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Mount Bischoff Acid Mine Drainage Investigations Final Report

Prepared for

Mineral Resources Tasmania

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EXECUTIVE SUMMARY

Mineral Resources Tasmania (MRT) commissioned a joint venture consisting of Pitt & Sherry and John Miedecke & Partners (JMP) to undertake site investigations and develop a prioritised program of works to address the acid mine drainage issue at Mount Bischoff.

This investigation incorporates both field work and assessment of previous studies conducted at the site with the primary objectives of identifying and quantifying the principal sources of acid drainage and metal contamination to the Arthur River, recommending rehabilitation works to minimise the acid and metal loads discharging into receiving waters and identification of public safety hazards, geological features and cultural heritage values.

This executive summary summarises the findings and recommendations of the investigations. Detailed information on the methods used, analytical results and remediation options analysis are presented within the main report. The findings have been segregated into three sections, those relating to the surface workings (ie: open pits and alluvial workings), those relating to the underground workings (such as shafts and adits) and those relating to the quality of the receiving waters (Tinstone Creek, Waratah River and Arthur River).

The investigation of acid drainage at Mount Bischoff and this resultant report has been undertaken within budgetary and time constraints. As such, the results presented are based only on the available information. The recommendations then, are based on the need for additional assessment to gain a thorough understanding of the site prior to high expenditure on major works. The recommendations also take into consideration the fact that future funding for remediation works on the site may be limited. An additional document has been completed by JMP to discuss recommendations that do not meet the assessment criteria specified in this report.

Primary Mine Discharges

On the information available to date, the primary discharges points are as follows:

- Level 9 adit discharge from the Bischoff Extended workings into Tinstone Creek, a tributary of the Arthur River.
- Unidentified discharges into the Arthur River above its junction with the Waratah River. Possible sources are the old Magnet mine area, old Silver Cliff and Persic mines, deposited tailings in the Arthur River upstream of the Waratah River or other unknown sources.
- Discharges from several adits, including the Stanhope adit and the main tunnel North Entrance adits of Mount Bischoff, into Websters Creek a tributary of the Waratah River.
- General discharges from the southern workings or 'front workings' of Mount Bischoff to tributaries of the Waratah River above its junction with Websters Creek.

- Unidentified inputs to the Waratah River below the 'Gun Club Creek'. Possible sources are the old waste rock deposits of the North Valley workings or old unnamed mine workings (visible on aerial photographs as surface disturbances) sited in the Cliff Creek catchment, a tributary of the lower Waratah River.

Major Pollutants

On the limited database available at this stage, the pollutants of primary importance to the water quality of the Arthur River, Waratah River and Tinstone Creek are listed below.

- Zinc appears to be the primary pollutant with respect to toxicity.
- Copper, arsenic, aluminium and iron appear secondary with respect to toxicity but are also significant.
- Iron, and to a lesser extent, manganese and aluminium, are the primary pollutants from a mass load perspective. However, the total suspended particulate matter in the Arthur River is low and comparable with background levels, suggesting there may be limited impact from the particulate iron, at the time of the investigation.

Surface Workings

- Material with acid producing potential is visible throughout the workings and this is consistent with the geochemical assessment.
- Minimal rainwater ponding was observed on the mine site. Direct ingress to underground workings was evident. Discharge flows from the mine appear consistent with rainfall inputs, however this requires validation.
- Approximate surface areas with the potential for rainfall ingress at each of the individual mining areas are:

  a) Upper Mount Bischoff = 14ha;
  b) Lower Mount Bischoff = 9ha;
  c) Bischoff Extended = 10ha.
- Minimal opportunities were identified to divert worthwhile quantities of clean surface waters from ingress to the mine workings.
- Water quality of the identified discharges approximately correlates to the mineralisation associated with each area.
- Acid neutralising material exists on site but it use appears uneconomic due to access and mine development issues. Geo-conservation values are also usually associated with these areas.
- Discharges from the large area occupied by the North Valley waste rock dumps and tailings into the Waratah River remain unsubstantiated. However, following further investigation the area may have the potential for a strategically located, flat, site wide pollutant collection and treatment area, if required in future.
- The lower level Mount Bischoff surface workings are more amenable to civil remediation works.

- Real and present safety issues are apparent throughout most of the workings.
- Public safety and the safety of people undertaking any approved remediation works is of paramount importance.
- Potential future uses/users and people or organisations undertaking environmental remediation works on the site will need to address the safety issues and associated accountabilities and responsibilities.
- Heritage values and geo-conservation values identified by Morrison (2002) were confirmed, particularly in the upper level workings. Tourism potential also exists throughout the workings.

Underground Workings

- Historic mine drawings and plans indicate extensive and expansive underground workings. These plans do not indicate any evidence of an underground connection between the Mount Bischoff and Bischoff Extended workings.
- Major surface expressions and subsidence from the underground works are evident in both mine areas.
- There are significant acid drainage discharges from both areas.
- Level 9 adit, and to a lesser extent Level 6 adit, appear the major pollutant sources from the Bischoff Extended mine into the Tinstone Creek catchment.
- Stanhope adit and the main tunnel North Entrance adits, as well as several other smaller discharges, appear the major pollutant sources for inputs into Websters Creek and then the Waratah River.
- A more precise and accurate hydrological understanding of the mine areas is needed. This will give a better correlation between rainfall and mass emissions from the workings and impact on receiving waters.
- Safety is the primary concern for any proposed remediation work underground. Of particular concern is the lack of any recent information on the hydro-geological condition and geo-technical stability of the underground mine areas.

Receiving Waters

- Waratah River and Tinstone Creek are the primary receiving water bodies for emissions from the workings. These water bodies flow into the Arthur River.
- Arthur River and Waratah River appear to flow all the year round. Tinstone Creek appears ephemeral in nature, as does its tributaries and the tributaries of the Waratah River.
- Protected Environmental Values for the Arthur River catchment have been established pursuant to the *State Policy on Water Quality Management 1997*. Certain pollutants emitted from the mine workings result in levels exceeding the strictest values and their water quality trigger values in

Tinstone Creek, Waratah River and Arthur River. The strictest values were for the 95% level of protection for modified freshwater aquatic ecosystems, as outlined in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000.

- A site specific reference site could be used instead of the guideline trigger values. The water analyses at site W6 above the Waratah town waterfall was in general compliance with the guidelines anyway, as was Ritchie Creek except for slightly higher aluminium, iron, zinc and sulphate.
- Unless substantial remediation or treatment of the emissions can be implemented, the water quality objectives for the Protected Environmental Values may not be achievable.
- The extent of the impact of the emissions from the mine workings downstream in the Arthur River are unknown and may vary significantly for varying storm events. An approximation using catchment dilution indicates that the water quality objectives in the Arthur River may be approached downstream of its junction with the Hellyer River. The Hellyer River confluence is approximately 18km downstream of the Waratah River confluence.
- It is not possible to accurately determine the reduction in mass emissions, moderation of toxicity or the reduction in environmental impacts from the proposed remediation works. Apart from full remediation or treatment of all discharges, the reduction in environmental impacts is likely to be marginal.
- There is no data to evaluate whether the current mass emissions from the mine workings and associated environmental impact in the Arthur River are naturally moderating or increasing over time since the cessation of operations.
- There is a need to build a scientific database of the chemical, physical and biological details of the catchments to better understand the site emissions and impacts. This data would also assist the proper assessment of any future remediation programs, should funding become available.

Recommendations

- Where possible the remediation options were analysed with respect to safety, cost, potential mass emission reduction, potential environmental impact reduction, heritage / geology / tourism values, applicability, practicality and MRT's "no regrets' philosophy. Due to the lack of information, budgetary constraints and the high cost of major works, no major works can be recommended, at this time. More information is recommended prior to committing to large-scale programs and expenditure.

- While compiling recommendations, Pitt & Sherry have been mindful that any works on the site should comply with the following:
  - Expenditure on individual works should be within the budget for this project and not require ongoing expenditure. A number of recommendations have been made with a view to potential future work on this site should future funding be available.
  - Works should comply with a "no regrets" philosophy as required by MRT. Under such a philosophy, the works should benefit the site in some way, even if the acid drainage load is not reduced. These works should also not result in an increased environmental risk or liability.
  - Works should not jeopardise future land use and expectations
  - Works should not compromise the current retention lease over the area
  - Works should improve site safety
  - Works should assist the environment to naturally moderate pollution
  - Works should not alter the current hydrological balance prevailing in the area as this could disrupt natural pollutant attenuation currently occurring or increase discharges to the receiving waters at times of low flow
  - Works will not jeopardise the implementation of future developing pollution treatment technologies

- Recommendations at this stage involve several minor earthworks and structural works programs that will make the site safer and amenable to future programs and include the following:
  - Encapsulation of the sulphidic dumps at Happy Valley area.
  - Addition of crushed limestone to Happy Valley area.
  - Optimising the passive remediation occurring at current detention ponds at the front of the mine works (Old Allen's Workings).
  - Upgrade the current passive treatment of the 'Gun Club Creek' discharge.
  - Upgrade the access to the 'Gun Club Creek' area and foot track to Websters Creek.
  - Educational / tourist information area and boards at front workings.
  - Water and flow monitoring of selected sites to be implemented.
  - Fencing and grates around easily accessible shafts and adits.
  - Upgrade of existing car parks with limestone base.
  - Installation of boom gates or equivalent (boulders / berms) at specific access tracks.
  - Removal of rubbish from front area and accessible sites.

- Upgrade vehicle track into Tinstone Creek using normal road gravel. (Strategic access to significant discharge for future actions)
- Upgrade restricted vehicular track from below the Gun Club to the Arthur River / Waratah River confluence.
- Install new foot track to Level 9 adit using limestone. (Strategic monitoring site and future action area)
- Install new foot track from to the confluence of the Tinstone creek and the Arthur River.

These recommendations are summarised for the Riverworks Steering Committee in a consolidated table (Table 9).

Table 9: Summary of Recommendations

Note: This summary table does not include all the detailed information used for the options analysis presented in Appendix I.

Works Option	Potential sites	Indicative Cost*	Net environmental benefit	Potential environmental risk / liability	Site Safety Issues	Geological / mining heritage	Tourism Potential	Practicality (machinery access, safety of works)	No regrets**	Rank
A. Road upgrade /berms/gates/ signs	1. Brown Face road 2. Pig Flat / Happy Valley 3. Level 9 adit footpath from road 4. Gun Club Creek 5. Waratah River 6. Tinstone Creek 7. Footpath from Level 9 adit to Tinstone Creek 8. Front workings	1. $1000 (gate) 2. $20000 (inc. carpark & alkalinity) 3. $3000 (inc. alkalinity) 4. $5000 (inc. alkalinity) 5. $14000 (inc alkalinity) 6. $25000 (road) $8000 (footpath) 7. $9000 (inc alkalinity) 8. $7500 (inc carpark & alkalinity)	Good - Increase access for investigations, designate tracks for use, alkalinity addition.	Low environmental risk.	Will help rectify project safety issues Unknown safety liability re public access	No significant issues identified to date	May increase tourism potential	Practical	✓	1
B. Shaft/Void fill /bund	Brown Face (Morrisons Report)	Up to $20,000 per shaft	Unknown, may decrease water ingress	Moderate due to subsidence risk	Will increase safety	Potential issues particularly on upper workings	N/A	Practical in most cases	✓	NR
C. Adit & shaft cover / grate / fence	Slaughteryard Face (12 sites)	$1900 per shaft (fencing) (approx. 12 required = $22000)	No environmental benefit	Low	Will increase safety	Potential issues, less than filling shafts	May increase tourism potential	Practical in most cases	✓	1
D. Slope stabilisation / ground levelling	Pig Flat / Happy Valley / front area – ground levelling	$27500 inc carpark & alkalinity	Will marginally direct drainage, alkalinity addition	Low	May increase safety	Limited issues	May increase tourism potential	Practical	✓	3
E. Adit plugging and workings flooding	1. Level 9 adit & flood to Level 6 adit 2. Level 9 adit & level 6 adit & flood to Level 5 adit	$20-25,000 per adit	Unknown, plugging alone potentially low - no benefit	Potentially high – plug maintenance, underground stability once flooded	May decrease site safety	Limited issues	N/A	Unknown – needs further assessment and investigation	✗	NYR
F. Underground water diversion	Plug winzes between level 6 and 9.	Was not investigated.	Unknown, diversion alone potentially low - no benefit	Unknown – could be high, maintenance required	Unknown	Depends where water discharges	No potential	Unknown – needs further assessment and investigation	✗	NYR
G. Clean surface water diversion	Desert Face	Was not investigated	Depends on volumes – requires more investigation	Potentially low – need more information on hydrology and mass loads, potential maintenance	Unknown – depends on location and proximity to roads	Depends on location	No potential	Access to Desert Face could be difficult & dangerous	✗	NYR
H. Contaminated surface water diversion	1. Upgrade existing Gun Club Creek diversion 2. Websters Creek to Waratah ponds 3. Discharge from level 6 or 9 adit	1. $500 if soft, $1500 if hard 2. $100,000/2km for armoured drain 3. $100,000/2km for armoured drain	Unknown, diversion alone potentially low - no benefit	Potential for risk – depends on effect of altering hydrology and mass loads, design criteria, potential maintenance	Unknown – depends on location and proximity to roads	Depends on location	No potential	Unknown – requires further investigation	✗	NYR
I. Material encapsulation	Happy Valley Face	$ 3000 if soft $12000 if hard	Good – should remove a small pollution source	Low	Low to none	Depends on location	No potential	Practical	✗	2
J. Revegetation (possible trial with *Restio*)	Gossan / Greisen Face Main Entrance / Happy Valley	$5000 for trial	Good – should minimise erosion	Low to none	Low to none	Depends on location	Potential to increase tourism – clean up of site	Practical	✓	3
K. Passive alkalinity addition (see also road works)	1. Stanhope Face 2. White Face 3. Pig Flat / Happy Valley 4. Desert Face	1. $20000 2. $20000 3. $20 000 4. $20000	Good – should enter waterways and increase acid buffering	Low to none – potential for maintenance or additional alkalinity	Could be improving access safety	Depends on location	No potential	Practical	✗	2

