

The Impact of a Derelict Base Metal Mine on the Aquatic Environment

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ABSTRACT

The water pollution hazard posed by the derelict Conrad mine site, to the water and associated stream sediment of Borah and Maids Creeks and the nearby Copeton Dam storage, has been assessed.

Mine water, tailings and tailings dump leachate have polluted water and stream sediments in Borah Creek downstream of the mine site. Acidity, arsenic, copper, lead, iron, silver and zinc are the principal pollutants. Under dry and low flow conditions, mine water was found to be the dominant polluting source, however, leachate and run-off from tailings dumps were also significant under and following wet conditions. Soluble arsenic, lead, iron and silver species in mine water and leachate were found to be rapidly incorporated into sediments, but acidity, copper, and zinc persisted in the creek water.

Under low flow conditions, the water of Maids Creek is polluted with copper and zinc (up to 4.4 and 34 mg/l for copper and zinc respectively) and the pH is decreased (from pH 5 - 7 to pH 3 - 6) by entry of Borah Creek water. Values found in Maids Creek were variable and related to flow regime and distance downstream from Borah Creek confluence. Water in Copeton Dam storage, having a much larger volume of water with a higher bicarbonate buffering capacity (50mg/l versus 15mg/l), is not affected by entry of Maids Creek water.

Polluted sediment from Borah Creek has contaminated Maids Creek for 2km downstream to Copeton Dam storage. Stream sediment downstream of the Borah Creek confluence, contains up to 1.0% As and 1.4% Pb in the less than 200 micron size fraction.

Under high flow conditions, arsenic was found to be moved out from the mine site as insoluble species, associated with suspended sediment in run-off.

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INTRODUCTION

A number of abandoned metalliferous mines in New South Wales have been investigated by the Department of Mineral Resources to assess potential environmental problems so that appropriate remedial measures can be carried out. The investigations generally comprise the sampling of water, stream sediment and waste dumps, and location of sources of pollution and safety hazards.

The Conrad mine, an abandoned base metal mine, has been comprehensively investigated, however, this paper only discusses the impact of the mine site on downstream water quality, with particular regard to toxic metal pollution.

LOCATION

The Conrad mine is situated 21 km southsouthwest of Inverell in the New England region of New South Wales. The mine workings lie within the catchment of Maids Creek, which flows into the Copeton Dam storage on the Gwydir River. The mine site is located 3.5 km upstream of the dam storage.

Copeton Dam reservoir, with a total storage of 1.4 million megalitres, is used for water conservation purposes, downstream irrigation, stock watering and as a domestic water supply to the nearby town of Inverell. The water storage is used extensively for fishing, swimming and boating.

GEOLOGY AND MINERALIZATION

The Conrad lodes are located within a tongue of acid granite, close to its contact with a mass of porphyritic adamellite (Tingha granite). The main Conrad lode consists of an almost vertical vein, over 3 km long and about 0.6 m wide [1].

The mineralogy of the vein is complex. The ore minerals comprise major arsenopyrite, sphalerite, argentiferous galena, chalcopyrite and stannite (copper-iron-tin sulphide), along with minor cassiterite and tetrahedrite (copper-antimony-silver sulphide) [2]. The wall rocks have been slightly kaolinized and impregnated with arsenopyrite for up to 0.6 m on each side of the ore-body [3].

The gangue minerals are predominantly quartz with minor amounts of kaolin. Secondary mineralisation is insignificant and the ore-body at depth is essentially unweathered.

MINING HISTORY

The Conrad mine is the largest hard rock base metal mine in the New England region, and was mined intermittently between 1898 and 1957, when the mine finally closed due to low metal prices and high production costs.

There were two periods of significant mining activity, namely 1898 to 1913, when up to 500 men were employed, and 1950 to 1957, when 60 men were employed. Zinc, copper and silver-lead concentrates were

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produced, and, in the early mining period, these were smelted on site to produce silver-lead and lead-tin bullion, copper matte and arsenic oxide.

Alluvial tin and diamonds have been worked in the downstream reaches of Maids Creek nearby, but no production figures or when the operations were carried out are known. The bed of Maids Creek has been extensively disturbed as a result of these operations.

SITE DESCRIPTION

The mine is located in the valley of Borah Creek in undulating timbered granite terrain on the western edge of the New England Plateau. Only very small-scale cattle or sheep grazing is carried on in the vicinity of the mine and, apart from the attraction of the mine itself, the area is an isolated one.

