habitats.

Table 4.2.3: Prospective sediment removal sites identified in the 2017 survey.

Thread Distance from Sediment Dam One (m)	Length (m)	Average Width (m)	Previously Excavated	Mean Zinc Concentration mg/kg	Approximate Sediment Load (m ³)	Approximate Zinc Load (Kg)
300	40	4	Yes	1000	10	17.3
660	30	4	Yes	700	7	9.1
830	30	4	Yes	670	7	8.7
890	30	5	Yes	670	8	9.0
1270	50	7	Yes	1100	21	41.6
1430	20	5	Yes	1100	6	11.9
1650	20	4	Yes	1300	5	11.2
2200	10	5	Yes	800	3	3.6
2230	40	6	No	800	14	20.7
3200	20	7	No	780	8	11.8
3700	40	6	No	780	14	20.2
4240	50	4	No	620	10	11.2
4290	25	4	No	620	6	6.7

4.3 Protocols for Future Monitoring

To date the primary focus of the North Mitton SQMP has been to identify potential contaminant removal sites. That will remain an objective of the program into the foreseeable future but for the purposes of ongoing routine monitoring, increasing emphasis will be placed on trend analysis and early detection of any emerging impacts on downstream environments.

To that end the following routine monitoring protocols have been devised for future use:

- To ensure that results can be readily compared from year to year, composite samples will be taken at the same reach locations and over the same reach length each year, as shown in Figure 4.3.1 and listed in Table 4.3.1.
- The spatial scope of the site network has been extended by approximately 4 km to encompass the stream reaches up and downstream of the Gum Hole Plains tributary in order to ensure early detection if there is any migration of the contaminated sediment and to confirm the predicted assimilation capacity of downstream reaches.
- Sampling personnel will take composite samples for analysis by collecting subsamples along the full length of each reach.
- While traversing reaches where contamination is known to be present, personnel will take GPS waypoints and photographs, and conduct sediment volume estimates within any sub-reaches which appear to have trapped sufficient sediment to be potential candidates for non-destructive removal works.
- All samples will be sieved to remove material >2 mm, analysed for minus 2 mm dilute acid extractable Zn, Cd and Pb, and sieved to determine percent passing 63 µm.

Figure 4.3.1 Proposed sites for routine monitoring of North Mitton Creek.

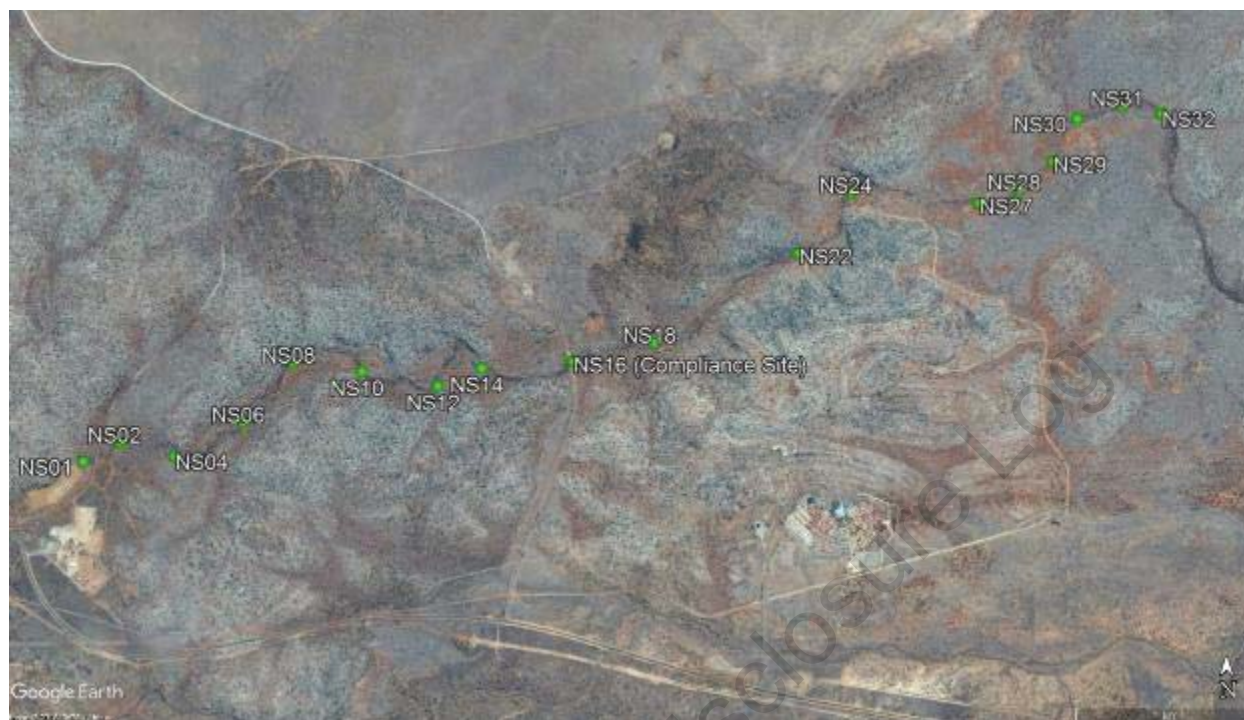


Table 4.3.1 Proposed sites for routine SQMP monitoring of North Mitton Creek.

Creek	Reach	Start Point (m)	Longitude	Latitude	Reach Length (m)
North Mitton	NS01	0	138.6320650	-18.7313450	250
North Mitton	NS02	250	138.6339650	-18.7303970	500
North Mitton	NS04	750	138.6368640	-18.7310840	500
North Mitton	NS06	1250	138.6404650	-18.7293910	500
North Mitton	NS08	1760	138.6431210	-18.7264290	500
North Mitton	NS10	2260	138.6467160	-18.7268680	500
North Mitton	NS12	2760	138.6507100	-18.7276020	500
North Mitton	NS14	3270	138.6530180	-18.7267020	500
North Mitton	NS16	3850	138.6578230	-18.7263650	500
North Mitton	NS18	4390	138.6621100	-18.7254290	500
North Mitton	NS22	5390	138.6697066	-18.7209623	500
North Mitton	NS24	5890	138.6724703	-18.7179487	500
North Mitton	NS27	6640	138.6792306	-18.7184551	250
North Mitton	NS28	6890	138.6813606	-18.7178077	250
North Mitton	NS29	7140	138.6831393	-18.7163750	250
North Mitton	NS30	7390	138.6844358	-18.7142397	250
North Mitton	NS31	7640	138.6867909	-18.7136095	250
North Mitton	NS32	7890	138.6888939	-18.7139783	250

5. COGLAN CREEK

5.1 Historical background

The monitoring sites network for Cogan Creek is shown in Figure 5.1.1. REMP site Cog1, a small pool formed by seepage water situated immediately downstream of the evaporation dam saddle wall, has been monitored annually in post-wet season REMP surveys for more than a decade. The site was originally located closer to the dam but it was necessary to gradually move it further downstream because it developed into a *Typha* (bulrush) wetland with vegetation so dense that the water column could no longer be accessed by sampling personnel.

Figure 5.1.1 Current monitoring sites on Cogan Creek. Red markers denote compliance sites, green denote REMP sites and orange markers are SQMP sites.



Not surprisingly, given that the water is sourced from evaporation dam seepage and the site is subject to high evapoconcentration rates, Cog1 has historically reported poor water quality characterised by high salt concentrations. Metal concentrations were generally low until 2012 when elevated Zn concentrations were detected. No such water quality problems were evident further downstream at the EA compliance site (C_SW_REC) or at Cog2, which was the only other REMP site on Cogan Creek at that time. This seemed to indicate that impacts were localised to Cog1, but as a precautionary measure, in 2014 new REMP sites were established in the closest waterholes downstream of Cog1 to better assess the extent of influences.

The Cogan Creek system was subject to a detailed assessment of the influences of the adjacent Evaporation Dam in 2015 (TropWATER 2015a), and this led to the establishment of SQMP monitoring sites CS01 to CS02. The study confirmed that effects attenuated rapidly with distance downstream from Cog1, and to date subsequent REMP and SQMP monitoring has supported that contention (see Table 5.1.1 for example).

It is apparent from annual REMP reports that the wetland at Cog1 has historically performed a valuable function, removing dissolved metals from the water column and sequestering them into the bottom sediments. As a consequence Zn concentrations have risen to levels well above the SQG-high. However, most of this zinc is likely bound up in the form of non-toxic organic complexes, as evidenced by the prolific wetland plant growth. Notably the contaminated sediment has been stabilised by plant roots extending to soil depths of up to 0.5 m and is therefore unlikely to be mobilised as long as the plant roots remain viable.

Table 5.1.1 SQMP sediment analysis results for Coglan Creek in 2016

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb	Mn	P
16CS01	0	250	850	<0.4	12	610	110
16CS02	250	250	36	<0.4	<5	140	31
16Cog1b	1720	15	39	<0.4	6	88	66
16Cog1c	3240	15	13	<0.4	<5	76	20
16Cog2	4380	15	11	<0.4	<5	22	23
16RCog	0	0	<5	<0.4	<5	270	7

Notably, in 2014 Century installed clean water diversions and dirty water sumps with pump-back systems. This will have reduced contaminant inputs to the upper reaches of the stream sufficiently to expect that further increases in contaminant load will be minimal.

REMP reports have advised against attempting any sediment removal works at this stage and have instead recommended:

- Avoiding any disturbances which could potentially undermine the functionality of the wetland at Cog1
- Monitoring the condition of the wetland to ensure that it is remaining viable
- Continued monitoring of water and sediment quality at sites immediately downstream of the wetland to ensure early detection of any potential metal releases which could occur if the wetland were to fail.

5.2 Current Status

As would be expected based on historical findings, there were no TL exceedances at the Coglan compliance site in 2017 (Table 5.2.1). The SQMP results for 2017 (Table 5.2.2) exhibited the same rapid attenuation in metal concentrations that has been evident previously. The result for CS01 (1800 mg/kg) was numerically higher than last year (850 mg/kg) but given the heterogeneous nature of these sediments that is likely to be largely a consequence of random variability.

Table 5.2.1 EA sediment compliance results for Coglan Creek in 2017.

EA Stream sediment trigger levels (mg/kg)	Site	C_SW14_REF	C_SW08_REC
	Sample Date	30/06/2017	30/06/2017
10	Cadmium	<0.1	<0.1
270	Copper	0.7	0.8
220	Lead	2.3	1.2
52	Nickel	<0.5	<0.5
410	Zinc	2.1	4.8
70	Arsenic	2.4	1.4
3 x greater than reference site	Selenium	<1	<1
For interpretation purposes	Manganese	17	170
For interpretation purposes	< 63µm Particle size (%)	5.7	5.2

Table 5.2.2 SQMP sediment analysis results for Coglan Creek in 2017.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb
17CS01	0	250	1800	0.6	5
17CS02	250	270	18	<0.1	<0.5
17Cog1b	1720	30	55	0.2	<0.5
17Cog1c	3240	30	<0.5	<0.1	<0.5
17Cog2	4380	30	13	0.1	<0.5
17RCog	0	30	5.1	<0.1	2.3

Cog1 historically received sufficient seepage to sustain the wetland plants; however, the sumps installed in 2014 to capture the seepage and return it to the evaporation dam, may potentially be starving the wetland of water. The effects of this have probably been exacerbated by a lack of major rainfall events over the past two wet seasons. *Typha* plants naturally senesce during dry periods but their rhizomes (i.e. roots) remain viable and regrow once wet conditions return. This makes it difficult to gauge whether or not the plants are still viable, but there are signs that their health may be suffering and grounds to suspect that natural rainwater runoff may be insufficient to maintain the wetland in the long term. If so, that raises questions about the potential fate of the metals contained in the wetland sediments. Assessing those potential effects will be the primary focus of future monitoring activities.

5.3 Protocols for Future Monitoring

REMP Sampling

The existing REMP sites (including the reference site) will be sampled during each annual post-wet survey. They will not be resampled in the dry season SQMP unless anomalous results have been reported in the REMP survey.

SQMP sampling

Given existing uncertainties regarding the ongoing functionality of the Cog1 wetland, the routine SQMP monitoring site network (listed in Table 5.3.1 and shown on Figure 5.1.1) now includes extra sites immediately downstream of Cog1 in order to increase early detection capacity in the event that the wetland fails and the contaminated sediments become mobile. Sampling and analysis methods will be the same as those used in North Mitton Creek.

Table 5.3.1 Proposed sites for routine SQMP monitoring of Coglan Creek.

Creek	Reach	Start Point (m)	Longitude	Latitude	Reach Length (m)
Coglan	CS00	0	138.6746912	-18.7909194	360
Coglan	CS01	360	138.6774271	-18.7919856	250
Coglan	CS02	610	138.6788470	-18.7936050	250
Coglan	CS03	860	138.6812226	-18.7938295	250
Coglan	CS04	1110	138.6833961	-18.7931737	250
Coglan	CS05	1360	138.6856024	-18.7924322	500

6. LITTLE ARCHIE CREEK

6.1 Historical background

A one-off survey designed to characterise all streams in the Century study area was conducted in 2014 as an aid to closure planning. That study detected Zn concentrations above the SQG-High in sediments within the uppermost reaches of Little Archie Creek. REMP sites on Little Archie and Archie Creek had been monitored since 2006 and had never detected anomalous Zn levels. However, at that time the nearest REMP site LAr1 (see Figure 6.1.1) was situated several km downstream of the anomalous reaches that had been sampled in 2014. LAr1 had originally been selected as a REMP site on the basis that it was the closest waterhole to the mine that reliably holds water long enough to allow sampling of aquatic biota.

Figure 6.1.1 Current monitoring sites on Little Archie Creek. Green markers denote REMP sites and purple markers are SQMP sites. SQMP sites are numbered consecutively in downstream order from LS00 to LS09.



During the 2015 REMP survey an attempt was made to locate additional REMP monitoring sites that were closer to the mine. This resulted in the establishment of two additional sites (PH387 and PH099, see Figure 6.1.1) which appeared to be capable of periodically holding water long enough to be sampled for aquatic biota and which could be sampled for sediment every year. The 2015 and 2016 REMP reports provided no indication of metal enrichment in the sediments at those sites, suggesting that Zn contamination was confined to the very small, highly ephemeral stream reach immediately proximal to the mine site. To determine the full extent of the contamination, ten SQMP reach sampling sites (LS00 to LS09) were established to encompass the uppermost 1.6 km of the creek.

The 2016 SQMP results (Table 6.1.1) indicated that two reaches – LS00, a 90 m reach situated at the foot of the dam wall and LS03, a 100 m reach located 280 m downstream – contained mean Zn concentrations greater than the SQG-High. However, the exceedance levels were very minor indicating that minimal dilution would be required to achieve compliance. The quantities of sediment present in this section of the creek was also small compared to the aquatic habitats further downstream. Moreover, many sites in this study area which contain considerably higher sediment Zn concentrations maintain healthy aquatic communities. Accordingly, it was concluded that the physical disturbances caused by removal works would potentially present a greater threat to the integrity and environmental values of the creek than would the existing metal residues. The existing concentrations are nevertheless non-compliant so ongoing monitoring has been recommended to ascertain temporal trends.

Table 6.1.1 SQMP analysis results for Little Archie Creek in 2016. Values in red exceed the SQG-High and blue exceed the SQG-Low.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb	Mn	P
16LS00	0	90	450	2.1	32	900	4400
16LS01	90	90	96	0.6	25	970	2300
16LS02	180	100	66	0.5	27	1100	1600
16LS03	280	100	470	1.9	51	1200	1400
16LS04	380	100	240	1.1	47	1200	1100
16LS05	480	100	280	1.3	55	1300	1000
16LS06	580	250	180	0.7	31	910	440
16LS07	830	250	94	<0.4	24	890	270
16LS08	1080	250	150	0.6	28	960	240
16LS09	1330	300	82	<0.4	25	860	140

6.2 Current Status

Table 6.2.1 SQMP analysis results for Little Archie Creek in 2017. Values in red exceed the SQG-High and blue exceed the SQG-Low.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb
17LS00	0	80	950	3.3	23
17LS01	80	100	51	0.4	20
17LS02	180	100	71	0.5	29
17LS03	280	100	320	1.2	41
17LS04	380	90	200	0.9	43
17LS05	470	100	220	1.1	46
17LS06	570	270	82	0.3	25
17LS07	840	240	54	0.3	22
17LS08	1080	260	83	0.4	23
17LS09	1340	430	61	0.4	23

The 2017 SQMP results tabulated above ostensibly recapitulate the 2016 findings in the sense that elevated concentrations were detected in the same reaches as last year. The results for LS00 were twice as high as last year, but LS03 was lower this year and did not exceed the SQG. These variations are almost certainly a consequence of random sampling errors due to the heterogeneity of the sediments which is a typical characteristic of streams in this study area. However, further monitoring will be needed to confirm that assumption and ensure that there are no emerging trends.

6.3 Protocols for Future Monitoring

REMP Sampling

The REMF sites shown in Figure 6.1.1 will be sampled annually during the postwet REMF surveys.

SQMP Sampling

The REMF sites will be resampled during annual SQMP dry season surveys only if anomalous results have been obtained from the preceding REMF sampling trip.

The SQMP reaches listed in Table 6.1.1 will be sampled annually in the dry season using the same methods that are employed in North Mitton and Coglean Creeks. Once there has been a flow event large enough to potentially alter the distribution of bed sediments in this creek this component of the program will be reviewed.

Table 6.1.1 Proposed sites for routine SQMP monitoring of Little Archie Creek.

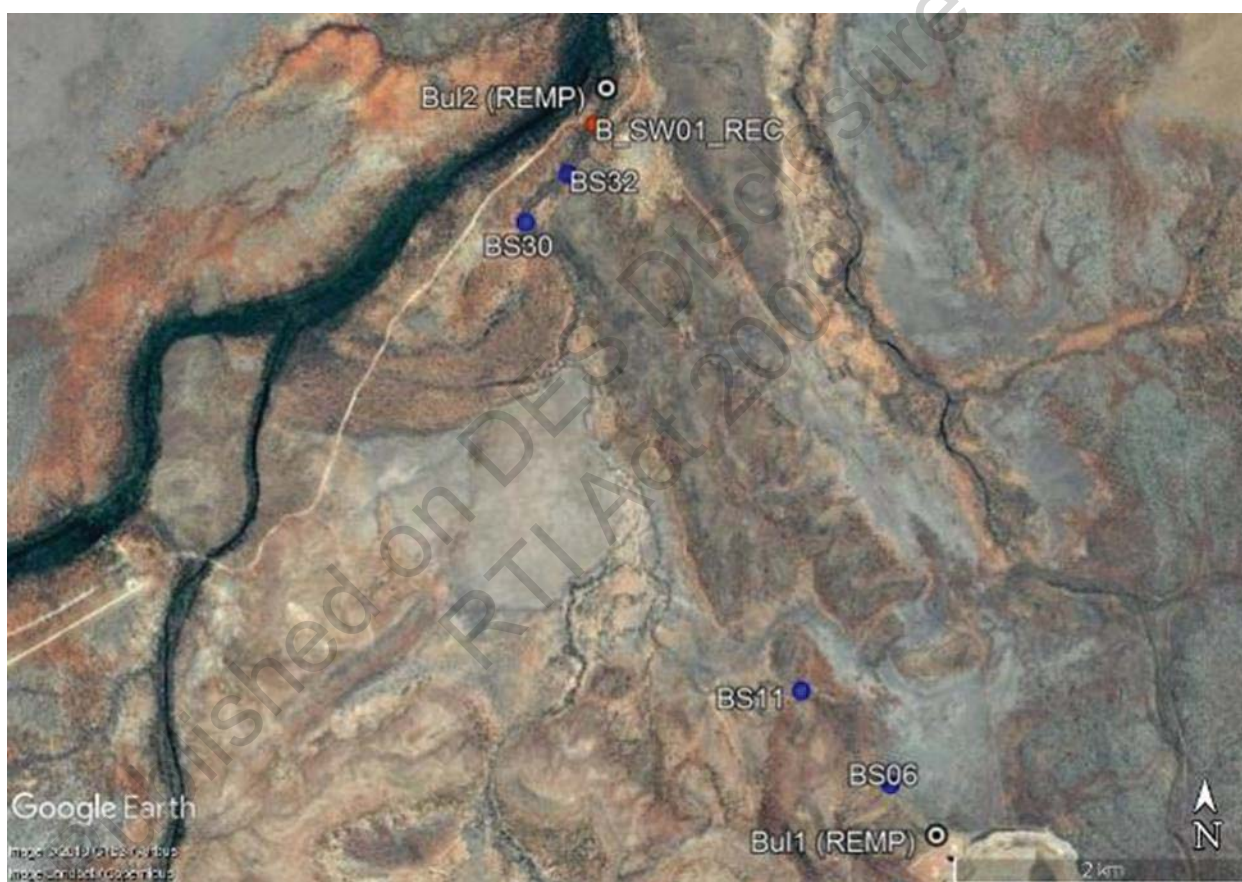
Creek	Reach	Start Point (m)	Longitude	Latitude	Reach Length (m)
Little Archie	LS00	0	138.6179260	-18.6981710	80
Little Archie	LS01	80	138.6178260	-18.6975000	100
Little Archie	LS02	180	138.6174540	-18.6971650	100
Little Archie	LS03	280	138.6169160	-18.6965100	100
Little Archie	LS04	380	138.6168510	-18.6956740	90
Little Archie	LS05	470	138.6174160	-18.6950280	100
Little Archie	LS06	570	138.6179640	-18.6943200	270
Little Archie	LS07	840	138.6169120	-18.6925390	240
Little Archie	LS08	1080	138.6178250	-18.6909290	260
Little Archie	LS09	1340	138.6187040	-18.6892180	430

7. BULLRIDGE CREEK

7.1 Historical background

Bullridge Creek is a highly ephemeral creek which contains only one waterhole capable of retaining water long enough to potentially support an aquatic ecosystem. Two REMP monitoring sites were established in this creek in 2006 and have been monitored annually since then. These comprised Bul1, which is a small temporary pool situated at the foot of the sediment dam that seldom holds water long enough for biological sampling to be carried out, and Bul2 which is located in the above-mentioned waterhole in the lower reaches of the creek, a short distance downstream from the EA compliance site and upstream of the confluence with Lawn Hill Creek (see figure 7.1.1).

Figure 7.1.1 Monitoring sites on Coglan Creek. Red marker denotes compliance site, white denotes REMP sites and blue markers are SQMP sites. In the interests of clarity only one of the SQMP sites between the dam and site BS11 are shown here. The locations of SQMP sites BS01 to BS11 are shown in Figure 7.3.1.



To date no anomalous results have been reported at Bul2 or the compliance site (B_SW01_REC). However, there have been historical indications of metals enrichment in the sediments at Bul1 with Zn concentrations above the SQG-High and Cd above SQG-Low. In 2015 an investigation was carried out to determine the spatial extent of the contamination and this led to the establishment of SQMP reach sampling sites BS01 to BS08, and BS30 to BS33 (the locations and lengths of which are indicated in results tables).

The 2016 SQMP results (Table 7.1.1) indicated that Zn levels significantly greater than the SQG-High were largely confined to the first 300 m of the stream. Concentrations generally attenuated with increasing distance downstream but the results obtained at thread distance of 650 to 900 m were slightly above the SQG-High and at 1.15 km the SQG-Low was still exceeded.

Table 7.1.1 SQMP analysis results for Bullridge Creek in 2016. Values in red exceed the SQG-High and blue exceed the SQG-Low.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb	Mn	P
16BS01	0	100	1500	1.9	80	1800	960
16BS02	100	100	2400	3.7	97	2900	1100
16BS03	200	100	1900	2.7	50	2300	750
16BS04	300	100	520	0.7	47	810	330
16BS05	400	250	300	0.4	30	690	140
16BS06	650	250	460	0.6	35	940	150
16BS07	900	250	180	<0.4	24	490	59
16BS08	1150	250	220	<0.4	25	520	73
16BS30	6650	250	33	<0.4	10	300	43
16BS31	6900	250	44	<0.4	12	390	41
16BS32	7150	250	41	<0.4	8	260	37
16BS33	7400	250	59	<0.4	11	370	36

7.2 Current Status

As has been the case historically, no exceedances were reported at the Bullridge Creek EA compliance site in 2017 (Table 7.2.1). As expected the metals levels at Bul2 were also low in 2017 while at Bull most sediment metals showed some enrichment with Zn exceeding the SQG-High, and Cd and Pb exceeding the SQG-Low. As has generally been the case in recent years, Bull had dried out prior to the 2017 REMP survey and could only be sampled for sediment.

Table 7.1.1 EA Compliance sampling results for Bullridge Creek in 2017.

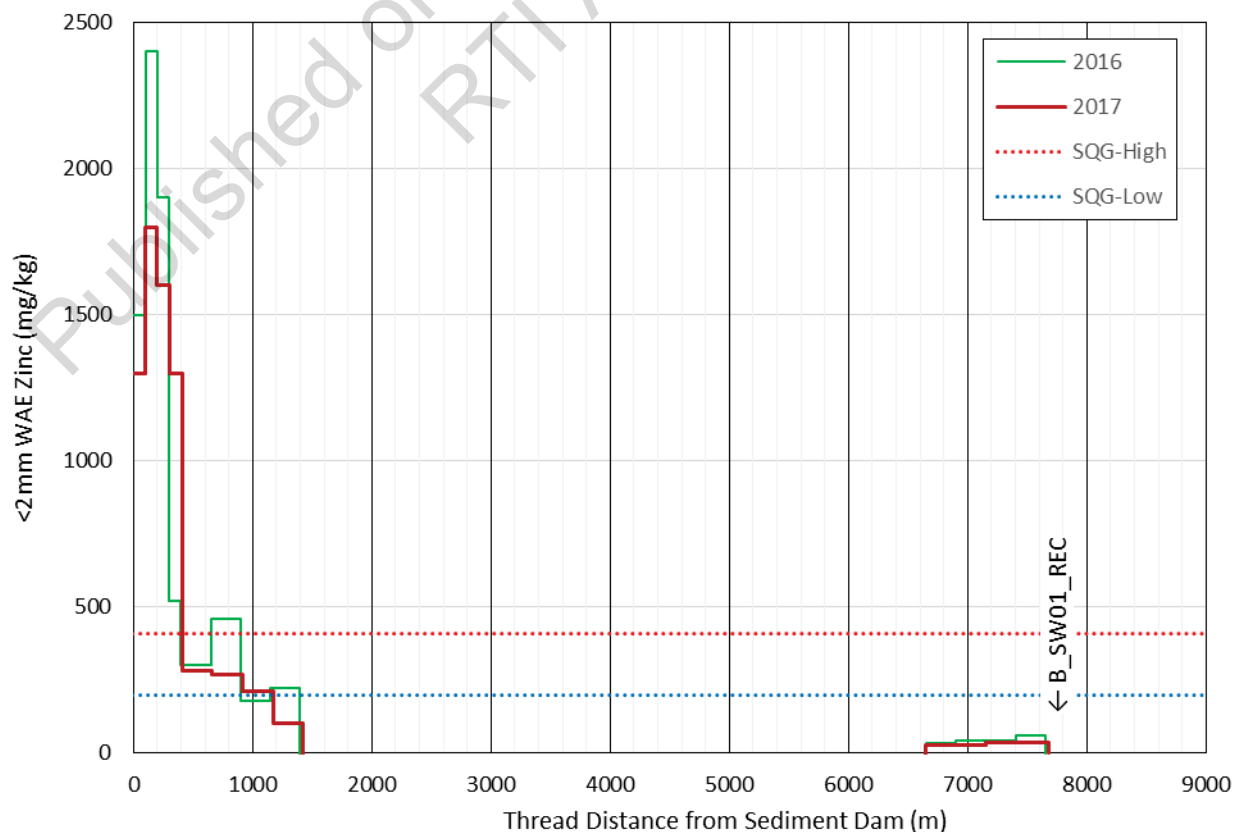
EA Stream sediment trigger levels (mg/kg)	Site	B_SW01_REC
	Sample Date	30/06/2017
10	Cadmium	<0.1
270	Copper	3
220	Lead	13
52	Nickel	2.1
410	Zinc	21
70	Arsenic	3.1
3 x greater than reference site	Selenium	<1
For interpretation purposes	Manganese	270
For interpretation purposes	< 63µm Particle size (%)	20.0

The 2017 SQMP results ((Table 7.2.1) are compared to the 2016 results in Figure 2.2.1. On face value the comparison suggests that there may have been some downstream movement of contaminated sediment during the 2016-2017 wet season. However, given the heterogeneity of these sediments it is possible that the apparent effect is simply a consequence of random variability.

Table 7.2.1 SQMP analysis results for Bullridge Creek in 2017. Values in red exceed the SQG-High and blue exceed the SQG-Low.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb
17BS01	0	100	1300	1.3	34
17BS02	100	100	1800	2.1	69
17BS03	200	100	1600	2.0	38
17BS04	300	110	1300	1.8	72
17BS05	410	250	280	0.4	27
17BS06	660	260	270	0.4	23
17BS07	920	250	210	0.3	21
17BS08	1170	250	100	<0.1	17
17BS30	6650	250	25	0.1	11
17BS31	6900	250	25	<0.1	9.6
17BS32	7150	240	36	<0.1	13
17BS33	7390	290	35	0.1	11

Figure 7.2.1 SQMP analysis results for Bullridge Creek in 2017. Values in red exceed the SQG-High and blue exceed the SQG-Low.



7.3 Protocols for Future Monitoring

In order to increase our capacity to detect sediment movements and discriminate between random variations and emerging trends, the spatial scope of the sampling sites in the upper reaches of the creek has been extended 750 m further downstream by adding sites BS09 (a 250 m reach) and BS11 (a 500 m). Due to the consistently low results reported at to date at SQMP sites in the lower reaches of the creek, sites BS31 and BS33 have been discontinued and the length of reaches BS30 and BS32 have been increased to cover those sections of the stream (see Table 7.3.1).

Figure 7.3.1 Location of routine SQMP reach sampling sites in the upper reaches of Bullridge Creek. Sites in the lower reaches of the creek are shown in Figure 7.1.1.

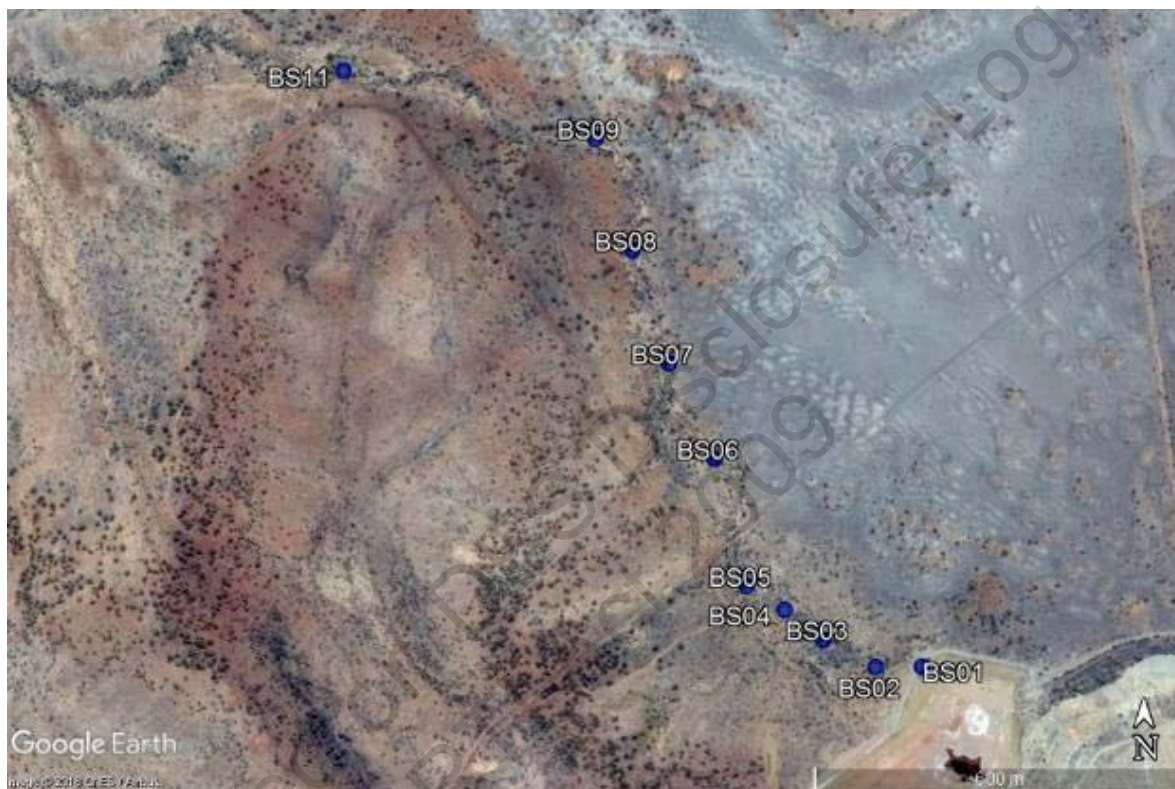


Table 7.3.1 Routine SQMP reach sampling sites on Bullridge Creek.

Creek	Reach	Start Point (m)	Longitude	Latitude	Reach Length (m)
Bullridge	BS01	0	138.5832820	-18.7072610	100
Bullridge	BS02	100	138.5825720	-18.7072660	100
Bullridge	BS03	200	138.5817670	-18.7068680	100
Bullridge	BS04	300	138.5811730	-18.7064320	100
Bullridge	BS05	400	138.5805880	-18.7060890	250
Bullridge	BS06	650	138.5800970	-18.7042410	250
Bullridge	BS07	900	138.5793960	-18.7028520	250
Bullridge	BS08	1150	138.5788330	-18.7012040	250
Bullridge	BS09	1400	138.5782595	-18.6995786	250
Bullridge	BS11	1650	138.5743895	-18.6985824	500
Bullridge	BS30	2150	138.5567850	-18.6702780	500
Bullridge	BS32	2650	138.5595180	-18.6673590	500

The 2018 survey will include an assessment of the relative benefits and risks of attempting to remove any of the contaminated sediment, and will identify potential removal sites if that proves to be a feasible tactic. Methodology will be consistent with that employed in North Mitton Creek.