Works Option	Potential sites	Indicative Cost*	Net environmental benefit	Potential environmental risk / liability	Site Safety Issues	Geological / mining heritage	Tourism Potential	Practicality (machinery access, safety of works)	No regrets**	Rank
L. Aerobic detention ponds	1. Happy Valley Face 2. Main entrance adit 3. Gun club area	1. $500 if soft, $4500 if hard 2. $500 if soft, $4500 if hard 3. Unknown	Unknown – requires additional investigation	Potential to increase contaminant loads at low flow times	Muddy / wet conditions	None known	No potential	Practical if can dispose of existing iron precipitate	✕	4
M. Active treatment	Waratah River ponds (Gun Club area)	Full treatment plant = $M's HALT, SAP, ALD trial $20000+ plus maintenance	Potentially high	Potentially high (large store of contaminants)	Operating equipment and maintenance	None known	No potential	Requires further investigation	✕	NYR
N. Monitoring	1. Monthly regime at 5 points 2. Bimonthly regime 3. Quarterly regime 4. Biota assessment 5. Toxicity assessment	1. $28000 per yr (not including tracks) 2. $14000 3. $7000 4. $15000 5. $15000	N/A – would increase site understanding	None	None	N/A	No potential	Practical – would aid further assessment into other remediation options. Access to some areas difficult	✓	1
O. Rubbish collection	Commonwealth Building	$1000	Good	None	None	None known	Clean up of site	Practical	✓	1
P. Weed Control	Front workings	$5000	Good	Introduction of chemicals to the site	Chemical use	N/A	Clean up of site	Practical	✓	3
Q. Educational / informative notice boards	1. Main entrance adit 2. Various other places	1 & 2 combined. $5000	N/A – would increase AMD and environmental awareness	None	Potential liability arising from attracting visitors to site	May increase heritage awareness	May increase tourism potential	Practical	✓	2

* see Table 4, Appendix I for more detailed costing

** Does the proposed works benefit the site, regardless of whether the acid discharge from the site is ameliorated.

NYR = Not Yet Recommended. Further work / investigation is necessary to assess the cost / benefits of this option.

NR = Not recommended (this option is not recommended when compared to option C)

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	Name	Signature	Date
Authorised by:	**Dr Ian Woodward**		**24 January 2003**

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- Derek Sutton - (Waratah resident) - electronic mining heritage records and local knowledge
- Peter Fahey – (Waratah resident) - rainfall information.

GLOSSARY & ABBREVIATIONS

AFR	Acid Forming Rock
ANC	Acid Neutralising Capacity – quantifies the ability of the host rock to buffer or neutralise the acid.
BOM	Bureau of Meteorology
DPIWE	Department of Primary Industries, Water and Environment
GPS	Global Positioning System
H_2SO_4	Sulphuric acid
JMP	John Miedecke & Partners Tasmania Pty Ltd
LUPAA	*Land Use and Planning Approvals Act 1993*
Mount Bischoff	refers to the surface and underground workings of the Mount Bischoff Tin Mining Company. These workings are generally located to the east of the topographical Mount Bischoff and are associated with the significant surface workings.
MRD	*Mineral Resources and Development Act 1995*
MRT	Mineral Resources Tasmania
Bischoff Extended	refers to the primarily underground workings of the Bischoff Extended Mining Company. These workings are generally to the west of the topographical Mount Bischoff.
NAFR	Non-Acid Forming Rock
NAPP	Net Acid Producing Potential – the theoretical balance between the capacity to generate acid and the capacity to neutralise any acid that is produced.
PAFR	Potentially Acid Forming Rock
PEV	Protected Environmental Values
WHSA	Workplace Health and Safety Act 1995.

1 Introduction

Mineral Resources Tasmania (MRT) has received funding from the Riverworks Program to undertake remediation works at Mount Bischoff.

A joint venture consisting of Pitt & Sherry and John Miedecke & Partners (JMP) has been commissioned by MRT to undertake site investigations and develop a prioritised program of works to address the acid mine drainage issue at Mount Bischoff. Mount Bischoff is located directly north of the township of Waratah and was the site of the first major mineral resource to be developed in western Tasmania.

Acid drainage from this site is a concern as the site is located within the Arthur River catchment. The Arthur River is one of the states largest wild rivers and the catchment encompasses large areas of wilderness with high state and national conservation status.

The Mount Bischoff investigation incorporates both fieldwork and assessment of previous studies conducted at the site.

The objectives of this investigation and report are to:

- Identify and quantify the principal sources of acid drainage and metal contamination to the Arthur River
- Recommend rehabilitation works to minimise the acid and metal loads discharging into receiving waters
- Identify hazards to public safety and recommend precautionary actions
- Identify geological features and cultural heritage items for protection

This report summarises the findings of the initial scientific study of the site and assesses the various remediation and management options.

It must be noted that, due to time and budgetary constraints, this report is not a complete scientific study of the site. Also, again due to time and budgetary constraints, the recommendations made for rehabilitation and pollution reduction are based on relatively inexpensive works that will provide a definite benefit, based on the limited knowledge gained during this assessment. The recommended works also comply with the specified selection criteria related to budget and the 'no regrets' philosophy (Section 7). An additional report compiled by JMP discusses possible remediation works that are outside these criteria.

2 Background

2.1 Geology

The geology of the Mount Bischoff area, discussed by Morrison (2002), is briefly summarised below:

- The regional geology comprises Late Proterozoic to Cambrian relatively unmetamorphosed siltstone, sandstone, shale and dolomite.

- These metasediments have been locally intruded by Devonian granitic dykes and partially covered by Tertiary basalt.

- Mineralisation, controlled by the granitic dykes, has three styles:
  - Stratiform replacement of dolomite horizons
  - Altered porphyry dykes
  - Mineralised fractures and fault fissures

- The majority of high sulphide ore is dolomite replacement style

- Dolomite replacement ore bodies are the major source of acid mine drainage.

The detailed geology of the Mount Bischoff area, including the regional setting, is contained in Groves *et al* (1972), and the St Valentines map sheet report, Tasmania Department of Mines (1989).

The Mount Bischoff tin deposit is discussed in detail by Halley (1987), Halley and Walshe (1995), and Solomon & Groves (2000).

2.2 Mining History

The history of mining in the Mount Bischoff area has been summarised by Groves *et al* (1972). The following summary is largely based on that report.

1871: James "Philosopher" Smith discovers tin in Tinstone Creek.

1873: Mount Bischoff Tin Mining Company floated.

1873 – 1880: Development phase: sluicing works started and were later compensated with two jigs and two small battery stampers. A 40-head battery stamper was installed in 1880. A small plant was built on Mount Bischoff itself but, due to low tin recovery, was closed when the Ringtail plant was commissioned in 1883. The primary mine areas during this time were the Brown, White and Slaughteryard faces. By 1875 trial shafts were being sunk and a tramway was established. In 1879 the underground workings were commissioned with an adit with a self-acting incline, and the first shaft was sunk.

In 1878 the West Bischoff Mining Company was floated to exploit the western slopes.

1881 – 1886: Expansion of the ore dressing stage: a steam locomotive replaced horses for transporting ore from the mine. Sluicing was discontinued in 1893 as material amenable to that technology ran out. In its largest phase, up to 32 sluices were running on Mount Bischoff in 1886. In 1884 a jaw crusher was installed in the mine. Slime sheds to treat jig tailings were built, and the Ringtail tailings treatment plant was built and replaced the existing small plant. In 1884 electricity replaced kerosene lamps. Work commenced on another tailing treatment plant. The Waratah mill was upgraded.

By 1881 the West Bischoff Mining Company had a treatment plant, water wheel and a 15 head battery stamper. By 1882 the treatment plant was treating oxidised pyritic ore. In 1885 the company was in financial trouble and tributers[1] were operating the plant.

1887 – 1907: 1888 saw the first record of productive underground mining. Ore treatment now consisted of crushers, the Waratah mill with battery stampers and slime sheds to retreat battery tailings, the Ringtail Plant to treat sluice and Waratah Mill tailings, the Catch'em Plant to retreat Ringtail Plant tailings (only operated until 1895) and the North Valley Mill built to handle sulphide ore (burnt down in 1906). In 1893 sluicing was largely discontinued with the ore being hauled directly to the battery. The production of the mine started to decline markedly in this period. A hydro-electric station was built adjacent to the operation in 1905.

In 1907 the Bischoff Extended Tin Mining Company was formed, operating a steam driven plant and working the western underground area.

1908 – 1914: This time period saw experimental work undertaken, aimed at treating low grade and pyritic ores. The mill was modified to use Card and Wifley tables (vibrating screens) and pyrite concentrates were roasted in a furnace. The main tunnel through Mount Bischoff was completed allowing an economic ore pass from the overhead workings. During this time stopes and the like were backfilled with mullock to retard the spontaneous combustion from the marcasite component of the ore. An aerial ropeway was constructed between the main Mount Bischoff area and North Valley.

The mine closed in 1914 and was reopened on a cooperative basis a few months later. The cooperative basis lasted until 1915, when the company took over the operation again.

[1] Individuals operating for personal gain, not on behalf of the company.

1915 – 1927: The southern slopes of Mount Bischoff continued to be the primary source for production during this period, albeit at a decreased rate. Almost all remaining ore was sulphidic. To deal with the increased sulphur content, two roasters were built between 1921 and 1925. A new treatment plant was built in 1925 to treat the calcine. The North Valley operation ceased in 1920 when the aerial ropeway was destroyed in a bushfire. The mine was a marginal operation during this time.

1928-1947: The company commenced work on the alluvial material within the Waratah River until the operations ceased in 1929. Mining continued to be carried out by tributers while the company operated the calciners and calcine concentrating plant. Tributors installed small batteries in the open cut area and the North Alluvial Face. In 1937, a large flood destroyed a large amount of the alluvial workings.

In 1942, the Commonwealth acquired the mine to provide tin for the war effort. The mine was finally closed in 1947. The associated power plant was scrapped in 1950. Various small mining operations have occurred on Mount Bischoff since 1947.

2.3 Acid Mine Drainage

Acid mine drainage is caused when pyritic material within the rock is exposed to oxygen. The oxidation of the pyrites causes an excess of hydrogen to be formed, resulting in acidic water. As metals are more available in acidic conditions, acid mine drainage water often has high metal concentrations also.

The generally accepted chemical equations behind acid mine drainage have been well referenced[2] and are as follows:

(Equation 1) $2FeS_2 + 2H_2O + 7O_2 \rightarrow 2Fe^{2+} + 4SO_4 + 4H^+$

(Equation 2) $4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$

(Equation 3) $4Fe^{3+} + 12H_2O \rightarrow 4Fe(OH)_3 + 12H^+$

(Equation 4) $FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$

Equation 1: The initial step where pyrite (FeS_2) reacts with water to form ferrous iron, sulphate and acid.

Equation 2: Ferrous iron (Fe^{2+}) is converted to ferric iron (Fe^{3+}).

[2] US Department of the Interior – Office of Surface Mining (Updated 3/5/2002) Factors Controlling Acid Mine Drainage Formation (www.osmre.gov/amdform.html)

Equation 3: Ferric iron is hydrolysed to form solid ferric hydroxide, with the release of additional acid. This equation is pH dependent: at less than pH 3.5 no precipitate is formed and the ferric iron remains in solution, while at pH greater than 3.5 a yellow/brown precipitate commonly known as “Yellow Boy” is formed.

Equation 4: Essentially a beginning of the cycle again with the ferric iron created in the previous three equations now oxidising additional pyrite. This cycle continues until conditions are no longer conducive to acid production, for example when all pyrite has been oxidised.

Factors that can affect the production of acid in the natural environment include:

- Presence of oxygen
- Microbiological controls
- Depositional environment
- Presence of natural alkalinity in the form of carbonates or silicates.

Once acid is being produced, many chemical factors such as pH and temperature, as well as the rate of rainfall infiltration, material permeability, transport mechanisms for the water and exposure of the pyrites to oxygen can affect the rate of production.