Borah Creek, a non-perennial creek with a catchment of 7 sq km, is a tributary of Maids Creek, which drains an area of 45 sq km and flows into the Copeton Dam storage on the Gwydir River. The susceptibility to weathering of lode mineralisation has determined the position of Borah Creek to be along the outcrop of the Conrad lode.

Surface workings at the site extend over a distance of about 2km and run downslope from east to west generally parallel to Borah Creek. They comprise two main three-compartment timber-lined shafts, the Conrad and King Conrad, being 275 and 125 m deep respectively, together with eleven other single compartment shafts and four adits.

Continuous underground workings extend along the lode for about 1.6km, but they are now inaccessible and the lower levels are flooded. Extensive stoping in the upper levels of the workings were carried out in the period up to 1913 and in the lower levels between 1955 to 1957. Stopes east of the Conrad shaft have collapsed to the surface in the bed of the east-west gully which ran to Borah Creek but is now blocked with fill. There are two collapses, each about 1m by 2m, which now divert surface water in the gully into the underground workings.

Problems of appearance and stability are presented by all mine waste dumps at the mine site. There are three main waste dumps (see Table 1 for composition), and comprise, in order from east to west:-

1. The "fault dump", a fine grained tailings dump of about 22,000 tonnes produced in the 1954-1957 period, is mainly quartz, with varying amounts of muscovite and kaolinite. Distinctively coloured layers occur due to the presence of green scorodite (iron (III) arsenate hydrate), yellow beudantite (a secondary lead iron arsenic hydroxy sulphate) and Prussian Blue (iron (III) ferrocyanide). Dark grey to black layers contain varying amounts of pyrite, stannite, chalcopyrite, cassiterite, arsenopyrite and galena.
2. The "road dump", a road embankment constructed of about 37,000 tonnes of coarse to fine mullock, is bare and a burnt yellow-brown colour, and reaches a height of up to 10 m. The dump was found to contain major amounts of quartz, muscovite

The Third International Mine Water Congress, Melbourne Australia, October 1988

and felspar and minor amounts of kaolin, beudantite and gypsum. Sufficient sulphide mineralization is present to have developed a strongly oxidized and acid surface. It is subject to erosion at its base by Borah Creek.

3. The "old dump", a coarse grained tailings dump of about 19,000 tonnes relict from the early mining period and situated downslope of the mine workings, is deeply gully eroded and is being undercut by Borah Creek. It consists of coarse angular milky quartz fragments and a finer bright yellow material, which was found to consist of major amounts of quartz and muscovite with minor amounts of kaolinite and beudantite.

SOURCES OF CONTAMINATION TO DOWNSTREAM WATERS

Sources of trace metal pollution and acidity are related essentially to:-

1. discharge of contaminated water from underground openings, which have been observed at different times from a small shaft (the Alwell shaft) and a collapsed adit in the vicinity of the King Conrad shaft, and from springs west of this adit and generally located within the bed of Borah Creek,
2. throughflow from waste dumps and contaminated fill and waste filled drainage lines, and, while large areas of fill are apparently permeable, the most significant contributor is the "fault dump" with the "old dump" being of secondary importance, and
3. run-off from contaminated fill and waste dumps which have significant surface area and comprise erodible material; the major contributions are the two tailings dumps, the slag and fill area around the Conrad shaft, and the "road" dump.

A series of sampling sites were chosen in Borah and Maids Creeks downstream to the Copeton Dam storage, to monitor the impact of toxic metals and acidity from the mine site on the quality of water and stream sediments. The range of values found for selected parameters at the most significant sites are given in Tables 2 and 3.

RESULTS AND DISCUSSION

Under normal conditions, mine water discharge and tailings dump leachate are the most significant sources of pollution to Borah Creek. The most obvious point sources of pollution were leachate from the "fault" tailings dump and mine water flowing out from a small shaft (the Alwell). Samples of these waters taken during this investigation were found to have variable composition and the range of values found for selected parameters are given in Table 2.