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APPENDIX A Raw Monitoring Results for Page Creek - 2014 to 2017

Table A.1 Minus 2 mm WAE metals results for Page Creek sediment samples collected in 2014.

Sample	Sample Depth (cm)	Thread Distance from A01	Lead (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)	Phosphorus (mg/kg)
O01-11	0-15	-1.7	3	1	<1	59	<50
O01-12	15-35	-1.7	3	1	<1	130	<50
O01-13	35-50	-1.7	3	1	<1	5	<50
O02-11	0-15	-1.1	3	1	<1	130	<50
O02-13	15-35	-1.1	3	1	<1	11	<50
O03-11	0-15	-0.8	3	1	<1	43	<50
O03-12	15-35	-0.8	3	1	<1	3	<50
O03-13	35-50	-0.8	3	1	<1	3	<50
O04-11	0-15	-0.4	3	1	<1	140	<50
O04-12	15-35	-0.4	3	1	<1	130	<50
O04-13	35-50	-0.4	3	1	<1	21	<50
P02-11	0-15	-0.1	3	1	<1	68	<50
P01-11	0-15	0.0	6	1	<1	130	<50
P01-13	15-35	0.0	3	1	<1	200	<50
A01-11	0-15	0.0	8	1	<1	220	<50
A01-12	15-35	0.0	11	1	1	330	<50
A01-13	35-50	0.0	7	1	<1	230	<50
P03-11	0-15	0.4	8	1	<1	380	<50
P03-13	15-35	0.4	13	1	1	390	100
A02-11	0-15	0.4	9	1	<1	280	<50
P04-11	0-15	0.6	51	1	2	510	87
P05-11	0-15	0.7	12	1	1	380	<50
P05-13	15-35	0.7	3	1	<1	150	<50
A03-11	0-15	0.9	47	1	2	680	390
P09-11	0-15	1.0	7	1	<1	210	80
P10-11	0-15	1.0	30	1	1	270	200
N01-11	0-15	1.3	16	1	1	310	550
N02-11	0-15	1.4	21	1	<1	240	620
N03-11	0-15	1.5	26	1	<1	270	530
N04-11	0-15	1.6	27	1	<1	270	380
N05-11	0-15	1.6	7	1	<1	140	170
O05-11	0-15	2.0	17	1	2	560	680
O05-13	15-35	2.0	6	1	2	850	550
A05-11	0-15	2.6	8	1	1	390	380
A05-12	15-35	2.6	3	1	2	660	610
A05-13	35-50	2.6	3	1	5	1800	2300
P08-11	0-15	2.9	9	1	2	560	750
O06-11	0-15	3.0	11	1	2	490	1500
O06-12	15-35	3.0	7	1	2	640	1900
O06-13	35-50	3.0	3	1	3	910	2000
B01-11	0-15	3.0	26	1	1	420	860
B01-12	15-35	3.0	6	1	1	460	1400
B01-13	35-50	3.0	9	1	2	480	1800
B02-11	0-15	3.2	13	1	4	960	1900
B02-12	15-35	3.2	10	1	3	480	75
B02-13	35-50	3.2	3	1	<1	170	<50
B03-11	0-15	3.4	14	1	2	620	920
B03-12	15-35	3.4	11	1	2	610	830
B03-13	35-50	3.4	12	1	<1	65	170
B04-11	0-15	3.6	13	1	3	860	1800
B04-12	15-35	3.6	8	1	1	3	92

Sample	Sample Depth (cm)	Thread Distance from A01	Lead (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)	Phosphorus (mg/kg)
B04-13	35-50	3.6	7	1	<1	71	<50
B05-11	0-15	3.8	14	1	3	970	1700
B05-13	15-35	3.8	5	1	<1	190	110
C01-11	0-15	4.0	15	1	4	1100	1500
C01-13	15-35	4.0	6	1	<1	200	170
C02-11	0-15	4.3	16	1	3	1000	1400
C02-12	15-35	4.3	9	1	1	320	79
C02-13	35-50	4.3	12	1	<1	370	460
C02-21	0-15	4.3	22	1	4	1600	960
C03-11	0-15	4.7	16	1	4	2400	1400
C03-12	15-35	4.7	3	1	2	380	130
C03-13	35-50	4.7	3	1	<1	240	170
C04-11	0-15	4.8	25	1	4	1500	800
C04-12	15-35	4.8	9	1	<1	370	62
C04-13	35-50	4.8	3	1	<1	150	68
C05-11	0-15	5.1	31	1	3	1500	810
C05-12	15-35	5.1	13	1	<1	260	270
C05-13	35-50	5.1	6	1	<1	24	130
C06-11	0-15	5.3	16	1	4	1700	700
C06-12	15-35	5.3	9	1	<1	240	510
C06-13	35-50	5.3	7	1	<1	150	780
C07-11	0-15	5.8	19	1	3	1500	1300
C07-13	15-35	5.8	10	1	<1	76	430
C07-21	0-15	5.8	12	1	2	930	450
C07-22	15-35	5.8	6	1	<1	44	850
C07-23	35-50	5.8	6	1	<1	13	250
D01-11	0-15	5.9	19	1	2	740	6400
D01-13	15-35	5.9	14	1	5	1100	3500
D01-21	0-15	5.9	20	1	2	800	6300
D01-23	15-35	5.9	20	1	2	1100	3300
D02-11	0-15	6.1	34	1	6	2200	4900
D02-21	0-15	6.1	26	1	3	990	4300
D02-23	15-35	6.1	24	1	4	1100	4400
D03-11	0-15	6.4	23	1	4	1900	1200
D03-12	15-35	6.4	5	1	<1	160	440
D03-13	35-50	6.4	11	1	<1	53	320
D03-21	0-15	6.4	12	1	3	830	1700
D03-23	15-35	6.4	6	1	2	450	650
D04-11	0-15	6.6	7	1	4	1500	740
D04-12	15-35	6.6	3	1	1	310	610
D04-13	35-50	6.6	3	1	<1	190	240
D04-21	0-15	6.6	14	1	2	870	880
D04-22	15-35	6.6	9	1	2	360	530
D04-23	35-50	6.6	8	1	<1	91	430
D05-11	0-15	6.8	13	1	3	1400	1000
D05-13	15-35	6.8	9	1	1	380	430
D06-11	0-15	6.9	20	1	3	940	410
E01-11	0-15	7.0	36	1	2	710	510
E01-21	0-15	7.0	28	1	2	630	400
E01-22	15-35	7.0	12	1	2	1100	230
E01-23	35-50	7.0	18	1	<1	700	280
E02-11	0-15	7.1	32	1	2	780	640
E03-11	0-15	7.3	10	1	4	1600	1500
E03-13	15-35	7.3	8	1	1	560	1700
E03-21	0-15	7.3	21	1	2	1500	890
E03-22	15-35	7.3	7	1	2	570	1200

Sample	Sample Depth (cm)	Thread Distance from A01	Lead (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)	Phosphorus (mg/kg)
E03-23	35-50	7.3	8	1	<1	220	2200
E04-11	0-15	7.5	11	1	2	670	920
E04-12	15-35	7.5	9	1	3	700	1200
E04-13	35-50	7.5	7	1	1	540	1700
E05-11	0-15	7.8	25	1	3	1000	1300
E05-13	15-35	7.8	12	1	1	440	1300
E06-11	0-15	8.0	10	1	2	720	440
E06-13	15-35	8.0	8	1	1	580	790
E07-11	0-15	8.3	13	1	2	670	780
E07-12	15-35	8.3	17	1	3	900	1700
E07-13	35-50	8.3	3	1	<1	40	330
E07-21	0-15	8.3	15	1	3	1100	1100
E07-22	15-35	8.3	16	1	4	640	470
E07-23	35-50	8.3	7	1	<1	120	950
E08-11	0-15	8.5	19	1	1	600	720
E08-12	15-35	8.5	18	1	2	1000	1200
E08-13	35-50	8.5	10	1	1	390	800
E09-11	0-15	9.0	10	1	2	850	770
E09-12	15-35	9.0	9	1	4	610	900
E09-13	35-50	9.0	9	1	<1	330	1100
E10-11	0-15	9.3	15	1	3	1600	960
E10-12	15-35	9.3	3	1	<1	3	<50
E10-13	35-50	9.3	6	1	<1	48	1700
E10-21	0-15	9.3	7	1	3	1500	680
E10-22	15-35	9.3	3	1	2	500	710
E10-23	35-50	9.3	6	1	<1	170	500
E11-11	0-15	9.5	12	1	2	660	570
E11-12	15-35	9.5	9	1	<1	210	180
E11-13	35-50	9.5	18	1	<1	280	220
E12-11	0-15	9.7	13	1	3	1400	1300
E12-13	15-35	9.7	6	1	1	390	800
E13-11	0-15	9.9	6	1	2	610	990
E13-13	15-35	9.9	3	1	<1	190	600
E14-11	0-15	10.0	12	1	3	990	810
E14-13	15-35	10.0	6	1	<1	340	970
E14-21	0-15	10.0	9	1	2	720	460
E14-23	15-35	10.0	3	1	1	440	350
E14-31	0-15	10.0	12	1	2	650	420
E14-32	15-35	10.0	10	1	3	1000	670
E14-33	35-50	10.0	5	1	<1	220	750
F01-11	0-15	10.6	14	1	4	1800	760
F01-12	15-35	10.6	11	1	3	1100	960
F01-13	35-50	10.6	6	1	2	540	870
F01-21	0-15	10.6	12	1	2	820	540
F02-11	0-15	11.0	12	1	2	750	310
F02-13	15-35	11.0	9	1	2	680	310
F02-21	0-15	11.0	12	1	1	500	300
F02-22	15-35	11.0	21	1	3	1800	810
F02-23	35-50	11.0	3	1	<1	200	210
F03-11	0-15	11.5	11	1	2	880	460
F03-13	15-35	11.5	6	1	3	750	480
F04-11	0-15	11.7	9	1	4	1400	980
F04-13	15-35	11.7	7	1	1	410	320
F04-21	0-15	11.7	9	1	2	980	470
F04-23	15-35	11.7	7	1	5	2200	570
F04-31	0-15	11.7	9	1	3	1100	570

Sample	Sample Depth (cm)	Thread Distance from A01	Lead (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)	Phosphorus (mg/kg)
F04-32	15-35	11.7	8	1	3	1500	520
F04-33	35-50	11.7	7	1	1	410	230
F05-11	0-15	12.4	11	1	3	1100	650
F05-12	15-35	12.4	11	1	3	1000	470
F05-13	35-50	12.4	9	1	6	880	180
F06-11	0-15	12.6	15	1	4	1500	560
F07-11	0-15	13.0	10	1	5	2300	500
F07-13	15-35	13.0	7	1	3	1000	280
F08-11	0-15	13.3	10	1	7	2800	550
F08-12	15-35	13.3	9	1	7	2700	410
F08-13	35-50	13.3	10	1	<1	270	250
F09-11	0-15	13.4	8	1	7	2600	920
F09-12	15-35	13.4	9	1	10	3600	500
F09-13	35-50	13.4	17	1	7	2400	350
F10-11	0-15	13.7	7	1	3	1000	200
F10-12	15-35	13.7	6	1	7	2500	510
F10-13	35-50	13.7	3	1	<1	300	100
F11-11	0-15	14.2	7	1	7	2900	500
F11-12	15-35	14.2	6	1	3	790	180
F11-13	35-50	14.2	7	1	7	2700	380
F12-11	0-15	14.8	5	1	4	1500	230
F12-12	15-35	14.8	6	1	7	2600	200
F12-13	35-50	14.8	6	1	6	1100	410
G01-11	0-15	15.6	5	1	4	1100	330
G01-12	15-35	15.6	6	1	4	1700	200
G01-13	35-50	15.6	5	1	<1	220	120
G02-11	0-15	15.7	9	2	4	810	540
G02-12	15-35	15.7	5	1	6	1800	340
G02-13	35-50	15.7	9	1	2	220	190
G03-11	0-15	16.6	3	1	6	1700	570
G03-12	15-35	16.6	3	1	8	2600	320
G03-13	35-50	16.6	7	1	<1	250	110
G04-11	0-15	17.3	3	1	7	2400	390
G04-12	15-35	17.3	3	1	10	3100	250
G04-13	35-50	17.3	3	1	<1	200	110
G05-11	0-15	19.0	3	1	6	1800	600
G05-12	15-35	19.0	3	1	3	900	470
G05-13	35-50	19.0	6	1	<1	72	450
G06-11	0-15	19.6	5	1	2	760	970
G06-12	15-35	19.6	7	1	9	3100	2200
G06-13	35-50	19.6	6	1	7	2400	2500
G07-11	0-15	19.8	5	1	5	1900	1900
G07-12	15-35	19.8	7	1	5	2100	1900
G07-13	35-50	19.8	6	1	6	2200	2700

Table A.2 Minus 2 mm WAE metals results for Page Creek sediment samples collected in 2015.

Reach	Sample ID	Thread Distance from A00 (m)	WAE <2mm (mg/kg)			
			Cadmium	Lead	Zinc	Phosphorus
A	15PCa	500	<0.4	16	48	19
A	15PCb	1000	<0.4	26	75	13
A	15PCc	1500	<0.4	29	100	18
A	15PCd	2000	<1	52	220	51
A	15PCE	2500	<1	26	300	51
A	15PCf	3000	1.5	58	560	380
A	15PCg	3500	1.4	140	480	710
A	15PCh	4000	1.5	57	420	380
A	15PCi	4500	1.2	40	250	460
A	15PCj	5000	1.6	77	480	1800
B	15PCk	5500	2.6	67	780	1700
B	15PCL	6000	3.6	52	1000	2000
B/C	15PC01	6600	3.3	54	1100	1600
C	15PC02	7100	3.6	50	1400	1200
C	15PC03	7600	4.2	47	1600	1200
C	15PC04	8100	4.1	41	1500	1000
C/D	15PC05	8600	5.5	50	1500	4500
D	15PC06	8900	3.4	35	970	1200
D	15PC07	9400	3.1	31	1000	770
D/E	15PC08	9900	3.7	34	1000	840
E	15PC09	10400	2.9	29	1000	1000
E	15PC10	10900	1.6	21	520	460
E	15PC11	11400	2	31	690	570
E	15PC12	11900	1.7	27	650	620
E	15PC13	12400	1.5	22	600	540
E	15PC14	12900	1.3	19	490	450
E	15PC15	13400	1.2	23	480	380
E/F	15PC16	13900	2	26	700	410
F	15PC17	14400	1.5	23	570	330
F	15PC18	14900	1.5	24	560	370
F	15PC23	15400	1.5	18	610	330
F	15PC24	15900	1.5	24	540	310
F	15PC25	16400	1.5	18	530	280
F	15PC26	16900	2.2	16	740	280
F	15PC27	17400	3.6	17	1200	450
F	15PC35	17900	3.3	23	1100	360
F	15PC19	18550	2.3	13	760	230
F	15PC20	19050	<1	8	200	64
F	15PC21	19550	2.1	12	700	270
F/G	15PC22	20050	<1	12	220	390
G	15PC41-1	-	<1	8	120	76
G	15PC28	20550	1.1	10	320	270
G	15PC29	21050	1.4	9	400	360
G	15PC30	21550	1.6	8	450	180
G	15PC31	22050	4.4	10	1200	360
G	15PC36	22550	4.8	18	1300	340
G	15PC37	23050	3.3	12	960	1100
G	15PC40-1	-	1.8	24	370	6300
G	15PC38	23550	<1	11	230	150
G	15PC32	24225	3.1	14	890	3400
G	15PC33	24725	4.1	13	1200	3200
G	15PC34	25225	4.4	22	1400	2600

Table A.3 Minus 2 mm WAE metals results for Page Creek sediment samples collected in 2016.

Sample	Sample Depth (cm)	Thread Distance from A01	Lead (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)	Phosphorus (mg/kg)	Manganese (mg/kg)
A01-11	0-15	0.0	19	-	<1	100	<50	740
A01-12	15-35	0.0	15	-	<1	84	<50	520
A02-11	0-15	0.4	23	-	<1	310	<50	520
A03-11	0-15	0.9	31	-	<1	330	180	400
P09-11	0-15	1.0	17	-	<1	200	99	340
N02-11	0-15	1.4	29	-	<1	270	360	690
N04-11	0-15	1.6	32	-	<1	260	310	430
A05-11	0-15	2.6	11	-	1	400	650	390
A05-12	15-35	2.6	15	-	4	1100	1500	530
B01-11	0-15	3.0	28	-	2	560	1600	360
B01-12	15-35	3.0	16	-	3	900	2100	470
B03-11	0-15	3.4	26	-	3	780	1700	580
B03-12	15-35	3.4	22	-	3	910	1400	450
B05-11	0-15	3.8	22	-	3	940	1900	560
B05-12	15-35	3.8	21	-	1	430	550	300
C01-11	0-15	4.0	35	-	3	960	1600	920
C01-13	15-35	4.0	22	-	2	470	420	450
C02-11	0-15	4.3	28	-	2	900	1500	650
C02-12	15-35	4.3	14	-	<1	360	330	230
C05-11	0-15	5.1	38	-	3	1300	960	720
D04-11	0-15	6.6	19	-	2	980	930	580
E05-11	0-15	7.8	20	-	1	440	1000	510
E10-11	0-15	9.3	19	-	2	600	650	490
E10-13	15-35	9.3	28	-	2	970	1200	750
E10-21	0-15	9.3	17	-	1	420	600	570
E10-23	15-35	9.3	12	-	<1	51	480	260
F07-11	0-15	13.0	13	-	2	630	360	640
F07-12	15-35	13.0	13	-	2	720	280	670
F08-11	0-15	13.3	18	-	4	1300	510	1100
F08-12	15-35	13.3	17	-	5	1600	660	1100
F09-11	0-15	13.4	14	-	3	1100	370	870
F09-12	15-35	13.4	14	-	4	1400	390	840
F10-11	0-15	13.7	11	-	2	810	260	750
F10-12	15-35	13.7	14	-	4	1400	380	980
F11-11	0-15	14.2	14	-	4	1200	320	1100
F11-12	15-35	14.2	13	-	5	1400	480	820
G02-11	0-15	15.7	12	-	1	420	200	640
G02-12	15-35	15.7	12	-	6	1400	550	930
G03-11	0-15	16.6	6	-	1	410	350	420
G03-12	15-35	16.6	14	-	7	1600	730	1300
G04-11	0-15	17.3	7	-	2	480	160	480
G04-12	15-35	17.3	10	-	5	1400	350	1100
G04-13	35-50	17.3	11	-	<1	160	240	630
G05-11	0-15	19.0	10	-	3	880	760	850
G05-12	15-35	19.0	9	-	6	1500	680	870
G05-13	35-50	19.0	9	-	6	1600	850	950
G06-11	0-15	19.6	12	-	5	1400	2500	1000
G06-12	15-35	19.6	12	-	5	1500	3200	830
G07-11	0-15	19.8	3	-	<1	250	900	270
G07-12	15-35	19.8	13	-	6	1700	3600	1000

Table A.4 Minus 2 mm WAE metals results for Page Creek sediment samples collected in 2017.

Sample	Sample Depth (cm)	Thread Distance from A01	Lead (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)
A01-11	0-15	0.0	5	-	<1	72
A01-13	15-35	0.0	10	-	<1	110
A02-11	0-15	0.4	10	-	<1	220
A03-11	0-15	0.9	18	-	<1	240
P09-11	0-15	1.0	40	-	<1	290
N02-11	0-15	1.4	69	-	1	440
N04-11	0-15	1.6	28	-	<1	180
A05-11	0-15	2.6	15	-	1	320
A05-12	15-35	2.6	10	-	1	390
B01-11	0-15	3.0	15	-	1	500
B01-12	15-35	3.0	20	-	2	610
B03-11	0-15	3.4	25	-	2	640
B03-12	15-35	3.4	25	-	<1	270
B05-11	0-15	3.8	25	-	2	830
B05-12	15-35	3.8	15	-	1	440
C01-11	0-15	4.0	26	-	2	830
C01-13	15-35	4.0	21	-	1	500
C02-11	0-15	4.3	23	-	2	750
C02-12	15-35	4.3	26	-	4	1000
C05-11	0-15	5.1	34	-	2	1100
D04-11	0-15	6.6	15	-	1	580
E05-11	0-15	7.8	20	-	1	540
E10-11	0-15	9.3	15	-	2	660
E10-13	15-35	9.3	15	-	1	480
E10-21	0-15	9.3	15	-	1	600
E10-23	15-35	9.3	10	-	<1	160
F07-11	0-15	13.0	5	-	<1	310
F07-12	15-35	13.0	10	-	<1	240
F08-11	0-15	13.3	10	-	4	1400
F08-12	15-35	13.3	10	-	2	810
F09-11	0-15	13.4	5	-	1	480
F09-12	15-35	13.4	10	-	3	1200
F10-11	0-15	13.7	10	-	3	1000
F10-12	15-35	13.7	10	-	3	1100
F11-11	0-15	14.2	15	-	5	1500
F11-12	15-35	14.2	15	-	6	1800
G02-11	0-15	15.7	10	-	2	640
G02-12	15-35	15.7	10	-	5	1400
G03-11	0-15	16.6	5	-	3	790
G03-12	15-35	16.6	10	-	3	810
G04-11	0-15	17.3	5	-	4	1300
G04-12	15-35	17.3	10	-	6	1600
G04-13	35-50	17.3	5	-	<1	49
G05-11	0-15	19.0	5	-	2	640
G05-12	15-35	19.0	5	-	3	980
G05-13	35-50	19.0	5	-	4	1200
G06-11	0-15	19.6	13	-	3	1000
G06-12	15-35	19.6	10	-	3	1100
G07-11	0-15	19.8	9	-	2	630
G07-12	15-35	19.8	12	-	4	1200

APPENDIX B Raw Monitoring Results for Lawn Hill Creek - 2017

Table B.1 Sediment Zinc results for Lawn Hill Creek monitoring sites in June 2017. Values highlighted in blue font are greater than the ISQG-Low.

Sample	Cadmium	Zinc	Lead
L1a (composite)	0.5	130	12
L1a-1	0.4	53	5
L1a-2	0.5	120	5
L1a-3	0.3	52	5
L1a-4	0.4	41	5
L1a-5	0.4	92	5
L1a-6	0.3	59	<0.5
L1a-7	0.3	55	5
L1a-8	0.4	100	10
Transect Median	0.4	57	5.0
L1b (composite)	1.2	230	17
L1b-1	0.2	100	5
L1b-2	0.6	160	5
L1b-3	1.0	210	5
L1b-4	1.0	200	10
L1b-5	0.9	200	10
L1b-6	0.9	220	10
L1b-7	1.0	200	10
L1b-8	0.4	79	5
Transect Median	0.9	200	7.5
L2a-1	0.1	58	10
L2a-2	0.2	62	10
L2a-3	0.4	67	10
L2a-4	0.3	55	10
L2a-5	0.3	64	10
L2a-6	0.3	73	10
L2a-7	0.1	20	5
L2a-8	0.2	38	5
Transect Median	0.3	60	10.0
L02-1	0.3	54	<0.5
L02-2	0.2	3	<0.5
L02-3	0.3	31	5
L02-4	0.5	61	15
L02-5	0.4	52	15
L02-6	0.4	53	15
L02-7	0.4	47	15
L02-8	0.3	34	5
Transect Median	0.4	50	15.0
L03 (composite)	0.3	57	11
L3a (composite)	0.1	22	13
L04 (composite)	<0.1	22	12
L05 (composite)	0.2	29	17
RL3 (composite)	<0.1	6	7.5
RL2 (composite)	<0.1	1	5
RL1 (composite)	0.2	6	5
RL0 (composite)	0.1	9	5.8



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A Report for New Century Resources

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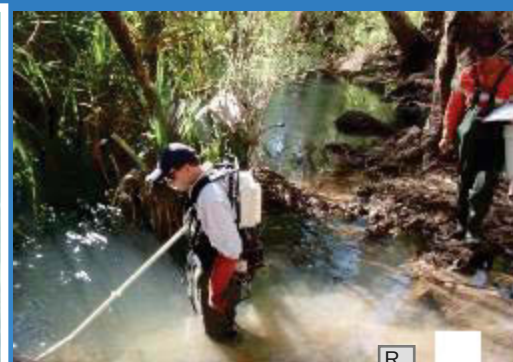
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Page 69 of 139

**CENTURY MINE SEDIMENT QUALITY MONITORING PROGRAM (SQMP)
REVIEW, 2018**

A REPORT FOR NEW CENTURY RESOURCES

Report No. 18/49

December 2018

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TABLE OF CONTENTS

1. INTRODUCTION	4
1.1 Site Description	5
1.1.1 Climate.....	5
1.1.2 Surface Hydrology	5
1.1.3 Rainfall and Stream Flow	6
1.2 Relevant EA Conditions	8
1.3 Century REMP.....	10
1.3.1 Historical Background.....	10
1.3.2 REMP Site Network	10
1.4 Sediment Quality Assessment methods.....	13
1.4.1 Sampling	13
1.4.2 Analysis	14
2.1 Historical background	16
2.2 Current Status of Page Creek Sediments	25
2.3 Protocols for Future Monitoring	32
3. LAWN HILL CREEK.....	35
3.1 Historical background	35
3.2 Current Status.....	36
3.3 Protocols for Future Monitoring	38
4. NORTH MITTON CREEK.....	39
4.1 Historical background	39
4.2 Current Status	43
4.3 Protocols for Future Monitoring	46
5. COGLAN CREEK	48
5.1 Historical background	48
5.2 Current Status	49
5.3 Protocols for Future Monitoring	51
6. LITTLE ARCHIE CREEK	52
6.1 Historical background	52
6.2 Current Status	54
6.3 Protocols for Future Monitoring	54
7. BULLRIDGE CREEK	55
7.1 Historical background	55
7.2 Current Status	56
7.3 Protocols for Future Monitoring	58
8. REFERENCES	60

1. INTRODUCTION

A sediment quality monitoring program (SQMP) involving annual dry season sampling of the bottom sediments in receiving streams potentially impacted by Century mine has been in place since 2009. The program originally stemmed from the recommendations of an environmental evaluation report addressing a non-compliant water release during the 2008-2009 wet season and was initially designed to monitor the fate of contaminated sediments deposited in Page Creek. Since then the program has evolved in an *ad hoc* manner pursuant to recommendations made in numerous reports generated by other environmental evaluations, investigations triggered by EA trigger level (TL) exceedances, the receiving environment monitoring program (REMP) and the SQMP. As a consequence the SQMP site network now includes sites in all of the creeks in the immediate receiving environment surrounding the mine (namely Page, North Mitton, Coglean, Bullridge and Little Archie Creeks), as well as Lawn Hill Creek (the receiving environment for water and sediment discharged from Page Creek).

This evolutionary process has required the adoption of a variety of different sampling tactics, site networks and assessment methods, and has yielded numerous *ad hoc* reports each dealing with separate issues and different individual streams. This has made it extremely difficult for managers, regulators and investigators to maintain an overview of the current status of the receiving environments or to accurately gauge existing and emerging management priorities.

The purpose of this review is to provide a single document that:

- assesses the current status of stream sediments throughout the study area in the context of historical events and findings; and,
- details the monitoring methods that will be employed in future SQMP sampling campaigns until circumstances change.

It is proposed that this document will be updated annually to incorporate new data, findings and recommendations, and record any proposed changes to the existing monitoring protocols. These revisions will generate a report that serves a dual role as an annual SQMP results report and an SQMP monitoring design document.

The objectives of the SQMP are as follows:

- Evaluate temporal trends in the extent and magnitude of non-compliant metal residues in the stream sediments of receiving waters potentially influenced by Century Mine.
- Notify managers if there is any evidence of fresh contamination entering the receiving waters, and assist in identifying their source.
- Assess the potential environmental risks associated with the existing contaminant residues in each receiving stream (this will include reference to the biological effect data provided in annual REMF reports).
- Inform managers of any existing or emerging remediation requirements and recommend potential mitigation measures for consideration.
- Where relevant, assist in identifying sections of stream where contaminated sediment removal works could be carried out with the greatest effect and least harm to the integrity of the stream.
- Evaluate the effectiveness of remediation works.
- Generate a statistically strong database which the REMF can use to examine correlations between sediment quality and biological condition, as an aid for devising local site-specific sediment quality guidelines.
- Revise the program as necessary to ensure that methodology remains appropriate to existing circumstances and addresses any recommendations stemming from other investigations such as the REMF.

Because the existing SQMP largely stems from the recommendations of previous investigations triggered by TL exceedances and EE notices, the scope of works of the current program comfortably meets all the monitoring and assessment requirements specified in relevant EA conditions (C15 to C16, see Figure 1.2.4). In fact, now that the SQMP encompasses all of the receiving streams in this study area, the existing program is effectively an ongoing extension of the trigger investigations required under EA condition C16 (d). Moreover, it is apparent from the data presented in this report that, due to the heterogeneity of sediments in this study area and the irrelevance of existing “reference” sites (all of which are located in inherently unsuitable mineralogical settings), the compliance assessment methods specified in the EA are far less reliable than the methods being employed in the SQMP.

The SQMP employs statistically strong reach-based composite SQMP sampling techniques, the results of which demonstrate that the site-based sampling methods stipulated in the EA are ineffective as an impact assessment tool. In fact the individual monitoring sites specified in the EA are subject to such high levels of random error and effects from localised influences, that the EA compliance assessment results are rendered virtually meaningless. There are therefore sound scientific grounds to suggest that the EA conditions in question have now effectively been superseded and should be amended accordingly.

The required amendment could potentially be accomplished by simply altering the footnote on condition C16 (d) to include an exemption for sites which are under investigation in the SQMP, with the caveat that the SQMP design (presented in this document) and any subsequent alterations to that design, have been sanctioned by the administering authority.

1.1 Site Description

1.1.1 Climate

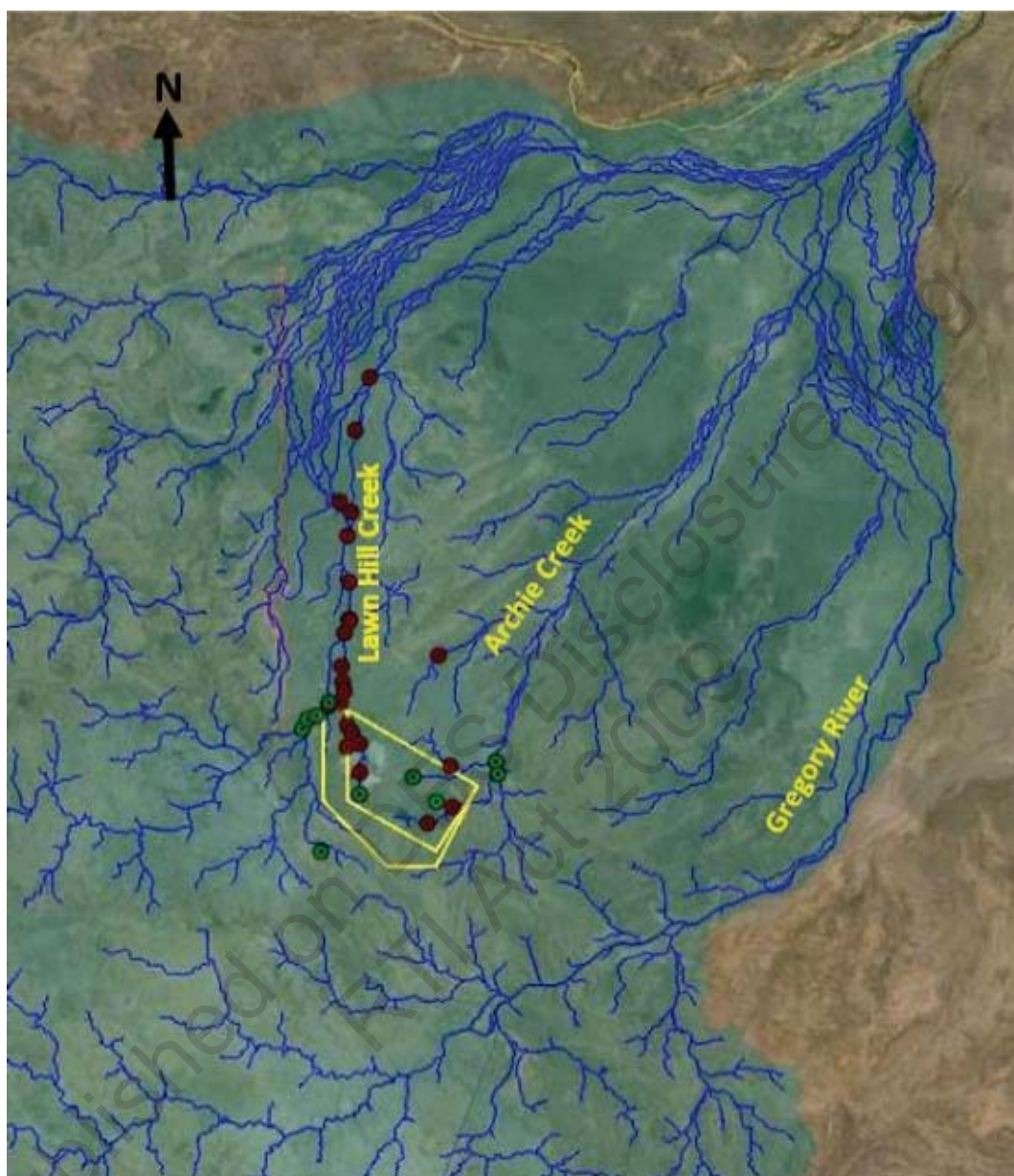
The New Century Resources Mine deposit is located in the Gulf of Carpentaria region of north-western Queensland approximately 250 km north-north-west of Mount Isa. The climate of the Gulf of Carpentaria region as a whole has been routinely described as dry tropical, yet monsoonal. There is a defined wet season occurring between December and March with minimal rainfall occurring over the remainder of the year. Average rainfall decreases with increasing distance from the coast and accordingly the climate of some of the more inland areas such as the Century Mine site are more aptly described as semi-arid with monsoonal influences (Dames & Moore 1994). The complex and unpredictable El Niño – La Niña Southern Oscillation (ENSO) phenomena exert significant influence on weather variability through time. Yearly weather patterns can range from effectively failed wet seasons through average years to strong wet seasons with pronounced monsoonal or often cyclonic activity. The long-term rainfall record for the Century area demonstrates considerable variability with Dames & Moore (1994) emphasising the uncertainty of typical climatic descriptors such as annual rainfall averages for this environment.