2.4 Previous Site Investigation

The following site specific or site relevant surveys have been carried out:

- Tasmanian Acid Drainage Reconnaissance Report 1 *Acid Drainage from Abandoned Mines in Tasmania*, Tasmanian Geological Survey Record 2001/05 (2001)
- *Mount Bischoff Mine Remediation Project, Inception Report and Work Plan*, John Miedecke & Partners (2002)
- *Mineral Resources Tasmania Mount Bischoff Mine Remediation Project, Geology Report,* K C Morrison Pty Ltd (2002)
- Geochemistry analysis resulting from samples taken during the Morrison (2002) study.

These findings of these reports are summarised in the following sections.

2.4.1 Tasmanian Acid Drainage Reconnaissance Report 1

A localised acid mine drainage investigation conducted by Dr Shivaraj Gurung found that:

- There was continuous discharge of high acid / high metal / high sulphate waters from the main Mount Bischoff entrance adit, resulting in the accumulation of oxidised sediments enriched with toxic levels of metals at exposed sites above the headwaters of the Waratah River.
- The mineralised carbonate host rock has typical NAPP[3] values of over 450 kg H_2SO_4/t.
- The available ANC[4] of 116 kg H_2SO_4/t is either insufficient or too restricted to neutralise the high amount of acid being generated.
- The high concentrations of tin, copper, lead and zinc in the mineralised host rock can be progressively leached by surface waters that drain into Waratah River.
- Base flow transportation of metals downstream may have minimal impact.
- The mass flux[5] of metal-laden mine waste sediments during 50 or 100 year flood events can seriously impact on the ecosystem of the receiving environment.

2.4.2 Mount Bischoff Mine Remediation Project, Inception Report and Work Plan

The main conclusions of this report were:

- Significant acid generation is an ongoing process at Mount Bischoff.
- The occurrence of significant quantities of unoxidised iron sulphides over the surface of the disturbed area indicates that a significant proportion of the sulphides are likely to be relatively unreactive.
- Tinstone Creek and Waratah River are significantly contaminated with aluminium, iron, manganese and zinc.
- Tinstone Creek contributed and continues to contribute environmentally significant loads and concentrations of aluminium, iron, manganese and zinc to the Arthur River.

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[3] Net acid producing potential - the theoretical balance between the capacity to generate acid and the capacity to neutralise any acid that is produced.
[4] Acid neutralising capacity – quantifies the ability of the host rock to buffer or neutralise the acid.
[5] In this report, this term refers to the total amount of a pollutant - calculated from flows and water samples to result in a mass flux of kilograms per day

- Significant loads of iron and aluminium, in flocculated hydroxide forms, are present in the Arthur River below Tinstone Creek; these are deposited in the river and may have significant effects on aquatic fauna habitat.
- The concentrations of metals decrease downstream, from the Waratah River junction, in the Arthur River.
- The Level 9 adit was identified as the primary source of acid mine drainage into Tinstone Creek.

2.4.3 Mineral Resources Tasmania Mount Bischoff Mine Remediation Project, Geology Report

The major conclusions of this report were:

- The main historic workings occur on three topographic levels ranging from approx 630 – 700m RL[6].
- The lower and middle levels comprise mainly sulphidic rock materials with high acid generating potential, have low mining heritage and geo-conservation values and are well suited to landscaping and rehabilitation.
- The upper level has a low proportion of sulphidic rock, most of the high quality mining heritage and tin geology sites, excellent potential for development as a field education and tourism asset and some sites requiring public safety barriers.
- The site has several dangerous open shafts and several sources of major acid drainage.
- There are some outcrops of acid-reactive dolomite around the workings but they do not represent a significant source of neutralising material.
- Crushed Gordon Limestone from Lynchford, near Queenstown, appears to be the optimum source of acid neutralising material.
- Substantial quantities of basalt, clay and weathered rock are available from private land in the Waratah area; a deposit of siltstone soil and clean regolith, at the southern end of the workings, is suitable for quarrying and use in remediation.
- Contamination by broom, gorse and blackberry seed will be an issue for most soils locally sourced.

[6] A height datum relative to sea level.

2.4.4 Mineral Resources Tasmania Mount Bischoff Mine Remediation Project, Geochemical Analyses

Fifty five rock chip samples were taken as part of the above geological investigation (**2.4.3**) and fifty four samples were analysed for:

- pH (1:5 paste[7], 10g/50mL)
- conductivity (1:5 paste, 10g/50mL)
- percentage sulphur
- metals (cobalt, arsenic, bismuth, gallium, zinc, tungsten, copper, nickel, tin and lead)
- ANC
- NAPP.

The sample site locations are shown in Figure 1 and the analytical results, summarised in Section 4.1.8, are included in full in Appendix A.

2.5 Legislative Framework

The following legislation is applicable to any current or future activity on the Mount Bischoff mine workings:

- *Forest Practices Act 1985*
- *Forestry Act 1920*
- *Mineral Resources Development Act 1995 (MRDA)*
- *Land Use Planning and Approvals Act 1993 (LUPAA)*
- *Environmental Management and Pollution Control Act 1994 (EMPCA)*
- *State Policy on Water Quality Management 1997*
- *Workplace Health and Safety Act 1995 (WHSA).*

This legislation generally has associated regulations, which are also applicable.

Any works undertaken on the land must have the approval of the landowner, which in this case is Forestry Tasmania. The works are predominantly on land classed as State Forest, hence Forestry Tasmania is custodian of the land.

Mineral Resources Tasmania (MRT) is the custodian of all minerals on the workings. MRT has issued a Retention Licence to a private mining company and that company also has rights in the area. Any other person(s) accessing and moving minerals on or from the workings should have approval of MRT pursuant to the MRDA.

[7] 1:5 soil water mix.

Any activity proposed on the workings will require approval from the local planning authority. In this case it is the Waratah / Wynyard Council. The proposed works on the mine site will require approval in accordance with the LUPAA and the local planning scheme.

All current and future use of, and works on, the land must be in accordance with the WHSA.

2.6 Tasmanian Policy on Water Quality Management

As mentioned, the Arthur River is one of the states largest wild rivers and its catchment encompasses areas of high state and national conservation value. Apart from forestry, there is limited human impact within the catchment, with the Mount Bischoff mine being one of the more significant areas of disturbance. Remediation and/or reduction of the pollution from this area will enhance an already significant natural asset of the State.

To aid the protection of the State's surface water resources, the Department of Primary Industries, Water and Environment, (DPIWE), have established Protected Environmental Values (PEVs) for the rivers and creeks around the historic Mount Bischoff mine, in accordance with the State Policy on Water Quality Management 1997.

The PEVs are outlined in Table 3 of the Arthur River catchment section of DPIWE, 'Environmental Management Goals for Tasmanian Surface Waters, Catchments within the Circular Head & Waratah / Wynyard Municipal Areas' January 2000.

Based on the land tenure and the fact that most of the Arthur River waters in the area flow through or originate in State Forest, the following PEVs apply to the Arthur River and Tinstone Creek.

'A: Protection of Aquatic Ecosystems

(ii) Protection of modified (not pristine) ecosystems

a. from which edible fish are harvested;

having regard for the Forestry Tasmania's 'Management Decision Classification System'.

B: Recreational Water Quality & Aesthetics

(i) Primary contact water quality

(ii) Secondary contact water quality

(iii) Aesthetic water quality

That is, at a minimum, water quality management strategies should seek to provide water of a physical and chemical nature to support a modified, but healthy aquatic ecosystem from which edible fish may be harvested (and) which will allow people to safely engage in recreational activities such as swimming, kayaking, paddling or fishing in aesthetically pleasing waters....'.

However, separate PEVs apply for the Waratah River downstream of the historic Mount Bischoff workings. They are basically the same as the Arthur River PEVs outlined above but exclude primary contact water quality.

For the Waratah River, the DPIWE Environmental Management Goals document also states:

'That is, as a minimum, water quality management strategies for down stream of the Mount Bischoff mine to the confluence with the Arthur River should seek to provide water of a physical and chemical nature to support the modified aquatic ecosystem, from which edible fish are not harvested; which will allow people to safely engage in recreation activities such as prospecting in aesthetically pleasing waters'.

There are no separate Tinstone Creek PEVs to those prescribed for the Arthur River, probably because the condition of, and impacts on, the creek were not fully appreciated until recently. However, the PEVs in Table 3 have a foot note which states:

'Historic mining activities or other historic land uses may have resulted in long term water quality impacts to some streams or rivers within these reserve classes and to their associated ecosystems. This may mean that the water quality in these rivers or streams may not currently support pristine or near pristine ecosystems or primary contact recreational activities. This should be taken into consideration at the time that management decisions are being made for individual rivers or streams. Water quality data is not currently available for most surface waters in these areas'.

The National Water Quality Management Strategy, Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2000, identifies trigger values for the protection of aquatic ecosystems, which are the strictest guideline values for the most stringent PEV (protection of aquatic ecosystems). These trigger values are presented and discussed in Section 5.6.

3 Methodology

3.1 Desktop Assessment

All available relevant literature, MRT mine plans and drawings, topographic maps, orthophotomaps and aerial photos were examined for the desktop assessment. Visible surface disturbances, tentatively identified as adits and surface workings, were identified on the orthophoto maps and aerial photographs and compared with available mine plans. Potential water ingress and discharge areas were also identified.

A field investigation plan was developed on the basis of these observations (Appendix B). The field plan aimed to cover all areas of interest in the limited time available while providing a sound scientific data baseline suitable for future comparison. It was acknowledged, however, that any water data collected in the field would represent a 'snap shot' of the site at that particular time in those particular conditions.

3.2 Field Investigation

The field investigations were undertaken between the 4th and 7th of November 2002, the following people being on site for some or all of the time as part of this investigation:

- Jim Lockley – Pitt & Sherry
- Michael Pollington – Pitt & Sherry
- Kim Ferguson – Pitt & Sherry
- Aniela Grun – Pitt & Sherry
- John Miedecke – JMP
- Ken Morrison – KC Morrison Pty Ltd
- Wojciech Grun – MRT
- Tony Webster – MRT
- Greg Dickens – MRT
- Daniel Ray – DPIWE.

The people involved split into various work groups over the period of the site investigation to evaluate the identified issues/aspects with a view to addressing the specific objectives of the project. The following aspects were investigated:

- Mine disturbance
- Water quality
- Potential water ingress areas
- Potential water egress areas (specifically adits)
- Potential drainage channels
- Nature and extent of surface water pooling
- Safety aspects of the site
- Heritage values (mining and geological)
- Educational values (particularly geological)
- Tourism potential (including access for mineral collectors / fossickers).

Water quality in rivers and creeks in the vicinity of the mine (Waratah River, Tinstone Creek and the Arthur River) as well as any tributaries of these in the region was investigated. Areas where there was obvious and visible contamination entering the larger rivers were identified and sampling was undertaken above and below these points.

In order to ensure that a mass balance of contamination could be established in the waterways surrounding the mine, at each location:

- A Hydrolab®[8] was used to gain an immediate understanding of the water quality
- GPS[9] coordinates were obtained
- Water samples were taken
- A stream gauging and flow measurement was undertaken with a water flow meter[10] to measure the flow rate and water volume.

Visual inspection of the site was undertaken where feasible to:

- Determine the extent of mining disturbance
- Assess areas of potential water ingress
- Identify areas of geological (including educational) significance
- Identify areas of mining heritage significance
- Assess the significance of potential drainage channels

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[8] Hydrolab® Minisonde Water Quality Mulitprobe & Surveyor 4 Logger (Supplier: Aqualab Scientific Pty Ltd)

[9] GPS 12 Personal Navigator™ (Supplier: Garmin)

[10] Water flow Meter G.O. Environmental 1295 Northwest 163rd Street Miami Florida USA (Supplier: Enviroquip)

- Identify and assess water ponding areas
- Identify possible safety risks
- Identify aspects/areas of tourism potential.

Water samples were taken at any areas of significant water seepage / drainage from mine workings. GPS readings were taken at all areas of significant interest.

4 Results

The field investigation areas have been divided into three sections:

- Surface workings
- Underground workings (surface expressions of)
- Receiving waters.

These sites were investigated and water samples were taken where appropriate.

4.1 Surface Workings

The surface workings of Mount Bischoff can be conveniently divided into two primary areas (Morrison 2002):

- An upper level where the workings are predominately of high heritage value and low acid producing geology.
- A lower level predominately of low heritage value and high acid producing geology.

Both these areas have undergone extensive mining activity and are significantly degraded. The landforms that remain are steep, potentially dangerous, open to the weather and have negligible vegetation.

The field sheets completed during the surface workings investigations are presented in Appendix C.

4.1.1 Upper Surface Workings – Mount Bischoff

The upper level of the surface workings of Mount Bischoff consists of the Brown Face, Stanhope Face, Slaughteryard Face and Desert Face (Figure 2 and Plates A-E).