The "fault" dump was found to be undergoing extensive active leaching of toxic metals by throughflow and evidence of piping within the dump was provided by a bubbling movement of slimes out from the toe of the dump. This leachate was the most polluted water found in this

The Third International Mine Water Congress, Melbourne Australia, October 1988

TABLE 1
Composition of Mine Dump Material[#]

Sample	As %	Cd *	Cu *	Fe %	Pb %	Mn *	S %	Sn %	Zn *
1	6.2	200	1000	5.5	0.27	100	3.1	0.07	600
2	0.4	<1	330	0.8	1.65	65	1.4	3.7	750
3	0.8	6	550	1.9	1.1	175	0.9	0.34	450

[#] Composite sample of series of channel samples taken down eroding face of dumps
 1. "Fault" tailings dump 2. "Old" tailings dump 3. "Road" dump
 * concentration in microgram/gram

TABLE 2
Analysis of Water for Selected Metals
Range of Values Found During Sampling

Sample	pH	E.C. mS/cm	SO ₄ ²⁻ # ₄	As *	Cu *	Fe *	Pb *	Zn *
9	2.6	3.0	1800	9	1	600	0.8	230
	3.1	5.8	6000	65	62	1850	4.2	950
16	2.8	1.2	600	7	0.2	145	0.2	8
	3.2	1.9	890	14	1.2	330	2.0	60
6	2.5	0.3	103	0.06	1.2	3	0.2	11
	3.7	1.3	620	0.69	8.6	40	1.1	55
4	3.2	0.1	25	0.03	0.3	1.5	0.01	3
	5.3	0.8	360	0.08	4.4	8.5	1.4	34
3	3.2	0.1	25	0.04	0.3	1.0	<0.01	2
	5.9	0.7	360	0.27	3.1	5.9	1.5	32
2	4.0	0.7	25	0.01	0.1	0.3	<0.01	2
	5.8	0.3	180	0.08	1.8	4.4	1.0	12
5	5.2	0.04	<5	<0.01	<0.01	0.1	<0.01	<0.01
	7.4	0.08				0.9		

* concentration in mgm/litre

9. Leachate from "Fault" Tailings Dump 16. Water from mine workings
 6. Borah Creek before Maids Creek confluence (1.5km d/s of mine)
 3. Maids Creek 0.2km downstream of Borah Creek (1.7km d/s of mine)
 4. Maids Creek 0.7km downstream of Borah Creek (2.2km d/s mine)
 2. Maids Creek at Copeton Dam storage (3.5km d/s of mine)
 5. Maids Creek upstream of Borah Creek confluence

The Third International Mine Water Congress, Melbourne Australia, October 1988

investigation, however the flow was always found to be small (less than 5 litre/min) and represents a small but chronic contribution to the pollution load in Borah Creek, at least under normal conditions.

Concentration values for arsenic, cadmium, copper, iron, sulphur and zinc in the "old" tailings dumps were found to be much lower than those found in the more recently formed "fault" tailings dump (see Table 1). These elements are mobile under acidic and oxidising conditions and so similar concentration values are found in both dumps even though oxidation and leaching has been active in the "old" dump for about 50 years longer than in the "fault" dump.

In particular, arsenic concentration values in samples from the "old" dump were found to be less than 1% compared with values of up to 20% found in samples from the "fault" tailings dump. Beudantite was the predominant arsenic mineral in the "old" dump, however, in the "fault" dump, this was found to be scorodite. Arsenopyrite was the only arsenic mineral in the ore and occurred as mono-mineralic particles [4]. When deposited as tailings, conversion to secondary arsenic minerals readily took place, due to the relatively large surface area exposed in these particles.

Scorodite is reported to weather readily to produce limonite [5], which indicates that large quantities of arsenic, which are presently incorporated within the "fault" dump as scorodite, can be expected to be eventually released to Borah Creek. The stability of beudantite to weathering is not known, but its presence in the "old" tailings dump suggests it is more stable than scorodite.

In the "fault" dump, oxidized arsenic species, such as scorodite and beudantite, were found in layers with high quartz and low kaolinite contents. These layers would be relatively permeable to throughflow, and so oxidation and leaching of sulphides would readily take place. Metal sulphides, however, were found only in layers with relatively high kaolinite and mica contents, which render these layers less permeable to throughflow and thus oxidation and leaching would be restricted under these circumstances.

Water samples taken in Borah Creek upstream of the mine site were found to be similar in composition to those taken in Maids Creek upstream of the Borah Creek confluence (see Table 2). Under low to normal flow conditions, these samples also exhibited a distinct opalescence, due to suspended clay, however, water samples taken adjacent to and downstream of the mine site, were completely clear and colourless. These downstream waters were found to be of poor quality with regard to chemical composition and the range of values found for selected parameters is given in Table 2.