1.1.2 Surface Hydrology

The creek systems that drain the Century Mine are all ephemeral streams. Page Creek rises to the south of the mine site and flows in a northerly direction over the northern block of the Century Mine deposit to its confluence with Lawn Hill Creek. In order to accommodate the mine workings, the upper reaches of Page Creek underwent a substantial diversion in 1997, and again in 2001, to re-route stream-flow around the western margin of the mine pit. The diversion channel, identified in TropWATER reports as Reach A of Page Creek, was subject to a minor realignment in 2013 and 2014.

Other notable ephemeral systems including Coglean, Bullridge, Mitton, Little Archie and Archie Creeks arise to the west and south-west of the mine site. Most of these highly ephemeral systems share similar land and drainage characteristics, arising from the Argylla land system (Dames & Moore 1994). The exceptions are Mitton Creek and Little Archie Creek, which drain part of the Thornton land system to the north-west of the mine site.

Figure 1.1.1. Location of New Century Resources REMP sites (test sites in red, control sites in green) in relation to Gulf Rivers Strategic Environmental Area shown as green shaded area (Queensland Government 2014). Yellow lines denote New Century Resources mining leases. Map base - Google Earth

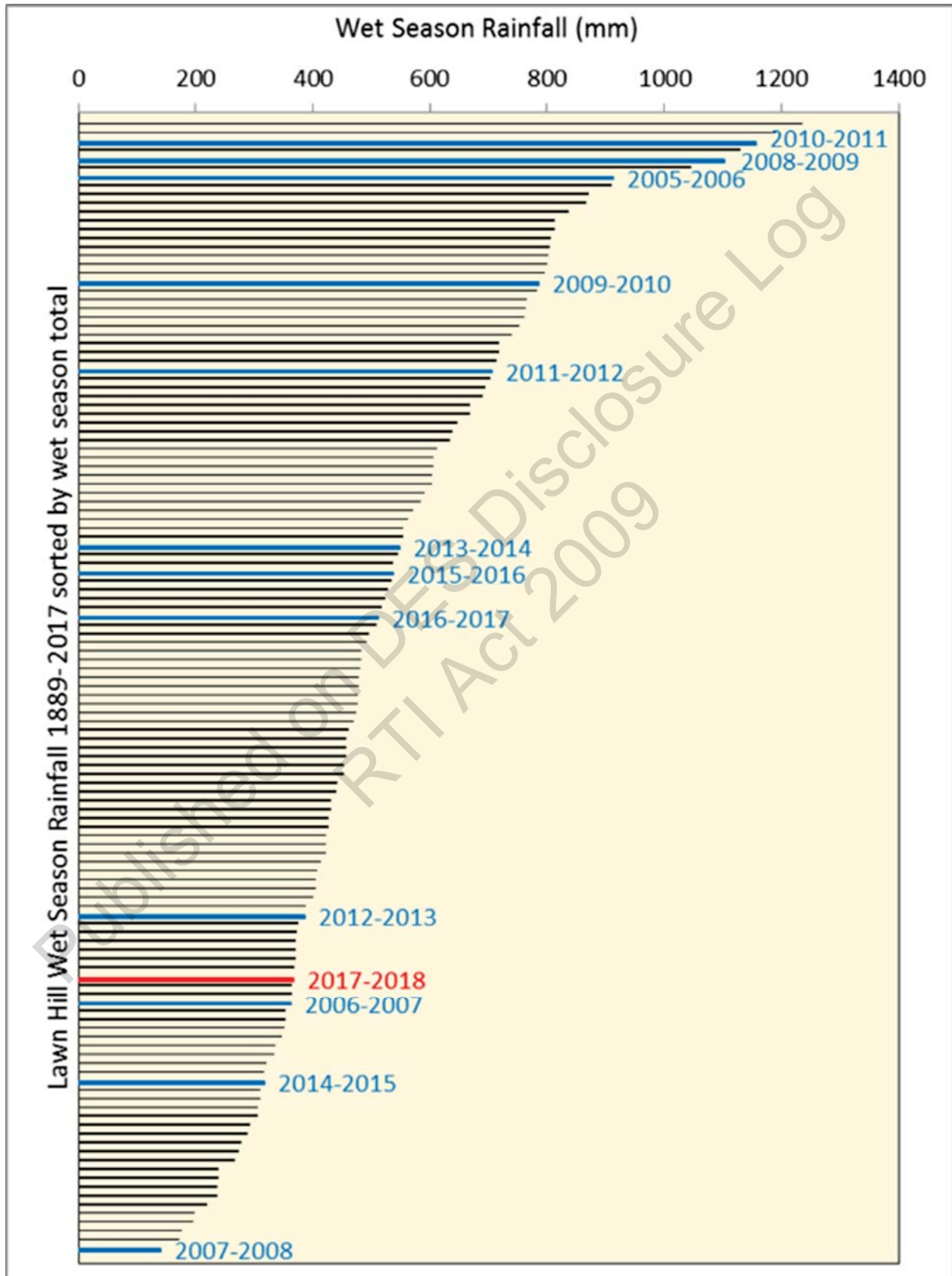


Spring Creek (which flows into Louie Creek) and Bullridge Creek flow in a northerly direction and ultimately discharge into Lawn Hill Creek, while Mitton and Coglan Creeks flow in an easterly path and discharge into Archie Creek (Figure 1.1). Lawn Hill Creek itself arises in the limestone and sandstone hills of Lawn Hill National Park to the west of Century Mine. Spring fed and perennial, it eventually flows into the Gulf of Carpentaria via the Gregory and Nicholson Rivers.

1.1.3 Rainfall and Stream Flow

Long term records for Lawn Hill (Figure 1.1.2) indicate that annual rainfall has consistently been less than or equal to the long term average since 2012. Conditions were particularly dry in the 2012-2013 and 2014-2015 wet seasons and the effects of that (low groundwater levels and parched soils) carried through into the intervening years resulting in lower than normal streamflow even in the average rainfall years. The 2017-2018 wet season is the sixth consecutive year that none of the ephemeral creeks in the Century Mine receiving environment have experienced any swiftflow events with sufficient energy to mobilise significant quantities of streambed sediment.

Figure 1.1.2 Annual wet-season rainfall at Lawn Hill 1889-2018 ranked in order of decreasing total rainfall (mm). Data from Climate Data Online, Bureau of Meteorology. <http://www.bom.gov.au/climate/data>. Bureau of Meteorology station number: 29031, Station name: LAWN HILL (note that 2016-17 data was derived in part from Century Mine rainfall data due to missing records in the Lawn Hill BOM data).



1.2 Relevant EA Conditions

Figure 1.2.1 Excerpt from Environmental Authority EPML00888813 (October 31, 2017) – Schedule C – Table 4.

Schedule C - Table 4 (Receiving water reference sites and downstream compliance monitoring points)

Monitoring Points	Receiving Waters Location Description	GDA 94 MGA zone 54	
		Easting	Northing
Receiving Water Reference Sites			
P_SW17_REF	Page Creek upstream	246 864	7 925 109
C_SW14_REF	Coglan Creek upstream	256 260	7 923 258
SM_SW05_REF	South Mitton Creek upstream	253 265	7 926 237
Downstream Compliance Monitoring Points			
B_SW01_REC	Bull Ridge Creek	242 739	7 934 568
P_SW03_REC	Page Creek	246 684	7 930 113
NM_SW04_REC	North Mitton Creek	253 031	7 927 828
C_SW08_REC	Coglan Creek	260 217	7 923 065
SM_SW04_REC	South Mitton Creek	258 044	7 926 163

1. Reference sites must:

- be from the same bio-geographic and climatic region;
- have similar geology, soil types and topography;
- contain a range of habitats similar to those at the test sites;
- have a similar flow regime; and
- not be on rivers in the test sites that are tributaries of the test sites, also provide in a riverine at the reference site.

Figure 1.2.2 Satellite image showing Century Mine Lease boundaries and the location of the EA receiving water monitoring sites specified in EA EPML00888813.

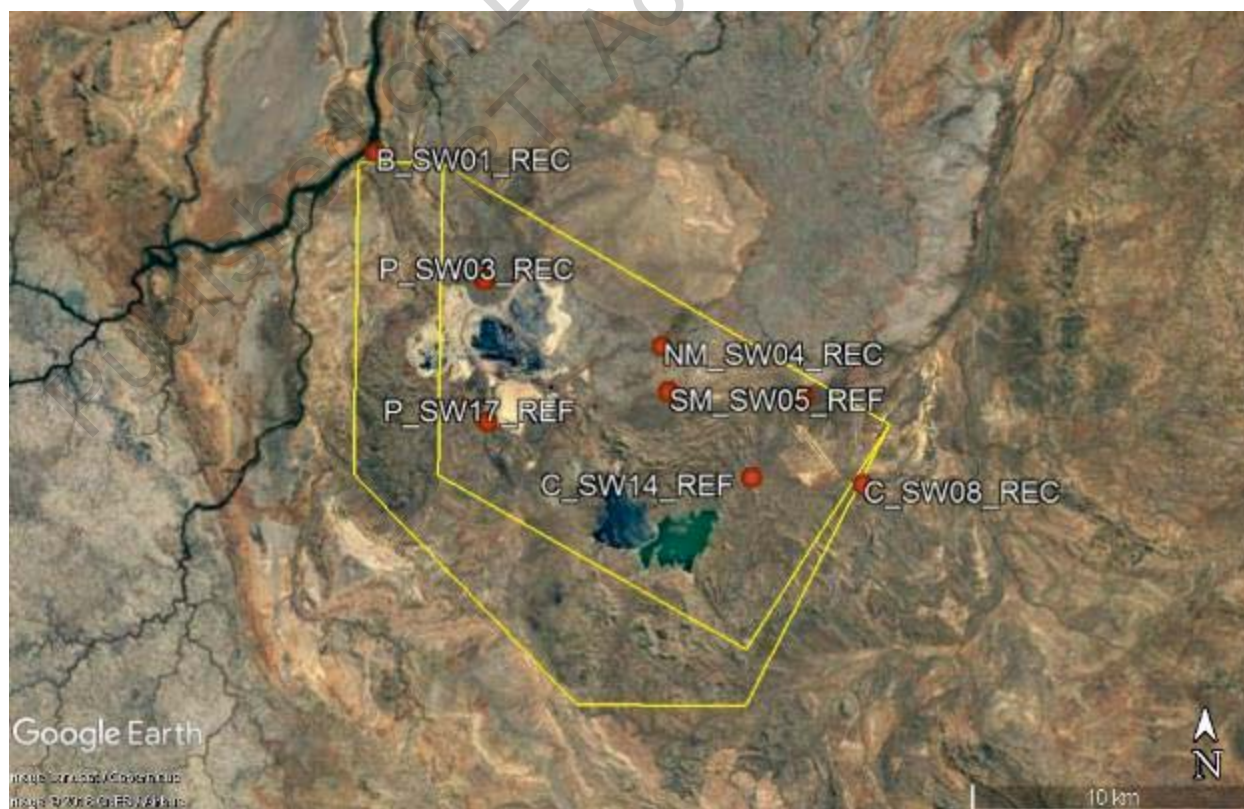


Figure 1.2.3 Excerpt from Environmental Authority EPML00888813 (October 31, 2017) – Conditions C13 and C14

Stream sediment																					
C13	<p>Sediment quality of receiving waters and reference waters must be monitored annually (after the wet season) at the monitoring locations defined in Schedule C - Table 4 (Receiving water reference sites and downstream compliance monitoring points) and identified on Schedule J - Figure 2 (Receiving water monitoring points and reference sites) and for the parameters defined in Schedule C - Table 7 (Stream sediment trigger levels).</p> <table border="1"> <caption>Schedule C - Table 7 (Stream sediment trigger levels)</caption> <thead> <tr> <th>Parameter¹</th><th>Trigger Level</th></tr> </thead> <tbody> <tr> <td>Arsenic (mg/kg)</td><td>70²</td></tr> <tr> <td>Cadmium (mg/kg)</td><td>10²</td></tr> <tr> <td>Copper (mg/kg)</td><td>270²</td></tr> <tr> <td>Lead (mg/kg)</td><td>220²</td></tr> <tr> <td>Manganese (mg/kg)</td><td>For interpretation purposes</td></tr> <tr> <td>Nickel (mg/kg)</td><td>52²</td></tr> <tr> <td>Selenium (mg/kg)</td><td>3 times greater than reference site³</td></tr> <tr> <td>Zinc (mg/kg)</td><td>410²</td></tr> <tr> <td>Particle size distribution</td><td>For interpretation purposes</td></tr> </tbody> </table> <p>1. All samples must be sieved to remove the >2 mm sediment fraction prior to analysis 2. Trigger level derived from ANZECC (2000) Interim Sediment Quality Guidelines - High 3. Reference sites as specified in Schedule C - Table 4 (Receiving water reference sites and downstream compliance monitoring points)</p>	Parameter ¹	Trigger Level	Arsenic (mg/kg)	70 ²	Cadmium (mg/kg)	10 ²	Copper (mg/kg)	270 ²	Lead (mg/kg)	220 ²	Manganese (mg/kg)	For interpretation purposes	Nickel (mg/kg)	52 ²	Selenium (mg/kg)	3 times greater than reference site ³	Zinc (mg/kg)	410 ²	Particle size distribution	For interpretation purposes
Parameter ¹	Trigger Level																				
Arsenic (mg/kg)	70 ²																				
Cadmium (mg/kg)	10 ²																				
Copper (mg/kg)	270 ²																				
Lead (mg/kg)	220 ²																				
Manganese (mg/kg)	For interpretation purposes																				
Nickel (mg/kg)	52 ²																				
Selenium (mg/kg)	3 times greater than reference site ³																				
Zinc (mg/kg)	410 ²																				
Particle size distribution	For interpretation purposes																				
C14	<p>All stream sediment sampling must be undertaken in accordance with the most recent version of Australian Standard AS 5667.12 <i>Guidance on Sampling of Bottom Sediment</i>.</p>																				

Figure 1.2.4 Excerpt from Environmental Authority EPML00888813 (October 31, 2017) – Conditions C15 to C17.

Sediment quality monitoring program (SQMP)	
C15	<p>The holder of the environmental authority must develop and implement a SQMP.</p> <p>The SQMP must incorporate the following:</p> <ul style="list-style-type: none"> (a) compare reference site sediment quality data to downstream compliance monitoring point data; (b) propose appropriate locally-derived sediment quality trigger values for downstream compliance monitoring points once a sufficient body of data has been collected; and (c) identify if downstream compliance monitoring point data trends indicate that contaminants are accumulating at the site(s).
C16	<p>If the quality characteristics of sediments at the downstream compliance monitoring points defined in Schedule C - Table 4 (Receiving water reference sites and downstream compliance monitoring points) exceed any of the trigger levels specified in Schedule C - Table 7 (Stream sediment trigger levels), the holder of this environmental authority must compare results of the downstream site to the data from reference monitoring sites and:</p> <ul style="list-style-type: none"> (a) where the downstream result is the same or a lower value than the reference site value for the quality characteristic during the same sampling event then no action is to be taken; (b) where the downstream results exceed the reference site, undertake an investigation as to whether the exceedance is attributable to the mining activity; (c) if the exceedance is not attributable to the mining activity then no further action is required; (d) if the exceedance is attributable to the mining activity, complete the investigation in accordance with the ANZECC & ARMCANZ 2000 methodology, into the potential for environmental harm and provide a written report to the administering authority within three (3) months, outlining: <ul style="list-style-type: none"> (i) details of the investigations carried out; and (ii) actions taken or to be taken to minimise environmental harm including measures to remediate the receiving environment to the extent of the contamination. <p><i>Note: Where an exceedance of a trigger level has occurred and is being investigated, in accordance with C16(d) of this condition, no further reporting is required for subsequent trigger events of an equal-to or lesser extent for that quality characteristic.</i></p>
C17	<p>The holder of this environmental authority must implement the measures proposed under condition C16 to remediate the receiving environment to the extent of the contamination.</p>

1.3 Century REMP

1.3.1 Historical Background

Since 2005, TropWATER (formerly the Australian Centre for Tropical Freshwater Research - ACTFR) has been engaged annually by Century Mine (currently Century Mining Ltd) to carry out limnological assessments in receiving environments associated with the mine. This entailed assessment of ambient water and sediment quality, ecological condition, macroinvertebrate and fish communities.

In 2009 it proved necessary to significantly expand the scope of monitoring activities and alter some of the established methodology in order to meet the requirements of a DES (then DERM) Environmental Evaluation (EE) order issued to Century Mine in connection with a wet season discharge incident. This included the introduction of sediment pore water sampling, the establishment of three upstream control sites and three downstream impact sites on Lawn Hill Creek, and the implementation of annual dry season sediment surveys to assess the distribution of sediment metals residues within the streambed of Page Creek and Lawn Hill Creek. In 2010 two additional limnological impact monitoring sites were established on Lawn Hill Creek, and in 2011 the site network on Lawn Hill Creek was further expanded by including four additional sites downstream of the Page Creek confluence and another which is situated between the entry points of Bullridge and Page Creeks.

The original program was established on behalf of Century as a voluntary program. However, in 2015 implementation of the Receiving Environment Monitoring Program (REMP) became a mandatory requirement under Environmental Authority (EA) EPML0088813. The site network and monitoring parameter suites have been subject to ongoing review since that time in order to ensure that the program meets the requirements set out in EA conditions C18 to C20.

Mining operations at MMG Century Mine ceased in August 2015 (with all ore processing completed in January 2016) and the mine was subject to closure planning and management for a brief period until Century Mine Ltd initiated tailings reclamation works which resulted in the recommencement of zinc production in 2018. As a consequence of these alterations it is anticipated that the nature, location and extent of potential contaminant sources will change over time and this may necessitate further ongoing amendments to the design of the REMP.

1.3.2 REMP Site Network

The REMP site network currently comprises nine impact sites and four controls in Lawn Hill Creek, eight impact sites and two controls in Page Creek, eleven impact sites located on other ephemeral/intermittent streams and five ephemeral/intermittent reference sites (Table 1.3.1 and Figure 1.3.1). A concerted effort has been made to include sites that correspond to the EA compliance locations listed in Figure 1.2.1. However, since most of those sites do not retain water long enough to be suitable candidates for biological assessment, it has been necessary to instead establish the REMP sites in the closest existing waterholes, and in some cases that is a significant distance away. Where relevant, Table 1.3.1 lists the closest applicable EA compliance site.

Even though the monitoring sites have been established in the locations with the greatest potential to retain water, some of the streams under investigation are so ephemeral that they dry out too quickly to be sampled in all but the wettest years. When there is water present each site is sampled for water quality, sediment pore water quality, macroinvertebrates and fish. Sediment samples are collected at all sites regardless of whether or not water is present.

Table 1.3.1. Current Century Mine REMP Sites. *indicates the EA reference or compliance site that is most closely located with the REMP site. Sites L1a, L1b and L1c are situated within three separate braids of Lawn Hill Creek. The L1c braid has not been sampled since 2013 as it became hydraulically inactive. However, the site will be sampled in the future if that braid ever becomes active again.

Site	Old Site ID	EA Compliance Site Equivalent*	Status	Km upstream of Site L5	WGS84 Latitude Longitude (S) (E)		Stream order	Water regime
Lawn Hill Creek								
RL3	LH ref3	N/A	Reference	47	18°41.37'	138°31.83'	4	perennial
RL2	LH ref2	N/A	Reference	45.5	18°40.61'	138°32.22'	4	perennial
RL1	LH ref1	N/A	Reference	44.3	18°40.35'	138°32.89'	5	perennial
RL0		N/A	Reference	41.7	18°39.48'	138°33.73'	5	perennial
L1a		N/A	Impact	31	18°34.00'	138°35.11'	5	perennial
L1b	LH1	N/A	Impact	31	18°34.05'	138°35.15'	5	perennial
L1c		N/A	Impact	31	18°34.02'	138°35.21'	5	perennial
L2a		N/A	Impact	26.3	18°31.52'	138°35.16'	5	perennial
L02	LH2	N/A	Impact	20.1	18°28.46'	138°35.04'	5	perennial
L3a		N/A	Impact	17.1	18°26.88'	138°35.30'	5	perennial
L03	LH3	N/A	Impact	18.9	18°26.19'	138°34.49'	5	perennial
L04	L4	N/A	Impact	6.8	18°21.44'	138°35.58'	5	perennial
L05	L5	N/A	Impact	0	18°17.96'	138°36.57'	5	perennial
Page Creek								
R01	Page ref1	P_SW17_REF	Control	55.5	18°45.58'	138°35.88'	2	ephemeral
R02								
A01	Page1	N/A	Impact	52.7	18°44.12'	138°35.91'	3	ephemeral
C01	Page2	P_SW03_REC	Impact	48.5	18°42.23'	138°35.90'	3	ephemeral
D01	Page3	N/A	Impact	46.5	18°41.49'	138°35.34'	3	ephemeral
E01	Page4	N/A	Impact	45.4	18°41.02'	138°35.02'	3	ephemeral
F01	Page5	N/A	Impact	42.4	18°39.51'	138°34.52'	4	ephemeral
F04	F04	N/A	Impact	41.2	18°38.89'	138°34.72'	4	intermittent
F09	F09	N/A	Impact	39	18°38.15'	138°34.71'	4	intermittent
G07	Page7	N/A	Impact	32.7	18°34.88'	138°34.84'	4	ephemeral
Other ephemeral and intermittent creeks								
Bul1	Bullridge1	N/A	Impact	48.75	18°42.43'	138°35.00'	1	ephemeral
Bul2	Bullridge2	B_SW01_REC	Impact	42.5	18°39.86'	138°33.66'	3	ephemeral
Cog1	Coglan1	N/A	Impact	N/A	18°47.45'	138°40.44'	3	semi-permanent
Cog2	Coglan2	C_SW08_REC	Impact	N/A	18°46.32'	138°42.49'	4	intermittent
Cog1b	Coglan	N/A	Impact	N/A	18°47.22'	138°41.31'		ephemeral
Cog1d	Coglan	N/A	Impact	N/A	18°46.89'	138°42.04'		ephemeral
RCog1	Coglan ref1	C_SW14_REF	Control	N/A	18°46.06'	138°41.25'	2	ephemeral
RM1	Mitton Ck	SM_SW05_REF	Control	N/A	18°44.43'	138°39.63'	3	ephemeral
MS	Mitton Spring	NM_SW04_REC	Impact	N/A	18°43.53'	138°42.12'	2	permanent/spring
RAr1	Archie ref1	N/A	Control	N/A	18°44.24'	138°45.55'	5	permanent
RAr2	Archie1	N/A	Control	N/A	18°43.41'	138°45.41'	5	permanent
LAr1	Little Archie	A_SW01_REC	Impact	N/A	18°36.27'	138°41.94'	4	semi-permanent
PH99	Little Archie	A_SW01_REC	Impact	N/A	18°39.29'	138°39.54'		ephemeral
PH387	Little Archie	A_SW01_REC	Impact	N/A	18°37.18'	138°40.68'		ephemeral
RSpr1	RSpr1	N/A	Control	64.3	18°49.37'	138°33.18'	3	ephemeral
NM24	North Mitton	N/A	Impact	N/A	18°43.54'	138°39.13'		ephemeral

Figure 3.1.1. Location of Century Mine REMP Sites. Control sites are shown in green and potential impact sites in red. The Century Mining Limited leases are outlined in yellow with access road in red.



1.4 Sediment Quality Assessment methods

1.4.1 Sampling

REMP Sampling Protocols

REMP sediment sampling is conducted by using a plastic or stainless steel hand trowel to collect a minimum of six random subsamples of benthic sediment from different locations at each site. The subsamples are collected in a plastic bag to yield a single composite sample. Subsamples are taken with the aim of representing the general composition of the near-surface sediment layer at each site, as it contains the most recently deposited material and is also the microhabitat most heavily utilised by benthic and demersal biota. This is the most appropriate material to sample in order to assess the potential for impacts on the biota inhabiting each waterhole, but it is not optimal for evaluating sediment contaminant loads and/or the potential for future impacts on downstream receiving waters. These latter issues are addressed in the SQMP.

When present, sediment pore water is extracted from a depth of 10 to 20 cm below the surface of the benthic sediment using a stiff plastic tube attached to a plastic syringe. A clean unused disposable plastic tube and syringe is used at each site. A hollow slotted re-usable stainless steel spear is used as an outer casing for the plastic tube at sites where the bottom is too hard for the plastic to penetrate. The outer casing is thoroughly washed with phosphate-free detergent and Milli-Q super high purity water, and dried after each use. In order to ensure that surface water is not drawn into the syringe, pore water samples are collected from the exposed edges of the bottom sediment at each water body. In most cases this is still well within the main streambed. Samples are centrifuged and filtered (at 0.45 µm) and are then submitted to a NATA registered commercial laboratory for analysis of filterable Ca, Cd, Mg, Pb and Zn by ICP-MS.

SQMP Sampling Protocols

SQMP sampling is always conducted in the dry season in order to maximise accessibility to all sections of the stream and streambed. SQMP sampling methods are tailored to suit the different geomorphological conditions at each site (which range from small bedrock constrained low order streams with sparse/rocky substratum, to large sandy higher order streams). Methods have also varied over time in order to meet different monitoring objectives.

Sediments at some of the key sites in Lawn Hill Creek, which is by far the largest stream in the SQMP site network, have proven to be particularly heterogeneous. This linked, with the fact that it is the only perennial waterway in the SQMP, has necessitated the adoption of specialised approaches which are detailed where relevant later in this report.

At all other sites, in cases where a slug of contaminated sediment has been detected the initial response has typically been to conduct intensive and extensive sampling aimed at accurately determining the full extent of the contamination and precisely identifying locations where removal works should be carried out. In cases where sediment depth exceeds 15 cm this entails the collection of separate depth profile samples representative of the 0-15cm, 15-35cm and 35-50cm horizons. In cases where the sediment is shallow this generally entails the collection of large numbers of subsamples representative of defined stream reaches (typically ≤100 m in length). Further intensive sampling is then conducted to assess the effectiveness of removal works and identify key sites for ongoing monitoring to assess any potential movement of residual contaminants and/or any additional contaminant inputs.

Ongoing routine monitoring typically employs similar tactics to those used for the detailed assessments but the number of sites employed are reduced. In small streams this is done by collecting composite samples representative of longer reaches. For example four 60 m reaches would be replaced by a single 240 m reach.

High resolution monitoring is typically reinstated if there are non-compliant sediments present and there is a large wet season swift flow event with the potential to have significantly altered the streambed, or if routine monitoring detects any potentially adverse trends.

1.4.2 Analysis

REMP

In years when there has been sufficient stream flow to potentially alter the texture and mobility of stream sediments, the <2 mm and <63 µm sediment fractions of REMF samples are subjected to dilute (1M HCl) acid extraction and analysed for metals listed in Table 1.4.1. If there have been no flow events during the preceding wet season large enough to trigger that requirement, only the <2 mm fraction is analysed. That is the appropriate fraction to use for assessing compliance with ANZECC sediment quality guidelines (SQGs) and evaluating the potential relevance to benthic fauna.

Note that historically the dilute acid extraction (DAE), which targets bioavailable metals, has been referred to as a weak acid extraction or WAE, in line with the convention established by ANZECC 2000. This misnomer (HCl is by definition a strong acid, regardless of its concentration) was corrected in a 2013 review of the ANZECC sediment quality guidelines.

Table 1.4.1. Physical and chemical analyses performed on benthic stream sediment samples collected in annual REMF surveys.

- | |
|---|
| <ul style="list-style-type: none">• Sieving to reject the plus 2mm fraction• Sieving to determine the mass percentage passing 63µm• Dilute acid extractions of the <2 mm (and where necessary) <63 µm sediment fraction, and ICP analysis of the extracts to determine arsenic, cadmium, copper, lead, manganese, nickel, selenium and zinc concentrations. |
|---|

SQMP

As exemplified by the 2018 REMF sediment analysis results shown in Table 1.4.2, none of the REMF sites have reported any anomalous results for metals other than zinc, cadmium and lead. The other REMF metals will not be included in the SQMP analysis suite unless this situation changes (i.e. unless anomalies are detected in the REMF samples). Hence SQMP samples are currently only analysed for <2 mm DAE zinc, cadmium and lead.

During the early stages of the SQMP elevated phosphorus levels were reported at many sites. However, phosphorus monitoring has been discontinued based on the following findings:

- Natural phosphorus inputs from the Phantom Hills and Mt Jennifer phosphate deposits are the principle source of elevated concentrations in the receiving streams.
- There is no correlation between metal and phosphorus concentrations at mine-contaminated sites demonstrating that the phosphorus derives from a source other than the mine (close correlation between zinc and cadmium has proven to be a diagnostic feature of mine-sourced contamination in this study area).
- Aqueous phosphorus levels have been consistently low at all sites and there have been no indications of any adverse biological effects even at sites with highly elevated sediment phosphorus concentrations, indicating that the sedimentary phosphorus has low solubility and limited bioavailability.

Table 1.4.2 <2 mm DAE metal results for surficial sediment samples collected in connection with the 2018 REMP. Results that exceed the ANZECC SQG-high are shown in blue, while those that exceed the SQG-low are green.

Site	<2 mm DAE metal (mg/kg)							
	Cadmium	Copper	Lead	Nickel	Zinc	Arsenic	Manganese	Selenium
<i>Page Creek</i>								
R01	<0.1	1	7.2	0.8	5.7	<0.5	300	<1
R02	0.6	4	25	2.2	150	1	460	<1
A01	0.7	6	32	2.6	180	2	550	<1
C01	2.2	7	49	9.5	770	2	790	<1
D01	8	9	57	8.4	1300	2	650	<1
E01	4.3	7	39	5.7	880	2	710	<1
F01	0.4	2	13	2.3	150	1	480	<1
F04	0.9	3	17	3.4	290	1	710	<1
F09	1.2	3	16	3.9	470	1	810	<1
G07	1.4	3	12	4	500	1	800	<1
<i>Spring Creek</i>								
RSpr1	<0.1	1	1.9	0.6	2.7	<0.5	80	<1
<i>Bullridge Creek</i>								
Bul1	2.1	10	120	10	1300	2	1200	<1
Bul2	0.1	4	14	2.3	39	1	410	<1
<i>Coglan Creek</i>								
RCog1	<0.1	1	2	<0.5	2.9	<0.5	19	<1
Cog1	0.3	4	6	11	2000	3	1100	1
Cog1b	<0.1	3	3	1.7	23	1	61	<1
Cog1d	<0.1	1	1.4	<0.5	7.1	1	19	<1
Cog2	<0.1	6	5.2	2.2	44	2	85	<1
<i>N. Mitton-Mitton</i>								
RM1	<0.1	2	20	0.6	21	1	73	<1
NM24	0.4	9	24	4.3	230	2	860	<1
MS	0.2	5	13	2	100	1	320	<1
<i>L. Archie-Archie</i>								
RAr1	0.1	5	4.4	1.5	18	1	260	<1
RAr2	0.1	3	28	2	33	2	540	<1
PH99	0.1	7	15	7.5	7.3	4	1000	<1
PH387	0.1	8	12	3.1	14	2	550	<1
LAr1	<0.1	7	11	2.8	8.8	2	330	<1
<i>Lawn Hill Ck</i>								
<i>Above Page Ck</i>								
RL3	<0.1	-	5	-	9	-	-	-
RL2	0.1	-	6.7	-	12	-	-	-
RL1	0.1	-	16	-	20	-	-	-
RL0	<0.1	-	8	-	19	-	-	-
<i>Below Page Ck</i>								
L1a*	0.3	-	7	-	82	-	-	-
L1b*	0.7	-	11	-	160	-	-	-
L2a*	0.3	-	11	-	68	-	-	-
L2*	0.2	-	11	-	52	-	-	-
L3	0.2	-	7	-	44	-	-	-
L3a	0.2	-	13	-	29	-	-	-
L4	0.1	-	9	-	28	-	-	-
L5	0.1	-	9	-	17	-	-	-
<i>SQG-Low</i>	1.5	65	50	21	200	-	-	-
<i>SQG-High</i>	10	270	220	52	410	-	-	-

* - Mean values obtained from 8 subsamples. Results for individual subsamples are detailed in the SQMP Report 2018.

2. PAGE CREEK

2.1 Historical background

Limnological monitoring of receiving streams, comprising sampling of water, sediment and biological indicators, has been carried out at Century by TropWATER (previously known as ACTFR) since 2005. Prior to 2009, monitoring of Page Creek focused on a few sites located within the small highly ephemeral stream reaches immediately downstream of the mine-site and within the boundaries of the mine lease. However, in order to address the requirements of an Environmental Evaluation (EE) Order issued by DERM (now DES) in connection with a non-compliant release event in 2009, exploratory surveys were conducted along the length of Page Creek and downstream into Lawn Hill Creek. There had already been evidence of contaminant accumulation and ecological impairment in Page Creek in previous years prior to any non-compliant releases having been reported, it is therefore uncertain how much of the impact observed in 2009 was actually attributable to the non-compliant discharge event referred to in the EE Order.

This uncertainty notwithstanding, the study showed that:

- benthic sediments throughout most of Page Creek contained high enough residues of mine-derived contaminants, and especially zinc, to potentially be ecologically harmful;
- contaminant concentrations at the sites closest to the mine, where ongoing zinc and cadmium accretion had previously been detected, had increased disproportionately in 2009; and;
- zinc and phosphorus levels in the benthic sediments of Lawn Hill Creek sites located immediately downstream of Page Creek were measurably higher than the levels at upstream reference sites.