Table 1: Key observations for the upper level surface workings

	Acid Generation Potential*	Safety issues	Heritage values	Drainage	Other
Brown Face	High Acid Potential . Substantial dolomite outcrop nearby	Open stopes visible in bottom of pit but access very difficult. Road very close to steep faces, requires barrier.	High. Large pit on dolomite ore. Mining Equipment.	No visible pooling in the bottom of the pit even after heavy rain. Assume infiltration	Potential for tourist lookout over pit and over Waratah River valley
Stanhope Face	Low Acid Generating Potential	Damming of water – drowning risk – some possible shafts/ subsidence in areas.	High. Old stone walls for sluicing dams. Hexagonal, timber framed shaft. Colourful geology. Quarry in porphyry dyke.	Water pools in dam, not overtopping even after heavy rain. No obvious drainage lines.	Potential for tourist attraction
Slaughteryard Face	High Acid Potential	Large void covered by some large boulders, requires better filling. Some shafts require capping, grating, filling or fencing	High. Old magazine nearby. Stope with wooden 'toms' (supports). Fossicking area.		Ideal spot for viewing Brown Face – but safety issues. Graffiti on rock face requires removal
Desert Face	Low acid generation potential			Would drain to Brown Face catchment	Access difficult, limited vegetation growth

* Observed through presence of sulphidic rock and/or iron staining / drainage.

4.1.2 Lower Surface Workings – Mount Bischoff

The lower section of the Mount Bischoff workings consists of Gossan Face, Greisen Face, White Face, Pig Flat, Allen's Workings and Happy Valley Face (Figure 2 and Plates E-I).

Table 2: Key observations on the lower level surface workings

	Acid Generation Potential*	Safety issues	Heritage values	Drainage	Other
Gossan Face	High Acid potential		Low.	Drain down to the front of the workings and surface drainage joins the main adit drainage. Ultimately drains to Happy Valley.	Could be landscaped to form free draining natural landform. Some natural revegetation in the area.
Greisen Face	High Acid Potential. Rock samples also indicate high potential to generate Arsenic and Tin. Dolomite nearby.	Open Stopes	Open Stopes in dolomite	Drain down to the front of the workings and surface drainage joins the main adit drainage. Ultimately drains to Happy Valley.	Could be landscaped to form free draining natural landform. Some natural revegetation in the area.
White Face	High Acid Generating Potential. Rock samples also indicate high potential to generate Arsenic.		Low.	Drains into Happy Valley workings that then drain to Happy Valley over Kenworthy Road.	
Pig Flat	High Acid Potential. Rock samples also indicate high potential to generate Arsenic and Tin.	Some adits in the general area, none particularly well defined		Very flat area, generally drains surface water toward font of workings	Potential for carpark – tourist area. Some natural revegetation in the area.
Allen's Workings	High Acid Potential. Significant dolomite resource.	Open trenches, and ponds and Adits.	Low.	Major Acid Drainage to Happy Valley Face	
Happy Valley Face	Some areas of pyritic material stockpiled.	Steep slopes on the southern side of Kenworthy operation.	Generally Low. Small locally built mill nearby.	Drains to Happy Valley over Kenworthy Road	

* Observed through presence of sulphidic rock and/or iron staining / drainage.

4.1.3 Surface Water and Catchments

In general, it is evident that minimal water ponding or pooling occurs on the mine site during rainfall events. Incident rainfall ingress is basically directly into the mine through open workings and fractured ground, active subsidence being observed in several areas. JMP has observed rainfall flowing to underground workings via shafts, stopes and fractures in the surface workings.

There is a small water storage dam, with possible heritage value, at the top of the works, above Brown Face, but this appears to have minimal impact on the hydrology of the workings.

The surface workings area is divided basically into three catchments.

The first catchment is that of Brown Face. Any incident water captured within the Brown Face open pit area infiltrates through the underground workings at the bottom of the face. The Brown Face catchment also receives some surface water drainage from Desert Face.

The second catchment is the surface runoff from the remainder of the upper level workings and the majority of the lower level surface workings after large rain events and the adit drainage from the main front adits, which joins near the access road and enters Happy Valley from the south side of the Valley.

The third catchment consists of the surface drainage from White Face and Happy Valley Face that joins and flows into Happy Valley over Kenworthy Road. This drainage includes surface runoff from stockpiles of pyritic material.

The retention time of rainfall within the individual and overall underground workings is unknown. However, during the field investigation, it appeared that the drainage flows from the lower level Mount Bischoff surface workings dropped substantially within a short time period (1 day) after the cessation of rain. Likewise, there is anecdotal evidence that drainage flow increases substantially shortly after rainfall.

The retention time in the Mount Bischoff Extended mine is unknown at this time.

4.1.4 Waste Rock

No significant waste rock dumps were identified in the surface workings area.

Several small scree slopes and waste rock dumps were documented around the Bischoff Extended workings, North Valley and Happy Valley workings.

4.1.5 Tailings / Concentrate

Two small tailings/concentrate dumps were identified. One is located directly below the old Kenworthy Mill and the other on the floor under the White Face workings.

Both dumps appear to contain significant amounts of disseminated pyrite and therefore have the potential to produce acid drainage.

4.1.6 Exposed Slopes

Most of the slopes around the works are greater than the natural slope of the surroundings (approximately 20^{o}). Mining areas have faces steepened dramatically in most areas and present a challenge in relation to access and rehabilitation.

The higher workings appear to contain little pyrite but the lower workings have significant pyrite distributed across the old working faces.

4.1.7 Surface Area of Workings

The upper workings of the Mount Bischoff mine are approximately 450m x 300m with an area of approximately 13.5ha.

The lower workings of the Mount Bischoff mine are approximately 350m x 250m with an area of 8.8ha.

The area for potential rainfall ingress into the underground Bischoff Extended mine is approximately 10ha.

The total disturbed area of Mount Bischoff mine (excluding the Bischoff Extended workings) is approximately 22.3ha (0.26% of the overall Arthur River catchment area above the Waratah River junction). Given the steep terrain, access difficulties and safety issues, rehabilitation of the works may be limited to the more readily accessible areas of little mining heritage values.

Assuming that an average 8mm/day of rain fell on the above area before the investigation, at equal intensity for each area and that the workings were hydraulically loaded, then the following discharge totals could be expected:

- 12.5L/s from the upper Mount Bischoff workings
- 8L/s from the lower Mount Bischoff workings
- 9L/s from the Bischoff Extended workings.

The above indicative flows are not inconsistent with the flows observed around the site. Level 9 adit flow from the Bischoff Extended mine on the 5/11/02 was approximately 25L/s. This may have included a large amount of groundwater inputs external to the actual incident rainfall ingress area, given that the adit is approximately 100m to 150m below these workings or it could suggest a connection between the workings, although this is not confirmed.

4.1.8 Mineralogy

The site investigation of the exposed workings confirmed Morrison's (2002) view that the upper area contains little acid forming material. However, the exposed faces of the lower workings contain significant amounts of acid producing minerals.

Some acid neutralising material is present on the site. It appears to be a limited resource and may be uneconomic to utilise.

Some clay or low permeability material suitable for encapsulation of acidic material is present on the mine site but it appears to be difficult to access and of limited quantity.

A small area of siltstone soil and regolith occurs on the edge of the access road, between the Allen's Workings and the Don Hill Workings. Significant quantities of basalt soil, clay and weathered rock occur on privately owned land on the outskirts of Waratah.

Pitt & Sherry's interpretation of the geochemical analyses results (Section 2.4.4) are as follows:

- 11 samples had a paste pH value of less than 4.
- 6 samples had a paste conductivity value of more than 1000μS/cm, with only one sample having a value above 2000μS/cm.
- Approximately 32% of the rocks sampled are acid-forming (AFR) with another 46% being potentially acid-forming (PAFR). Only 12% can be classified as non-acid forming (NAFR).
- Some rock material is a potential source of high levels of arsenic, tin and lead and to a lesser extent copper and zinc.
- Rock material is unlikely to be a significant source of nickel and cobalt.
- High levels of metals are predominantly associated with the AFR and PAFR rocks.
- High NAPP values are potentially associated with gossan and sulphidic materials, and to a lesser extent with quartz porphyry, quartzite and slate.
- A total of 21 out of 54 samples exceed the DPIWE, Information Bulletin No.105, Classification and Management of Contaminated Soil for Disposal, September 2002, Level 3 contaminated soil criteria for at least one metal. Of these 21 samples, the Level 3 criteria are exceeded for arsenic in 12 samples, tin in 14 samples and lead in 3 samples (refer Table 3 below for a comparison summary).

Table 3: Rock sample metal contamination level comparison to DPIWE soil criteria (number of samples falling within each contamination level out of the total 54 samples)

Metal	Level 1 Fill Material	Level 2 Low Level Contaminated Soil	Level 3 Contaminated Soil	Contaminated soil for remediation
Tin	14	18	8	14
Arsenic	10	22	10	12
Lead	43	7	1	3
Zinc	46	18	-	-
Copper	42	12	-	-
Nickel	54	-	-	-
Cobalt	54	-	-	-
Based on DPIWE's 'Classification & Management of Contaminated Soil for Disposal, September 2002'				

4.1.9 North Valley Waste Dumps

To the north of Mount Bischoff lying adjacent the Waratah River banks are extensive deposits of mining and, possibly, mineral processing waste dumps.

The dumps extend from Websters Creek in the south to the junction of the Arthur River to the north.

The dump areas are approximately 2 km in length and in some locations up to 250m in width.

It was not possible to determine the approximate volume of material that forms the dumps or their contents. Mining activity occurred in this area up to the 1990s.

The hydrology of the area is not known. It is possible that the Waratah River is running close to its original course. However, groundwater and/or Waratah River waters may flow through the dumps.

The pollution flux from this area is not known but an attempt to quantify this input is undertaken later in the document.

Several possibly constructed water ponds exist at the Cliff Creek junction. These ponds may have been used in historic operations and have some heritage value.

More work needs to be done on the dumps to quantify the amount and their contents and chemical properties if their true relation to the water quality in the area is to be confirmed.

At present it appears as if Cliff Creek runs into the dumps and the ponds may be hydraulically connected to it and offering some moderation in the quality and flow of Cliff Creek waters.

4.2 Underground Workings

The Mount Bischoff and Bischoff Extended mining areas consist of a large amount of underground workings that intersect the surface as adits, glory holes, shafts and the like in a variety of locations in the project area.

Old mine plans and drawings were supplied by MRT for the desktop assessment of the investigation. The plans indicated extensive underground mine developments and interconnections for individual areas, but did not indicate a connection between the Bischoff workings and the Bischoff Extended workings (selected maps presented in Appendix J).

Field investigations were concentrated on surface expressions of the underground workings identified in the desktop assessment. In particular, those seen as potentially contributing significant acid mine drainage to the Waratah River or Tinstone Creek or as potential pathways for water ingress into the underground workings were targeted.

Field observations confirmed most of the information contained in the MRT drawings and plans. Field sheets for the underground workings observations are included in Appendix C. Field investigation sites are displayed in Figure 3 and Plates J-S. Water sample analysis results are presented in Appendix D.

Table 4: Key observations of underground workings

Site	Safety issues	Heritage value	Drainage	Other
Level 9 Adit MW1	Not easily accessed. Very steep track part of the way.	Various heritage sites including dumps, chimneys and tramway.	Flows into Tinstone Creek. Build up of iron precipitate below the adit and along creek. pH 3.1. High metal levels, particularly arsenic, zinc, iron and manganese.	Lowest level of the Bischoff Extended workings. Little workings between level 9 and level 6. Possibly put in as drainage or ore pass.
Level 6 Adit (not on figure – not accessed during field investigations)	Not easily accessed. Track established.	Significant heritage site.		Lowest level of the actual workings of Bischoff Extended.
Stanhope Adit ('Brown Face Adit', Queen Workings) MW2	Very difficult to access by foot – steep & heavily vegetated ground		Visible staining from adit down small valley – Websters Creek. pH 2.4. High metal levels, particularly arsenic, iron, copper and zinc.	Machinery access would be extremely difficult if possible at all.

Site	Safety issues	Heritage value	Drainage	Other
North Entrance Adit(s) (‘North Face Adits’) MW3, MW4	Very difficult to access by foot – steep & heavily vegetated ground	Main adit is a well formed timber supported adit	Two adits, upper and lower. Both have visible iron staining but not significant amounts. pH 2.3 – 2.6. High metal levels, particularly arsenic, iron, copper, zinc and lead	Machinery access would be extremely difficult if possible at all.
‘Happy Valley Adit” MW8	Not easy to access from Kenworthy road – down scree slope		pH 2.9. High metal levels, particularly arsenic, copper, iron, manganese and zinc. Drains to Happy Valley. Not previously seen flowing.	Visible from Kenworthy Road – very visible staining
White Face Adit MW16	Easy to access – track already established	Could be Adit No. 1.	Drains down slope to Kenworthy Road – ultimately to Happy Valley. pH 2.1. High metal levels, particularly arsenic, zinc, copper, iron and manganese.	Potentially draining from White Face surface catchment. A second adit is downhill to the south east. Inaccessible.
Main Entrance Adit	Easy to access – unsure on stability inside. Large pool of water and drainage could cause slip / drown hazards		Draining down to front of all workings, pools in large pool that apparently dries up in summer and down to Happy Valley. Visible iron staining around adit and water deep orange/brown colour.	Probably be the Main tunnel entrance for the Mount Bischoff main tunnel ore pass
Unknown Adit MW12	Accessible.	Adit and mullock heap	Ponding at adit. No evidence of scouring due to outflows. pH 4.4. Slightly elevated iron.	
Subsidence BE6, BE8, BE9			Sites of mine subsidence were located that could be ingress points	
Bischoff Tramway BE17	Tramway is overgrown. Significant drop off if cleared.	Dry stone walls up to 20 metres high to access the Wheal workings.		Good views looking North over the Waratah River.