The Alwell shaft was found to be the discharge point for the top water level of the flooded mine workings. This shaft is partly collapsed and timber filled and is located in the creek bank downslope from the King Conrad shaft. Mine plans show that surface water entering the mine workings through collapsed stopes (see Site Description) passes through about 1.2km of workings at a depth of between 70 and 120 metres below surface level before being discharged from the springs or from the Alwell shaft.

The Third International Mine Water Congress, Melbourne Australia, October 1988

During 1979-80, severe drought conditions prevailed in the study area and very low flow conditions were experienced in the Borah-Maids Creeks system. Flow from the tailings dump and the Alwell shaft ceased, and it was discovered that contaminated water was being discharged via a series of springs located within the bed of Borah Creek. The springs could only be observed and sampled under low flow conditions because creek flow usually covers them. Samples from these outflows were found to be clear and colourless, with variable composition, generally within the range of values found for mine water from the Alwell shaft (see Table 2). The springs represent mine water seepage to the creek bed either through old workings or from joint fracturing. Under these conditions, water quality was poor in Maids Creek downstream to the Copeton Dam storage, although the creek flow involved was very low (0.01 to 0.10 megalitres/day).

Samples of active stream sediment taken on different sampling occasions at sampling sites in Borah Creek adjacent to and downstream of the mine site were found to vary in colour, composition and size fraction. The range of values for selected parameters are given in Table 3. Stream sediment samples taken upstream of the mine site were found to be similar to those taken in Maids Creek upstream of the Borah Creek confluence, with low metal content typical of an unpolluted natural environment and containing little fine grained material (less than 1% of less than 200 micron size fraction).

Stream sediment samples taken at various times just downstream of the mine-water springs were three distinctly different colours, namely:-

1. deep red-brown colored and containing 46-51% of less than 200 micron sized material, which was found to contain 9-15% iron, 2-3% arsenic and 0.8-1% lead,
2. light green coloured, which was due to a thin layer of finely divided scorodite, along with quartz, muscovite and jarosite (hydrated potassium iron sulphate hydroxide), and
3. light yellow-brown coloured and found to be mainly quartz, muscovite and kaolinite with minor beaudantite.

The red-brown and light green coloured sediments appear to be hydromorphically formed, when mine water, containing up to 330mg/l and 14mg/l iron and arsenic respectively, undergoes oxidation, hydrolysis and adsorption reactions, on being discharged to Borah creek. Arsenic in aqueous solution (as arsenite, AsO_2^-) has been shown to be very rapidly adsorbed by hydrous iron oxides [6], and this could account for the high arsenic content of the iron rich red-brown sediments.

Water in Maids Creek was found to be typical for water draining a granite terrain, with a pH of 5 - 7 and a low buffering capacity (bicarbonate 15mg/l). Entry of acidic Borah Creek water (pH 2.5 - 3.7) causes a pH change to pH 3 - 6, however, water in Copeton Dam storage, having a much larger volume and a higher bicarbonate concentration (50 mgm/l), is not affected by the entry of Maids Creek.

Low concentrations of metals, typical of an unpolluted natural environment, were found in Maids Creek stream sediments upstream of

The Third International Mine Water Congress, Melbourne Australia, October 1988

TABLE 3
Analysis of Stream Sediment (-200 micron fraction) for Selected Metals
Range of Concentration Values Found During Sampling

Sample Site	Fraction %	Ag *	As %	Cu *	Fe %	Pb %	Sn %	Zn *
6	2 - 20	90	0.43	200	1.4	0.37	0.23	175
		300	1.5	660	13	1.1	3.1	1200
4	1 - 26	30	0.08	160	1.0	0.25	0.08	160
		300	1.0	900	3.4	1.45	2.8	635
3	1 - 8	25	0.08	150	0.8	0.11	0.06	150
		400	0.65	500	5.6	0.64	0.6	450
2	1 - 3	20	0.07	150	0.7	0.16	0.07	150
		60	0.60	420	3.7	0.59	0.19	310
5	<1	<2	<0.01	<10	0.7	<0.01	<0.01	60
					2.3			110

* concentration in microgram/gram
 See Table 2 for Sampling Site location

TABLE 4
Load Calculations (g/hour) at Site 3
Comparison of Low Flow Regime with Storm Event