Later in 2009 MMG Century engaged TropWATER to conduct a detailed survey of sediments and aquatic habitats in Page Creek as a precursor to remediation works. This entailed collecting sediment profile samples down to a maximum depth of 500 mm, as well as recording stream morphology data and habitat descriptions, at 109 sampling stations located at regular intervals along the length of the creek (see Figures 3.1 and 3.2). For the purposes of these investigations the creek was divided into seven reaches designated as A to G, and sites were identified using the reach ID as a prefix followed by a two digit number indicative of the site's position in the reach (e.g. C02 is the second site in reach C). Note that the first site in each reach corresponds to a REMP biological monitoring site, though these cannot always be sampled each year as they sometimes dry out during the wet season.

The 2009 study showed that the intrinsic habitat values of the creek were not particularly high. There were two sites that received higher potential value scores than the rest of the creek because during wet years they held semi-permanent water and/or saturated bed sands. However, these were in very poor condition due to impacts from anthropogenic pressures unrelated to mining activities, especially cane toads, feral pigs, cattle and horses. Sediment contamination was discovered in all sections of Page Creek downstream of the mine, and although the most significant deposits were concentrated in the surficial sediment layers in close proximity to the mine-site, the vertical distribution in downstream reaches was quite heterogeneous.

Notably there were a number of sites on Page Creek where elevated zinc levels extended to sediment depths in excess of the maximum sampling depth of 500 mm. This could potentially have been caused by vertical leaching of contaminants previously deposited on the surface sediment. However, subsequent investigations (TropWATER 2013) suggest that metal had very limited solubility so it is more likely that basal sands had mixed during high flow events, which would in turn suggest that a significant proportion of the contaminated sediment is potentially mobile under high flow conditions. Accordingly an annual Sediment Quality Monitoring Program (SQMP) was established to track any subsequent contaminant movements and this has been ongoing since 2009.

Figure 2.1.1 Page Creek SQMP sites located in stream reaches A to D, and Silver King tributary sites T01-1 and T01-2. Upstream control site R01 is sampled in the post-wet season REMP survey each year but it is no longer-sampled in the dry season [Google Earth].

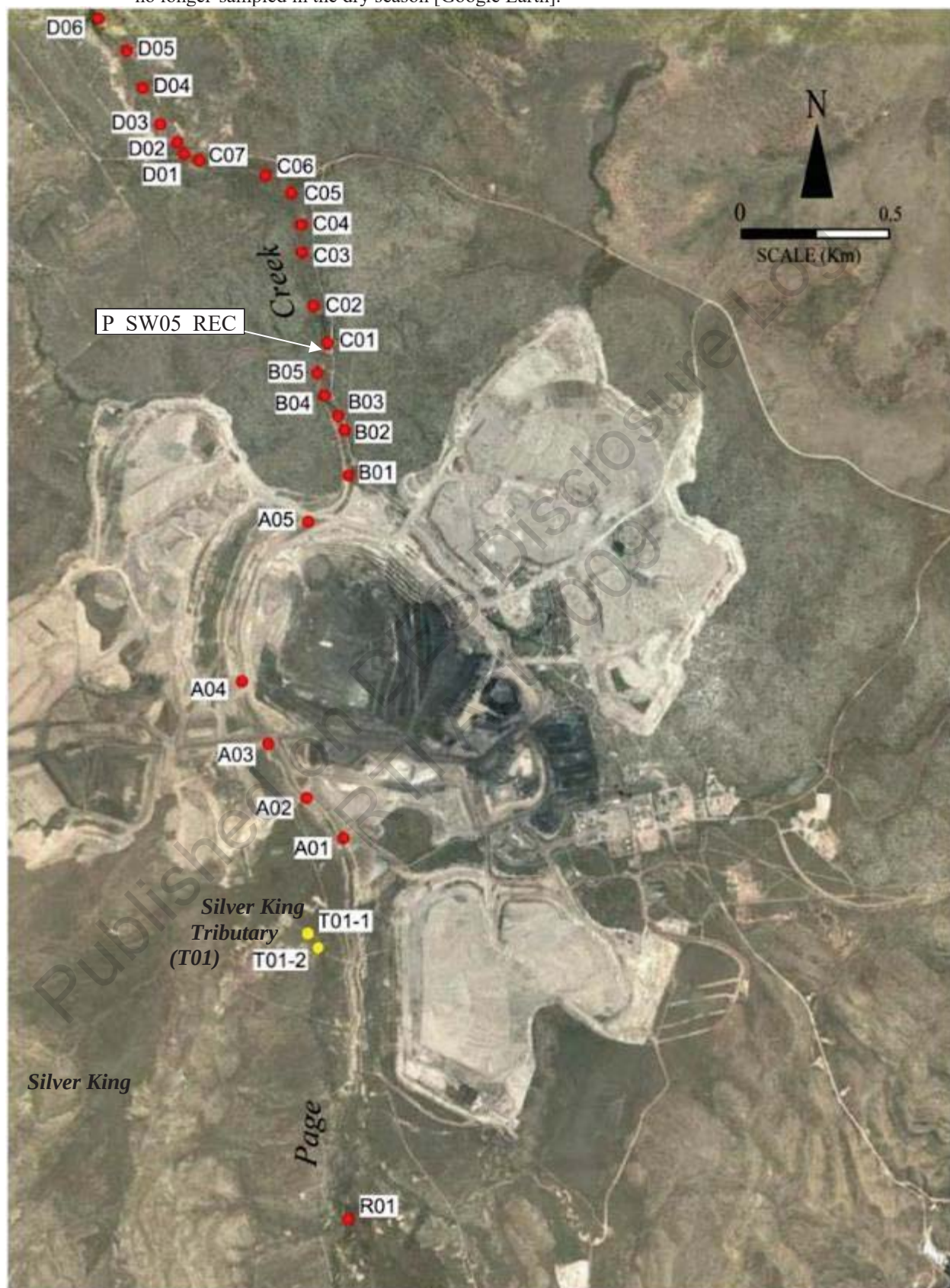


Figure 2.1.2 Page Creek sites located in stream reaches E to G. [Google Earth]. Tributary sites (prefixed T) were sampled in 2010 but have not been sampled since.



Table 2.1.1 Historical Page Creek SQMP site locations. (Datum: Australian Geodetic 1984 – UTM 54).

SITE NAME	East	North	Distance downstream from A01 (km)	SITE NAME	East	North	Distance downstream from A01 (km)
A01	246608	7926551	0.0	E07	244331	7933324	8.3
A02	246512	7927056	0.4	E08	244411	7933554	8.5
A03	246146	7927274	0.9	E09	244252	7934000	9.0
A04	245950	7927707	1.3	E10	244075	7934277	9.3
A05	246562	7929023	2.6	E11	244019	7934462	9.5
B01	246739	7929195	3.0	E12	243964	7934647	9.7
B02	246718	7929355	3.2	E13	243998	7934798	9.9
B03	246693	7929535	3.4	E14	244018	7934829	10.0
B04	246575	7929704	3.6	E15	244054	7934947	10.4
B05	246539	7929879	3.8	F01	244077	7935163	10.6
C01	246603	7930120	4.0	F02	244247	7935533	11.0
C02	246505	7930344	4.3	F03	244348	7936028	11.5
C03	246442	7930738	4.7	F04	244433	7936208	11.7
C04	246426	7930917	4.8	F05	243987	7936726	12.4
C05	246365	7931134	5.1	F06	243979	7936916	12.6
C06	246175	7931270	5.3	F07	244140	7937307	13.0
C07	245691	7931390	5.8	F08	244238	7937551	13.3
D01	245566	7931460	5.9	F09	244412	7937568	13.4
D02	245468	7931571	6.1	F10	244603	7937801	13.7
D03	245272	7931862	6.4	F11	244271	7938165	14.2
D04	245248	7932041	6.6	F12	244043	7938651	14.8
D05	245116	7932136	6.8	G01	244248	7939478	15.6
D06	245032	7932256	6.9	G02	244269	7939540	15.7
E01	245004	7932321	6.99	G03	244717	7941203	16.6
E02	244995	7932458	7.1	G04	244785	7940492	17.3
E03	245014	7932611	7.3	G05	244460	7942940	19.0
E04	244837	7932718	7.5	G06	244490	7943442	19.6
E05	244632	7932941	7.8	G07	244554	7943603	19.8
E06	244510	7933120	8.0				

Table 2.1.2 Tributary sites surveyed in 2010 (Datum: Australian Geodetic 1984-UTM 54)

Basis for Tributary Selection	Site Name	East	North	Distance of site from Page Creek (km)	Distance of confluence from Site A01 (km)
Drains Silver King base metal deposit	T01-1	246686	7925918	0.58	-0.5
	T01-2	246600	7925948	0.52	-0.5
Drains Phantom Hills phosphate deposit	T02-1	246610	7933277	1.71	7.6
	T02-2	246420	7933256	1.49	7.6
	T02-3	246233	7933115	1.27	7.6
	T02-4	245681	7932972	0.68	7.6
	T02-5	245417	7932791	0.33	7.6
	T02-6	245223	7932731	0.10	7.6
Drains Mt Jennifer phosphate deposit	T04-1	245251	7941000	1.30	19.0
	T04-2	245169	7941069	1.18	19.0
	T04-3	245027	7941308	0.90	19.0
	T05-4	244855	7941662	0.48	19.0
	T05-5	244766	7941779	0.31	19.0
	T05-6	244589	7941937	0.10	19.0

In 2010 sediment profile sampling was also carried out at the REMP control site situated in the upper reach of Page Creek (Site R01) and at the REMP reference sites (RSpr1 and RSpr2) located on Spring Creek (which was added to the routine sampling site network in 2010 because, morphologically and hydrologically, it is more similar to the middle reaches of Page Creek than any other potential reference stream in the region). However, as can be seen from the results in Table 2.1.3 these sites do not drain naturally mineralised sections of the catchment area, so although they are useful reference sites for biological monitoring purposes, they do not provide a valid basis for gauging the sedimentary metals status of Page Creek, the catchment of which is a naturally mineralised geological anomaly. Accordingly, the REMP reference sites have not been included in the SQMP.

Table 2.1.3 Minus 2 mm DAE metals results obtained at reference sites in 2010 (ACTFR 2010b)

Location	Sample Depth (cm)	Zinc (mg/kg)	Cadmium (mg/kg)	Phosphorus (mg/kg)	Lead (mg/kg)	Arsenic (mg/kg)
R01-11	5	15	< 0.1	< 10	15	< 0.5
R01-21	5	8.5	< 0.1	< 10	25	0.6
R01-22	25	13	< 0.1	< 10	22	0.6
R01-23	50	12	< 0.1	< 10	23	< 0.5
RSpr1-11	5	15	< 0.1	150	4.1	0.8
RSpr1-12	25	51.5	0.1	130	11.5	< 0.5
RSpr1-13	50	11	< 0.1	140	4.1	0.5
RSpr1-21	5	9.6	< 0.1	140	3.7	0.5
RSpr1-22	25	8.4	< 0.1	140	4.6	< 0.5
RSpr1-23	50	8.1	< 0.1	130	3.6	0.7
RSpr2-11	5	22	< 0.1	140	3.8	0.5
RSpr2-12	25	7.3	< 0.1	120	4	< 0.5
RSpr2-13	50	7.4	< 0.1	130	3.7	< 0.5
RSpr2-21	5	1.4	< 0.1	140	6.4	1.1
RSpr2-22	25	13	< 0.1	93	6.3	0.5
RSpr2-23	50	21	< 0.1	100	6.25	< 0.5

The phosphorus (P) results obtained from tributaries draining the Phantom Hills and Mount Jennifer phosphate deposits in 2010 (Table 2.1.4) and subsequent analysis of the spatial distribution of P concentrations in the main Creek relative to the tributaries, led to the conclusion that the majority of the P in the middle to lower reaches of Page Creek, and further downstream in Lawn Hill Creek, was a consequence of runoff from the natural P mineral deposits (ACTFR 2012). It was particularly apparent that P is not a reliable indicator of mine-related influences in this catchment area and it was also evident from REMP monitoring results that the sedimentary P had limited solubility and bioavailability, and therefore presented little risk to the aquatic ecosystem. Subsequent annual monitoring results strongly supported those initial conclusions and accordingly in 2017 a decision was made to discontinue routine monitoring of P concentrations, under the proviso that P may be reintroduced to the analysis suite in the future if there were any indications of potential changes to the existing situation.

The elevated Zn, Cd and Pb levels reported from the Silver King tributary led to the establishment of new diversion drain sites to better discriminate between potential input sources to the diversion channel. Major clean up works involving removal and/or stabilisation of metal-enriched materials were subsequently conducted in the Silver King catchment area. Since then minor quantities of metal-enriched sediment from Silver King have remained present in the upper reaches of the creek but there have been no indications of any further sedimentary metal releases from Silver King. However, there have been no major rainfall events during that period and it will not be possible to test the effectiveness of the remediation works until there has been a rainfall runoff event large enough to potentially mobilise any residual sedimentary materials.

Table 2.1.4 Minus 2 mm DAE metals results for unimpacted tributary sites sampled in 2010. Metals values greater than the ISQG-high are shown in red and those that lie between the ISQG-low and ISQG-high are shown in blue. Phosphorus values greater than the 80th and 95th percentiles of this dataset are shown in blue and red, respectively.

Tributary	Sample	Sample Depth (cm)	Distance of confluence from A01 (km)	Zinc (mg/kg)	Cadmium (mg/kg)	Phosphorus (mg/kg)	Lead (mg/kg)	Arsenic (mg/kg)
Silver King	T01-11	5	-0.5	2380	6.0	<50	475	0.5
	T01-12	25	-0.5	4820	14.0	<50	627	0.5
	T01-13	50	-0.5	2440	6.0	830	41	2.0
	T01-21	5	-0.5	6730	20.0	<50	1420	2.0
	T01-22	25	-0.5	1630	4.0	1960	32	2.0
	T01-23	50	-0.5	2610	6.0	1620	35	2.0
Phantom Hills	T02-11	5	7.6	110	<0.5	2370	-	<0.5
	T02-12	25	7.6	46.8	<0.5	1750	-	1.0
	T02-13	50	7.6	5.07	<0.5	<50	-	<0.5
	T02-21	5	7.6	3.88	<0.5	<50	-	<0.5
	T02-31	5	7.6	11.1	<0.5	<50	-	<0.5
	T02-32	25	7.6	10.1	<0.5	90	-	<0.5
	T02-33	50	7.6	23.4	<0.5	60	-	<0.5
	T02-41	5	7.6	6.05	<0.5	80	-	<0.5
	T02-42	25	7.6	5.36	<0.5	130	-	<0.5
	T02-43	50	7.6	1.88	<0.5	<50	-	<0.5
	T02-51	5	7.6	21	<0.5	<50	-	0.6
	T02-61	5	7.6	2.7	<0.5	<50	-	<0.5
	T02-62	25	7.6	30.1	<0.5	4510	-	<0.5
	T02-63	50	7.6	39.9	<0.5	6290	-	0.6
Mt Jennifer	T04-11	5	19.0	32	0.5	13200	17	2.0
	T04-21	5	19.0	877	3.0	1310	22	1.0
	T04-31	5	19.0	14	0.5	90	19	1.0
	T04-32	25	19.0	1260	3.0	3080	28	2.0
	T04-41	5	19.0	325	1.0	810	13	0.5
	T04-42	25	19.0	1770	5.0	670	41	2.0
	T04-51	5	19.0	1260	4.0	320	43	2.0
	T04-61	5	19.0	1580	4.0	420	40	2.0

The new sites established in the diversion included control sites located upstream of site A01. That upper section of the diversion has been designated as “Reach 1A”. In 2014 a minor realignment of the diversion resulted in site A04 being bypassed and four new sites were established in order to obtain baseline data for the new section of channel. The current diversion site network, which has not changed since 2014, is shown in Figure 2.1.3.

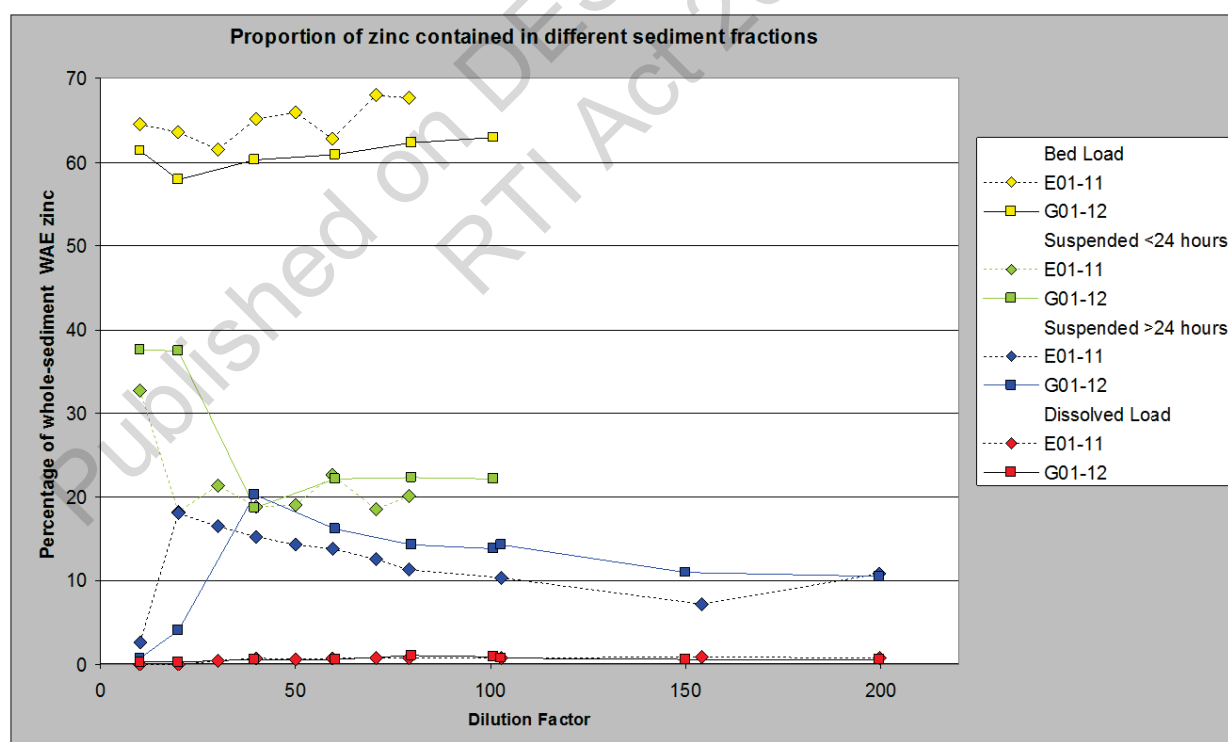
Figure 2.1.3 Page Creek Diversion channel sites sampled in 2014. [Google Earth 2017].



An analytical quality control issue emerged prior to the implementation of the 2014 sampling program when it became apparent that there was a matrix-dependent bias between different analytical laboratories (i.e. the size of the bias varied depending on the mineral composition of the sample). Subsequent QC failures were experienced in 2014 and 2015, and accordingly those samples were temporarily withheld until the issue had been resolved. This was accomplished by preparing matrix-matched QC standards which are now included with each new batch of samples, and by conducting numerous interlaboratory comparison tests to identify the best performing laboratory. It has become evident that none of the commercial laboratories involved in the comparison tests provide consistently reliable results over time-frames of several years. Accordingly, in order to be able to reliably detect trends it will be important to ensure that the existing QC procedures are maintained and to accept that it may prove necessary to periodically change laboratories. The 2014 and 2015 results were eventually analysed and are compared to the 2016 and 2017 results in subsequent sections of this report.

Analysis of the concentration changes that have occurred over time, and visual observations on site, both suggest that much of the metal-enriched sediment in Page Creek is being transported in the form of small discrete slugs which move *en masse* during the peak of flow events. This is a common occurrence when dealing with coarse-grained sediments which are too heavy to become suspended in the water column and instead move downstream by saltation (i.e. rolling/bouncing along the bottom). This observation is consistent with expectations based on laboratory testing (ACTFR 2012) which found that the majority of the contaminated sediment comprised sands which were not readily suspendable (see Figure 2.1.4).

Figure 2.1.4 Results of laboratory tests involving the agitation of sediment samples at varying water:sediment dilution ratios to determine the potential instream mobility of the sediment under simulated turbulent high flow conditions (ACTFR 2012).



The contaminated sediments were therefore considered to be readily amenable to capture in sediment traps. In response to that finding a sediment trap was installed in the lower reaches of Page Creek in 2014 (location shown in Figure 2.1.2) in order to prevent the sediment from reaching Lawn Hill Creek. It is planned that sediment trapped by this structure will be removed on a routine annual basis.

In 2014 it was also evident that even though there had been average rainfall during the preceding wet season, stream flow had been insufficient to significantly alter the spatial distribution of sedimentary contaminants in the creek. It was therefore decided to reduce sampling intensity until there were any indications of potentially significant changes, in which case the more intensive sampling employed in 2014 would be re-employed. The tactic employed in 2015 was to collect 58 composite samples each representative of a stream reach of nominally 500 m. An attempt was also made to quantify the contaminant load within each reach, by employing a variety of techniques, including ground penetrating radar, to obtain estimates of sediment volume. Unfortunately the streambed proved to be too rough and too heterogeneous for that tactic to be feasible.

The reach compositing approach proved to be excessively laborious, so an alternative tactic was employed in 2016 and 2017. This entailed sampling at 50 of the discrete depth profiling locations that had been sampled each year between 2010 and 2014. Site selections were done by statistically analysing selected subsets of the 2014 data to ensure that the mean Zn concentrations in each reach were the same as the mean values generated by the full dataset. That statistical analysis suggests that 50 is the minimum number of samples required to accomplish that objective. The results obtained from these different sampling approaches are compared in the next section of this report.

Historically there has always been a strong correlation between Zn and Cd in Page Creek ($R^2 \geq 0.89$) indicating that these two metals originate from a common source (the mine) and are currently exhibiting similar mobility properties. This is very strong correlation given that a significant proportion of the Cd results are at or below the reporting limit and therefore less clearly defined than the higher Zn results. Since the existing Zn concentrations are much higher than Cd (in terms of both absolute concentration and potential risk) the Zn data are more relevant for risk assessment and more amenable to accurate analysis and graphical displays. This report therefore focuses heavily on the trends exhibited by Zn, on the understanding that they also accurately reflect Cd trends. Each year the correlation is checked to ensure that this assumption is still supported.

The Silver King catchment appears to be the only potentially significant source of anthropogenic Pb enrichment in Page Creek. There are a few isolated slugs of such sediment in the diversion channel and the upper reaches of Page Creek where Pb concentrations have historically exceeded the SQG-Low but to date Pb has not emerged as a significant issue compared to Zn (which has consistently exceeded the SQG-High along the full length of Page Creek) and Cd (which has regularly exceeded the SQG-Low at most receiving sites). Pb has been retained in the analysis suite primarily to serve as an indicator to identify sediments sourced from Silver King. Recent Pb results are tabulated in this report but to date occurrences of elevated levels have not been sufficiently frequent or widespread to warrant detailed analysis.

Manganese (Mn) has not historically been included in the SQMP monitoring but it was added to the analytical suite on a one-off basis in 2016 as part of an investigation triggered by an EA TL exceedance at P_SW03_REC. That investigation recommended that the Mn TL be removed from the EA on the grounds that high values were not a reliable indicator of risks to the ecosystem or effects from the mine. That recommendation was accepted by the administering authority and Mn is now monitored at compliance sites for interpretation purposes only. Accordingly Mn has not been included in the routine SQMP analytical suite.

2.2 Current Status of Page Creek Sediments

Annual REMP reports indicate that instream biological conditions have improved measurably since 2012. As is usually the case when dealing with stagnant retracting waterholes in ephemeral creeks, there has on occasion been evidence of ecological impairment at both reference and impact sites, but in recent years all such instances appear to have been attributable to natural deterioration processes and/or livestock impacts. Notably, since 2013 there has been no evidence of any correlation between sediment metal residue concentrations and ecological condition, some of the highest diversity and abundances having often been reported at the sites with the highest contaminant levels.

As would be expected based on historical data, the Zn concentration at the sediment compliance site exceeded the EA TL (Table 2.2.1) in 2018. A trigger investigation report has been submitted to DES as required under EA condition C16. Stream sediments in this study area are so heterogeneous that the individual grab samples that are used to assess compliance carry very little statistical weight especially in comparison to the statistically strong datasets being collected in the SQMP. Ostensibly, and particularly in cases such as this where exceedances are to be expected each year, the compliance sampling required under the current EA has been rendered redundant by the SQMP investigations. TropWATER recommend negotiating with DES to include an EA clause that exempts a site from condition C16 if that site is currently subject to intensive investigation under an SQMP that has been sanctioned by the Administering Authority.

Table 2.2.1 Minus 2 mm DAE metals results for sediment compliance on Page Creek in 2018.

EA Stream sediment trigger levels (mg/kg)	Site	P_SW17_REF	P_SW03_REC
10	Cadmium	<0.1	3.1
270	Copper	1.3	6
220	Lead	5.1	55
52	Nickel	1.5	9.7
410	Zinc	9.2	1000
70	Arsenic	0.6	2.8
3 x greater than reference site	Selenium	<1	<1
For interpretation purposes	Manganese	340	1200
For interpretation purposes	< 63µm Particle size (%)	13.0	27.0

Raw Data generated by SQMP sampling campaigns since 2014 are presented in Tables A.1 to A.4 of Appendix A. Annual summary statistics for data collected since 2009 are shown in Table 2.2.2 and these are displayed in boxplots in Figures 2.2.1 (lead), 2.2.2 (phosphorus) and 2.2.3 (cadmium) and 2.2.4 (zinc). It is apparent in these figures that Pb concentrations are generally low and there is no evidence of any statistically significant temporal trends in Pb or P concentrations. This contrasts with Zn and Cd both of which have shown significant declines in mean concentrations since 2009. Notably mean Zn values have decreased by more than 50%. This appears to be a consequence of dilution by natural sediment inputs rather export to downstream environments because Zn concentrations in Lawn Hill Creek have not changed significantly (see next section). Despite the substantial reduction in mean concentrations 71.4% of the Zn results reported in 2018 were still greater than the SQG-High. A further 50% reduction in Zn concentrations will be required in order for mean values fall below the SQG-High.

Table 2.2.1 Annual statistics for <2 mm WAE metal results obtained from SQMP sampling in Page Creek since 2009. Values that exceed the ANZECC SQG-high are shown in red, while those that exceed the SQG-low are blue.

Metal	Year	Mean	95% Confidence Interval	Median	n	Minimum	Maximum	20th Percentile	80th Percentile	% greater than SQG-high	% greater than SQG-low
Zinc	2009	1805	408	980	195	95	23000	386	2200	78.5	92.8
	2010	1401	108	1400	183	65	4600	828	1900	91.8	97.8
	2011	1125	117	1000	168	19	3200	420	1700	80.4	88.7
	2012	1255	184	903	152	58	5320	443	1710	80.3	89.5
	2013	1126	137	1020	172	6	4470	211	1780	72.1	80.2
	2014	862	105	660	199	3	3600	226	1500	63.8	83.4
	2015	772	126	670	58	48	2200	374	1200	75.9	91.4
	2016	826	140	845	50	51	1700	354	1400	74.0	90.0
	2017	719	123	640	50	49	1800	306	1100	74.0	90.0
	2018	746	134	780	49	46	2100	342	1100	71.4	87.8
Cadmium	2009	3.8	1	2.8	195	0.0	23	0.0	6	5.1	67.7
	2010	4.3	1	3.5	183	0.0	53	1.9	6	2.7	85.2
	2011	3.3	0	2.9	168	0.0	14	1.0	5	1.8	72.0
	2012	3.4	1	2.0	152	0.0	17	1.0	5	7.2	73.0
	2013	2.9	0	3.0	172	0.0	14	0.0	5	1.7	68.6
	2014	2.3	0	1.9	199	0.0	10	0.0	4	0.0	57.3
	2015	2.9	0	2.3	49	1.1	8	1.5	4	0.0	71.4
	2016	2.5	1	2.3	50	0.0	7	0.0	4	0.0	64.0
	2017	2.0	0	1.8	50	0.0	6	0.0	3	0.0	54.0
	2018	2.4	1	2.1	49	0.0	9	0.0	4	0.0	0.0
Lead	2009	32	3	26	195	6	150	17	44	0.0	13.3
	2010	29	3	27	183	9	210	17	39	0.0	5.5
	2011	28	2	26	168	5	100	19	35	0.0	4.8
	2012	21	3	16	152	3	241	11	26	0.7	3.9
	2013	26	6	17	172	3	342	10	30	1.7	5.8
	2014	11	1	9	199	3	51	6	15	0.0	0.5
	2015	28	6	23	58	8	140	13	41	0.0	13.8
	2016	17	2	15	50	3	38	12	22	0.0	0.0
	2017	15	3	11	50	5	69	10	21	0.0	2.0
	2018	21	4	17	49	9	65	11	26	0.0	0.0
Phosphorus	2009	755	135	500	195	25	11000	260	982		
	2010	866	126	620	183	25	6100	334	1200		
	2011	466	64	370	168	25	3600	200	620		
	2012	970	305	475	152	25	20100	240	1096		
	2013	1028	191	720	172	25	9290	174	1490		
	2014	799	134	530	199	25	6400	200	1100		
	2015	1035	368	440	58	13	6300	274	1440		
	2018	823	223	550	50	25	3600	304	1420		

Figure 2.2.1 Boxplot showing interannual variations in the distribution of lead results obtained from SQMP sampling in Page Creek. Boxes display 20th, 50th and 80th percentiles. Boxplot error bars are maxima and minima.

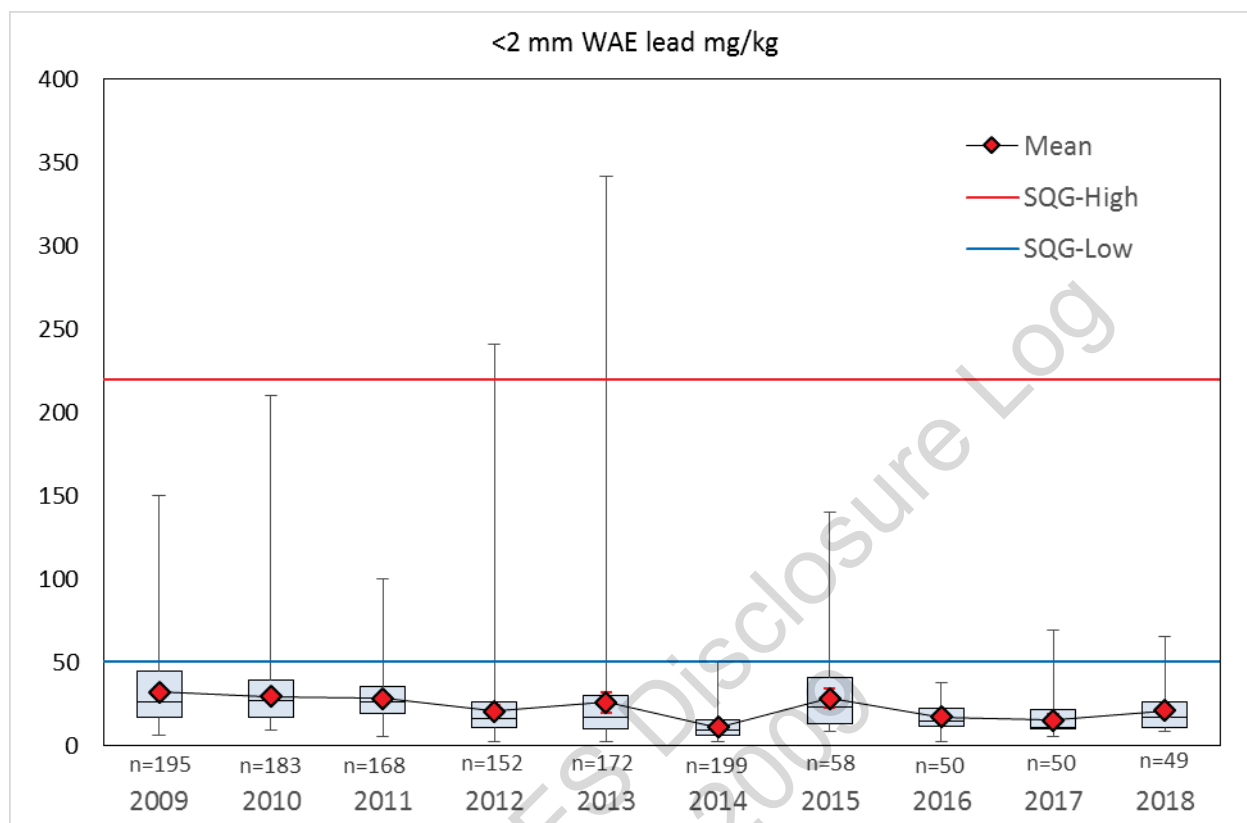


Figure 2.2.2 Boxplot showing interannual variations in the distribution of phosphorus results obtained from SQMP sampling in Page Creek. Boxes display 20th, 50th and 80th percentiles. Error bars are maxima and minima.