There is also another small adit off Kenworthy Road that daylights after approximately 30m. This adit is easy to access and dry and could provide potential for tourist access.

With the exception of Level 6 Adit and Level 9 Adit, the remaining adits located on the Bischoff Extended workings only had evidence of low flows or seeps. There are a few sites where underground workings may have subsided.

Three distinct types of algae were frequently observed growing in surface water seeps and acidic drainage water. These species could possibly indicate acid water conditions and/or the presence of certain metals.

The most significant heritage feature appears to be the Bischoff Tramway on the north facing slopes of Mount Bischoff.

4.3 Receiving Waters

The receiving waters of primary interest around the historic Mount Bischoff mine workings are:

- Arthur River
- Waratah River
- Tinstone Creek.

The field sheet observations are included in Appendix C and sample sites are displayed on Figure 3 and Plates U-Z. Water analysis results for these samples are presented in Appendix D.

The Arthur River appears to flow all year round. Several small catchment dams exist upstream but may not significantly affect the overall river hydrology. It is likely that the Arthur River catchment in this area has substantial groundwater inputs. The main pollutant inputs to the Arthur River from the Mount Bischoff mine appear to be via the Waratah River and Tinstone Creek tributaries.

The old Silver Cliff and Persic mines, located approximately 1.5 kilometres to the north west of Mount Bischoff appear to drain primarily to the Arthur River catchment also.

The Waratah River has several major water storage facilities upstream of the Waratah Falls in the Waratah township, which could significantly alter or moderate the river flow patterns. The river appears to flow all year round and has adjacent small catchment ponds in the lower reaches possibly associated with historic mining methods in the area. These historic mining methods could have altered the course of the river over many years. Groundwater inputs to this river could also be significant. Waratah River is a major receiving water for the mine emissions.

Websters Creek is one of several drainage lines that report to the Waratah River. It appears to carry a major portion of the mine emissions to the Waratah River's North Valley area. It appears ephemeral in nature.

An unnamed tributary, called "Gun Club Creek" for this report, enters the Waratah River between Websters Creek and the Gun Club. The water does not visibly appear to be highly contaminated and has some rudimentary diversion and treatment ponds on its lower reaches.

Several unnamed ephemeral drainage lines are apparent, running into the Waratah River below the township. One of interest is at the southern end or 'front' of the workings and drains this important area into the Happy Valley end of the Waratah. There are other surface disturbances visible in the area that would also drain to the Waratah River catchment.

Tinstone Creek may be ephemeral in nature and contains some small catchment ponds remnant from historic mining activity in the creek. Groundwater would represent a substantial input to this smaller catchment. It is a primary receiving water for the mine emissions.

Ritchie Creek is a major tributary of Tinstone Creek, which was inadvertently included in the field study. Field data from Ritchie Creek can be used as a future background water body for the area.

Table 5: Key issues of receiving waters

Location	Safety	Heritage	Drainage	Other
Websters Creek	Difficult access		This creek appears to be collecting drainage from the Stanhope and North Entrance adits – flows directly to Waratah River	
Gun Club Creek	Good access from Gun Club			Rudimentary diversion and treatment works in the lower reaches
Waratah River	Good access in lower reaches. Difficult in upper reaches.	Evident in certain areas.	Waratah River visibly deteriorated after Websters Creek junction (precipitate and Hydrolab® results)	Flow dropped by 20% between 5^{th}(raining) &6^{th}(dry). Highs flows are evident.
Ritchie Creek	Difficult to access		Major Tinstone Creek downstream tributary	This creek was initially thought to be Arthur River – not visibly contaminated.

Location	Safety	Heritage	Drainage	Other
Tinstone Creek	Difficult to access. Steep track constructed part of the way.	Old tramway route. Evidence of old alluvial workings to Ritchie Creek.	Tinstone Creek visibly deteriorated in terms of quality after Adit 9 (precipitate and Hydrolab® results)	Flows dropped as rainfall eased.
Arthur River	Good access to Waratah Confluence. Difficult to access to Tinstone and Magnet junctions		River flow dropped by 20% between 5th (raining) and 6th (dry)	High flows evident

4.4 Catchment Details

Catchment details are delineated in Figure 4, which shows that the Arthur River catchment area to its confluence with the Waratah River is 8489 ha.

Of this, 4420 ha or 52% is above the Tinstone Creek catchment and above the Waratah River catchment; however, it includes the Magnet River catchment.

The whole Tinstone Creek catchment is 876 ha or 10% of the Arthur River catchment area to the junction with the Waratah River and includes the Ritchie Creek catchment of 630 ha or 7%. The section of the Tinstone Creek catchment impacted by emissions from Bischoff is 246 ha or 3%, which excludes the Ritchie Creek.

The whole Waratah River catchment is 3193 ha or 38% of the Arthur River catchment to the confluence with the Waratah River. Of this catchment approximately half (19% of the Arthur River Catchment) is below the Waratah township with approximately half (19% of the Arthur River Catchment) above. The large reservoirs and dams above the township may affect the flows in the Waratah River.

Based on catchment areas and all things being equal the flow ratio of the Arthur River to the Waratah River at their confluence would be 5296:3193 or approximately 1.7:1. Flow measurements on the 5/11/02 and the 6/11/02 indicated 2.2:1. Flow measurements taken on the 2/10/01 indicate a 1.2:1 ratio.

The differing topography, groundwater inputs, vegetation, slopes, reservoirs, catchment locations and rainfall patterns could explain the differences.

The catchment response times or the time for individual catchments to reach maximum flows at the confluence of the Arthur River and Waratah River from an intense storm event are as follows:

- 6.6 hours for the Arthur River (to the Waratah River junction)
- 1.1 hours for the entire Tinstone Creek catchment
- 4.8 hours for the entire Waratah River catchment (provided minimal interference from reservoir storages).

This may not be of importance for long storm events with low rainfall intensities where the pollutant fluxes from the mine are likely to be synchronised with receiving water flows.

However, in short intense storm events, pollutant fluxes may not match the receiving waters hydrology (both in the response time and/or drainage time). Higher pollutant concentrations or fluxes may occur into receiving waters other than those documented in this report, particularly after a long dry spell in which pollutant loads have accumulated in the mine.

The response time of mine discharges to certain storm events are not known. Runoff from the surface workings in the southern end of the mine may occur within an hour or more. The deeper underground workings may have a discharge response time of several hours to a day or more, depending on the water ingress pathways, mine condition and state of collapse, groundwater inputs and hanging wall and foot wall rock fracturing or permeability.

Of interest, the catchment for the Hellyer and Wandle Rivers is approximately 565 square kilometres. This equates to approximately a seven-fold dilution of the Arthur River below its confluence with these rivers. This confluence is approximately 18 kilometres from the Waratah River junction. This dilution could significantly improve water quality.

Ideally, a database of catchment water quality over a substantial period of time with varying weather conditions and river flow rates would assist in a more accurate determination of appropriate remediation options and their effectiveness.

4.5 Rainfall Data

Rainfall data, both historic and up to and including the site investigation is contained in Appendix E.

These data include Bureau of Meteorology (BOM) data for Waratah and Savage River as well as locally collected rainfall figures.

Savage River data is referenced as the nearest location with Pan A evaporation data and for extrapolating Waratah rainfall in the absence of recent recording at the Waratah station. Personal communication with the BOM officers advised that, as a general rule of thumb, Waratah rainfall is approximately 10 to 15% higher than Savage River rainfall.

The readings from a private domestic station were also referenced for comparison. The private residence gauge indicated that 39mm of rain fell in the 5 days preceding the site investigation (Day ending (8am) 1/11/02 to 6/11/02). The BOM data show that 49mm fell at Savage River and therefore a reading at Waratah in the order of 53 to 56mm could be expected.

This basically indicates that in the lead up to the site investigation approximately 50mm of rain occurred at an average of 8 to 9mm/day, compared to the BOM Waratah monthly average for November of 167.8mm or 5 to 6mm/day. This is slightly above the November average and equivalent to June and July average daily rainfall rates.

Thus, the rainfall and the river flows and emission pattern monitored during the site investigation were more typical of an average winter pattern (June to August historically average 242mm per month[11], equivalent to approximately 8mm per day).

4.6 Hydrolab® Results

The Hydrolab® was used during the site investigation to assist in identification of surface waters and emissions that required further investigation or sampling for analyses.

The results are contained in Appendix F.

Comparison of the Hydrolab® field results with the laboratory results for pH and conductivity indicate a reasonable agreement. Some difference in the field recordings and the laboratory results is to be expected due to the time to get samples to the laboratory, maturation of the sample during this period and chemical composition and stability of the samples. These differences are discussed in Section 5.2.

All water samples were stored in Eskis® with ice packs up to submission to the laboratories.

The longest period of time from sampling to submission to the laboratory was 3 days.

[11] BOM Waratah Weather Station data

4.7 Analytical Results

The analytical results from water samples taken during the site investigation are contained in Appendix D.

The purpose of the water sampling was to compare surface water quality with appropriate guidelines and standards. The analyses are also required, along with flow rates, to establish mass fluxes from the mine and in catchment surface waters. This information can assist in the identification and prioritisation of potential remediation action plans.

The results indicate that clean surface waters have low conductivity, alkalinity, water hardness and therefore buffering capacity. Indicative of clean background waters in the area is sample WR6 (Waratah River at the town waterfall), and possibly Ritchie Creek sample (AR1).

The analytical results for the mine discharges and receiving waters are typical of acid mine drainage emissions and their impact on ambient water quality. This is characterised by low pH and alkalinity values and high concentrations of iron, sulphate, acidity, conductivity, aluminium and other heavy metals associated with the ore body or mineral waste.

No neutralisation curves for the neutralisation of certain samples were undertaken due to laboratory advice that the samples neutralise quickly and little change in pH occurred over time.

4.8 Flow rates

Flow rates were determined using a standard stream gauging methodology and water flow meter. For small adit emissions flow was directed through a pipe and flow was then measured with a bucket and stopwatch.

Flow data is contained in the field sheets (Appendix C) for mine drainage flows and Appendix G for the flow meter measurements.

The flow data are required to develop mass flows and mass balances around the mine site.

A rudimentary calibration of the flow meter was undertaken after the site investigation and for flows above 0.2m/s was found to be within ±5% accuracy, considered acceptable for the purposes of this investigation. Nearly all the flow measurements taken during the investigation were above 0.2m/s.

5 Discussion

5.1 Rainfall Data

The rainfall data is presented in Section 4.5 and Appendix E. The private data and extrapolated BOM Savage River data and BOM monthly average for the months proceeding the site monitoring are as follows:

October: Private = 141mm, Waratah (extrapolated from BOM Savage River 209 x 1.1) = 230mm, BOM Waratah October average = 204mm.

September: Private = 315mm, Waratah (extrapolated from BOM Savage River 336 x 1.1) = 370mm, BOM Waratah September average = 225mm.

The above indicates that October rains may have been around average while September was above average and that no sustained dry spells preceded the site investigation.

The annual rainfall average for Waratah is 2186mm, compared to an annual average Pan A evaporation of 910mm. However, it is the potential extreme weather patterns that can prevail during summer that may significantly alter emissions and river flow patterns and therefore alter impacts on the Arthur River, in the December to May period each year. A collation of possible Waratah summer weather scenarios follows:

- Highest monthly rainfall 300mm
- Mean monthly rainfall 100mm
- Mean monthly evaporation 150mm
- Lowest monthly rainfall 5mm
- Highest recorded daily rainfall 90mm

From June to November each year rainfall patterns, on average, would result in relatively constant flushing of mobile pollutants from the mine to typical receiving water flows.

5.2 Hydrolab® Results

As mentioned in Section 4.6, comparison of the Hydrolab® field results with the laboratory results for pH and conductivity indicated a reasonable agreement.

High temperature of the discharge from the Bischoff Extended Level 9 adit, annotated as TCAD1, was recorded (approximately 19°C compared to approximately 10°C ambient water temperature. This is indicative of active exothermic oxidation of the sulphides in the higher areas of the abandoned mine's mineralised workings with relatively poor air circulation and good insulation.

This is also consistent with the comments in Groves *et al* (1972), which state in part that the ore body in the Bischoff Extended mine was primarily pyritic with massive sulphides and that foul air was problematic for the mine. Expensive airshafts had to be installed for the mine to remain in operation on several occasions.