Parameter	13-3-79	Low Flow Regime*	15-3-79	Storm Event**
	Total	"Soluble" #	Total	"Soluble" #
pH	3.6		3.2	
E.C. ##	510		535	
SO ₄ ²⁻	720	720	10,400	10,400
As	0.21	0.14	167	3.1
Cd	0.39	0.39	8.6	8.6
Cu	6	6	87	87
Fe	4.6	4.3	700	545
Mn	6.1	6.1	145	145
Zn	43	43	1060	1060

* Flow 0.09 megalitres/day
 # Passes 0.6 micron glass fibre filter

** Flow 1.5 megalitres/day
 ## Measured in mS/cm

The Third International Mine Water Congress, Melbourne Australia, October 1988

the Borah Creek confluence. Very little fine material was present (less than 1% of less than 200 micron fraction), and the creek bed was very well vegetated with willow trees, rushes, and water weeds. Downstream of the confluence, the sediment was found to have up to 20% of the less than 200 micron fraction, which contained up to 1% arsenic and 1.4% lead. No vegetation is supported in the creek bed, but this may also reflect the extensive disturbance due to alluvial mining (see Mining History).

In March, 1979, sampling was carried out under a low flow regime, when flow in Borah creek (about 0.03 megalitres/day) was due entirely to discharge from the mine-water springs. Shortly after sampling was completed, localised heavy rain fell at the site, and the site was re-sampled. Flow in Borah Creek had risen to 0.3 megalitres/day and downstream in Maids Creek to 1.5 megalitres/day. Surface water was entering the mine workings through collapsed stopes (see Site Description), but no water was being discharged from the Alwell shaft to Borah Creek, because the top water level had not been reached.

Suspended sediment in run-off from all waste dumps, and in particular from the "fault" tailings dump, resulted in water in Borah Creek being turbid with a yellow-grey colour, however water in Maids Creek upstream of the Borah Creek confluence was clear with no suspended sediment. Load values for selected metals in Maids Creek about 0.2km downstream of the mine site under the two flow regimes are given in Table 4.

Although flow in Maids Creek had increased 16 fold due to the storm:-

1. pH and electrical conductivity values and concentration values for sulphate, cadmium, copper, manganese, zinc and "soluble" arsenic found on both sampling occasions were similar, and
2. the load for total arsenic had increased 800 times, with less than 2% of the load being moved as "soluble" arsenic species.

These results suggest that, at the time of sampling, dilution of the pollution load in Maids Creek with uncontaminated run-off was being offset by the addition of polluted run-off from the mine site. However, these results are only an instantaneous measurement at some point on the rising or falling stage of the hydrograph.

The large increase in arsenic load during the rain storm is due to suspended sediment from the mine site entering the creek system. The sediment contains relatively high concentrations of insoluble arsenic species, such as scorodite and beaudantite. This effect can be expected to occur whenever run-off conditions prevail at the mine site.

CONCLUSIONS

Mine water, tailings and tailings dump leachate have polluted water and stream sediments in Borah Creek downstream of the mine site. Acidity, arsenic, copper, lead, iron, silver and zinc are the principal pollutants. Under dry and low flow conditions, mine water was found to be the dominant polluting source, however, leachate and

The Third International Mine Water Congress, Melbourne Australia, October 1988

run-off from tailings dumps were also significant under and following wet conditions. Soluble arsenic, lead, iron and silver species in mine water and leachate were found to be rapidly incorporated into sediments, but acidity, copper, and zinc persisted in the creek water.

Under low flow conditions, the water of Maids Creek is polluted with copper and zinc (up to 4.4 and 34 mg/l for copper and zinc respectively) and the pH is decreased (from pH 5 - 7 to pH 3 - 6) by entry of Borah Creek water. Values found in Maids Creek were variable and related to flow regime and distance downstream of Borah Creek confluence. Copeton Dam storage, having a much larger volume of water with higher bicarbonate buffering capacity (50mg/l versus 15mg/l), is not affected by entry of Maids Creek water.

Polluted sediment from Borah Creek has contaminated Maids Creek for 2 km downstream to Copeton Dam. Stream sediment downstream of Borah Creek confluence contains up to 1.0% As and 1.4% Pb in the less than 200 micron size fraction.

Under high flow conditions, arsenic was found to be moved out from the mine site as insoluble species, associated with suspended sediment in run-off.

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