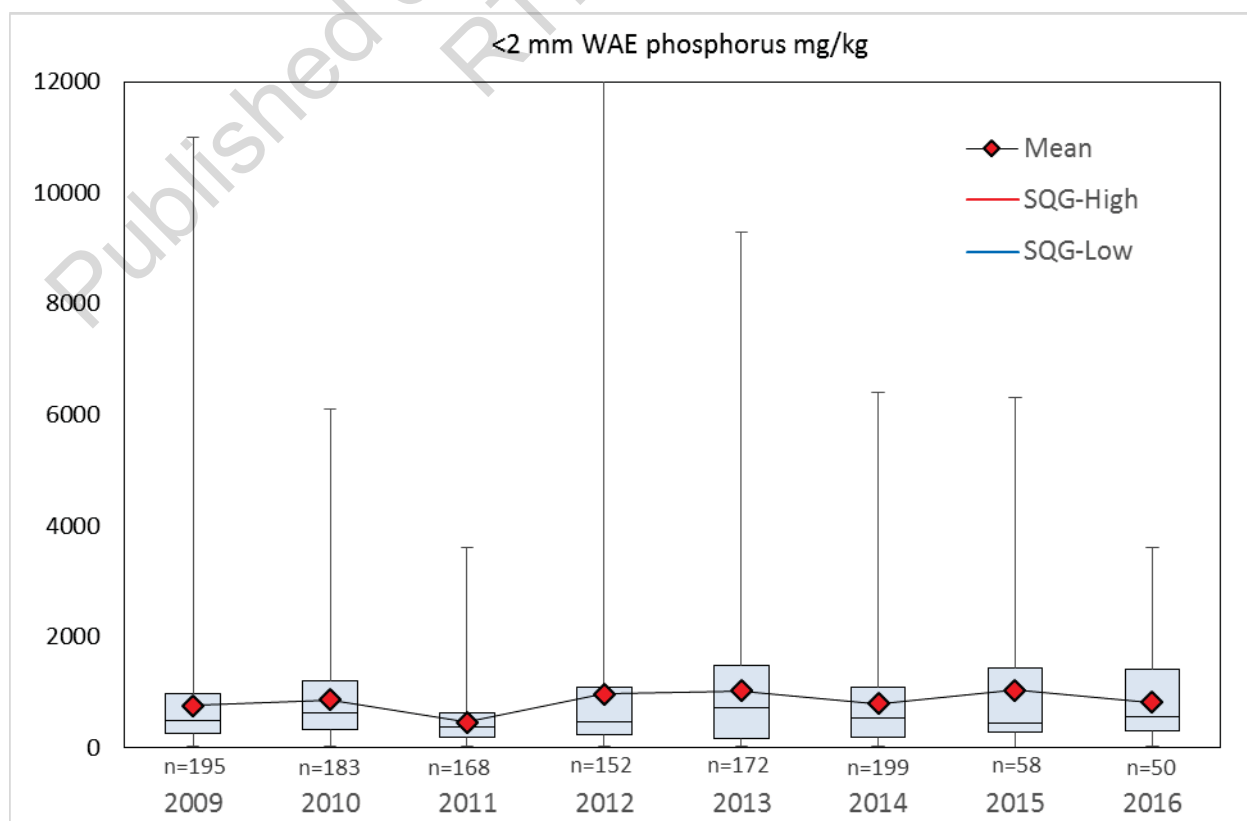


Figure 2.2.3. Interannual variations in the distribution of cadmium results obtained from SQMP sampling in Page Creek. Boxes display 20th, 50th and 80th percentiles. Boxplot error bars are maxima and minima. Red error bars are 95% confidence limits of the mean. Maxima of 53 mg/kg in 2010 not shown.

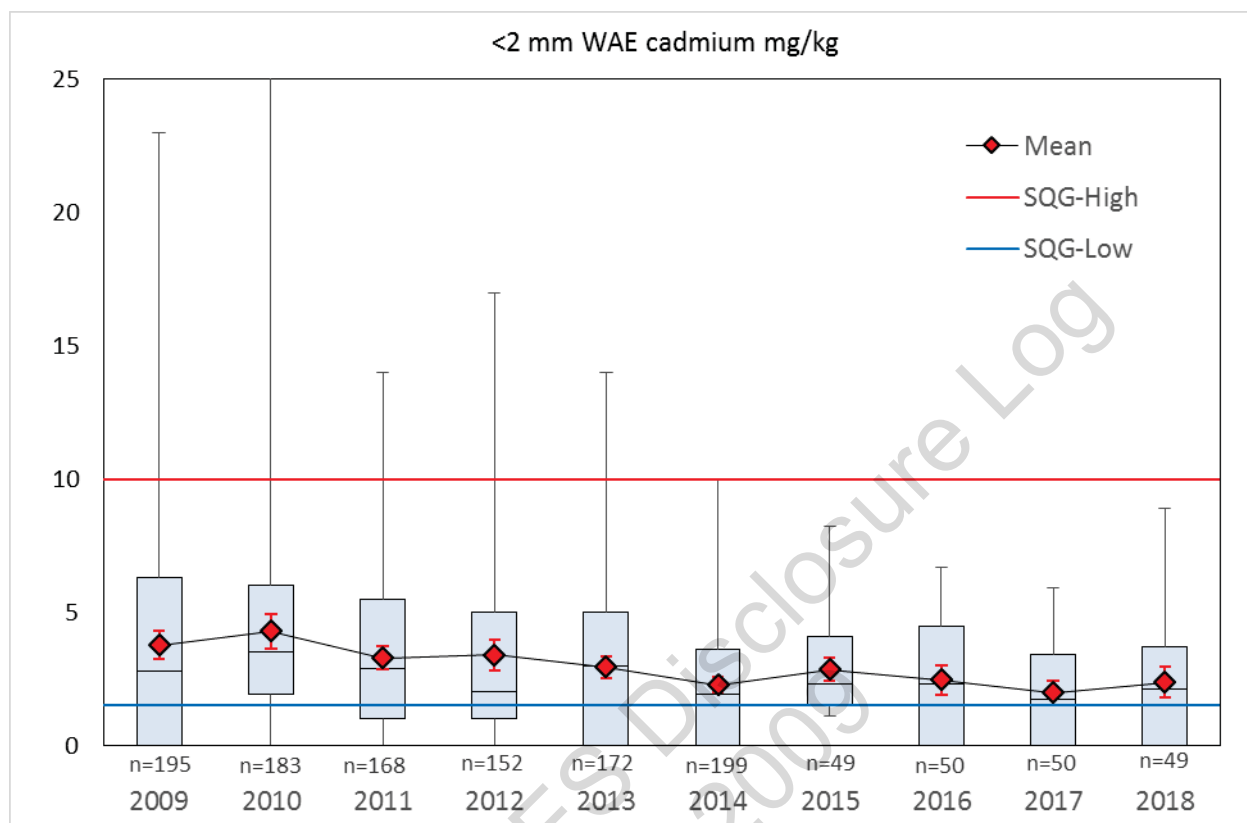


Figure 2.2.4a Interannual variations in the distribution of zinc results obtained from SQMP sampling in Page Creek. Boxes display 20th, 50th and 80th percentiles. Boxplot error bars are maxima and minima. Red error bars are 95% confidence limits of the mean.

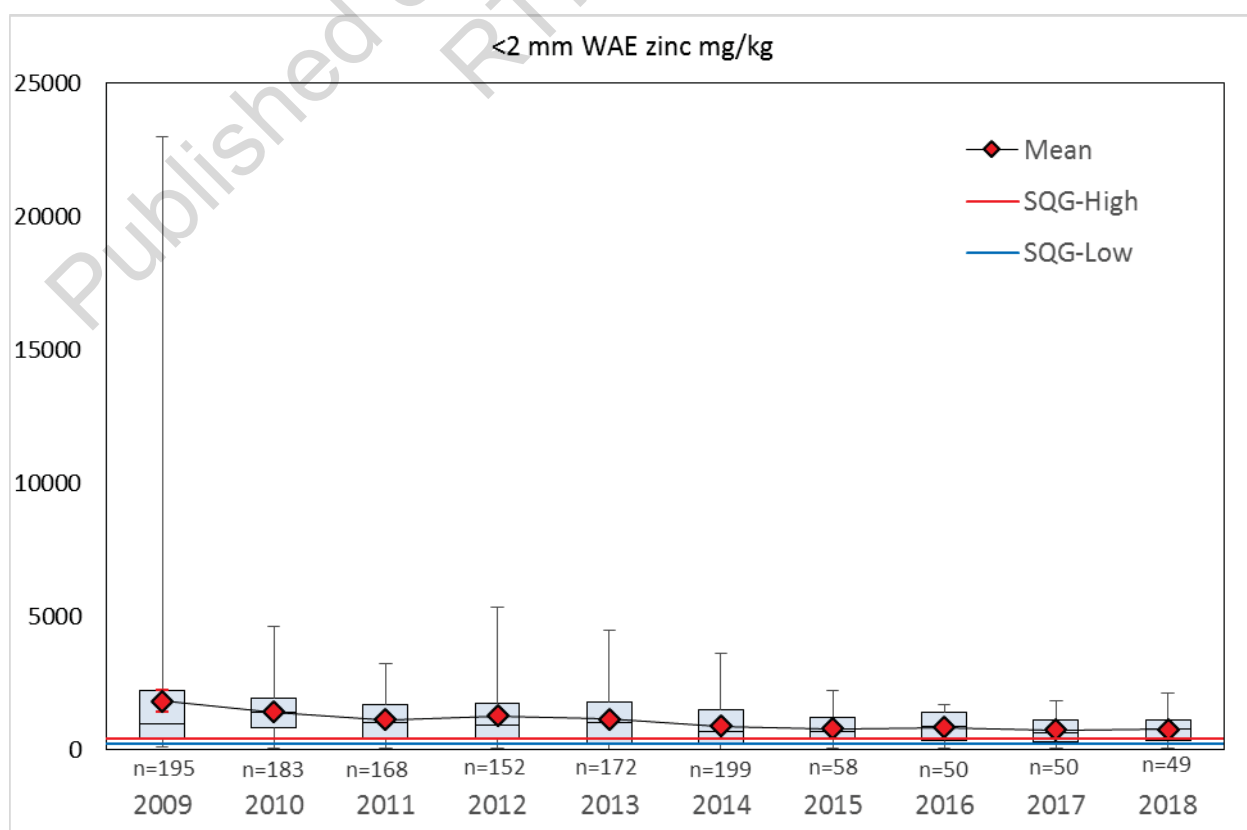
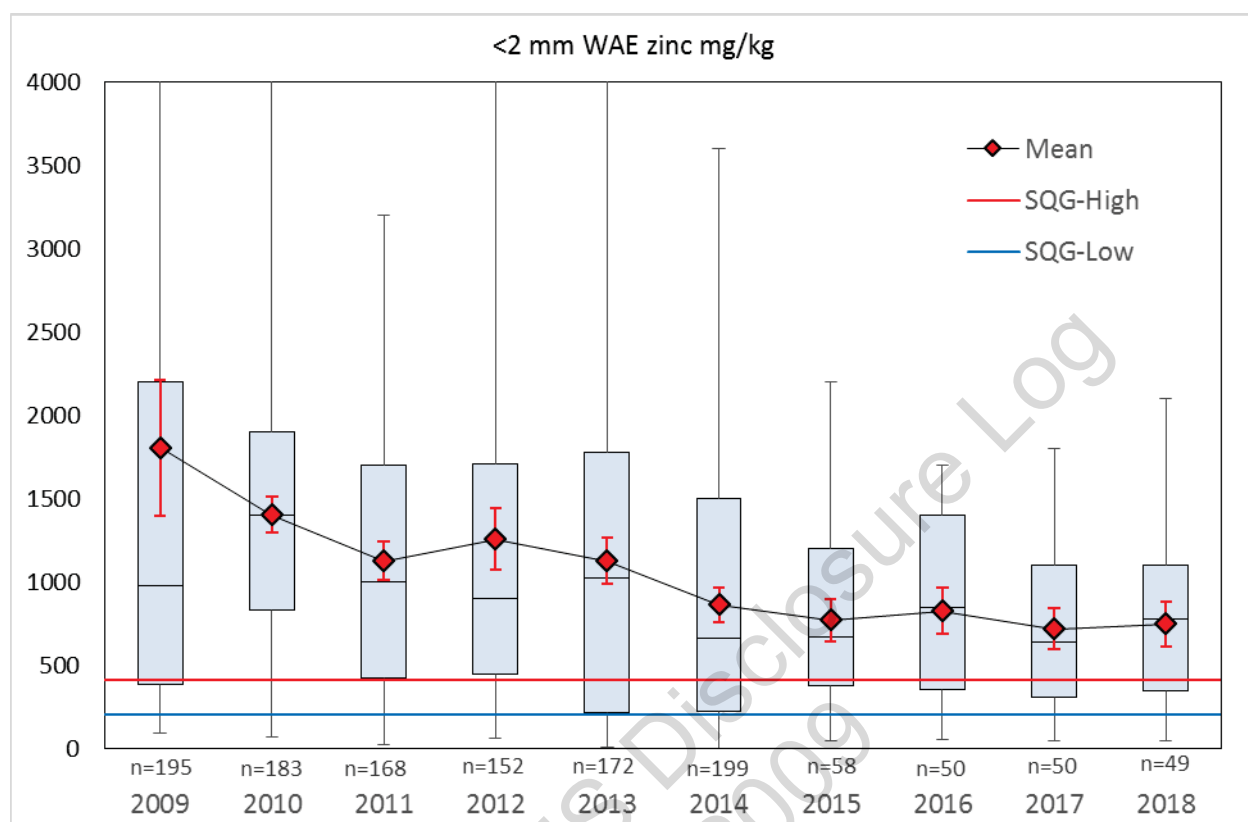


Figure 2.2.4b Rescaled version of Figure 2.2.4a. Boxes display 20th, 50th and 80th percentiles. Boxplot error bars are maxima and minima. Red error bars are 95% confidence limits of the mean.



Temporal trends in Zn concentrations within each individual stream reach are plotted in Figure 2.2.5. Analysis of the SQMP datasets for 2009 to 2018 indicates that the mean zinc levels in most reaches have declined moderately since 2013 although Reach F is the only case where the apparent decline was statistically significant and Reach A (the diversion channel) is the only reach where mean zinc levels were below the ISQG-High (the Cd in that Reach was also below the ISQG-Low). On face value this appears to indicate that recent inputs to Page Creek from the mine have been low and that pre-existing sedimentary metal residues have been moderately diluted by natural sediment inputs. These effects could potentially be a temporary consequence of the lack of large flow events since 2012 (resulting in surface deposition of unenriched natural sediments from localised soil sources) and an absence of movement within the streambed.

The short term effects of this are evident in the depth profiling data shown in Figure 2.2.5. It can be seen that the decreasing trends in Reaches A to D have primarily been confined to the surface (0-15cm) layer of the streambed. In Reaches E and F the decreasing trend is evident through the sediment profile implying that flows in that section of the stream since 2013 have been sufficiently energetic to induce vertical mixing of the streambed and some downstream transportation of bed sediments to Reach G. During the wetter years prior to 2013 this resulted in an increase in concentrations in Reach G; however, since then there have been significant declines in Reach G especially within the surficial sediment layer. In fact G is the only reach where surface Zn concentrations have been significantly lower than the deeper underlying sediments for the past four years.

These trends have developed over a drought period. It will not be possible to confidently ascertain longer term trends until there has been a large-scale flow event with the potential to more fully mobilise the bed sediments.

Figure 2.2.5. Spatiotemporal variations in Page Creek sediment zinc concentrations since 2009 clustered by reach. Error bars are 95% confidence intervals of the mean. An outlier of 15000 mg/kg for Reach A in 2009 and a maximum value of 23000 mg/kg for Reach C in 2009 are not shown:

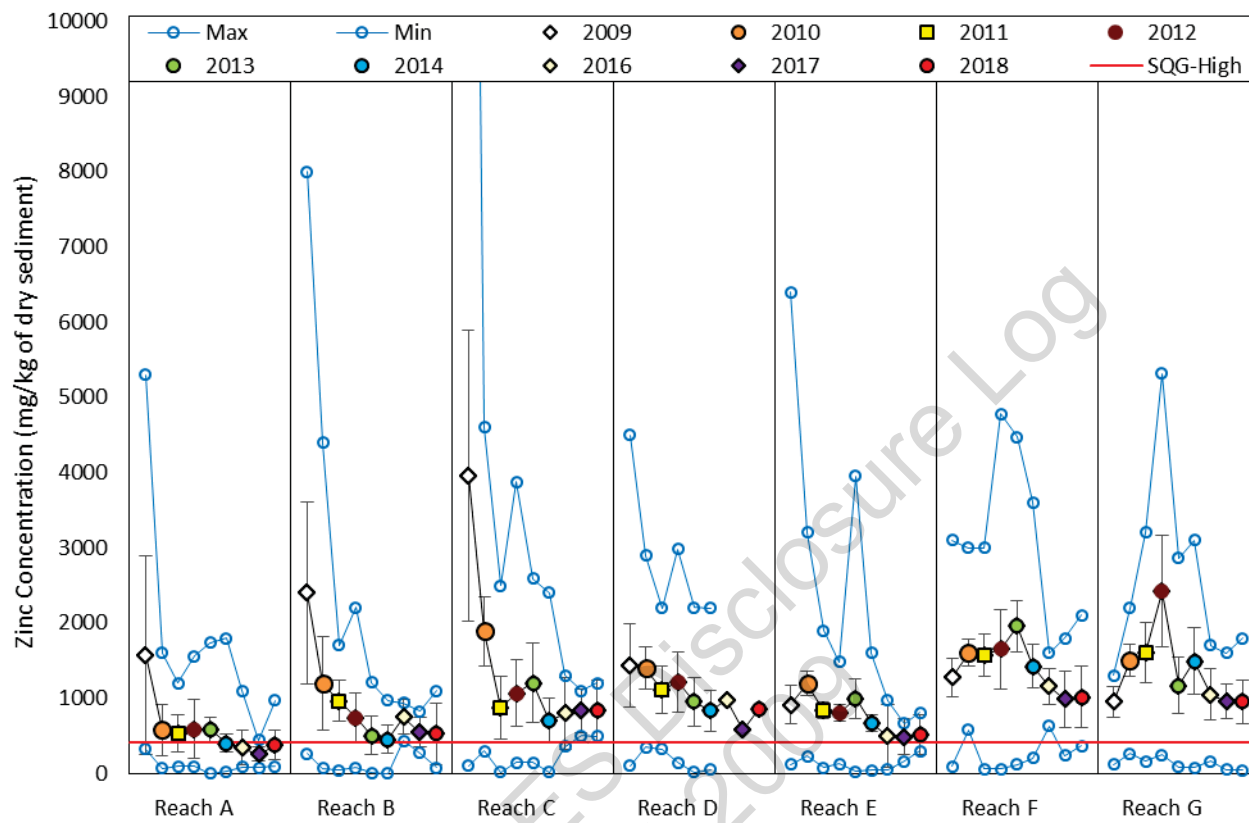
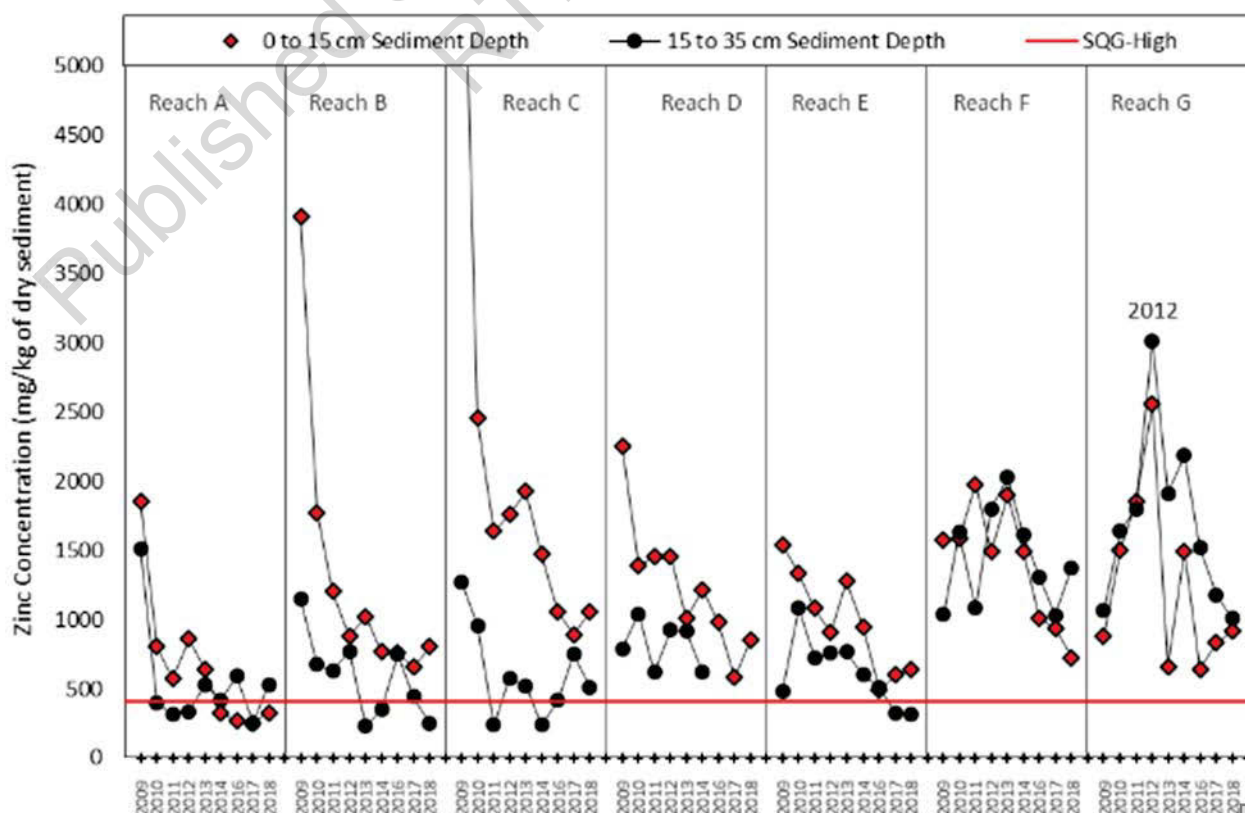


Figure 2.2.6 Variations in Page Creek zinc concentrations with sediment depth since 2009 clustered by stream reach. Points are mean values and are arranged chronologically as in Figure 2.2.5.



Laboratory-based investigations conducted in 2010 demonstrated that the sedimentary metal residues in Page Creek have low water solubility, and hence relatively low bioavailability and toxicity. Historical REMP data support that contention, as do the limited water quality results obtained in 2018; zinc and cadmium levels in surface water samples were low and in most cases undetectable, and sediment pore-water metal concentrations were consistent with a maximum solubility of 0.03 to 0.04 % (cf 0.1 to 2.7 % at regional reference sites). Notably there was no correlation between the metal concentrations in the solid and aqueous phases of the bottom sediment suggesting that the pore water metal mostly originated from sources other than the sediment.

The water quality conditions encountered at most Page Creek sites during the 2016 to 2018 REMP sampling campaigns were generally good by regional standards and this was reflected in the biological monitoring results. Notably the only water quality anomalies observed were clearly a result of natural deterioration, exacerbated by livestock pressures. In fact with respect to mine-related water quality parameters recent results have ranked amongst the best that have been recorded to date and there have been no indications of any potential impacts that could potentially be attributed to mine-sourced contaminant residues.

These findings strongly support the assertion that the metal residues in Page Creek have had minimal impact on the creek's ecosystem. Nevertheless, the quantities of Zn and Cd contained in the streambed present a potential risk to the more valuable, diverse and potentially more sensitive, biological communities downstream in Lawn Hill Creek. Accordingly ongoing monitoring and maintenance of the Page Creek sediment trap and, if necessary structural improvements, will remain a management priority well into the foreseeable future. Continued monitoring of zinc concentrations in the sediments of Lawn Hill Creek will also be essential in order to confirm the effectiveness of existing management measures (see Section 3).

Note that since the sediment trap was installed in 2014 there have been no flow events large enough to substantially mobilise the bed sediments, and hence no opportunity to fully test the structure's effectiveness. Due to a lack of any significant flow events very little sediment was captured in the trap in 2017 and 2018, but a total of 45 tonnes of sediment was removed from the trap in 2016. The average grade of the material (1223 mg/kg) was very close to the mean value for that stream reach, so the effects of the removal will not be immediately detected by monitoring the metal concentrations in Page Creek. However, the reduced load means that less natural sediment will be necessary to achieve effective dilution, so it is expected that this will eventually result in reduced concentrations over a number of years.

2.3 Protocols for Future Monitoring

Each year during the postwet season REMP sampling campaign the condition and composition of the Page Creek streambed of each REMP site will be assessed to determine if there is any evidence of potentially significant changes or emerging water quality issues that require investigation under the SQMP. The previous year's SQMP results will also be reviewed in order to determine if any new issues were identified.

Routine Sampling

If there is no evidence of circumstances having changed, routine SQMP sampling will be conducted during the dry season employing the same approaches that have been employed since 2016. This will entail collection of the 50 depth profile samples listed in Table 2.3.1, the locations of which are listed and mapped in the preceding sections of this report. Samples will be sieved to remove material >2mm, analysed for dilute acid extractable Zn, Cd and Pb, and wet sieved to determine percent passing 63 µm.

Table 2.3.1 Samples to be collected during routine SQMP sampling campaigns. Site locations are listed in Table 2.1.1 and mapped in Figures 2.1.1 to 2.1.3.

Reach	Sample	Sample Depth (cm)	Thread Distance from A01 (km)	Reach	Sample	Sample Depth (cm)	Thread Distance from A01 (km)
A	A01-11	0-15	0.0	F	F07-11	0-15	13.0
	A01-13	15-35	0.0		F07-12	15-35	13.0
	A02-11	0-15	0.4		F08-11	0-15	13.3
	A03-11	0-15	0.9		F08-12	15-35	13.3
	P09-11	0-15	1.0		F09-11	0-15	13.4
	N02-11	0-15	1.4		F09-12	15-35	13.4
	N04-11	0-15	1.6		F10-11	0-15	13.7
	A05-11	0-15	2.6		F10-12	15-35	13.7
	A05-12	15-35	2.6		F11-11	0-15	14.2
B	B01-11	0-15	3.0		F11-12	15-35	14.2
	B01-12	15-35	3.0	G	G02-11	0-15	15.7
	B03-11	0-15	3.4		G02-12	15-35	15.7
	B03-12	15-35	3.4		G03-11	0-15	16.6
	B05-11	0-15	3.8		G03-12	15-35	16.6
	B05-12	15-35	3.8		G04-11	0-15	17.3
C	C01-11	0-15	4.0		G04-12	15-35	17.3
	C01-13	15-35	4.0		G04-13	35-50	17.3
	C02-11	0-15	4.3		G05-11	0-15	19.0
	C02-12	15-35	4.3		G05-12	15-35	19.0
	C05-11	0-15	5.1		G05-13	35-50	19.0
D	D04-11	0-15	6.6		G06-11	0-15	19.6
E	E05-11	0-15	7.8		G06-12	15-35	19.6
	E10-11	0-15	9.3		G07-11	0-15	19.8
	E10-13	15-35	9.3		G07-12	15-35	19.8
	E10-21	0-15	9.3				
	E10-23	15-35	9.3				

Post Event Sampling

If the REMP determines that during the preceding wet season there has been an event with the potential to have altered the condition and/or composition of the Page Creek (for example a major flood or a potentially significant non-compliant release from the mine) monitoring will be intensified to include all of the sites sampled in 2014 (as listed in Table 2.3.2). Depth profile samples encompassing the 0-15cm, 15-35cm and 35-50cm sediment horizons will be collected at all sites where basal sands are deep enough to do so. Samples will be sieved to remove material >2mm, analysed for dilute acid extractable Zn, Cd and Pb, and wet sieved to determine percent passing 63 µm.

Table 2.3.2 Samples to be collected during post-event SQMP sampling campaigns. Site locations are mapped in Figures 2.1.1 to 2.1.3.

Reach	Site	Station	Longitude	Latitude	Distance from A01 (km)	Reach	Site	Station	Longitude	Latitude	Distance from A01 (km)
R01	R01	R01	138.5980	-18.7596	-2.6	D	D03	D03-1	138.5862	-18.6874	6.43
1A	A00	A00	138.5991	-18.7512	-2.40	D	D03	D03-2	138.5863	-18.6877	6.43
1A	O01	001-1	138.5989	-18.7500	-1.65	D	D04	D04-1	138.5858	-18.6858	6.61
1A	O02	002-1	138.5990	-18.7451	-1.09	D	D05	D05-1	138.5853	-18.6849	6.77
1A	O03	003-1	138.5991	-18.7421	-0.76	D	D06	D06-1	138.5838	-18.6839	6.92
1A	T01-1	T01-1	138.5978	-18.7411	-0.50	E	E01	E01-1	138.5835	-18.6833	6.99
1A	T01-2	T01-2	138.5981	-18.7415	-0.50	E	E01	E01-2	138.5835	-18.6832	6.99
1A	O04	004-1	138.5987	-18.7390	-0.42	E	E02	E02-1	138.5834	-18.6820	7.12
1A	P02	P02	138.5984	-18.7362	-0.10	E	E03	E03-2	138.5837	-18.6806	7.28
1A	P01	P01	138.5981	-18.7358	-0.04	E	E04	E04-1	138.5820	-18.6795	7.48
A	A01	A01-1	138.5979	-18.7355	0.00	E	E05	E05-1	138.5801	-18.6776	7.78
A	P03	P03	138.5961	-18.7327	0.36	E	E06	E06-1	138.5790	-18.6761	8.00
A	A02	A02-1	138.5956	-18.7323	0.40	E	E07	E07-1	138.5773	-18.6742	8.27
A	P04	P04	138.5949	-18.7313	0.57	E	E07	E07-2	138.5773	-18.6739	8.27
A	P05	P05	138.5945	-18.7303	0.69	E	E08	E08-1	138.5775	-18.6727	8.51
A	A03	A03-1	138.5937	-18.7290	0.86	E	E09	E09-1	138.5766	-18.6680	8.98
A	P09	P09	138.5929	-18.7279	1.00	E	E10	E10-1	138.5754	-18.6658	9.32
A	P10	P10	138.5928	-18.7277	1.03	E	E10	E10-2	138.5752	-18.6658	9.32
A	N01	N01	138.5919	-18.7260	1.28	E	E11	E11-1	138.5745	-18.6636	9.51
A	N02	N02	138.5913	-18.7246	1.38	E	E12	E12-1	138.5743	-18.6619	9.66
A	N03	N03	138.5913	-18.7239	1.45	E	E13	E13-1	138.5747	-18.6604	9.85
A	N04	N04	138.5913	-18.7224	1.58	E	E14	E14-1	138.5748	-18.6595	10.05
A	O05	005-1	138.5920	-18.7194	2.00	E	E14	E14-2	138.5748	-18.6594	10.05
A	A05	A05-1	138.5964	-18.7151	2.57	E	E14	E14-3	138.5749	-18.6592	10.05
A	P08	P08	138.5979	-18.7143	2.87	F	F01	F01-1	138.5751	-18.6577	10.59
A	O06	006-1	138.5991	-18.7139	3.00	F	F02	F02-1	138.5767	-18.6544	11.00
B	B01	B01-1	138.5996	-18.7126	3.03	F	F03	F03-1	138.5774	-18.6503	11.50
B	B02	B02-1	138.5994	-18.7100	3.19	F	F04	F04-1	138.5786	-18.6481	11.70
B	B03	B03-1	138.5992	-18.7087	3.37	F	F04	F04-2	138.5792	-18.6477	11.70
B	B04	B04-1	138.5981	-18.7071	3.58	F	F04	F04-3	138.5803	-18.6471	11.70
B	B05	B05-1	138.5977	-18.7059	3.76	F	F05	F05-1	138.5764	-18.6445	12.38
C	C01	C01-1	138.5983	-18.7037	4.01	F	F06	F06-1	138.5745	-18.6417	12.57
C	C02	C02-1	138.5976	-18.7013	4.25	F	F07	F07-1	138.5754	-18.6389	13.00
C	C02	C02-2	138.5981	-18.7011	4.25	F	F08	F08-1	138.5775	-18.6360	13.26
C	C03	C03-1	138.5970	-18.6977	4.65	F	F09	F09-1	138.5789	-18.6357	13.43
C	C04	C04-1	138.5970	-18.6964	4.83	F	F10	F10-1	138.5798	-18.6330	13.73
C	C05	C05-1	138.5962	-18.6941	5.06	F	F11	F11-1	138.5769	-18.6298	14.23
C	C06	C06-1	138.5945	-18.6927	5.29	F	F12	F12-1	138.5752	-18.6260	14.76
C	C07	C07-1	138.5899	-18.6919	5.79	G	G01	G01-1	138.5769	-18.6191	15.61
D	D01	D01-1	138.5893	-18.6916	5.93	G	G02	G02-1	138.5780	-18.6171	15.68
D	D01	D01-2	138.5888	-18.6912	5.93	G	G03	G03-1	138.5803	-18.6077	16.57
D	D02	D02-1	138.5883	-18.6905	6.08	G	G04	G04-1	138.5803	-18.6016	17.30
D	D02	D02-2	138.5881	-18.6902	6.08	G	G05	G05-1	138.5783	-18.5896	19.04
						G	G06	G06-1	138.5802	-18.5826	19.58
						G	G07	G07-1	138.5807	-18.5814	19.75

Investigative Monitoring Contingency

Each year the annual REMP and SQMP reports will recommend any additional *ad hoc* monitoring components which may need to be temporarily added to the SQMP in order to address emerging issues or assist sediment management activities. This could for example include the incorporation of additional sites to assess the effectiveness of a new remediation measure or the addition of new analytes to assess the potential significance of an anomaly detected by the REMP.

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3. LAWN HILL CREEK

3.1 Historical background

Since 2009 moderately elevated concentrations of sedimentary zinc and phosphorus in the stream reaches immediately downstream of the Page Creek confluence have provided the only evidence of potential mine-related influences on Lawn Hill Creek. Previous SQMP investigations have demonstrated that most of the phosphorus almost certainly originates naturally from the Mt Jennifer phosphate deposit which is immediately adjacent to Reach G of Page Creek and to Lawn Hill Creek itself, with some potential additional contributions (via Page Creek) from the Phantom Hills Phosphate deposits.

Most of the Zn in this section of Lawn Hill Creek clearly originates from Page Creek. However, Zn concentrations similar to those in the middle reaches of Page Creek (up to 1770 mg/kg) have been recorded in the Mt Jennifer tributary which enters Page Creek prior to its intersection with Lawn Hill. Moreover, the natural mineralisation associated with the Century ore body was probably always a source of measurable Zn enrichment to both Page and Lawn Hill Creeks. Accordingly, it is possible that a significant proportion of the Zn currently contained in the Lawn Hill Creek sediments is naturally occurring, but in the absence of pre-mine baseline data and until proven otherwise, it is conservative to assume that most of the Zn could potentially have originated from the mine. Certainly it is clear that a proportion of the current Zn residues in Page Creek originated from the mine.