The higher temperatures recorded for surface water testing on the 7/11/02 is indicative of the prevailing ambient air conditions.

Low dissolved oxygen values recorded for the Level 9 Adit and Happy Valley adit are indicative of the anoxic environment in the mine workings, enhanced by the removal of oxygen through the oxidation of sulphur and iron.

5.3 Analytical Results

The analytical results from water samples taken during the site investigation are contained in Appendix D and discussed in Section 4.7.

As mentioned, the analytical results for the mine discharges and receiving waters are characterised by low pH and alkalinity values and high concentrations of iron, sulphate, acidity, conductivity and aluminium, all indicative of acid mine drainage emissions.

Partial neutralisation may be apparent in some of the water analyses results. The North Entrance upper adit, Stanhope adit, Level 9 adit, Adit Site 27, Front waterfall and pond, Happy Valley adit, Happy Valley main drain, and White Face adit drain all show elevated calcium and/or magnesium concentrations.

This may have resulted from the interaction of acidic waters with dolomite in the ore body or located in the drainage pathway. The presence of calcium and magnesium in mine waters roughly correlates with the location of dolomite on the site.

The heavy metals analyses indicate that a significant proportion of the total metals are dissolved (or <0.45μm particulate). This may mean the metals are present in the more toxic speciations and are more bioavailable.

Analytical results show that the most significant concentrations in discharge waters are at the Bischoff Extended Adit 9 (TCAD1) discharge into Tinstone Creek and the Front Workings and drainage and Websters Creek discharge into the Waratah River.

Mineral Resources Tasmania requested that rubidium analyses be conducted on representative water samples from the site.

The Level 9 Adit (TCAD1) discharge rubidium concentration was 75.8 ug/L.

Gun Club Creek (WEB1) concentration was 5.4 ug/L.

Websters Creek (KIM 1) concentration was 37.3ug/L.

5.4 Mineralogy

Evaluation of the data shows that significant mineralisation extends across the entire mine site.

Different mineralisation in the various locations demonstrates varying effects on the quality of surface water runoff.

Rock types with low paste pH and conductivity invariably have high acid producing potential and heavy metals associated with the sulphides in the ore. The paste conductivity, however, was relatively low.

There was an approximate correlation between the surface rock samples and water quality in the area of the rocks sampled.

The elevated copper, lead, tin, zinc and arsenic in surface rocks from the front workings such as Allen’s workings, Greisen Face, North East Lodes, Pig Flat, Queen workings, Waratah River (North Valley) Tailings and White Face may account for the high levels in the Waratah Rver, Websters Creek and Waratah River above Websters Creek.

The lowest paste pH was from White Face. The highest paste conductivity was from Greisen Face. The highest NAPP rock was from White Face. The lowest NAPP and highest paste pH was from Allen’s workings. The highest arsenic sample was from the Queen workings (northern entrance) area. The highest zinc sample was from the Allen’s workings and White Face areas. The highest tin was from the Pig Flat. The highest lead was from the White Face. The highest copper was from the White Face area.

5.5 Emission Evaluation

Flux emissions of certain substances from individual discharge locations were calculated using the flow measurements and water sample analysis results. These flux emissions were then used to calculate mass loading into the receiving waters.

The analytical data summary and flux analyses are contained in Appendix H.

A summary of the data follows:

Between the 5/11/02 and 6/11/02 the Arthur River and Waratah River flows dropped by approximately 20%. However, the ratios of the respective flows stayed at approximately 2.2:1. On the 2/10/01 the ratio was 1.2:1.

For certain pollutants such as arsenic, sulphate and acidity and to a lesser extent aluminium and copper, a difference in hydrology resulted in changes in the percentage fluxes of individual pollutants from different areas compared to the total fluxes for Arthur River below the confluence with the Waratah River. Yet for other parameters such as iron, manganese and zinc, a surprisingly similar flux occurred on each of the three days regardless of flow changes. There also appears to be some natural attenuation of pollutants in Tinstone Creek, explaining the reduction of pollutants between the Level 9 adit discharge and Tinstone Creek downstream. More monitoring would be required to get a better understanding of the relationships.

The following table summarises the percentage flux emission data contained in Appendix H and this information is also illustrated in Figure 6. In this table, the percentage figure indicates the percentage of each substance from individual points or locations compared to the total mass emission for that substance for the entire Mount Bischoff site. For example, 27% of the aluminium load for the entire site is discharged from Level 9 adit.

Table 6: Indicative percentage emissions to the Arthur River below the Waratah River

Site	**Aluminium** %	**Arsenic** %	**Copper** %	**Iron** %	**Manganese** %	**Zinc** %	**Sulphate** %
Date 2/10/01*							
Level 9 Adit	27	41	4	63	48	39	31
Tinstone Creek below Level 9 Adit (TC2)	39	34	6	57	60	40	39
Arthur River above Waratah River (AR2)	49	36	6	45	75	87	75
Waratah River above Arthur River confluence (WR1)	51	64	94	55	25	13	25
Unaccounted for input	**10-22**	**0-2**	**0-2**	**0**	**15-27**	**47**	**36-44**
Site	**Aluminium** %	**Arsenic** %	**Copper** %	**Iron** %	**Manganese** %	**Zinc** %	**Sulphate** %
Date 5/11/02							
Level 9 Adit	19	71	3	67	57	34	90
Tinstone Creek below Level 9 Adit (TC2)	17	64	7	41	38	23	100
Arthur River above Waratah River (AR2)	65	54	10	54	76	88	33
Waratah River above Arthur River confluence (WR1)	34	46	90	46	24	12	67
Unaccounted for input	**48**	**0**	**3-7**	**0-13**	**19-38**	**54-65**	**0**

Site Date 6/11/02	Aluminium %	Arsenic %	Copper %	Iron %	Manganese %	Zinc %	Sulphate %
Waratah River above Websters Creek (WR3)	15	15	10	18	10	4	18
Websters Creek (KIM1)	9	34	53	25	1	5	67
Gun Club Creek (WEB1)	2	1	5	1	1	0	20
Waratah River above Arthur River (WR5)	35	67	87	50	25	13	46
Arthur River above Waratah River (AR2)	65	33	13	50	75	87	54
Unaccounted for input	**9**	**17**	**19**	**6**	**13**	**4**	**0**

* This data has been calculated from the Mediecke report (2002)

These results are discussed in the following sections.

Acidity

There appears little correlation from the results between acidity and flows for the three days. However, it appears from the data for 5/11/02 and 6/11/02 that remnant percentage acidity due to the Waratah River inputs varied from 86% to 55%.

Sulphate

There also appears to be little correlation between the sulphate and flow results for the three days. Data from 5 and 6/11/02 indicate that sulphate inputs to the Waratah River varied from 68% to 46%.

This may be due to variations in the ability of any available neutralising capacity to take effect during certain flow regimes in existence at the time of monitoring.

Tinstone Creek

It was difficult to identify a correlation between the Level 9 adit emissions and Tinstone Creek downstream. However, in general it appears that the majority of pollution in Tinstone Creek originates from the Level 9 adit.

Aluminium

There was approximately 65% of the aluminium originating from the Arthur River above Waratah River, with 35% from the Waratah River for the 5/11 and 6/11. This differs with the 50/50 observed on the 2/10/01.

Of interest is the apparent unaccountable aluminium of approximately 48%, which may be coming from another source like Magnet Creek.

It should be noted, however, that aluminium might be ubiquitous in the environment, which may affect the mass balances. Two sampling locations thought to be representative background levels in the area are Ritchie Creek (AR1) and the Waratah River upstream (WR6). These background sites showed aluminium levels of 325 µg/L and 49 µg/L respectively. These are compared with the measured ambient levels in the Waratah River (WR5) of 422 µg/L and 360 µg/L in the Arthur River, both downstream of the mine emissions. The downstream results are consistent with the Ritchie Creek levels, but significantly above the Waratah upstream levels.

Also apparent in the Waratah River is that approximately 15% originates from above the Websters Creek, where the most likely source is the Stanhope adit and main tunnel North Entrance adits. The North Entrance adits are a surface expression of the Mount Bischoff underground main tunnel that is approximately 750m long and potentially connects all the underground workings in this area (mine plans in Appendix J).

Approximately 9% is originating below the Gun Club Creek input. This could be from the tailings deposited around the creek.

<u>Arsenic</u>

Arsenic inputs to the river system appear to vary with flows.

At the higher flow approximately 54% was in the Arthur River while approximately 46% was in the Waratah River. On the days of lower flows these values are approximately 65% and 35% respectively.

On the 5/11/02 and 2/10/01, Tinstone appeared to account for most of the arsenic in the Arthur River. In the Waratah River on the 6/11/02, Websters Creek was the main source at approximately 34% of total while above Websters Creek was approximately 15%. Unaccounted was approximately17% possibly originating from the old tailings deposited below the Gun Club.

<u>Copper</u>

Copper fluxes were relatively constant over the three days in the data set.

Approximately 90% originates in the Waratah River with approximately 10% from Arthur River above Waratah River.

Tinstone Creek appears to account for most of the copper in the Arthur River above Waratah River, while Websters Creek accounts for 60% of the Waratah River or approximately 53% of the total.

10% of the mine emissions appear to originate from above the Websters Creek while an unaccounted 19% may originate from the tailings in the Waratah River below the Gun Club.

Iron

In general, approximately 50/50 represents the split of the iron emissions to the Arthur River from Tinstone Creek and the Waratah River, from the data to date.

There appears little iron input from the Magnet Creek, as the Tinstone Creek accounts for the iron in Arthur River above Waratah River.

Websters Creek and the Waratah River above Websters Creek account for all iron except approximately 6% which originates below the Gun Club.

Manganese

75% of the total manganese in the Arthur River below Waratah River is in the Arthur River above Waratah River and 25% is from the Waratah River, for the three days in the data set.

Tinstone Creek appears to contribute 38% to 60% of the total manganese flux in the Arthur River. It does not, however, appear to account for the total manganese in the Arthur River above the Waratah River and approximately 15% to 38% may originate from another source possibly the Magnet Creek.

In the Waratah River, approximately 12% comes from above the Gun Club Creek while 13% is unaccounted for, possibly from the tailings in the Waratah River below the Gun Club.

Zinc

From the three days of data available the zinc emissions appear to be distributed consistently at approximately 88% in the Arthur River above the Waratah River and 12% in the Waratah River above Arthur River, for the different flows recorded.

Tinstone Creek appears to account for approximately 23% to 40% of the total zinc, which leaves approximately 48% to 65% from another source that is likely to be the Magnet Creek. The historic Silver Cliff and Persic mines appear to be in the Cliff Creek catchment to the Waratah River.

The 12% total zinc originating in the Waratah River catchment appears to be sourced equally from above Websters Creek, Websters Creek itself and below the Gun Club.

Realisation of Metal Values

The dedicated discharge fluxes and Arthur River totals are summarised below:

Table 7: Discharge fluxes and Arthur River totals

Sites	Al kg/d	As kg/d	Cu kg/d	Fe kg/d	Mn kg/d	Zn kg/d	Acid t/d	SO_4 t/d
Level 9 adit (TCAD1) 2/10/01	25.4	0.8	0.3	335.3	17.0	19.7	0.9	2.2
Level 9 adit (TCAD1) 5/11/02	53.5	5.3	0.3	858.8	41.5	47.8	1.9	7.5
Waratah River above Websters Creek (WR3)	32.8	0.9	0.9	172.4	5.7	3.9	0.2	0.8
Websters Creek (KIM1)	18.2	2.0	4.6	243.0	0.8	4.7	1.0	3.1
Total 2/10/01	93.0	1.9	7.2	533.5	35.3	50.8	0.8	7.0
Total 5/11/02	275.6	7.5	9.7	1289	73.4	140.2	3.5	8.4
Total 6/11/02	215.6	5.9	8.7	956	56.1	103.2	3.3	4.7

There appear to be no metal flux quantities of commercial value for potential cost recovery for possible water treatment options.

The acid flux quantities vary greatly between this investigation and previous investigations. Nevertheless, quantities in the order of 3 tonne of acid per day are significant and comparable to other large acid drainage sites of concern in the state.

Most treatment options would require neutralisation or at least partial neutralisation of this acid load for metal removal from aqueous discharges to proceed as well as the associated storage and disposal of the by-products of the treatment process.

5.6 Water Analysis Comparison to PEVs

This section discusses how the receiving water sample results compare to the PEVs set for the Arthur River. The results are compared in Table 8 and bold figures indicate where the guideline values are exceeded.