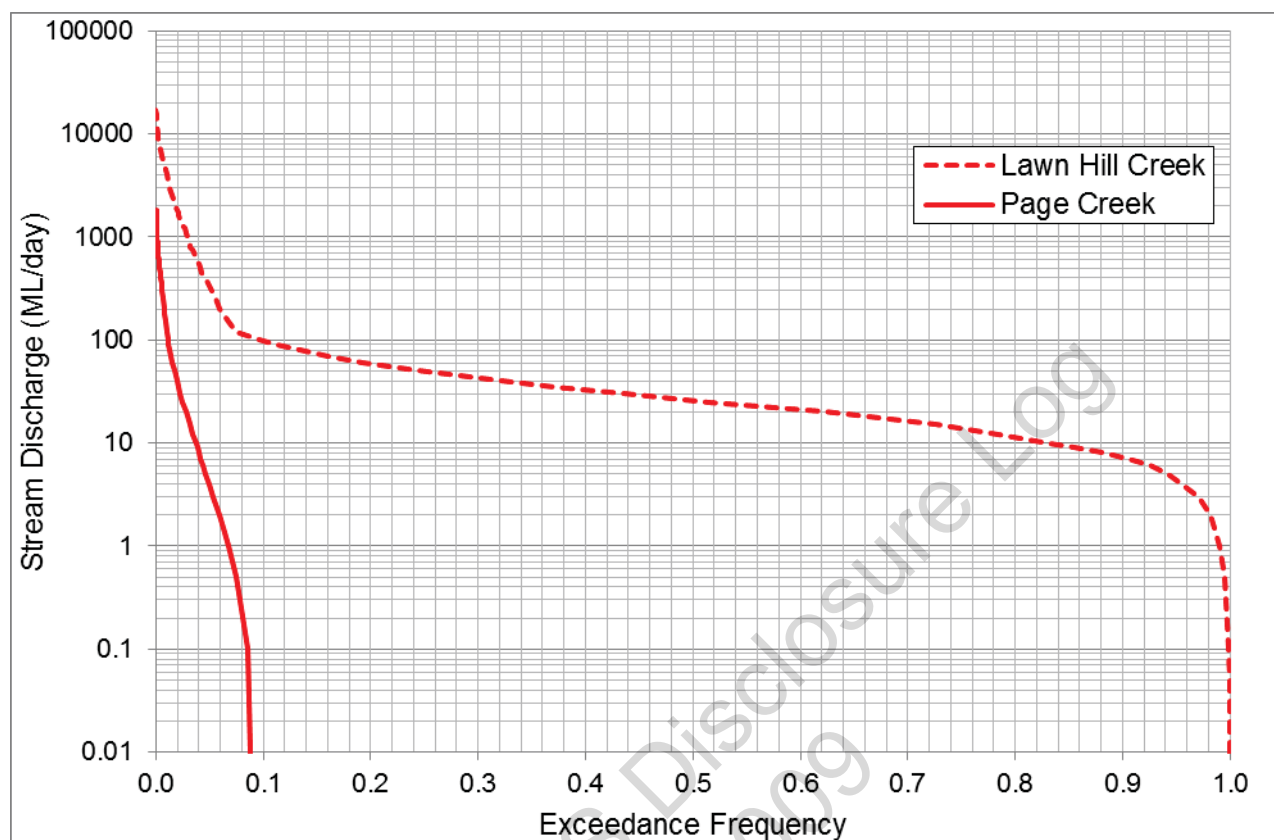
Currently risks of impact from the Page Creek metal residues appear to be relatively low. Lawn Hill Creek is much larger than Page Creek and has substantially greater dilution capacity (by more than an order of magnitude) as illustrated by the flow exceedance curves in Figure 3.1.1. This naturally mitigates the potential for impacts from Page Creek, and to date annual REMP monitoring has found no evidence of any adverse effects on the ecology, water quality or macroinvertebrate communities in Lawn Hill Creek. Sediment pore water samples have also yielded low values, and there has been no evidence of a potential correlation to sediment contamination levels (in fact the highest pore water Zn results have often been reported at the sites with the lowest sediment concentration).

However, Zn concentrations in the section of Lawn Hill Creek immediately downstream of Page Creek have remained elevated since 2009 and there is very little margin for even minor increases without exceeding the ANZECC SQGs. Moreover, Lawn Hill Creek is a high value ecosystem which supports biological communities that are more diverse and therefore potentially more sensitive, than those in Page Creek. Therefore, until proven otherwise, it would not be conservative to assume that the Lawn Hill Creek ecosystem has the same capacity to tolerate SQG exceedances. Accordingly it has been concluded that the Zn residues in Page Creek present sufficient potential risk to Lawn Hill Creek to warrant ongoing monitoring.

Sediments at the Lawn Hill Creek sites immediately downstream of Page Creek have proven to be highly heterogeneous, and in order to investigate the nature of the existing spatio-temporal variability it proved necessary to alter sampling methods between trips during the early stages of the SQMP. Initially composite surface samples were collected in triplicate to ascertain whether the composites were representative. The results indicated that variability between samples was unacceptably high, so during the 2012 REMP trip sites were sampled intensively with multiple replicates of both surface and depth profile samples being collected. The results showed that, although contamination was distributed through the sediment profile in a few places near the mouth of Page Creek, the metal residues at most sites were concentrated in the near-surface layer, suggesting that surface sampling is an adequate method of detecting any emerging impacts.

A routine sampling methodology (detailed in Section 3.3) was finally developed in 2013 and is still in use at this time.

Figure 3.1.1 Flow Exceedance curves for Lawn Hill and Page Creeks



3.2 Current Status

The SQMP Zn results for 2018 are presented in Table 3.2.1. These are compared to previous years in Figure 3.2.1. It can be seen that the sediments proximal to Page Creek are highly heterogeneous and this limits our capacity to resolve subtle temporal variations. That caveat notwithstanding, there have been no statistically significant variations over the course of the monitoring program to date, suggesting that there have been no significant inputs from Page Creek during that time. It is possible that Zn levels at the L1 sites may have declined slightly since 2009. However, the composite samples collected during the early stages of the SQMP do not carry sufficient statistical weight to test that assertion.

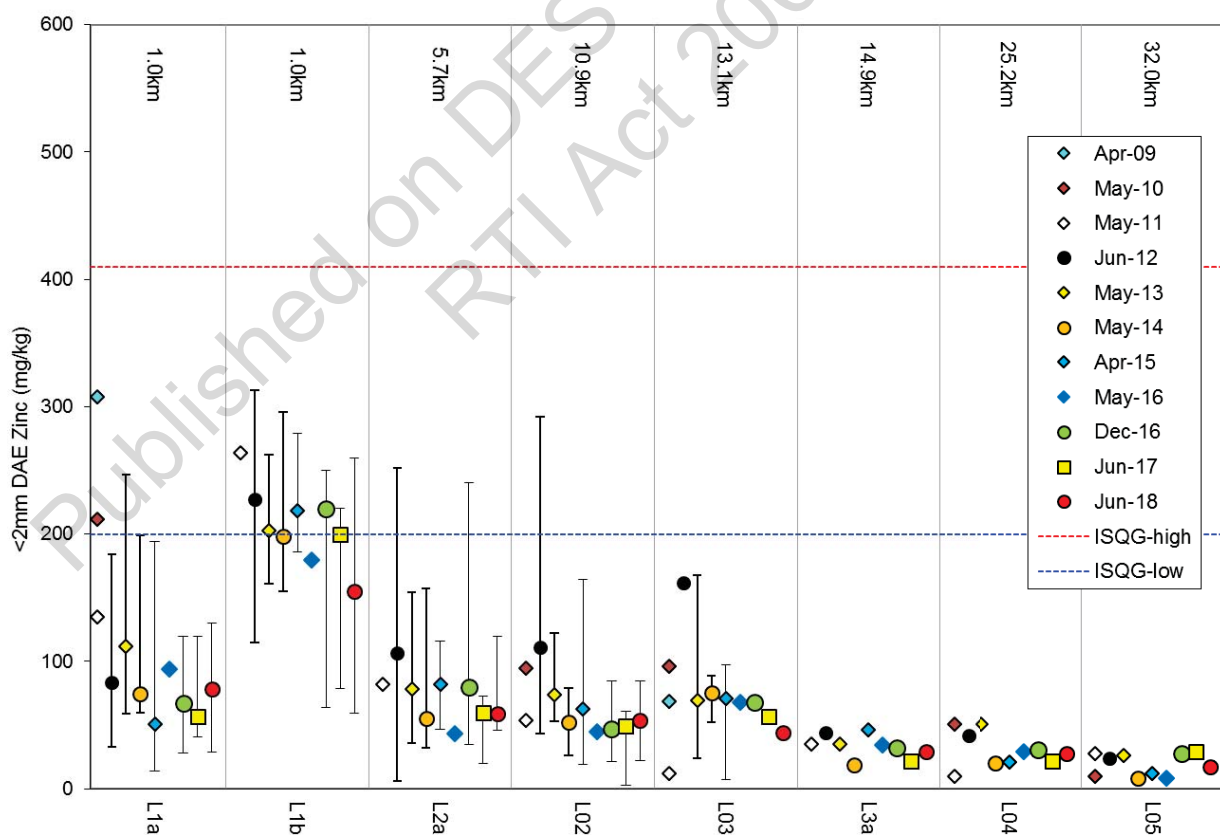
The obvious attenuation of concentrations with increasing distance from Page Creek provides an opportunity for the REMP to test for any potential correlations between sediment quality, water quality and ecological condition. To date no such correlations have been found and in fact on a number of occasions the poorest biological results have been reported at the sites with the lowest metal residues and vice versa. Notably the 2016 to 2018 REMP reports found that L1b, the site with the highest sedimentary zinc levels was within reference with respect to all key metrics, and all sites with zinc levels significantly above background have reported in AUSRIVAS Band-A (i.e., meeting reference condition for macroinvertebrate communities).

Accordingly, as in previous years, the moderately elevated concentrations of sedimentary zinc proximal to the page Creek confluence provide the only evidence of potential mine-related influences on Lawn Hill Creek, and to date there have been no indications of any ecological impacts that could potentially be attributable to the mine.

Table 3.2.1. Summary of sediment Zinc results for Lawn Hill Creek monitoring sites in June 2018. Values highlighted in blue font are greater than the ISQG-Low.

<2mm DAE Zinc (mg/kg)						
Site	Random Composite	Site Mean ($\pm$ 95% C.I.)	Upper limit of mean	Min	Median	Max
L1a	-	82 $\pm$ 34	117	29	78	130
L1b	-	160 $\pm$ 55	215	59	155	260
L2a	-	68 $\pm$ 19	88	46	59	120
L02	-	52 $\pm$ 18	71	22	54	85
L03	44	-	-	-	-	-
L3a	29	-	-	-	-	-
L04	28	-	-	-	-	-
L05	17	-	-	-	-	-

Figure 3.2.1. Spatiotemporal variations in Lawn Hill Creek sediment zinc concentrations since 2009. Points without error bars are obtained from composite samples. Points with error bars indicative of minimum and maximum values are medians obtained from 8 transect samples. Points are arranged chronologically within each site group. Data for upstream reference sites RL0 to RL3 (n=32; mean=11 mg/kg; maximum=25 mg/kg) are not shown.



3.3 Protocols for Future Monitoring

REMP sampling

The four upstream reference sites and eight of the nine test sites listed in Table 1.3.1 are sampled in the post wet season REMP surveys each year. The ninth test site listed in Table 1.3.1, L1c, has been discontinued because it is situated in a separate braid of the stream which became disconnected from the creek. It will be reinstated as a monitoring site if it ever re-establishes hydraulic connectivity with Lawn Hill Creek. (Note that sites L1a, L1b and L1c are situated on three different braids of the creek and are equidistant from Page Creek.)

SQMP Sampling

The REMP test sites listed in Table 3.3.1 are sampled during the annual dry season SQMP sampling campaign but the REMP reference sites, which have consistently reported low values, are not resampled. SQMP sampling methods vary between sites.

At sites with elevated Zn levels (currently comprising L1a, L1b, L2a and L2) separate samples for analysis are taken at eight stations located at regular intervals along a lateral (cross-sectional) transect crossing the full width of the stream. Each of the transect samples are composites prepared by collecting subsamples from a number of random points located immediately up and downstream of (i.e. at 90° to) the transect line. This yields 32 composite sediment samples comprising 8 replicates from each of the four sites.

The remaining four sites (L03 to L05), which have to date reported low to moderate Zn values, are sampled by collecting a single random composite at each site.

All samples are sieved to remove material >2 mm and analysed for dilute acid (1M HCl) extractable Zn, Cd and Pb. One low level and one high level QC standard are included in each batch of samples submitted for analysis.

Table 1.3.1. Current Lawn Hill Creek SQMP sampling schedule

Site	Thread Distance from Page Ck (km)	Longitude	Latitude	Samples
L1a	1.0	138.5853580	-18.5671070	8 Transect Samples
L1b	1.0	138.5858730	-18.5671320	8 Transect Samples
L2a	5.7	138.5858420	-18.5256830	8 Transect Samples
L02	10.9	138.5838240	-18.4742920	8 Transect Samples
L03	13.1	138.5743598	-18.4377008	One Composite
L3a	14.9	138.5884460	-18.4473870	One Composite
L04	25.2	138.5928455	-18.3578529	One Composite
L05	32.0	138.6086590	-18.2986730	One Composite

4. NORTH MITTON CREEK

4.1 Historical background

The upper reaches of North Mitton Creek were first surveyed by TropWATER in August 2014 as part of a broad one-off study to characterise waterways in the vicinity of the mine site as an aid to closure planning. That survey indicated that North Mitton creek and its associated vegetation communities were in reasonably intact condition, but bottom sediments in the creek were found to be enriched with mine-related metals, especially zinc. In response to that initial finding Century immediately contracted TropWATER to conduct a detailed study to quantify the source, nature and extent of the sedimentary contaminant residues, assess ecological risks, recommend remedial measures and target locations for potential sediment removal. Sampling was conducted at 42 locations established at gradually increasing intervals between the Sediment Dam One spillway and Mitton Springs site MS1 (which was already known to contain low metal concentrations based on REMP sampling results); a thread distance of approximately 10 km from the Sediment Dam Spillway (Figure 4.1.1).

Figure 4.1.1: Map showing the location of sites sampled during the initial survey of North Mitton Creek in 2014.



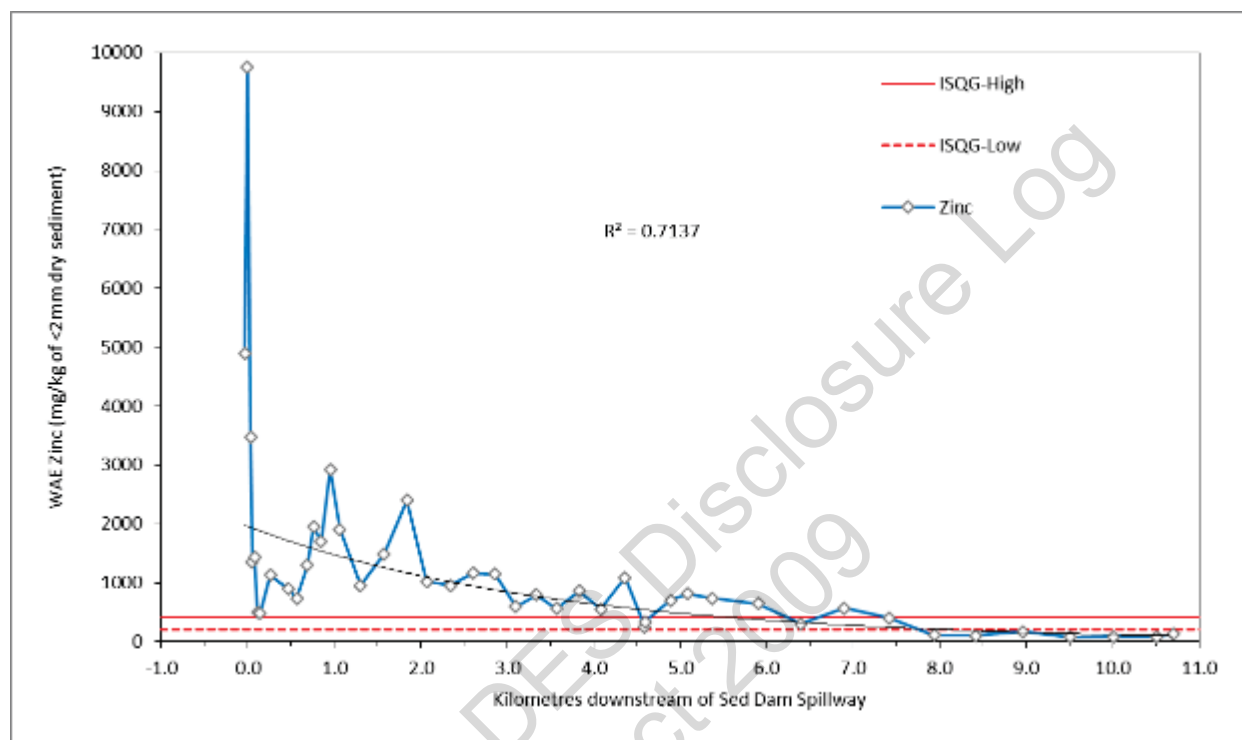
The results of that sediment sampling survey, completed in October 2014, indicated that sediments within a 7.4 km section of North Mitton Creek, between Sediment Dam One and the entry point of Gum Hole Plains tributary, contained elevated concentrations of mine-sourced zinc (plus minor quantities of cadmium and lead). Zinc concentrations within that stream-reach attenuated significantly with distance downstream (see Figure 4.1.2), but only three of the 42 sites sampled reported results that did not exceed the ANZECC 2000 ISQG-High, indicating that immediate remedial action was warranted. Zinc loads in the contaminated section of the creek totalled approximately 1400 kg, 540 kg of which was contained within a 1.32 km length of stream situated within 2 km of the sediment dam.

Pursuant to these findings Century commissioned excavation works to remove as much of the contaminated sediment as possible prior to the impending wet season. This work, which was completed in December 2014, primarily targeted accessible stream reaches that contained zinc loads in excess of 0.22 kg per lineal metre of streambed, but included removal of sediments from some other readily accessible stream locations situated within 3.5 km of the dam. In total 1260 m³ of bed material predicted to contain an estimated zinc

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load of 440 kg was excavated from a 710 m length of the streambed. A total of 7,650 m³ of contaminated sediment was also removed from the base of the sediment dam itself, and the dam release valve was sealed to ensure that future releases will occur only during overflows.

Figure 4.1.2 Spatial distribution of Zn concentrations in North Mitton Creek sites prior to removal works in December 2014.



A follow-up survey in 2015 entailed the collection of 32 samples composited from 89 reaches along the creek between the toe of the Sediment Dam One (SD1) spillway and the Compliance Sediment site NM_SW04_REC (3.7 km thread distance), in order to quantify the effects of removal works on sediment loads and identify any remaining hot spots to target for further removal works. The results of that survey have previously been reported (TropWATER 2015) and will not be reproduced in this report as the data have been superseded by the findings of more recent surveys.

One of the recommendations of the above investigations was to attempt to establish additional REMP monitoring sites in potentially impacted sections of North Mitton Creek. Surveys were subsequently conducted to locate prospective sites; however, due to the highly ephemeral nature of those upper creek reaches, very few potential candidates were identified. There were a few locations which appear to have retained water at some stage in the past and the REMP protocols have been revised to ensure that these sites will be routinely inspected in the future and sampled if they are ever found to be holding sufficient water. Accordingly, the pre-existing REMP site (MS1 - Mitton Springs), which has been sampled routinely since 2006, is the only impact site in the Mitton Creek section of the Century study area that regularly (though not always) retains sufficient water to be sampled for water quality and aquatic ecosystem condition indicators. During the 2016 REMP sampling campaign one of the prospective new sites (NM24) was holding sufficient water to be sampled; however, water levels were low and rapidly retracting, suggesting that regular sampling in the future is an unlikely proposition. This site was dry in 2017 and 2018.

The lack of aquatic habitats in the affected section of the creek limits the potential for harm to aquatic ecosystems inhabiting that part of the creek. Accordingly, investigations to date have focussed on assessing and minimising the potential for impacts on downstream environments that support more viable aquatic

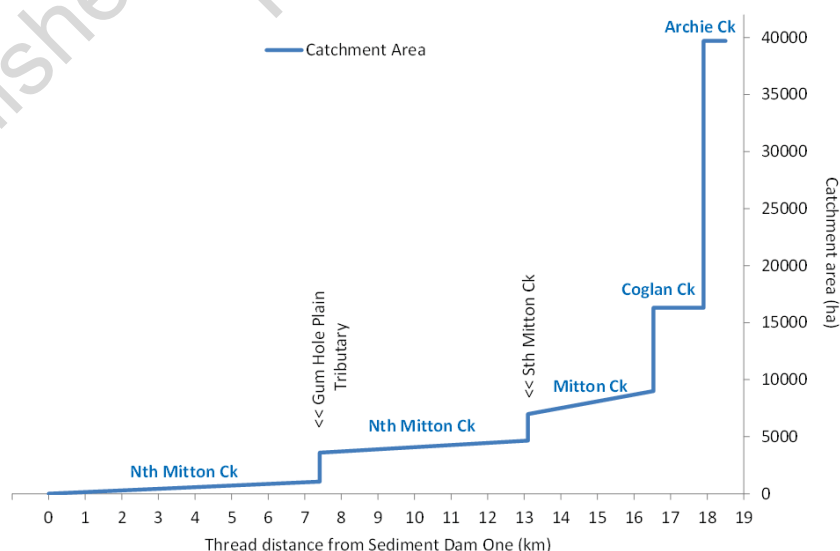
habitats. Risk assessments require increased consideration of Zn loads rather than concentrations. That is because the upper reaches of the creek are generally small and narrow with thin bottom sediments, so even though the Zn concentrations in the sediment are elevated, the total quantities of contaminated sediment present may be too low to present a risk to downstream receiving waters, especially those situated downstream of the Gum Hole Plains tributary (7.4 km from SD1) which receive substantial supplies of natural sediment. For this reason metal concentrations alone are not a useful indicator of risks to downstream environments.

This is a particular issue for North Mitton Creek because it rises at the spillway of Sediment Dam One and therefore the upper reaches have virtually no natural catchment area to provide dilution. In 2016 a dirty water diversion was constructed to reduce the spill risk of Sediment Dam One from a spill volume of 124.3 ML for a 1 in 20 year 2 month wet season event to a zero spill volume for the same wet season event. The control has been designed so successfully that the new sediment dam flood immunity is now great than a 1 in 100 year 2 month wet season event and accordingly the catchment area of the creek at the foot of the spillway is now effectively zero.

When conducting removal works it is necessary to maintain the geomorphological integrity of the stream and avoid damage to riparian communities (to do otherwise would potentially be more harmful than the contaminants being removed). Hence there will always be some residual Zn-enriched sediment remaining in the streambed, and given the limited supply of natural sediment it could take many years for that material to be diluted, if at all. It is therefore conceivable that Zn concentrations in North Mitton will remain in exceedance well into the foreseeable future even if the total quantities of Zn present are reduced to negligible levels.

Though the lithology of the catchments in this drainage system is diverse, the surface topography and edaphics are sufficiently uniform to suggest that cumulative catchment area will be a reasonably reliable first order indicator of relative sediment dilution capacity, and previous investigations have employed this as a method of assessing the capacity of the streams to safely assimilate metal loads. The catchment area breakdown for the stream reaches between SD1 and Archie Creek are shown in Figure 4.1.

Figure 4.1.3 Catchment areas of receiving streams between Sediment Dam One and Archie Creek.

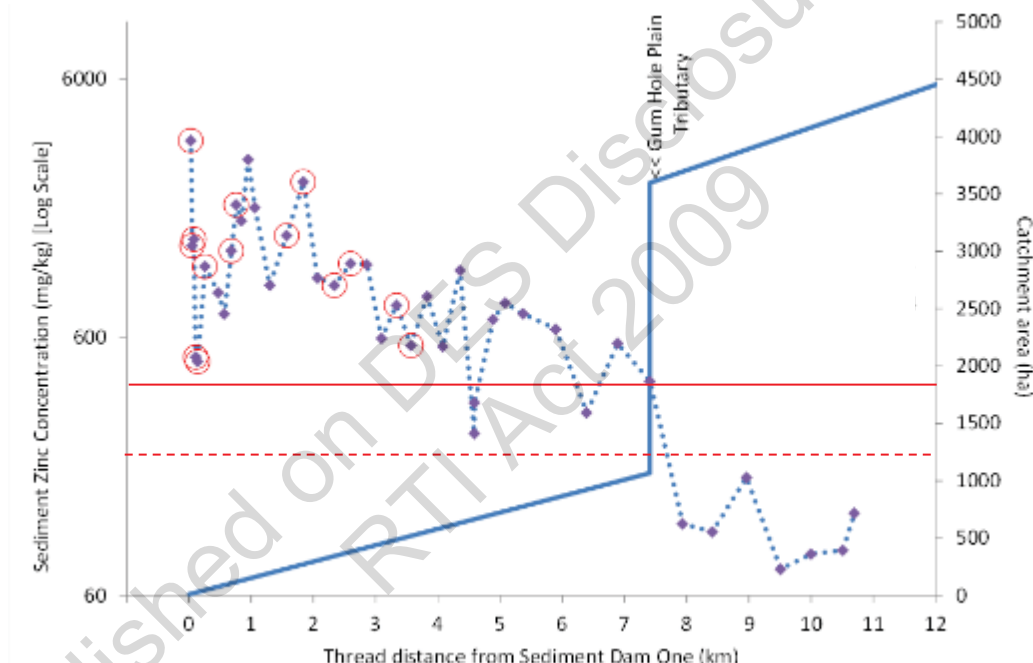


It can be seen that there is a quantum increase in effective catchment area about 7.4 km downstream from SD1 at the point where North Mitton Creek intersects an unnamed tributary which drains Gum Hole Plain (situated to the north of the creek). The 2014 investigation suggested that natural sediment supplies to the

receiving waters downstream of that point would be sufficient to ensure that the existing contaminant load could be safely assimilated if it were to ever be carried that far downstream. To date monitoring results support that contention, as the sediment zinc concentrations immediately downstream of the Gum Hole Plain tributary have consistently been below the ISQG-Low (see for example Figure 4.1.4), and REMP Site MS1 has never shown any signs of metal enrichment.

The 2015 report concluded that the risks presented by the existing post-removal Zn load was low enough to suggest that the physical impacts of any further removal works involving wholesale excavation of the creek bed could potentially present a greater threat to the environmental values of the stream. Accordingly it was recommended that any further removal works should be highly targeted and focussed on small defined hot spots. It was also suggested that some of the excavated sections could potentially act as sediment traps which could be periodically re-excavated after flow events in order to gradually remove sediment over a number of years with minimal impact to the majority of the stream.

Figure 4.1.4 Graph showing the effect of increasing catchment area on the sediment zinc concentrations in North Mitton Creek. The blue represents catchment area. The solid red line is the ISQG-High and the broken red line is the ISQG-Low. Red Circles denote sites where removal works were conducted in 2014.



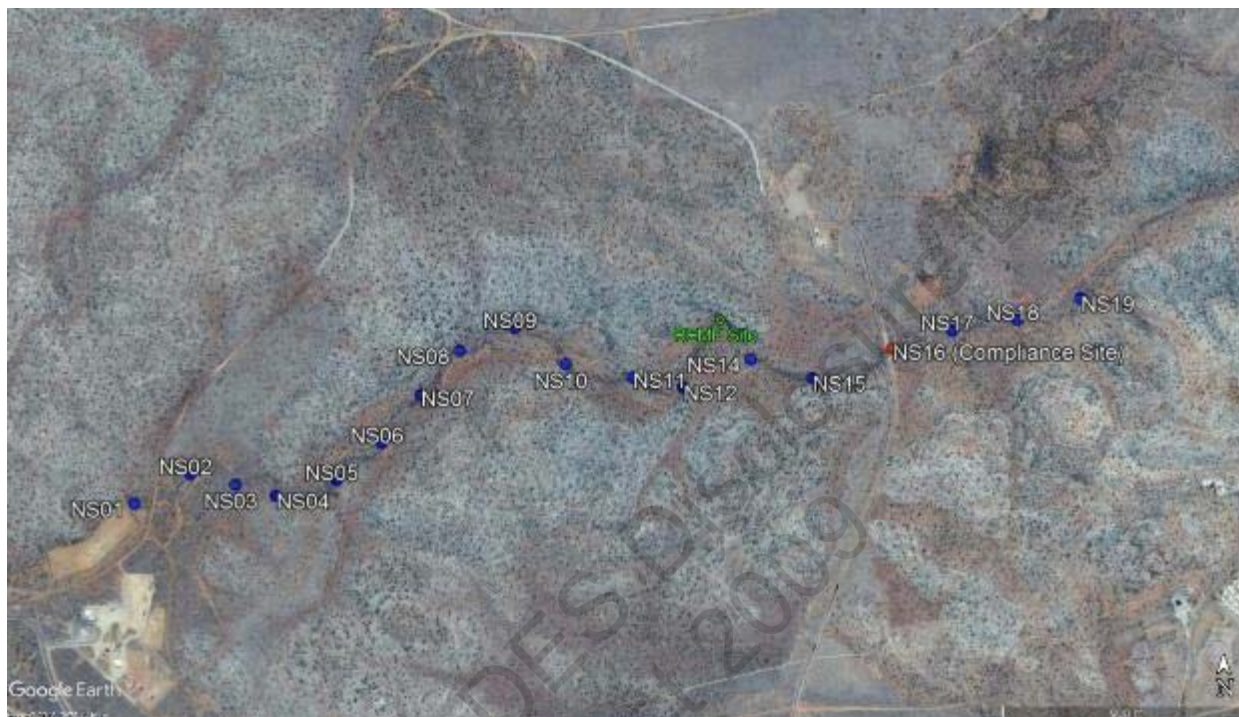
A Zn TL exceedance was reported at the North Mitton Compliance site in 2016. This triggered follow-up monitoring at the sites shown in Figure 4.1.5 to identify any further opportunities for sediment removal. The results of that survey have previously been reported and are not reproduced in this report as they have been superseded by the more recent survey results which are presented below.

Up until 2017 the primary monitoring objective in North Mitton Creek was to identify places where sediment removal works could be carried out with the greatest effect, and in order to accomplish that objective it was necessary to vary the location and length of the reaches being assessed to suit the different circumstances that were encountered each year. This was an effective means of obtaining the necessary management information, but the resulting dataset was not well suited for accurately tracking temporal trends.

During those early surveys a great deal of effort was expended attempting to quantify the sediment loads within each reach. It will probably always be possible to provide management with coarse estimates of the sediment loads at key/proposed removal locations so that they can gauge the approximate scope of the required works. However, the process of evaluating the sediment volume in every part of every reach is excessively laborious for ongoing routine monitoring purposes. More significantly, the bottom sediments

in many key sections of the creek are now so sparse (1 to 6 cm deep) that it is no longer feasible to obtain sediment load estimates that are sufficiently accurate to be used for trend assessment purposes. For example a sediment depth estimation error of only ± 2 cm (which is not easy to achieve) may now equate to an uncertainty level of $\pm 100\%$ or more.

Figure 4.1.5 North Mitton Creek SQMP stream reaches sampled in 2016 and 2017. Points mark the beginning of each reach (except for NS19 which marks the end of Reach NS18). The REMP and compliance sites are discrete sampling locations.



Accordingly, in 2018 an attempt was made to rationalise the program by establishing fixed site locations that could be resampled each year in order to assess temporal trends without undermining our capacity to identify sediment removal opportunities. The 2018 pilot trial entailed collecting composite samples representative of reaches nominally 250 to 500 m in length (actual reach lengths are recorded in the results tables). This procedure requires sampling personnel to traverse the entire length of each reach taking regular subsamples along the way in order to accumulate a representative composite sample. The new site network, which is documented in Section 4.3, extends further downstream in order to confirm that there are no increasing trends downstream of the Gum Hole Plain tributary.

4.2 Current Status

The North Mitton EA compliance site NM_SW04_REC is situated at the beginning of Reach NS16. The sediment Zn concentration reported at the compliance site in 2018 was 300 mg/kg which comfortably complied with the TL (see Table 4.2.1) even though the mean concentrations in the adjacent reaches (NS14 and NS16) were 1200 and 650 mg/kg, respectively (see Table 4.2.2). This highlights the inadequacies of site-based sampling methods when dealing with highly heterogeneous sediments.

Table 4.2.1: North Mitton Creek sediment compliance analysis results (concentrations in mg/kg) for North and South Mitton Creeks in 2018. Red font indicates results greater than the EA TL and blue results are greater than the SQG-Low.

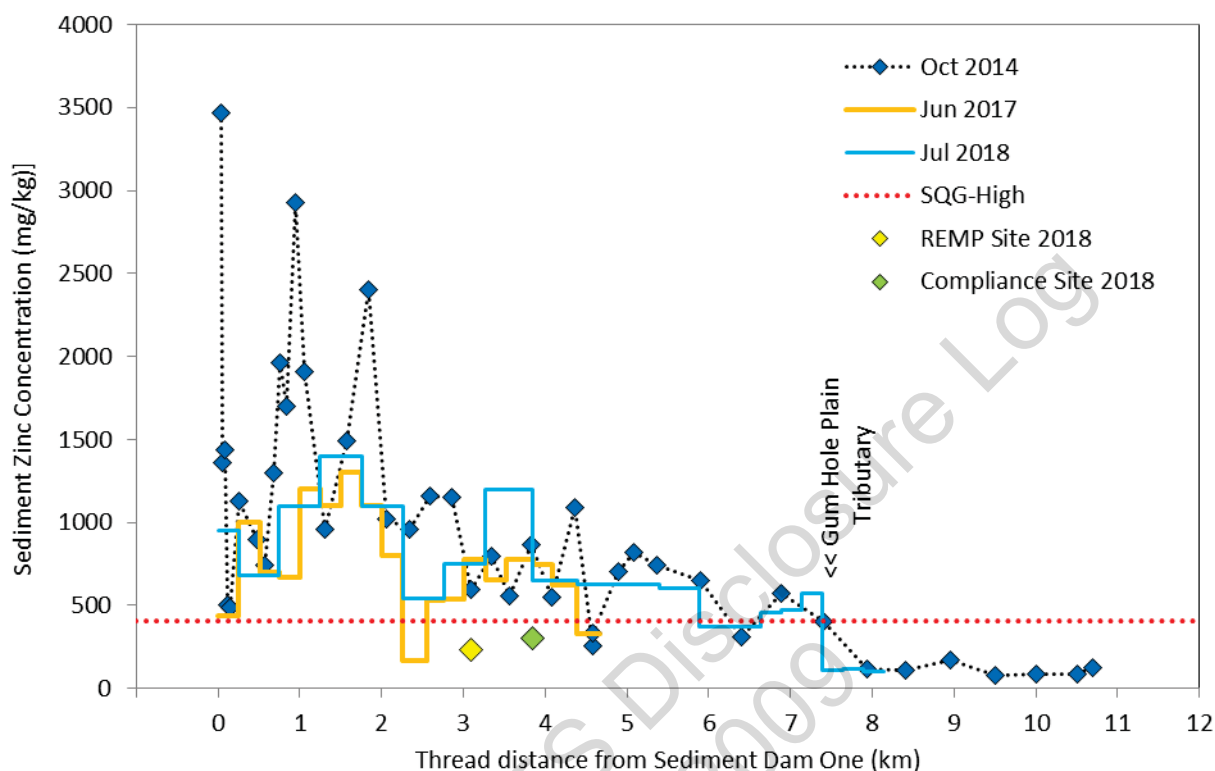
EA Stream sediment trigger levels (mg/kg)	Analysis	NM_SW04_REC	SM_SW05_REF	SM_SW04_REC
10	Cadmium	0.5	<0.1	<0.1
270	Copper	9.7	3.2	5.4
220	Lead	29	58	7.4
52	Nickel	5.8	1.4	2.7
410	Zinc	300	33	8.1
70	Arsenic	1.9	0.9	1.3
3 x greater than reference site	Selenium	<1	<1	<1
For interpretation purposes	Manganese	1200	110	440
For interpretation purposes	< 63µm Particle size (%)	54.0	28.0	72.0

Table 4.2.2: North Mitton Creek SQMP analysis results (in mg/kg) for 2018. Red font indicates results greater than the SQG-High and blue results are greater than the SQG-Low.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb
18NS01	0	250	950	1.2	60
18NS02	250	500	680	0.7	31
18NS04	750	500	1100	1.0	41
18NS06	1250	500	1400	1.4	40
18NS08	1760	500	1100	1.3	39
18NS10	2260	500	540	0.6	20
18NS12	2760	500	750	0.8	24
18NS14	3270	500	1200	1.3	32
18NS16	3850	500	650	0.7	21
18NS18	4390	1000	630	0.7	22
18NS22	5390	500	600	0.7	21
18NS24	5890	500	370	0.7	27
18NS27	6640	250	460	0.8	22
18NS28	6890	250	470	0.8	20
18NS29	7140	250	570	0.7	22
18NS30	7390	250	110	0.2	16
18NS31	7640	250	120	0.2	16
18NS32	7890	250	100	0.2	17

It is evident from the previous investigations discussed in 4.1 that removal works to date have effectively reduced the Zn load in upper reaches of the creek and hence the amount of dilution required for downstream waters to safely assimilate the contaminated sediment. This improvement is partially reflected in the Zn concentration data (see Figure 4.2.1) as there are no longer any extreme levels in excess of 1500 mg/kg. However, the relatively small amounts of residual sediment remaining within the upper 4 km of the creek contain Zn concentrations that are still above the SQG-High.

Figure 4.2.1 Zinc concentrations in 2017 and 2018 compared to 2014 (prior to sediment removal works). The 2017 samples were composites indicative of the mean concentration within each stream reach.



As noted previously, due to the small size of North Mitton's upper catchment area and the consequent paucity of natural water and sediment supply, it may take a long time for these residual sediments to become diluted. In risk terms the lack of water supply is also an extenuating factor as it decreases the likelihood of the contaminated bedload being carried downstream to more valuable environments.

It may still be advisable to attempt to accelerate natural dilution processes by exploiting any opportunities to further reduce the bedload, but only under the proviso that the work can be done without excessively damaging the integrity of the stream. In that regard it is pertinent to note the extensive evidence (discussed in previous sections) that Century Mine-sourced Zn has low bioavailability, and there are many sites in this study area with sediment Zn concentrations similar to the existing levels in North Mitton which support healthy aquatic ecosystems. In short, as things stand, the damage caused by excessive excavation of the streambed and banks would very likely have greater impact on the aquatic ecosystem than would the existing sediment contamination. Accordingly, any further removal works should be highly targeted, low impact and conducted using light excavation equipment or suction methods.

To that end, during the 2017 survey each reach was divided into sub-reaches, the length of which was dictated by changes in the morphology of the streambed. An attempt was made to estimate the sediment load within each sub-reach. As explained previously, due to the heterogeneity and sparse nature of the bed sediments, this excessively laborious procedure yielded first order load estimates which, though not sufficiently accurate to be used for quantitative trend analysis, were adequate to provide an indication of the approximate scope of any removal works that might be considered. These data were then analysed to identify sub-reaches which contained sufficient Zn load to be potential candidates for sediment removal.

The identified sub-reaches are listed in Table 4.2.4. It must be stressed that these simply represent the locations where managers would achieve the best return on investment and disturb the smallest sections of stream, if removal works were to be carried out. Effectively these are sites which deserve closer examination by Century environmental managers to determine if it is feasible to conduct removal works without excessively impacting on the inherent values of the stream and associated riparian habitats.

Table 4.2.3: Prospective sediment removal sites identified in the 2017 survey.

Thread Distance from Sediment Dam One (m)	Length (m)	Average Width (m)	Previously Excavated	Mean Zinc Concentration mg/kg	Approximate Sediment Load (m ³)	Approximate Zinc Load (Kg)
300	40	4	Yes	1000	10	17.3
660	30	4	Yes	700	7	9.1
830	30	4	Yes	670	7	8.7
890	30	5	Yes	670	8	9.0
1270	50	7	Yes	1100	21	41.6
1430	20	5	Yes	1100	6	11.9
1650	20	4	Yes	1300	5	11.2
2200	10	5	Yes	800	3	3.6
2230	40	6	No	800	14	20.7
3200	20	7	No	780	8	11.8
3700	40	6	No	780	14	20.2
4240	50	4	No	620	10	11.2
4290	25	4	No	620	6	6.7

4.3 Protocols for Future Monitoring

To date the primary focus of the North Mitton SQMP has been to identify potential contaminant removal sites. That will remain an objective of the program into the foreseeable future but for the purposes of ongoing routine monitoring, increasing emphasis will be placed on trend analysis and early detection of any emerging impacts on downstream environments.

To that end the following routine monitoring protocols have been devised for future use:

- To ensure that results can be readily compared from year to year, composite samples will be taken at the same reach locations and over the same reach length each year, as shown in Figure 4.3.1 and listed in Table 4.3.1.
- The spatial scope of the site network has been extended by approximately 4 km to encompass the stream reaches up and downstream of the Gum Hole Plains tributary in order to ensure early detection if there is any migration of the contaminated sediment and to confirm the predicted assimilation capacity of downstream reaches.
- Sampling personnel will take composite samples for analysis by collecting subsamples along the full length of each reach.
- While traversing reaches where contamination is known to be present, personnel will take GPS waypoints and photographs, and conduct sediment volume estimates within any sub-reaches which appear to have trapped sufficient sediment to be potential candidates for non-destructive removal works.
- All samples will be sieved to remove material >2 mm, analysed for minus 2 mm dilute acid extractable Zn, Cd and Pb, and sieved to determine percent passing 63 µm.

Figure 4.3.1 Proposed sites for routine monitoring of North Mitton Creek.

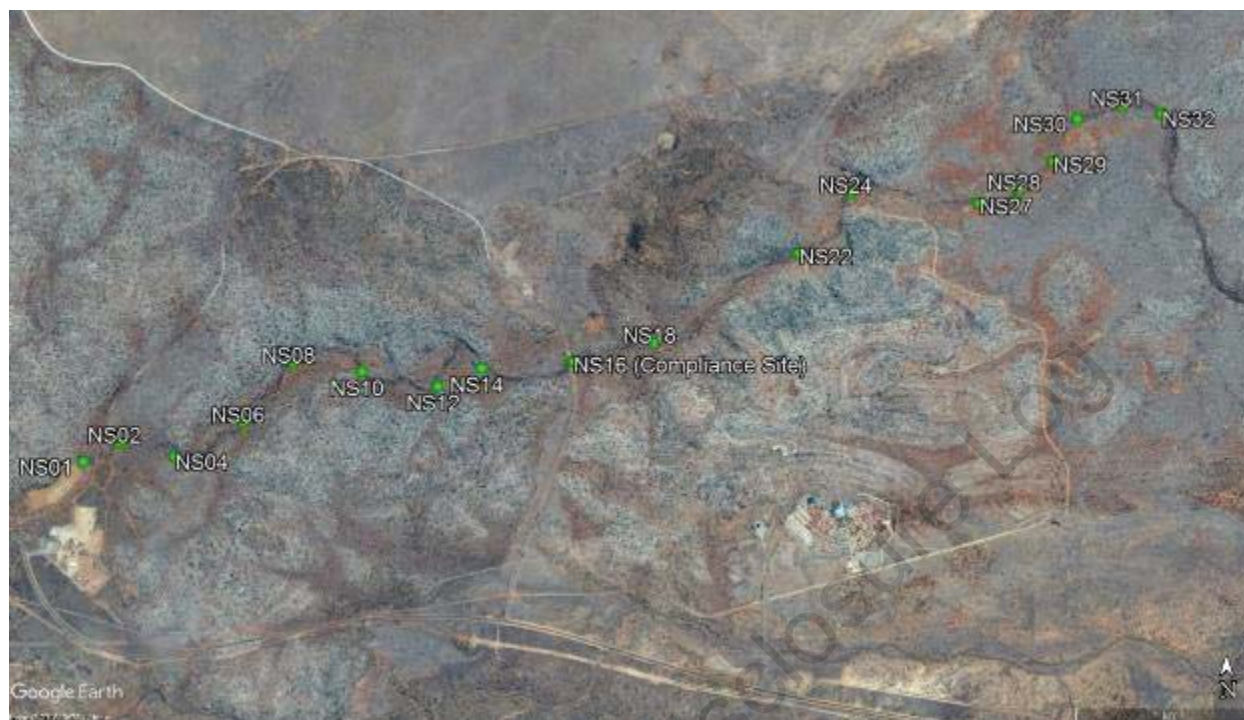


Table 4.3.1 Proposed sites for routine SQMP monitoring of North Mitton Creek.

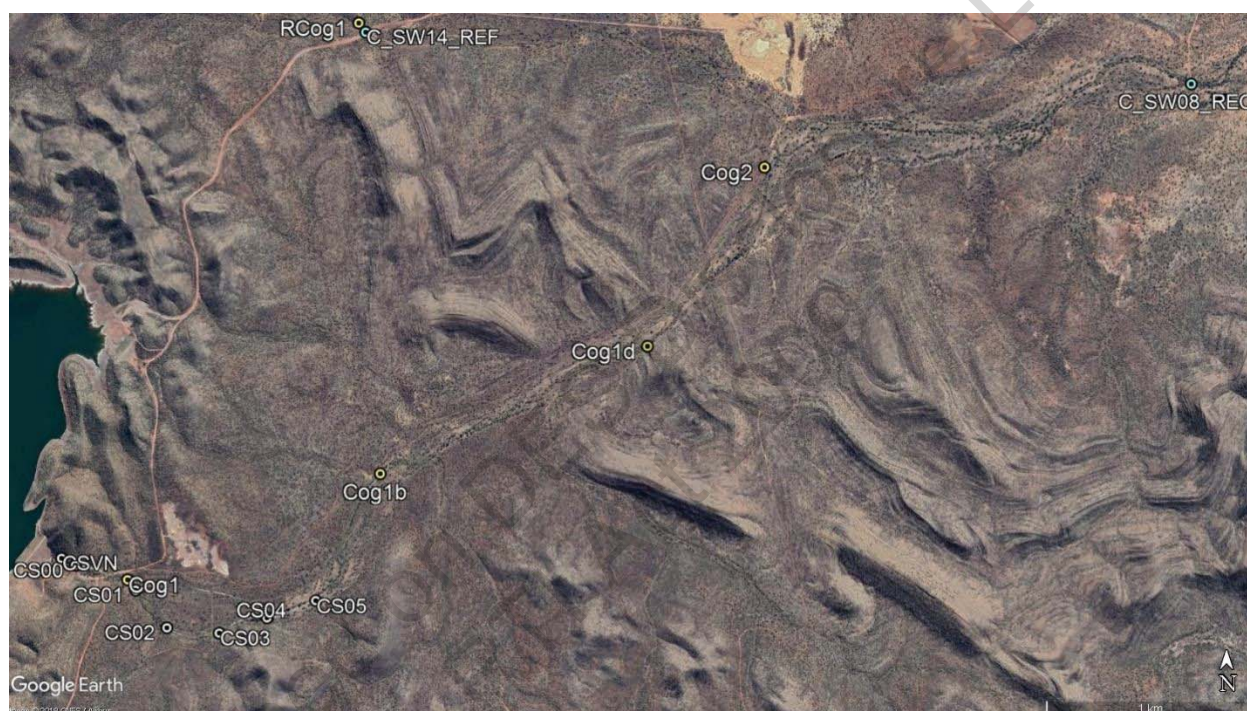
Creek	Reach	Start Point (m)	Longitude	Latitude	Reach Length (m)
North Mitton	NS01	0	138.6320650	-18.7313450	250
North Mitton	NS02	250	138.6339650	-18.7303970	500
North Mitton	NS04	750	138.6368640	-18.7310840	500
North Mitton	NS06	1250	138.6404650	-18.7293910	500
North Mitton	NS08	1760	138.6431210	-18.7264290	500
North Mitton	NS10	2260	138.6467160	-18.7268680	500
North Mitton	NS12	2760	138.6507100	-18.7276020	500
North Mitton	NS14	3270	138.6530180	-18.7267020	500
North Mitton	NS16	3850	138.6578230	-18.7263650	500
North Mitton	NS18	4390	138.6621100	-18.7254290	1000
North Mitton	NS22	5390	138.6697066	-18.7209623	500
North Mitton	NS24	5890	138.6724703	-18.7179487	500
North Mitton	NS27	6640	138.6792306	-18.7184551	250
North Mitton	NS28	6890	138.6813606	-18.7178077	250
North Mitton	NS29	7140	138.6831393	-18.7163750	250
North Mitton	NS30	7390	138.6844358	-18.7142397	250
North Mitton	NS31	7640	138.6867909	-18.7136095	250
North Mitton	NS32	7890	138.6888939	-18.7139783	250

5. COGLAN CREEK

5.1 Historical background

The monitoring sites network for Cogan Creek is shown in Figure 5.1.1. REMP site Cog1, a small pool formed by seepage water situated immediately downstream of the evaporation dam saddle wall, has been monitored annually in post-wet season REMP surveys for more than a decade. The site was originally located closer to the dam but it was necessary to gradually move it further downstream because it developed into a *Typha* (bulrush) wetland with vegetation so dense that the water column could no longer be accessed by sampling personnel.

Figure 5.1.1 Current monitoring sites on Cogan Creek. Blue markers denote compliance sites, yellow denote REMP sites and white markers are SQMP sites.



Not surprisingly, given that the water is sourced from evaporation dam seepage and the site is subject to high evapoconcentration rates, Cog1 has historically reported poor water quality characterised by high salt concentrations. Metal concentrations were generally low until 2012 when elevated Zn concentrations were detected. No such water quality problems were evident further downstream at the EA compliance site (C_SW_REC) or at Cog2, which was the only other REMP site on Cogan Creek at that time. This seemed to indicate that impacts were localised to Cog1, but as a precautionary measure, in 2014 new REMP sites were established in the closest waterholes downstream of Cog1 (Cog1b, Cog1c and COG1d) to better assess the extent of influences.

The Cogan Creek system was subject to a detailed assessment of the influences of the adjacent Evaporation Dam in 2015 (TropWATER 2015a), and this led to the establishment of SQMP monitoring sites CS01 to CS02. The study confirmed that effects attenuated rapidly with distance downstream from Cog1, and to date subsequent REMP and SQMP monitoring has supported that contention (see Tables 5.1.1 and 5.1.2 for example). Additional sites CSVN and CS00 were added to the routine SQMP network in 2018 (see Section 5.3).

It is apparent from annual REMP reports that the wetland at Cog1 has historically performed a valuable function, removing dissolved metals from the water column and sequestering them into the bottom sediments. As a consequence Zn concentrations have risen to levels well above the SQG-high. However, most of this zinc is likely bound up in the form of non-toxic organic complexes, as evidenced by the prolific wetland plant growth. Notably the contaminated sediment has been stabilised by plant roots extending to soil depths of up to 0.5 m and is therefore unlikely to be mobilised as long as the plant roots remain viable.

Table 5.1.1 SQMP sediment analysis results for Coglán Creek in 2016

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb	Mn	P
16CS01	0	250	850	<0.4	12	610	110
16CS02	250	250	36	<0.4	<5	140	31
16Cog1b	1720	15	39	<0.4	6	88	66
16Cog1c	3240	15	13	<0.4	<5	76	20
16Cog2	4380	15	11	<0.4	<5	22	23
16RCog	0	0	<5	<0.4	<5	270	7

Table 5.1.2 SQMP sediment analysis results for Coglán Creek in 2017.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb
17CS01	0	250	1800	0.6	5
17CS02	250	270	18	<0.1	<0.5
17Cog1b	1720	30	55	0.2	<0.5
17Cog1c	3240	30	<0.5	<0.1	<0.5
17Cog2	4380	30	13	0.1	<0.5
17RCog	0	30	5.1	<0.1	2.3

Notably, in 2014 Century installed clean water diversions and dirty water sumps with pump-back systems. This will have reduced contaminant inputs to the upper reaches of the stream sufficiently to expect that further increases in contaminant load will be minimal.

REMP reports have advised against attempting any sediment removal works at this stage and have instead recommended:

- Avoiding any disturbances which could potentially undermine the functionality of the wetland at Cog1
- Monitoring the condition of the wetland to ensure that it is remaining viable
- Continued monitoring of water and sediment quality at sites immediately downstream of the wetland to ensure early detection of any potential metal releases which could occur if the wetland were to fail.

5.2 Current Status

As would be expected based on historical findings, there were no TL exceedances at the Coglán compliance site in 2018 (Table 5.2.1). The SQMP results for 2018 (Table 5.2.2) exhibited the same rapid attenuation in metal concentrations that has been evident previously. The result for CS01 (1300 mg/kg) was numerically lower than last year (1800 mg/kg) but given the heterogeneous nature of these sediments that is likely to be largely a consequence of random variability.

Table 5.2.1 EA sediment compliance results for Cogan Creek in 2018.

EA Stream sediment trigger levels (mg/kg)	Site	C_SW14_REF	C_SW08_REC
10	Cadmium	<0.1	0.1
270	Copper	1.1	2.7
220	Lead	1.5	2.5
52	Nickel	0.6	1.3
410	Zinc	2.6	6.7
70	Arsenic	0.8	1.3
3 x greater than reference site	Selenium	<1	<1
For interpretation purposes	Manganese	19	210
For interpretation purposes	< 63µm Particle size (%)	10.0	44.0

Table 5.2.2 SQMP sediment analysis results for Cogan Creek in 2018.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb
18CSVN	-435	75	23000	11.0	19
18CS00	-360	360	7800	1.4	11
18CS01	0	250	1300	0.3	8.3
18CS02	250	250	36	<0.1	4.1
18CS03	500	250	26	<0.1	7.3
18CS04	750	250	48	<0.1	11
18CS05	1000	500	14	<0.1	3.4

Cog1 historically received sufficient seepage to sustain the wetland plants; however, the sumps installed in 2014 to capture the seepage and return it to the evaporation dam, may potentially be starving the wetland of water. The effects of this have probably been exacerbated by a lack of major rainfall events over the past three wet seasons. *Typha* plants naturally senesce during dry periods but their rhizomes (i.e. roots) remain viable and regrow once wet conditions return. This makes it difficult to gauge whether or not the plants are still viable, but there are signs that their health may be suffering and grounds to suspect that natural rainwater runoff may be insufficient to maintain the wetland in the long term. If so, that raises questions about the potential fate of the metals contained in the wetland sediments. Assessing those potential effects will be the primary focus of future monitoring activities.

5.3 Protocols for Future Monitoring

REMP Sampling

The existing REMP sites (including the reference site) will be sampled during each annual post-wet survey. They will not be resampled in the dry season SQMP unless anomalous results have been reported in the REMP survey.

SQMP sampling

Given existing uncertainties regarding the ongoing functionality of the Cog1 wetland, the routine SQMP monitoring site network (listed in Table 5.3.1 and shown on Figure 5.1.1) extra sites immediately upstream and downstream of Cog1 were added to the network in 2018 in order to increase early detection capacity in the event that the wetland fails and the contaminated sediments become mobile. Sampling and analysis methods will be the same as those used in North Mitton Creek.

Table 5.3.1 Proposed sites for routine SQMP monitoring of Coglan Creek.

Creek	Reach	Start Point (m)	Longitude	Latitude	Reach Length (m)
Coglan	CSVN	-435	138.6740600	-18.7906200	75
Coglan	CS00	-360	138.6746912	-18.7909194	360
Coglan	CS01	0	138.6774271	-18.7919856	250
Coglan	CS02	250	138.6788470	-18.7936050	250
Coglan	CS03	500	138.6812226	-18.7938295	250
Coglan	CS04	750	138.6833961	-18.7931737	250
Coglan	CS05	1000	138.6856024	-18.7924322	500

6. LITTLE ARCHIE CREEK

6.1 Historical background

A one-off survey designed to characterise all streams in the Century study area was conducted in 2014 as an aid to closure planning. That study detected Zn concentrations above the SQG-High in sediments within the uppermost reaches of Little Archie Creek. REMP sites on Little Archie and Archie Creek had been monitored since 2006 and had never detected anomalous Zn levels. However, at that time the nearest REMP site LAr1 (see Figure 6.1.1) was situated several km downstream of the metal-enriched reaches that had been sampled in 2014. LAr1 had originally been selected as a REMP site on the basis that it was the closest waterhole to the mine that reliably holds water long enough to allow sampling of aquatic biota.

Figure 6.1.1 Current monitoring sites on Little Archie Creek. Green markers denote REMP sites and purple markers are SQMP sites. SQMP sites are numbered consecutively in downstream order from LS00 to LS09.



During the 2015 REMP survey an attempt was made to locate additional REMP monitoring sites that were closer to the mine. This resulted in the establishment of two additional sites (PH387 and PH099, see Figure 6.1.1) which appeared to be capable of periodically holding water long enough to be sampled for aquatic biota and which could be sampled for sediment every year. The 2015 and 2016 REMP reports provided no indication of metal enrichment in the sediments at those sites, suggesting that Zn contamination was confined to the very small, highly ephemeral stream reach immediately proximal to the mine site. To determine the full extent of the contamination, ten SQMP reach sampling sites (LS00 to LS09) were established to encompass the uppermost 1.6 km of the creek.

The 2016 SQMP results (Table 6.1.1) indicated that two reaches – LS00, a 90 m reach situated at the foot of the dam wall and LS03, a 100 m reach located 280 m downstream – contained mean Zn concentrations greater than the SQG-High. However, the exceedance levels were very minor indicating that minimal dilution would be required to achieve compliance. The quantities of sediment present in this section of the creek was also small compared to the aquatic habitats further downstream. Moreover, many sites in this study area which contain considerably higher sediment Zn concentrations maintain healthy aquatic communities. Accordingly, it was concluded that the physical disturbances caused by removal works would potentially present a greater threat to the integrity and environmental values of the creek than would the existing metal residues. The existing concentrations are nevertheless non-compliant so ongoing monitoring has been recommended to ascertain temporal trends.

Table 6.1.1 SQMP analysis results for Little Archie Creek in 2016. Values in red exceed the SQG-High and blue exceed the SQG-Low.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb	Mn	P
16LS00	0	90	450	2.1	32	900	4400
16LS01	90	90	96	0.6	25	970	2300
16LS02	180	100	66	0.5	27	1100	1600
16LS03	280	100	470	1.9	51	1200	1400
16LS04	380	100	240	1.1	47	1200	1100
16LS05	480	100	280	1.3	55	1300	1000
16LS06	580	250	180	0.7	31	910	440
16LS07	830	250	94	<0.4	24	890	270
16LS08	1080	250	150	0.6	28	960	240
16LS09	1330	300	82	<0.4	25	860	140

The 2017 SQMP results tabulated below ostensibly recapitulated the 2016 findings in the sense that elevated concentrations were detected in the same reaches as last year. The results for LS00 were twice as high as 2016, but LS03 was lower and did not exceed the SQG. These variations are almost certainly a consequence of random sampling errors due to the heterogeneity of the sediments which is a typical characteristic of streams in this study area. However, further monitoring will be needed to confirm that assumption and ensure that there are no emerging trends.

Table 6.1.2 SQMP analysis results for Little Archie Creek in 2017. Values in red exceed the SQG-High and blue exceed the SQG-Low.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb
17LS00	0	80	950	3.3	23
17LS01	80	100	51	0.4	20
17LS02	180	100	71	0.5	29
17LS03	280	100	320	1.2	41
17LS04	380	90	200	0.9	43
17LS05	470	100	220	1.1	46
17LS06	570	270	82	0.3	25
17LS07	840	240	54	0.3	22
17LS08	1080	260	83	0.4	23
17LS09	1340	430	61	0.4	23

6.2 Current Status

Table 6.2.1 SQMP analysis results for Little Archie Creek in 2018. Values in red exceed the SQG-High and blue exceed the SQG-Low.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb
18LS00	0	80	920	3.1	53
18LS01	80	100	100	0.7	33
18LS02	180	100	100	0.5	30
18LS03	280	100	360	1.5	52
18LS04	380	90	210	0.9	36
18LS05	470	100	380	1.7	53
18LS06	570	270	120	0.5	32
18LS07	840	240	110	0.4	24
18LS08	1080	260	61	0.2	19
18LS09	1340	430	88	0.3	25

The 2018 SQMP results tabulated above closely recapitulate the 2016 findings and provide no indication of any potential or emerging trends.

6.3 Protocols for Future Monitoring

REMP Sampling

The REMP sites shown in Figure 6.1.1 will be sampled annually during the postwet REMP surveys.

SQMP Sampling

The REMP sites will be resampled during annual SQMP dry season surveys only if anomalous results have been obtained from the preceding REMP sampling trip.

The SQMP reaches listed in Table 6.1.1 will be sampled annually in the dry season using the same methods that are employed in North Mitton and Coglan Creeks. Once there has been a flow event large enough to potentially alter the distribution of bed sediments in this creek this component of the program will be reviewed.

Table 6.1.1 Proposed sites for routine SQMP monitoring of Little Archie Creek.

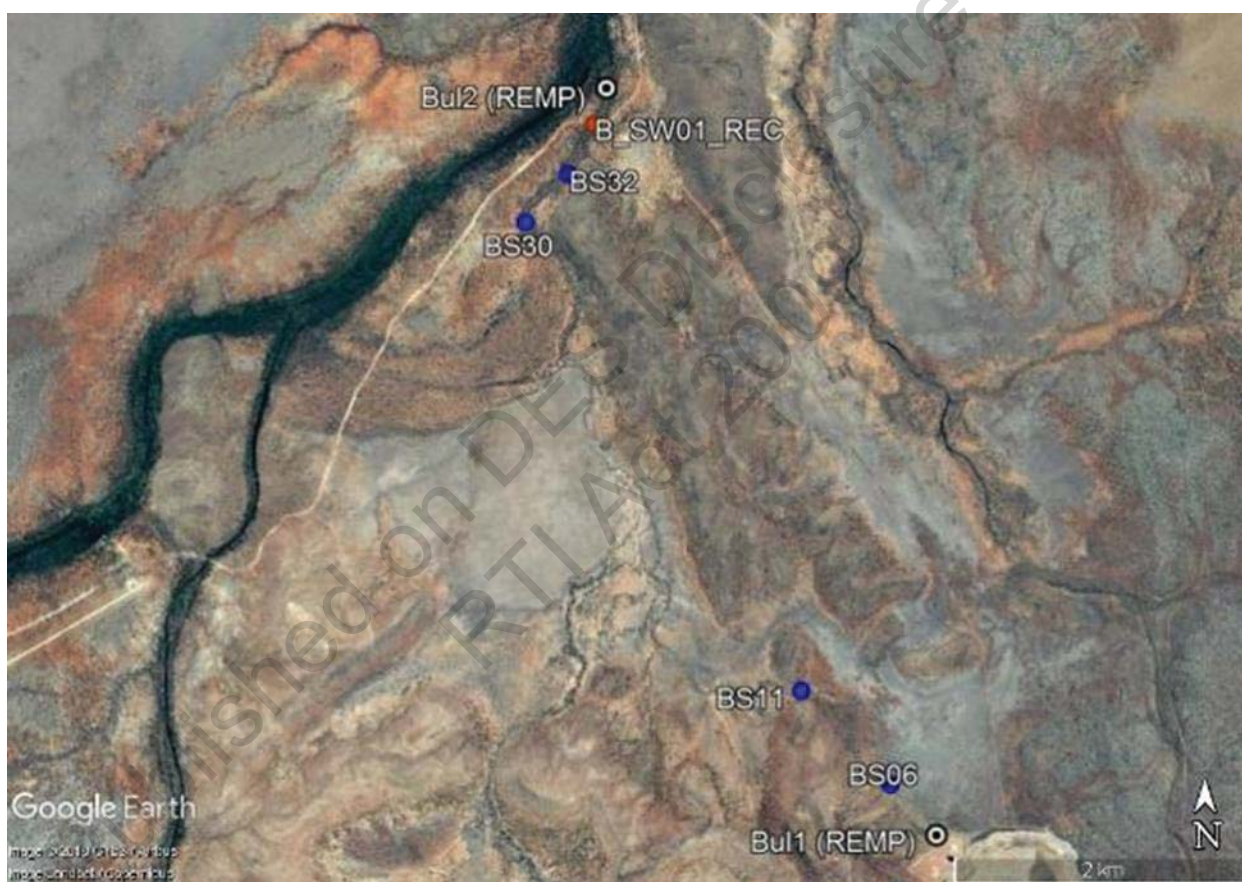
Creek	Reach	Start Point (m)	Longitude	Latitude	Reach Length (m)
Little Archie	LS00	0	138.6179260	-18.6981710	80
Little Archie	LS01	80	138.6178260	-18.6975000	100
Little Archie	LS02	180	138.6174540	-18.6971650	100
Little Archie	LS03	280	138.6169160	-18.6965100	100
Little Archie	LS04	380	138.6168510	-18.6956740	90
Little Archie	LS05	470	138.6174160	-18.6950280	100
Little Archie	LS06	570	138.6179640	-18.6943200	270
Little Archie	LS07	840	138.6169120	-18.6925390	240
Little Archie	LS08	1080	138.6178250	-18.6909290	260
Little Archie	LS09	1340	138.6187040	-18.6892180	430

7. BULLRIDGE CREEK

7.1 Historical background

Bullridge Creek is a highly ephemeral creek which contains only one waterhole capable of retaining water long enough to potentially support an aquatic ecosystem. Two REMP monitoring sites were established in this creek in 2006 and have been monitored annually since then. These comprised Bul1, which is a small temporary pool situated at the foot of the sediment dam that seldom holds water long enough for biological sampling to be carried out, and Bul2 which is located in the above-mentioned waterhole in the lower reaches of the creek, a short distance downstream from the EA compliance site and upstream of the confluence with Lawn Hill Creek (see figure 7.1.1).

Figure 7.1.1 Monitoring sites on Coglan Creek. Red marker denotes compliance site, white denotes REMP sites and blue markers are SQMP sites. In the interests of clarity only one of the SQMP sites between the dam and site BS11 are shown here. The locations of SQMP sites BS01 to BS11 are shown in Figure 7.3.1.



To date no anomalous results have been reported at Bul2 or the compliance site (B_SW01_REC). However, there have been historical indications of metals enrichment in the sediments at Bul1 with Zn concentrations above the SQG-High and Cd above SQG-Low. In 2015 an investigation was carried out to determine the spatial extent of the contamination and this led to the establishment of SQMP reach sampling sites BS01 to BS08, and BS30 to BS33 (the locations and lengths of which are indicated in results tables).

The 2016 and 2017 SQMP results (Tables 7.1.1 and 7.1.2, respectively) indicated that Zn levels significantly greater than the SQG-High were largely confined to the first 300 m of the stream. Concentrations generally attenuated with increasing distance downstream but the results obtained at thread distance of 650 to 900 m were slightly above the SQG-High and at 1.15 km the SQG-Low was still exceeded. Accordingly, in 2018 the spatial scope of the sampling sites in the upper reaches were extended 750 m further downstream by adding sites BS09 (a 250 m reach) and BS11 (a 500 m).