Table 8: Comparison of ANZEC guidelines with site results (ANZEC Guidelines as required by the DPIWE PEVs)

Site	pH	μS/cm	Al (μg/L)	As (μg/L)	Cd (μg/L)	Co (μg/L)	Cr (μg/L)	Cu (μg/L)	Fe (μg/L)	Mn (μg/L)	Ni (μg/L)	Pb (μg/L)	Zn (μg/L)
Guidelines for 95% protection	**>6.5**	**90**	**55**	**13**	**0.2**	**ID***	**1**	**1.4**	**ID***	**1900**	**11**	**3.4**	**8**
Arthur River 5/11/02	**6.3**	70	**360**	8	**1**	<1	**2**	**2**	1390	111	3	<5	**244**
Arthur River 6/11/02	**6.0**	70	**362**	<5	**1**	<1	**2**	**3**	1240	109	3	<5	**233**
Waratah River 5/11/02	**4.4**	**91**	**433**	**16**	**1**	1	<1	**40**	2710	80	3	<5	**79**
Waratah River 6/11/02	**4.5**	82	**217**	6	<1	<1	<1	**6**	1140	38	<1	<5	**26**
Tinstone Creek 5/11/02	**3.1**	**600**	**3500**	**367**	**12**	11	<1	**49**	40800	**2120**	**16**	**29**	**2500**

*ID = Insufficient data to derive trigger value hence there is no numerical guideline
NB: Al = aluminium, As = arsenic, Cd = cadmium, Co = cobalt, Cr = chromium, Cu = copper, Fe = iron, Mn = manganese, Ni = nickel, Pb = lead, Zn = zinc

As can be seen in Table 8, at the times of sampling, the water quality of the Arthur River above the Waratah River confluence was over the 95% protection guidelines for zinc (approx. 30 fold) and aluminium (approx. 6 fold). As previously mentioned however, aluminium appears to be naturally present in relatively high concentrations around the site.

pH was slightly below the guidelines, but is considered normal for West Coast rivers.

At the time of investigation, water quality of the Arthur River immediately downstream of the Waratah River can be extrapolated. Only minor changes to the Arthur River water quality would be expected from the Waratah River inputs. The Waratah River had lower concentrations of zinc, manganese, lead and nickel, similar cadmium concentration, but higher concentrations of iron, copper, arsenic, aluminium, conductivity, sulphate and acidity.

Of the higher metals and other parameters noted in the Waratah River the copper, and to a lesser extent the arsenic, are of importance for water quality downstream in the Arthur River.

At the time of investigation the flow ratio of the Arthur River to the Waratah River was 2.2:1 on the 5/11/02 and 6/11/02. The copper in the Waratah would have raised the copper in the Arthur immediately downstream to 10 times the guideline value.

This impact, however, may change under differing flow regimes and mass emissions from the mine. Further ambient information is necessary and future actions should include addressing this lack of monitoring data.

At the time of sampling, the Waratah River had a low pH of 4.4 and 4.5. It was also over the guidelines for copper by a factor of 30, Zn by a factor of 10, aluminium by a factor of 8 and just over on arsenic.

At the time of sampling, Tinstone Creek did not achieve the guidelines for pH, conductivity, aluminium by 60 fold, arsenic by 28 fold, cadmium by 60 fold, copper by 35 fold, lead by 8 fold, zinc by 300 fold with nickel and manganese being just over.

The water quality for the same sample sites on the Waratah and Arthur Rivers did not vary much from the 5/11/02 to the 6/11/02. The flow during this 24-hour period fell by approximately 20% in each river, following the cessation of rainfall on the evening of the 5/11/02.

Whether the guidelines are applicable to the Arthur River would require toxicity testing and/or biota studies to determine if the speciation of zinc, copper and aluminium are toxic.

Analytical results indicate that a significant proportion of the heavy metals in the Arthur River below Mount Bischoff are dissolved (or less than 0.45μm if particulate) and likely to be toxic or bioavailable. The Arthur River appears to have little dissolved organic carbon, alkalinity or water hardness to moderate toxicity.

Suffice to say that at least an order of magnitude of reduction of the zinc in the Arthur River below Mount Bischoff appears necessary to achieve some improved bio-diversity, on the data available at this time. A reduction in copper and aluminium could also be required but not to the same extent.

A significant amount of the zinc in the Arthur River below Mount Bischoff may be originating from the Magnet mine (50%) which is located to the west of Mount Bischoff on Magnet Creek.

Also, the impact on the Arthur River's water quality downstream of the Waratah River confluence, of 8 million tonnes of gangue (clay and other cilicate materials associated with ore bodies) and possibly 5 million tonnes of tailings from historic mining and mineral processing at Bischoff is not known. The material may have contained sulphides, metals and 30,000 tonnes of metallic tin (refer Groves *et al*, 1972 and Godfrey, 1984).

It should be mentioned that the PEVs generally relate to toxicity levels. While zinc is the primary pollutant from a toxic perspective, iron is the primary pollutant with respect to mass loads. Even so, the total particulate matter in the Arthur River appears low and comparable to background levels (WR6). This indicates that the impact from iron levels in the Arthur River, related to smothering of aquatic systems by iron precipitate, may be minimal. However, this could change with altered hydrological conditions.

6 Potential Remediation Options

The locations that were determined from the investigations to be making the highest contribution to the acid drainage issue at Mount Bischoff were subjected to a remediation options analysis. These sites are presented in Figure 5.

There are a number of factors and a number of options to consider for remediation. These factors for consideration have been broken into four tables, presented and summarised in Appendix I – issues, remediation options, contribution of contamination to the Arthur River and cost of potential remediation options.

Issues that must be considered for each site are:

- Safety for the public as well as the machinery and people conducting the works
- Potential geo-heritage values and whether works will affect these values
- Potential mining heritage values and whether works at the site would affect these values
- Ease of access for machinery conducting the works or ongoing monitoring
- Potential risk to the environment as a result of conducting the works – this could include sedimentation, proximity to waterways and potential to stop contamination from one location but exacerbate emissions from another. There is also a risk of attenuating pollutant discharge into a period where there is potential for increased environmental harm.

Contribution of contamination to the Arthur River is based on the flux analysis and the fact that most of the old working faces are hydraulically linked to the underground workings.

Remediation options that have been considered for each site are listed below. These options include safety issue remediation options as well as acid mine drainage remediation options.

- Upgrade of roads and footpaths such as improving the surface, gates, bunding and erecting appropriate signs
- Filling or bunding hazardous voids
- Improving the safety of shafts and adits through collapse (subsidence), covering, filling, bunding, fencing or grating of the opening
- Ground levelling and slope stabilisation
- Plugging of adits to stop contaminating emissions
- Flooding of underground workings to stop the oxidation of sulphidic materials

- Underground workings water diversion - that is diverting water underground prior to its emission from a particular site. This could be used to divert the water to an emission point that is more accessible or more amenable to remediation options
- Surface drainage diversion to minimise the amount of water that comes into contact with sulphidic materials
- Encapsulation of sulphidic waste rock / materials on the surface workings
- Revegetation and rehabilitation to stabilise areas and improve the visual amenity of the area
- Alkalinity addition to reduce acid loads and modify the speciation of pollutants entering the Arthur River. This could be in the form of a short term addition or a long term addition
- Aerobic detention ponds / wetlands to settle the iron precipitates or moderate the emission rate to the Arthur River
- Other passive treatment systems such as anoxic limestone drains, successive alkalinity producing systems (SAPS) and hydro active limestone treatment (HALT)
- Treatment of discharges to remove pollutants or modify the speciation of those pollutants.

6.1 Detailed Analysis

There are some remediation options that have been discussed in a number of project meetings or that may seem obvious. This section provides a detailed discussion of these options and why they are or are not recommended in this report.

Sealing / plugging of shafts
The approximate cost of sealing or plugging safely accessible shafts may be up to $20,000 per shaft, dependent upon the location.

Advantages
- Potential to reduce water ingress to the underground workings and reduce the fluxes of contaminants entering the receiving environment
- Potential to improve safety on the site.

Disadvantages
- Difficult or dangerous to access
- The potentially large number of shafts interconnecting the workings
- Requires proper design and materials (steel, concrete, clay)
- Clay resource of good quality in the vicinity would require sourcing.
- Water ingress may continue through fractures in the surrounding rock

- Could affect current groundwater levels and may result in a large perched water storage that could lead to ground subsidence as the underground workings approach the surface in most areas
- Heritage values could be affected
- Using heavy equipment around open shafts could be dangerous, especially if using clay in wet conditions
- Sealed holes may be subject to future ground movement and ongoing maintenance could be required
- There are a large number of shafts that would require capping/sealing and the cost may be prohibitive

Assessment – not recommended at this time.

Sealing/plugging of adits

The adit of prime concern from a pollution perspective at Mount Bischoff is Level 9 adit. An approximate cost of $20,000 to $25,000 for these plugs has been estimated. In lieu of plugging Level 9 adit, the shafts connecting level 9 with level 6 may be plugged.

Plugging Level 9 adit or the internal plugging of the underground shafts connecting level 6 and level 9 may divert the underground mine water discharge from the inaccessible Level 9 adit to the more accessible Level 6 adit.

From the available mine plans (Appendix J), flooding to Level 6 will not flood any significant sulphidic workings. Plugging Level 6 adit will flood approximately 1/3 of the underground sulphidic workings, which may result in an emission from Level 5 adit of approximately 2/3 of the current Level 9 adit discharge. This discharge would report to the same catchment as the existing Level 9 adit discharge. The overall percentage drop that could be expected in the Arthur River is approximately 10-15% (assuming that flooding 1/3 of the works will result in a 1/3 pollution reduction). Flooding to Level 4 adit by also plugging Level 5 adit is not feasible due to extensive surface expressions of the underground workings between level 4 and 5. If it were possible to flood to level 4, approximately 50% of the underground workings would be flooded.

The height difference between level 9 and level 6 is approximately 99 metres. The height difference between level 9 and level 5 is over 140 metres. A plug capable of withstanding this head for an acceptable time period would require a thorough study of the location and plug design. The plug design should also be peer reviewed by an independent engineering firm with expertise in this type of works.

Advantages

- Potential removal of a significant discharge of pollutants to Tinstone Creek
- Potential to improve safety.
- May relocate discharge to a more accessible or manageable location.

Disadvantages

- Must be properly assessed, designed and installed
- May result in a head of over 140 metres of water pressure on a plug at Level 9 adit. Plugs at Level 6 adit and the level 6 connecting winzes to workings below would need to be designed to withstand over 40 metres head of water from Level 6 to Level 5
- May result in a discharge from an unidentified point
- May not result in the flooding of any sulphidic ore body hence resultant discharge could have a similar contaminant load
- Mine hydrology is not fully understood hence the result in unpredictable
- May result in hydraulic pressures that the ground cannot hold
- The resultant discharge may impact on sensitive areas (ecological or heritage)
- Accessing the adits may be dangerous or problematic. Accessing and clearing access could cause excess sediment / pollution loads in receiving waters
- May not alter overall site pollutant loads, simply moves it to another location
- On going monitoring and maintenance

Assessment – not recommended at this time.

Mine water treatment

The capital cost of a central treatment plant of the order to treat the acid fluxes in the area would be in the order of millions of dollars. Additionally, the diversion or collection of the primary discharges, the reagents required, operating costs and the contaminated sludge disposal costs would make this option cost prohibitive.

The addition of alkalinity and Comalco 'red mud' or a 'red mud' derivative into the mine workings where accessible (safely) may significant reduce emissions from the workings.

Assessment – not recommended at this time. However, alkalinity additions into the workings and the localised passive treatment of discharges may result in a reduction of mass emissions and less toxic treatment products that can report to the river. A future trial with a Hydro Active Limestone Treatment (HALT) system and Comalco 'red mud' may be appropriate.

Waste rock/tailings encapsulation

The North Valley waste rock dumps are located within the Waratah River valley. The cost of relocation and disposal or encapsulation of these would be prohibitive. Not withstanding this, the contribution of pollution from these dumps is to be confirmed.

There are also identified pyritic waste dumps in the Happy Valley Face area that could be removed and encapsulated. It would cost approximately $10,000 to relocate and encapsulate this material on site.

Advantages

- Long term relocation of known pollutants
- Improvement to downstream water quality
- Removal/encapsulation of unstable waste material from the catchment.
- Materials could be encapsulated on site minimising removal costs.

Disadvantages

- Requires appropriate encapsulation material or disposal.

Assessment – Recommended for Happy Valley Face dumps. Not recommended for the North Valley dumps at this time.

Diversion of discharges

Diversion of discharges to the water ponds adjacent to the Waratah River below the Gun Club would provide a detention time for the discharge. This may result in the settling of some contaminants and the reduction of pollutant loads to the Arthur River.

The approximate cost for surface water diversion is $100,000 for a two kilometre appropriately designed and constructed diversion.

Advantages

- Major discharges would report to a centralised location.
- Potential for future treatment upgrades
- Potential for a significant improvement in water quality in Tinstone Creek, if Level 9 adit can be diverted to Level 5 adit and the Waratah River upstream of the Gun Club, if Webster Creek can be diverted to Gun Club Creek.
- Potential to attenuate discharge loads to a more favourable time period.