Table 7.1.1 SQMP analysis results for Bullridge Creek in 2016. Values in red exceed the SQG-High and blue exceed the SQG-Low.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb	Mn	P
16BS01	0	100	1500	1.9	80	1800	960
16BS02	100	100	2400	3.7	97	2900	1100
16BS03	200	100	1900	2.7	50	2300	750
16BS04	300	100	520	0.7	47	810	330
16BS05	400	250	300	0.4	30	690	140
16BS06	650	250	460	0.6	35	940	150
16BS07	900	250	180	<0.4	24	490	59
16BS08	1150	250	220	<0.4	25	520	73
16BS30	6650	250	33	<0.4	10	300	43
16BS31	6900	250	44	<0.4	12	390	41
16BS32	7150	250	41	<0.4	8	260	37
16BS33	7400	250	59	<0.4	11	370	36

Table 7.1.2 SQMP analysis results for Bullridge Creek in 2017. Values in red exceed the SQG-High and blue exceed the SQG-Low.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb
17BS01	0	100	1300	1.3	34
17BS02	100	100	1800	2.1	69
17BS03	200	100	1600	2.0	38
17BS04	300	110	1300	1.8	72
17BS05	410	250	280	0.4	27
17BS06	660	260	270	0.4	23
17BS07	920	250	210	0.3	21
17BS08	1170	250	100	<0.1	17
17BS30	6650	250	25	0.1	11
17BS31	6900	250	25	<0.1	9.6
17BS32	7150	240	36	<0.1	13
17BS33	7390	290	35	0.1	11

7.2 Current Status

As has been the case historically, no exceedances were reported at the Bullridge Creek EA compliance site in 2018 (Table 7.2.1). As expected the metals levels at Bul2 were also low in 2017 while at Bul1 most sediment metals showed some enrichment with Zn exceeding the SQG-High, and Cd and Pb exceeding the SQG-Low. As has generally been the case in recent years, Bul1 had dried out prior to the 2017 REMP survey and could only be sampled for sediment.

Table 7.1.1 EA Compliance sampling results for Bullridge Creek in 2018.

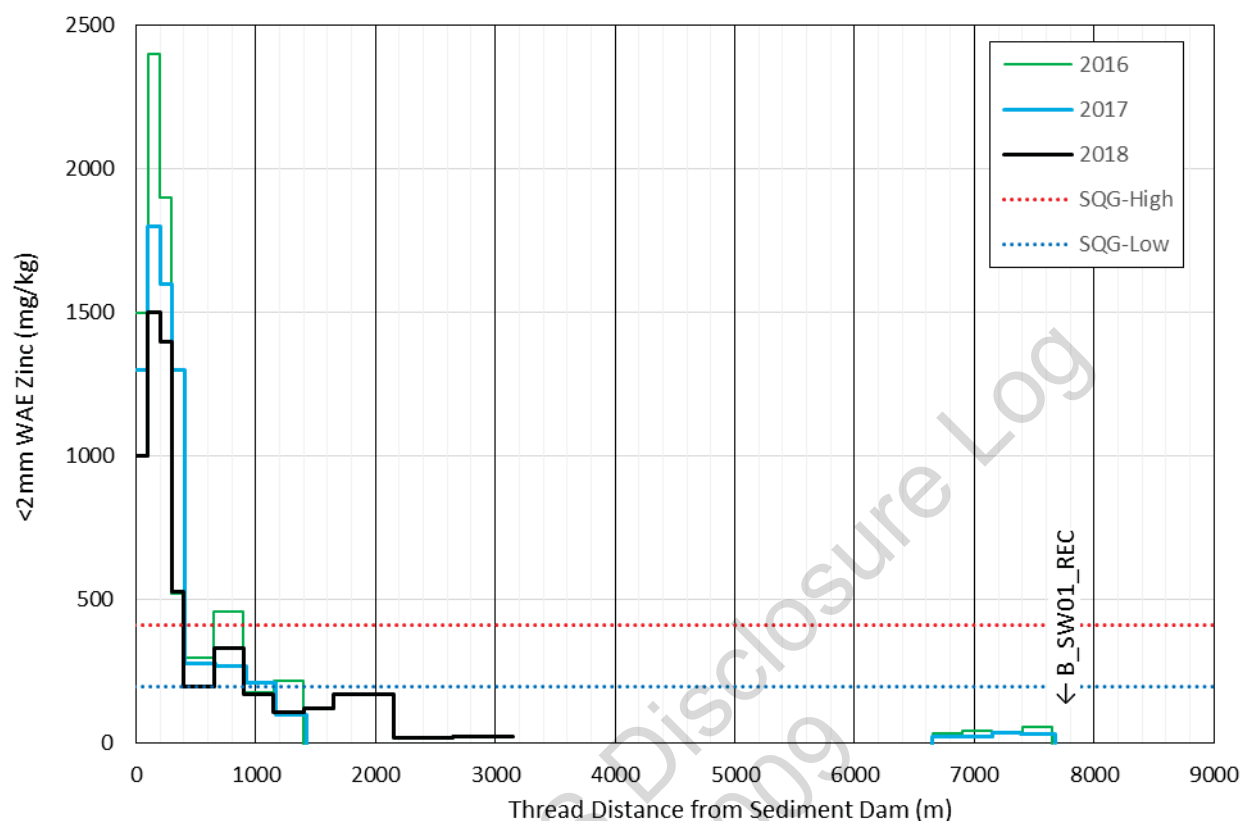
EA Stream sediment trigger levels (mg/kg)	Site	B_SW01_REC
10	Cadmium	<0.1
270	Copper	4.3
220	Lead	15
52	Nickel	2.5
410	Zinc	18
70	Arsenic	1.1
3 x greater than reference site	Selenium	<1
For interpretation purposes	Manganese	460
For interpretation purposes	< 63µm Particle size (%)	53.0

The 2018 SQMP results ((Table 7.2.1) are compared to the 2016 and 2017 results in Figure 2.2.1. On face value the comparison suggests that zinc concentrations in the upper reaches may have declined between 2016 and 2018. However, given the heterogeneity of these sediments it is possible that the apparent effect is simply a consequence of random variability. The extended site network indicates that detectable zinc enrichment is confined to the uppermost 2.1 km of the creek, but levels in excess of the EA TL only occur within the first 400 m immediately downstream of the dam.

Table 7.2.1 SQMP analysis results for Bullridge Creek in 2018. Values in red exceed the SQG-High and blue exceed the SQG-Low.

Sample ID	Thread (m)	Reach length (m)	Zn	Cd	Pb
18BS01	0	100	1000	1.4	46
18BS02	100	100	1500	1.8	67
18BS03	200	100	1400	1.8	48
18BS04	300	100	530	0.8	67
18BS05	400	250	200	0.3	27
18BS06	650	250	330	0.4	32
18BS07	900	250	170	0.3	27
18BS08	1150	250	110	0.2	26
18BS09	1400	250	120	0.2	43
18BS11	1650	500	170	0.3	43
18BS30	2150	500	19	<0.1	10
18BS32	2650	500	26	<0.1	16

Figure 7.2.1 SQMP analysis results for Bullridge Creek 2016 to 2018.



7.3 Protocols for Future Monitoring

In 2018, to increase our capacity to detect sediment movements and discriminate between random variations and emerging trends, the spatial scope of the sampling sites in the upper reaches was extended 750 m further downstream by adding sites BS09 (a 250 m reach) and BS11 (500 m). Due to the consistently low results reported to date at SQMP sites in the lower reaches of the creek, sites BS31 and BS33 were discontinued and the length of reaches BS30 and BS32 have been increased to cover those sections of the stream. The 2018 site network (see Figure 7.3.1 and Table 7.3.1) will be retained for future routine annual SQMP surveys.

Table 7.3.1 Routine SQMP reach sampling sites on Bullridge Creek.

Creek	Reach	Start Point (m)	Longitude	Latitude	Reach Length (m)
Bullridge	BS01	0	138.5832820	-18.7072610	100
Bullridge	BS02	100	138.5825720	-18.7072660	100
Bullridge	BS03	200	138.5817670	-18.7068680	100
Bullridge	BS04	300	138.5811730	-18.7064320	100
Bullridge	BS05	400	138.5805880	-18.7060890	250
Bullridge	BS06	650	138.5800970	-18.7042410	250
Bullridge	BS07	900	138.5793960	-18.7028520	250
Bullridge	BS08	1150	138.5788330	-18.7012040	250
Bullridge	BS09	1400	138.5782595	-18.6995786	250
Bullridge	BS11	1650	138.5743895	-18.6985824	500
Bullridge	BS30	2150	138.5567850	-18.6702780	500
Bullridge	BS32	2650	138.5595180	-18.6673590	500

Figure 7.3.1 Location of routine SQMP reach sampling sites in the upper reaches of Bullridge Creek. Sites in the lower reaches of the creek are shown in Figure 7.1.1.



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APPENDIX A Raw Monitoring Results for Page Creek - 2014 to 2017

Table A.1 Minus 2 mm DAE metals results for Page Creek sediment samples collected in 2014.

Sample	Sample Depth (cm)	Thread Distance from A01	Lead (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)	Phosphorus (mg/kg)
O01-11	0-15	-1.7	3	1	<1	59	<50
O01-12	15-35	-1.7	3	1	<1	130	<50
O01-13	35-50	-1.7	3	1	<1	5	<50
O02-11	0-15	-1.1	3	1	<1	130	<50
O02-13	15-35	-1.1	3	1	<1	11	<50
O03-11	0-15	-0.8	3	1	<1	43	<50
O03-12	15-35	-0.8	3	1	<1	3	<50
O03-13	35-50	-0.8	3	1	<1	3	<50
O04-11	0-15	-0.4	3	1	<1	140	<50
O04-12	15-35	-0.4	3	1	<1	130	<50
O04-13	35-50	-0.4	3	1	<1	21	<50
P02-11	0-15	-0.1	3	1	<1	68	<50
P01-11	0-15	0.0	6	1	<1	130	<50
P01-13	15-35	0.0	3	1	<1	200	<50
A01-11	0-15	0.0	8	1	<1	220	<50
A01-12	15-35	0.0	11	1	1	330	<50
A01-13	35-50	0.0	7	1	<1	230	<50
P03-11	0-15	0.4	8	1	<1	380	<50
P03-13	15-35	0.4	13	1	1	390	100
A02-11	0-15	0.4	9	1	<1	280	<50
P04-11	0-15	0.6	51	1	2	510	87
P05-11	0-15	0.7	12	1	1	380	<50
P05-13	15-35	0.7	3	1	<1	150	<50
A03-11	0-15	0.9	47	1	2	680	390
P09-11	0-15	1.0	7	1	<1	210	80
P10-11	0-15	1.0	30	1	1	270	200
N01-11	0-15	1.3	16	1	1	310	550
N02-11	0-15	1.4	21	1	<1	240	620
N03-11	0-15	1.5	26	1	<1	270	530
N04-11	0-15	1.6	27	1	<1	270	380
N05-11	0-15	1.6	7	1	<1	140	170
O05-11	0-15	2.0	17	1	2	560	680
O05-13	15-35	2.0	6	1	2	850	550
A05-11	0-15	2.6	8	1	1	390	380
A05-12	15-35	2.6	3	1	2	660	610
A05-13	35-50	2.6	3	1	5	1800	2300
P08-11	0-15	2.9	9	1	2	560	750
O06-11	0-15	3.0	11	1	2	490	1500
O06-12	15-35	3.0	7	1	2	640	1900
O06-13	35-50	3.0	3	1	3	910	2000
B01-11	0-15	3.0	26	1	1	420	860
B01-12	15-35	3.0	6	1	1	460	1400
B01-13	35-50	3.0	9	1	2	480	1800
B02-11	0-15	3.2	13	1	4	960	1900
B02-12	15-35	3.2	10	1	3	480	75
B02-13	35-50	3.2	3	1	<1	170	<50
B03-11	0-15	3.4	14	1	2	620	920
B03-12	15-35	3.4	11	1	2	610	830
B03-13	35-50	3.4	12	1	<1	65	170
B04-11	0-15	3.6	13	1	3	860	1800
B04-12	15-35	3.6	8	1	1	3	92
B04-13	35-50	3.6	7	1	<1	71	<50

Sample	Sample Depth (cm)	Thread Distance from A01	Lead (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)	Phosphorus (mg/kg)
B05-11	0-15	3.8	14	1	3	970	1700
B05-13	15-35	3.8	5	1	<1	190	110
C01-11	0-15	4.0	15	1	4	1100	1500
C01-13	15-35	4.0	6	1	<1	200	170
C02-11	0-15	4.3	16	1	3	1000	1400
C02-12	15-35	4.3	9	1	1	320	79
C02-13	35-50	4.3	12	1	<1	370	460
C02-21	0-15	4.3	22	1	4	1600	960
C03-11	0-15	4.7	16	1	4	2400	1400
C03-12	15-35	4.7	3	1	2	380	130
C03-13	35-50	4.7	3	1	<1	240	170
C04-11	0-15	4.8	25	1	4	1500	800
C04-12	15-35	4.8	9	1	<1	370	62
C04-13	35-50	4.8	3	1	<1	150	68
C05-11	0-15	5.1	31	1	3	1500	810
C05-12	15-35	5.1	13	1	<1	260	270
C05-13	35-50	5.1	6	1	<1	24	130
C06-11	0-15	5.3	16	1	4	1700	700
C06-12	15-35	5.3	9	1	<1	240	510
C06-13	35-50	5.3	7	1	<1	150	780
C07-11	0-15	5.8	19	1	3	1500	1300
C07-13	15-35	5.8	10	1	<1	76	430
C07-21	0-15	5.8	12	1	2	930	450
C07-22	15-35	5.8	6	1	<1	44	850
C07-23	35-50	5.8	6	1	<1	13	250
D01-11	0-15	5.9	19	1	2	740	6400
D01-13	15-35	5.9	14	1	5	1100	3500
D01-21	0-15	5.9	20	1	2	800	6300
D01-23	15-35	5.9	20	1	2	1100	3300
D02-11	0-15	6.1	34	1	6	2200	4900
D02-21	0-15	6.1	26	1	3	990	4300
D02-23	15-35	6.1	24	1	4	1100	4400
D03-11	0-15	6.4	23	1	4	1900	1200
D03-12	15-35	6.4	5	1	<1	160	440
D03-13	35-50	6.4	11	1	<1	53	320
D03-21	0-15	6.4	12	1	3	830	1700
D03-23	15-35	6.4	6	1	2	450	650
D04-11	0-15	6.6	7	1	4	1500	740
D04-12	15-35	6.6	3	1	1	310	610
D04-13	35-50	6.6	3	1	<1	190	240
D04-21	0-15	6.6	14	1	2	870	880
D04-22	15-35	6.6	9	1	2	360	530
D04-23	35-50	6.6	8	1	<1	91	430
D05-11	0-15	6.8	13	1	3	1400	1000
D05-13	15-35	6.8	9	1	1	380	430
D06-11	0-15	6.9	20	1	3	940	410
E01-11	0-15	7.0	36	1	2	710	510
E01-21	0-15	7.0	28	1	2	630	400
E01-22	15-35	7.0	12	1	2	1100	230
E01-23	35-50	7.0	18	1	<1	700	280
E02-11	0-15	7.1	32	1	2	780	640
E03-11	0-15	7.3	10	1	4	1600	1500
E03-13	15-35	7.3	8	1	1	560	1700
E03-21	0-15	7.3	21	1	2	1500	890
E03-22	15-35	7.3	7	1	2	570	1200
E03-23	35-50	7.3	8	1	<1	220	2200
E04-11	0-15	7.5	11	1	2	670	920

Sample	Sample Depth (cm)	Thread Distance from A01	Lead (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)	Phosphorus (mg/kg)
E04-12	15-35	7.5	9	1	3	700	1200
E04-13	35-50	7.5	7	1	1	540	1700
E05-11	0-15	7.8	25	1	3	1000	1300
E05-13	15-35	7.8	12	1	1	440	1300
E06-11	0-15	8.0	10	1	2	720	440
E06-13	15-35	8.0	8	1	1	580	790
E07-11	0-15	8.3	13	1	2	670	780
E07-12	15-35	8.3	17	1	3	900	1700
E07-13	35-50	8.3	3	1	<1	40	330
E07-21	0-15	8.3	15	1	3	1100	1100
E07-22	15-35	8.3	16	1	4	640	470
E07-23	35-50	8.3	7	1	<1	120	950
E08-11	0-15	8.5	19	1	1	600	720
E08-12	15-35	8.5	18	1	2	1000	1200
E08-13	35-50	8.5	10	1	1	390	800
E09-11	0-15	9.0	10	1	2	850	770
E09-12	15-35	9.0	9	1	4	610	900
E09-13	35-50	9.0	9	1	<1	330	1100
E10-11	0-15	9.3	15	1	3	1600	960
E10-12	15-35	9.3	3	1	<1	3	<50
E10-13	35-50	9.3	6	1	<1	48	1700
E10-21	0-15	9.3	7	1	3	1500	680
E10-22	15-35	9.3	3	1	2	500	710
E10-23	35-50	9.3	6	1	<1	170	500
E11-11	0-15	9.5	12	1	2	660	570
E11-12	15-35	9.5	9	1	<1	210	180
E11-13	35-50	9.5	18	1	<1	280	220
E12-11	0-15	9.7	13	1	3	1400	1300
E12-13	15-35	9.7	6	1	1	390	800
E13-11	0-15	9.9	6	1	2	610	990
E13-13	15-35	9.9	3	1	<1	190	600
E14-11	0-15	10.0	12	1	3	990	810
E14-13	15-35	10.0	6	1	<1	340	970
E14-21	0-15	10.0	9	1	2	720	460
E14-23	15-35	10.0	3	1	1	440	350
E14-31	0-15	10.0	12	1	2	650	420
E14-32	15-35	10.0	10	1	3	1000	670
E14-33	35-50	10.0	5	1	<1	220	750
F01-11	0-15	10.6	14	1	4	1800	760
F01-12	15-35	10.6	11	1	3	1100	960
F01-13	35-50	10.6	6	1	2	540	870
F01-21	0-15	10.6	12	1	2	820	540
F02-11	0-15	11.0	12	1	2	750	310
F02-13	15-35	11.0	9	1	2	680	310
F02-21	0-15	11.0	12	1	1	500	300
F02-22	15-35	11.0	21	1	3	1800	810
F02-23	35-50	11.0	3	1	<1	200	210
F03-11	0-15	11.5	11	1	2	880	460
F03-13	15-35	11.5	6	1	3	750	480
F04-11	0-15	11.7	9	1	4	1400	980
F04-13	15-35	11.7	7	1	1	410	320
F04-21	0-15	11.7	9	1	2	980	470
F04-23	15-35	11.7	7	1	5	2200	570
F04-31	0-15	11.7	9	1	3	1100	570
F04-32	15-35	11.7	8	1	3	1500	520
F04-33	35-50	11.7	7	1	1	410	230
F05-11	0-15	12.4	11	1	3	1100	650

Sample	Sample Depth (cm)	Thread Distance from A01	Lead (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)	Phosphorus (mg/kg)
F05-12	15-35	12.4	11	1	3	1000	470
F05-13	35-50	12.4	9	1	6	880	180
F06-11	0-15	12.6	15	1	4	1500	560
F07-11	0-15	13.0	10	1	5	2300	500
F07-13	15-35	13.0	7	1	3	1000	280
F08-11	0-15	13.3	10	1	7	2800	550
F08-12	15-35	13.3	9	1	7	2700	410
F08-13	35-50	13.3	10	1	<1	270	250
F09-11	0-15	13.4	8	1	7	2600	920
F09-12	15-35	13.4	9	1	10	3600	500
F09-13	35-50	13.4	17	1	7	2400	350
F10-11	0-15	13.7	7	1	3	1000	200
F10-12	15-35	13.7	6	1	7	2500	510
F10-13	35-50	13.7	3	1	<1	300	100
F11-11	0-15	14.2	7	1	7	2900	500
F11-12	15-35	14.2	6	1	3	790	180
F11-13	35-50	14.2	7	1	7	2700	380
F12-11	0-15	14.8	5	1	4	1500	230
F12-12	15-35	14.8	6	1	7	2600	200
F12-13	35-50	14.8	6	1	6	1100	410
G01-11	0-15	15.6	5	1	4	1100	330
G01-12	15-35	15.6	6	1	4	1700	200
G01-13	35-50	15.6	5	1	<1	220	120
G02-11	0-15	15.7	9	2	4	810	540
G02-12	15-35	15.7	5	1	6	1800	340
G02-13	35-50	15.7	9	1	2	220	190
G03-11	0-15	16.6	3	1	6	1700	570
G03-12	15-35	16.6	3	1	8	2600	320
G03-13	35-50	16.6	7	1	<1	250	110
G04-11	0-15	17.3	3	1	7	2400	390
G04-12	15-35	17.3	3	1	10	3100	250
G04-13	35-50	17.3	3	1	<1	200	110
G05-11	0-15	19.0	3	1	6	1800	600
G05-12	15-35	19.0	3	1	3	900	470
G05-13	35-50	19.0	6	1	<1	72	450
G06-11	0-15	19.6	5	1	2	760	970
G06-12	15-35	19.6	7	1	9	3100	2200
G06-13	35-50	19.6	6	1	7	2400	2500
G07-11	0-15	19.8	5	1	5	1900	1900
G07-12	15-35	19.8	7	1	5	2100	1900
G07-13	35-50	19.8	6	1	6	2200	2700

Table A.2 Minus 2 mm DAE metals results for Page Creek sediment samples collected in 2015.

Reach	Sample ID	Thread Distance from A00 (m)	WAE <2mm (mg/kg)			
			Cadmium	Lead	Zinc	Phosphorus
A	15PCa	500	<0.4	16	48	19
A	15PCb	1000	<0.4	26	75	13
A	15PCc	1500	<0.4	29	100	18
A	15PCd	2000	<1	52	220	51
A	15PCE	2500	<1	26	300	51
A	15PCf	3000	1.5	58	560	380
A	15PCg	3500	1.4	140	480	710
A	15PCh	4000	1.5	57	420	380
A	15PCi	4500	1.2	40	250	460
A	15PCj	5000	1.6	77	480	1800
B	15PCk	5500	2.6	67	780	1700
B	15PCL	6000	3.6	52	1000	2000
B/C	15PC01	6600	3.3	54	1100	1600
C	15PC02	7100	3.6	50	1400	1200
C	15PC03	7600	4.2	47	1600	1200
C	15PC04	8100	4.1	41	1500	1000
C/D	15PC05	8600	5.5	50	1500	4500
D	15PC06	8900	3.4	35	970	1200
D	15PC07	9400	3.1	31	1000	770
D/E	15PC08	9900	3.7	34	1000	840
E	15PC09	10400	2.9	29	1000	1000
E	15PC10	10900	1.6	21	520	460
E	15PC11	11400	2	31	690	570
E	15PC12	11900	1.7	27	650	620
E	15PC13	12400	1.5	22	600	540
E	15PC14	12900	1.3	19	490	450
E	15PC15	13400	1.2	23	480	380
E/F	15PC16	13900	2	26	700	410
F	15PC17	14400	1.5	23	570	330
F	15PC18	14900	1.5	24	560	370
F	15PC23	15400	1.5	18	610	330
F	15PC24	15900	1.5	24	540	310
F	15PC25	16400	1.5	18	530	280
F	15PC26	16900	2.2	16	740	280
F	15PC27	17400	3.6	17	1200	450
F	15PC35	17900	3.3	23	1100	360
F	15PC19	18550	2.3	13	760	230
F	15PC20	19050	<1	8	200	64
F	15PC21	19550	2.1	12	700	270
F/G	15PC22	20050	<1	12	220	390
G	15PC41-1	-	<1	8	120	76
G	15PC28	20550	1.1	10	320	270
G	15PC29	21050	1.4	9	400	360
G	15PC30	21550	1.6	8	450	180
G	15PC31	22050	4.4	10	1200	360
G	15PC36	22550	4.8	18	1300	340
G	15PC37	23050	3.3	12	960	1100
G	15PC40-1	-	1.8	24	370	6300
G	15PC38	23550	<1	11	230	150
G	15PC32	24225	3.1	14	890	3400
G	15PC33	24725	4.1	13	1200	3200
G	15PC34	25225	4.4	22	1400	2600

Table A.3 Minus 2 mm DAE metals results for Page Creek sediment samples collected in 2016.

Sample	Sample Depth (cm)	Thread Distance from A01	Lead (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)	Phosphorus (mg/kg)	Manganese (mg/kg)
A01-11	0-15	0.0	19	-	<1	100	<50	740
A01-12	15-35	0.0	15	-	<1	84	<50	520
A02-11	0-15	0.4	23	-	<1	310	<50	520
A03-11	0-15	0.9	31	-	<1	330	180	400
P09-11	0-15	1.0	17	-	<1	200	99	340
N02-11	0-15	1.4	29	-	<1	270	360	690
N04-11	0-15	1.6	32	-	<1	260	310	430
A05-11	0-15	2.6	11	-	1	400	650	390
A05-12	15-35	2.6	15	-	4	1100	1500	530
B01-11	0-15	3.0	28	-	2	560	1600	360
B01-12	15-35	3.0	16	-	3	900	2100	470
B03-11	0-15	3.4	26	-	3	780	1700	580
B03-12	15-35	3.4	22	-	3	910	1400	450
B05-11	0-15	3.8	22	-	3	940	1900	560
B05-12	15-35	3.8	21	-	1	430	550	300
C01-11	0-15	4.0	35	-	3	960	1600	920
C01-13	15-35	4.0	22	-	2	470	420	450
C02-11	0-15	4.3	28	-	2	900	1500	650
C02-12	15-35	4.3	14	-	<1	360	330	230
C05-11	0-15	5.1	38	-	3	1300	960	720
D04-11	0-15	6.6	19	-	2	980	930	580
E05-11	0-15	7.8	20	-	1	440	1000	510
E10-11	0-15	9.3	19	-	2	600	650	490
E10-13	15-35	9.3	28	-	2	970	1200	750
E10-21	0-15	9.3	17	-	1	420	600	570
E10-23	15-35	9.3	12	-	<1	51	480	260
F07-11	0-15	13.0	13	-	2	630	360	640
F07-12	15-35	13.0	13	-	2	720	280	670
F08-11	0-15	13.3	18	-	4	1300	510	1100
F08-12	15-35	13.3	17	-	5	1600	660	1100
F09-11	0-15	13.4	14	-	3	1100	370	870
F09-12	15-35	13.4	14	-	4	1400	390	840
F10-11	0-15	13.7	11	-	2	810	260	750
F10-12	15-35	13.7	14	-	4	1400	380	980
F11-11	0-15	14.2	14	-	4	1200	320	1100
F11-12	15-35	14.2	13	-	5	1400	480	820
G02-11	0-15	15.7	12	-	1	420	200	640
G02-12	15-35	15.7	12	-	6	1400	550	930
G03-11	0-15	16.6	6	-	1	410	350	420
G03-12	15-35	16.6	14	-	7	1600	730	1300
G04-11	0-15	17.3	7	-	2	480	160	480
G04-12	15-35	17.3	10	-	5	1400	350	1100
G04-13	35-50	17.3	11	-	<1	160	240	630
G05-11	0-15	19.0	10	-	3	880	760	850
G05-12	15-35	19.0	9	-	6	1500	680	870
G05-13	35-50	19.0	9	-	6	1600	850	950
G06-11	0-15	19.6	12	-	5	1400	2500	1000
G06-12	15-35	19.6	12	-	5	1500	3200	830
G07-11	0-15	19.8	3	-	<1	250	900	270
G07-12	15-35	19.8	13	-	6	1700	3600	1000

Table A.4 Minus 2 mm DAE metals results for Page Creek sediment samples collected in 2017.

Sample	Sample Depth (cm)	Thread Distance from A01	Lead (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)
A01-11	0-15	0.0	5	-	<1	72
A01-13	15-35	0.0	10	-	<1	110
A02-11	0-15	0.4	10	-	<1	220
A03-11	0-15	0.9	18	-	<1	240
P09-11	0-15	1.0	40	-	<1	290
N02-11	0-15	1.4	69	-	1	440
N04-11	0-15	1.6	28	-	<1	180
A05-11	0-15	2.6	15	-	1	320
A05-12	15-35	2.6	10	-	1	390
B01-11	0-15	3.0	15	-	1	500
B01-12	15-35	3.0	20	-	2	610
B03-11	0-15	3.4	25	-	2	640
B03-12	15-35	3.4	25	-	<1	270
B05-11	0-15	3.8	25	-	2	830
B05-12	15-35	3.8	15	-	1	440
C01-11	0-15	4.0	26	-	2	830
C01-13	15-35	4.0	21	-	1	500
C02-11	0-15	4.3	23	-	2	750
C02-12	15-35	4.3	26	-	4	1000
C05-11	0-15	5.1	34	-	2	1100
D04-11	0-15	6.6	15	-	1	580
E05-11	0-15	7.8	20	-	1	540
E10-11	0-15	9.3	15	-	2	660
E10-13	15-35	9.3	15	-	1	480
E10-21	0-15	9.3	15	-	1	600
E10-23	15-35	9.3	10	-	<1	160
F07-11	0-15	13.0	5	-	<1	310
F07-12	15-35	13.0	10	-	<1	240
F08-11	0-15	13.3	10	-	4	1400
F08-12	15-35	13.3	10	-	2	810
F09-11	0-15	13.4	5	-	1	480
F09-12	15-35	13.4	10	-	3	1200
F10-11	0-15	13.7	10	-	3	1000
F10-12	15-35	13.7	10	-	3	1100
F11-11	0-15	14.2	15	-	5	1500
F11-12	15-35	14.2	15	-	6	1800
G02-11	0-15	15.7	10	-	2	640
G02-12	15-35	15.7	10	-	5	1400
G03-11	0-15	16.6	5	-	3	790
G03-12	15-35	16.6	10	-	3	810
G04-11	0-15	17.3	5	-	4	1300
G04-12	15-35	17.3	10	-	6	1600
G04-13	35-50	17.3	5	-	<1	49
G05-11	0-15	19.0	5	-	2	640
G05-12	15-35	19.0	5	-	3	980
G05-13	35-50	19.0	5	-	4	1200
G06-11	0-15	19.6	13	-	3	1000
G06-12	15-35	19.6	10	-	3	1100
G07-11	0-15	19.8	9	-	2	630
G07-12	15-35	19.8	12	-	4	1200

Table A.5 Minus 2 mm DAE metals results for Page Creek sediment samples collected in 2018.

Reach	Sample	Sample Depth (cm)	Thread Distance from A01	Lead (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)
	G07-12	15-35	19.8	12	4	1200
A	A01-11	0-15	0.0	17	<1	140
	A01-12	15-35	0.0	15	<1	89
	A02-11	0-15	0.4	24	<1	280
	A03-11	0-15	0.9	43	1	370
	P09-11	0-15	1.0	54	1	440
	N02-11	0-15	1.4	65	1	420
	N04-11	0-15	1.6	39	<1	280
	A05-11	0-15	2.6	10	1	350
	A05-12	15-35	2.6	9	3	970
B	B01-11	0-15	3.0	21	2	530
	B01-12	15-35	3.0	20	2	570
	B03-11	0-15	3.4	27	3	780
	B03-12	15-35	3.4	17	<1	77
	B05-11	0-15	3.8	30	3	1100
	B05-12	15-35	3.8	17	<1	100
C	C01-11	0-15	4.0	39	3	860
	C01-13	15-35	4.0	27	1	490
	C02-11	0-15	4.3	36	3	1100
	C02-12	15-35	4.3	23	2	510
	C05-11	0-15	5.1	51	3	1200
D	D04-11	0-15	6.6	24	2	850
E	E05-11	0-15	7.8	26	1	520
	E10-11	0-15	9.3	25	2	810
	E10-12	15-35	9.3	18	<1	300
	E10-21	0-15	9.3	24	2	600
	E10-22	15-35	9.3	21	<1	330
F	F07-11	0-15	13.0	14	1	390
	F08-11	0-15	13.3	16	3	890
	F08-12	15-35	13.3	17	3	1100
	F09-11	0-15	13.4	17	4	1300
	F09-12	15-35	13.4	17	3	1100
	F10-11	0-15	13.7	9	<1	370
	F10-12	15-35	13.7	15	4	1200
	F11-11	0-15	14.2	16	2	670
	F11-12	15-35	14.2	18	9	2100
G	G02-11	0-15	15.7	13	1	420
	G02-12	15-35	15.7	10	5	1200
	G03-11	0-15	16.6	12	4	900
	G03-12	15-35	16.6	10	5	1400
	G04-11	0-15	17.3	10	4	1000
	G04-12	15-35	17.3	12	<1	140
	G04-13	35-50	17.3	11	<1	46
	G05-11	0-15	19.0	9	3	780
	G05-12	15-35	19.0	10	5	1300
	G05-13	35-50	19.0	11	8	1800
	G06-11	0-15	19.6	14	6	1500
	G06-12	15-35	19.6	12	3	900
	G07-11	0-15	19.8	11	3	890
	G07-12	15-35	19.8	11	4	1100

APPENDIX B Raw Monitoring Results for Lawn Hill Creek - 2018

Table B.1 Sediment Zinc results for Lawn Hill Creek monitoring sites in June 2018. Values highlighted in blue font are greater than the ISQG-Low.

Sample	Cadmium	Zinc	Lead
L1a-1	0.2	62	7.4
L1a-2	0.4	130	5.9
L1a-3	0.2	50	5.8
L1a-4	0.1	29	6.3
L1a-5	0.4	94	6.3
L1a-6	0.2	44	4.1
L1a-7	0.4	130	7.9
L1a-8	0.5	120	8.6
Transect Median	0.3	78	6.3
L1b-1	0.4	120	9.4
L1b-2	0.5	140	7.8
L1b-3	1.2	260	12
L1b-4	1.0	200	13
L1b-5	1.1	220	12
L1b-6	0.9	170	12
L1b-7	0.4	110	9.6
L1b-8	0.2	59	8.3
Transect Median	0.7	155	10.8
L2a-1	0.2	59	10
L2a-2	0.4	120	10
L2a-3	0.3	54	17
L2a-4	0.2	73	9.8
L2a-5	0.3	57	11
L2a-6	0.2	59	11
L2a-7	0.2	78	9.6
L2a-8	0.2	46	9.4
Transect Median	0.2	59	10.0
L02-1	0.2	46	6.8
L02-2	0.2	25	7.5
L02-3	0.1	22	5.2
L02-4	0.3	60	14
L02-5	0.3	56	15
L02-6	0.3	51	18
L02-7	0.3	85	14
L02-8	0.2	74	8.1
Transect Median	0.3	54	11.1
L03 (composite)	0.2	44	7.1
L3a (composite)	0.2	29	13
L04 (composite)	0.1	28	8.9
L05 (composite)	0.1	17	9.2
RL3 (composite)	<0.1	9	4.9
RL2 (composite)	0.1	12	6.7
RL1 (composite)	0.1	20	16
RL0 (composite)	<0.1	19	8.2