Disadvantages

- Cost prohibitive
- Would require significant ground disturbance
- Access to diversion routes is difficult
- Potential disturbance to heritage values in some areas
- Unless appropriate treatment is possible, a similar pollutant flux would report to the Arthur River but via the lower reaches of the Waratah River instead of Tinstone Creek and/or the upper reaches of the Waratah River
- The volume of the existing ponds is unknown

- The ponds may presently be assisting with remediation of current pollutant inputs. Any extra input may reduce retention time and reduce current efficiency
- Without treatment, there may not be a net environmental benefit of diversion alone
- The ponds may be hydraulically connected to the Waratah River and have no real pollution reduction value
- There is very limited alkalinity in the lower pond overflow, limiting the benefit of the ponds. For this option to be viable, long term alkalinity addition would be required
- Potential to attenuate discharge loads to a less favourable time period.

Assessment – Not recommended at this time.

7 Evaluation of Options

The priority remediation sites were ranked initially and separated by issues, contamination contribution, practical and applicable remediation options and cost and the ranking's were then consolidated into one table to allow evaluation of options. Appendix I includes the individual tables and the summary table. This summary table was used only as a guide to the best remediation options for each site and the recommendations have been derived from the analysis tables as well as site knowledge and appreciation of the limitations of the funding and each remediation option.

All sites were assessed against all possible remediation options to ensure that an objective and thorough analysis has been conducted.

The evaluation indicates that work on the middle level surface workings (Gossan Face, Pig Flat, White Face, Happy Valley Face) would be the easiest and cheapest. However as these sites potentially contribute approximately 10-20% in terms of contaminant loads, the works may not be particularly cost effective in reducing total contamination loads. The 10-20% contribution is based on the mass fluxes from the Happy Valley and White Face adit drainage, however it is acknowledged that the pollutant contribution of these faces to underground drainage emissions in other areas is unknown at this stage.

8 Recommendations

The recommendations included in this section do not recommend major works. This is due to the limited understanding of the site at this time and the budgetary limitations applying to this remediation program and the lack of funds available for future / ongoing works.

This report identifies the primary emission points of the site but the internal drainage and retention time within the underground workings and the hydrological cycles of the emissions and receiving waters has not been adequately assessed. The works required to contain or treat the primary discharge points would be expensive and could simply move the discharge to a new area. Until further assessment leads to a better understanding of the site, major works are not recommended. Hence, the works recommended in this report are works that will add alkalinity to the site in general as well as improve the safety and understanding of the site.

While compiling recommendations, Pitt & Sherry have been mindful that any works on the site should comply with the following:

- Expenditure on individual works should be within the budget for this project and not require ongoing expenditure. A number of recommendations have been made with a view to potential future work on this site should future funding be available.
- Works should comply with a “no regrets” philosophy as required by MRT. Under such a philosophy; the works should benefit the site in some way, even if the acid drainage load is not reduced. These works should also not result in an increased environmental risk or liability.Works should not jeopardise future land use and expectations
- Works should not compromise the current retention lease over the area
- Works should improve site safety
- Works should assist the environment to naturally moderate pollution
- Works should not alter the current hydrological balance prevailing in the area as this could disrupt natural pollutant attenuation currently occurring or increase discharges to the receiving waters at times of low flow
- Works will not jeopardise the implementation of future developing pollution treatment technologies

Based on the findings and options analysis described in Appendix I, the recommendations (and indicative ±30% costing, refer to Table 4 Appendix I for details) listed below are made. It is intended that these recommendations be implemented either individually or in combinations.

An additional report by JMP discusses remediation options that do not necessarily meet the criteria listed above.

Pollution Reduction

- Remove and encapsulate the sulphide tailings at the Happy Valley Face ($3,000-$12,000)
- Regrade and resurface the Pig Flat and Happy Valley workings area with crushed limestone/dolomite, excluding Gossan outcrops and geological features ($20,000)
- Install detention pond at Happy Valley Face to capture polluted surface water runoff ($500 - $4,500)
- The existing detention pond near the main entrance adit should be upgraded and increased in size ($500 - $4,500)
- Upgrade the existing diversion of the Gun Club Creek upstream of the Gun Club to the existing retention ponds ($500-$1,300). Upgrade the vehicular track reinstated in the area of the Gun Club Creek using crushed limestone/dolomite – this would add alkalinity to the treatment ponds ($5,000).

Educational ($5,000 for both recommendations)

- The main entrance adit area could be made into an educational tourist area with information boards explaining the history of Mount Bischoff and the process of acid mine drainage. There are large amounts of algal growths in the area which could be significant with respect to acid mine drainage research. These growths should be preserved until proper research has been completed
- Install tourism information and education signs.

Monitoring

- Implement a monthly water flow and water quality monitoring regime at the five principal sites – TCAD1, TC2, AR2, WR1 and Websters Creek (KIM1). This should result in information and a database that would underpin the works being conducted at Mount Bischoff ($28,000 per annum including analysis)
- Further site assessment should be conducted at the site to ensure major works can be recommended and designed with appropriate understanding of the site. This work should also include water quality, biota (approx. $15,000) and toxicity testing (approx. $15,000) in the receiving waters.

Revegetation

- A small revegetation trial could also be conducted around the main entrance adit or Happy Valley Face using *Restio tetraphyllus* (Tassel Cord Rush) as this species appears to thrive in acid conditions. This trial could also be important with respect to remediation of acid mine drainage affected areas ($5000)

- Weed control should be implemented on the site, especially where material is being moved around the site or vegetation clearing is being undertaken (eg for any diversion work or road clearing) ($5000).

Safety/Access

Most recommendations in this section also aim to increase the alkalinity on the site to aid pollution remediation.

- Place grates and/or fencing around all the identified safely accessible and dangerous shafts and adits ($1,850 per shaft/adit, approx. 12 hence = $22,000)
- Existing car park areas should be upgraded to proper standards using crushed limestone / dolomite as road sub base and surfacing to aid in neutralisation ($27,500)
- Install boom gates, signage and berms to areas accessible by motor vehicles and off road vehicles ($1000 per site approx. 5 sites hence =$5,000)
- Remove scrap steel from front workings (Commonwealth building) and dispose. Materials of heritage value should be stored in a dedicated area ($1000)
- Upgrade the temporary vehicle tracks to Tinstone Creek to a more stable structure ($25,000)
- Install a foot track from Tinstone Creek to Level 9 adit, constructed of crushed limestone ($3,000)
- Upgrade the temporary access track from the Gun Club to the junction of the Waratah River and Arthur River using crushed limestone/dolomite as the road base ($14,000)
- Install a proper walking track to Tinstone Creek monitoring site (TC2) from Level 9 adit. The track should be constructed with crushed limestone/dolomite ($9,000)
- Install a working track from TC2 to the confluence of Tinstone Creek and the Arthur River.

These recommendations are summarised for the Riverworks Steering Committee in a consolidated table (Table 9).

Table 9: Summary of Recommendations

Note: This summary table does not include all the detailed information used for the options analysis presented in Appendix I.

Works Option	Potential sites	Indicative Cost*	Net environmental benefit	Potential environmental risk / liability	Site Safety Issues	Geological / mining heritage	Tourism Potential	Practicality (machinery access, safety of works)	No regrets **	Rank
A. Road upgrade/berms/ gates/signs	1. Brown Face road 2. Pig Flat / Happy Valley 3. Level 9 adit footpath from road 4. Gun Club Creek 5. Waratah River 6. Tinstone Creek 7. Footpath from Level 9 adit to Tinstone Creek 8. Front workings	1. $1000 (gate) 2. $20000 (inc. carpark & alkalinity) 3. $3000 (inc. alkalinity) 4. $5000 (inc. alkalinity) 5. $14000 (inc alkalinity) 6. $25000 (road) $8000 (footpath) 7. $9000 (inc alkalinity) 8. $7500 (inc carpark & alkalinity)	Good - Increase access for investigations, designate tracks for use, alkalinity addition.	Low environmental risk.	Will help rectify project safety issues Unknown safety liability re public access	No significant issues identified to date	May increase tourism potential	Practical	✓	1
B. Shaft/Void fill/bund	Brown Face (Morrisons Report)	Up to $20,000 per shaft	Unknown, may decrease water ingress	Moderate due to subsidence risk	Will increase safety	Potential issues particularly on upper workings	N/A	Practical in most cases	✓	NR
C. Adit & shaft cover /grate/fence	Slaughteryard Face (12 sites)	$1900 per shaft (fencing) (approx. 12 required = $22000)	No environmental benefit	Low	Will increase safety	Potential issues, less than filling shafts	May increase tourism potential	Practical in most cases	✓	1
D. Slope stabilisation/ground levelling	Pig Flat / Happy Valley / front area – ground levelling	$27500 inc carpark & alkalinity	Will marginally direct drainage, alkalinity addition	Low	May increase safety	Limited issues	May increase tourism potential	Practical	✓	3
E. Adit plugging and workings flooding	1. Level 9 adit & flood to Level 6 adit 2. Level 9 adit & level 6 adit & flood to Level 5 adit	$20-25,000 per adit	Unknown, plugging alone potentially low - no benefit	Potentially high – plug maintenance, underground stability once flooded	May decrease site safety	Limited issues	N/A	Unknown – needs further assessment and investigation	✕	NYR
F. Underground water diversion	Plug winzes between level 6 and 9.	Was not investigated.	Unknown, diversion alone potentially low - no benefit	Unknown – could be high, maintenance required	Unknown	Depends where water discharges	No potential	Unknown – needs further assessment and investigation	✕	NYR
G. Clean surface water diversion	Desert Face	Was not investigated	Depends on volumes – requires more investigation	Potentially low – need more information on hydrology and mass loads, potential maintenance	Unknown – depends on location and proximity to roads	Depends on location	No potential	Access to Desert Face could be difficult & dangerous	✕	NYR
H. Contaminated surface water diversion	1. Upgrade existing Gun Club Creek diversion 2. Websters Creek to Waratah ponds 3. Discharge from level 6 or 9 adit	1. $500 if soft, $1500 if hard 2. $100,000/2km for armoured drain 3. $100,000/2km for armoured drain	Unknown, diversion alone potentially low - no benefit	Potential for risk – depends on effect of altering hydrology and mass loads, design criteria, potential maintenance	Unknown – depends on location and proximity to roads	Depends on location	No potential	Unknown – requires further investigation	✕	NYR
I. Material encapsulation	Happy Valley Face	$ 3000 if soft $12000 if hard	Good – should remove a small pollution source	Low	Low to none	Depends on location	No potential	Practical	✕	2
J. Revegetation (possible trial with *Restio*)	Gossan / Greisen Face Main Entrance / Happy Valley	$5000 for trial	Good – should minimise erosion	Low to none	Low to none	Depends on location	Potential to increase tourism – clean up of site	Practical	✓	3
K. Passive alkalinity addition (see also road works)	1. Stanhope Face 2. White Face 3. Pig Flat / Happy Valley 4. Desert Face	1. $20000 2. $20000 3. $20 000 4. $20000	Good – should enter waterways and increase acid buffering	Low to none – potential for maintenance or additional alkalinity	Could be improving access safety	Depends on location	No potential	Practical	✕	2

Works Option	Potential sites	Indicative Cost*	Net environmental benefit	Potential environmental risk / liability	Site Safety Issues	Geological / mining heritage	Tourism Potential	Practicality (machinery access, safety of works)	No regrets **	Rank
L. Aerobic detention ponds	1. Happy Valley Face 2. Main entrance adit 3. Gun club area	1. $500 if soft, $4500 if hard 2. $500 if soft, $4500 if hard 3. Unknown	Unknown – requires additional investigation	Potential to increase contaminant loads at low flow times	Muddy / wet conditions	None known	No potential	Practical if can dispose of existing iron precipitate	✕	4
M. Active treatment	Waratah River ponds (Gun Club area)	Full treatment plant = $M's HALT, SAP, ALD trial $20000+ plus maintenance	Potentially high	Potentially high (large store of contaminants)	Operating equipment and maintenance	None known	No potential	Requires further investigation	✕	NYR
N. Monitoring	1. Monthly regime at 5 points 2. Bimonthly regime 3. Quarterly regime 4. Biota assessment 5. Toxicity assessment	1. $28000 per yr (not including tracks) 2. $14000 3. $7000 4. $15000 5. $15000	N/A – would increase site understanding	None	None	N/A	No potential	Practical – would aid further assessment into other remediation options. Access to some areas difficult	✓	1
O. Rubbish collection	Commonwealth Building	$1000	Good	None	None	None known	Clean up of site	Practical	✓	1
P. Weed Control	Front workings	$5000	Good	Introduction of chemicals to the site	Chemical use	N/A	Clean up of site	Practical	✓	3
Q. Educational/informative notice boards	1. Main entrance adit 2. Various other places	1 & 2 combined. $5000	N/A – would increase AMD and environmental awareness	None	Potential liability arising from attracting visitors to site	May increase heritage awareness	May increase tourism potential	Practical	✓	2

* see Table 4, Appendix I for more detailed costing
** Does the proposed works benefit the site, regardless of whether the acid discharge from the site is ameliorated.
NYR = Not Yet Recommended. Further work / investigation is necessary to assess the cost / benefits of this option.
NR = Not recommended (this option is not recommended when compared to option C)

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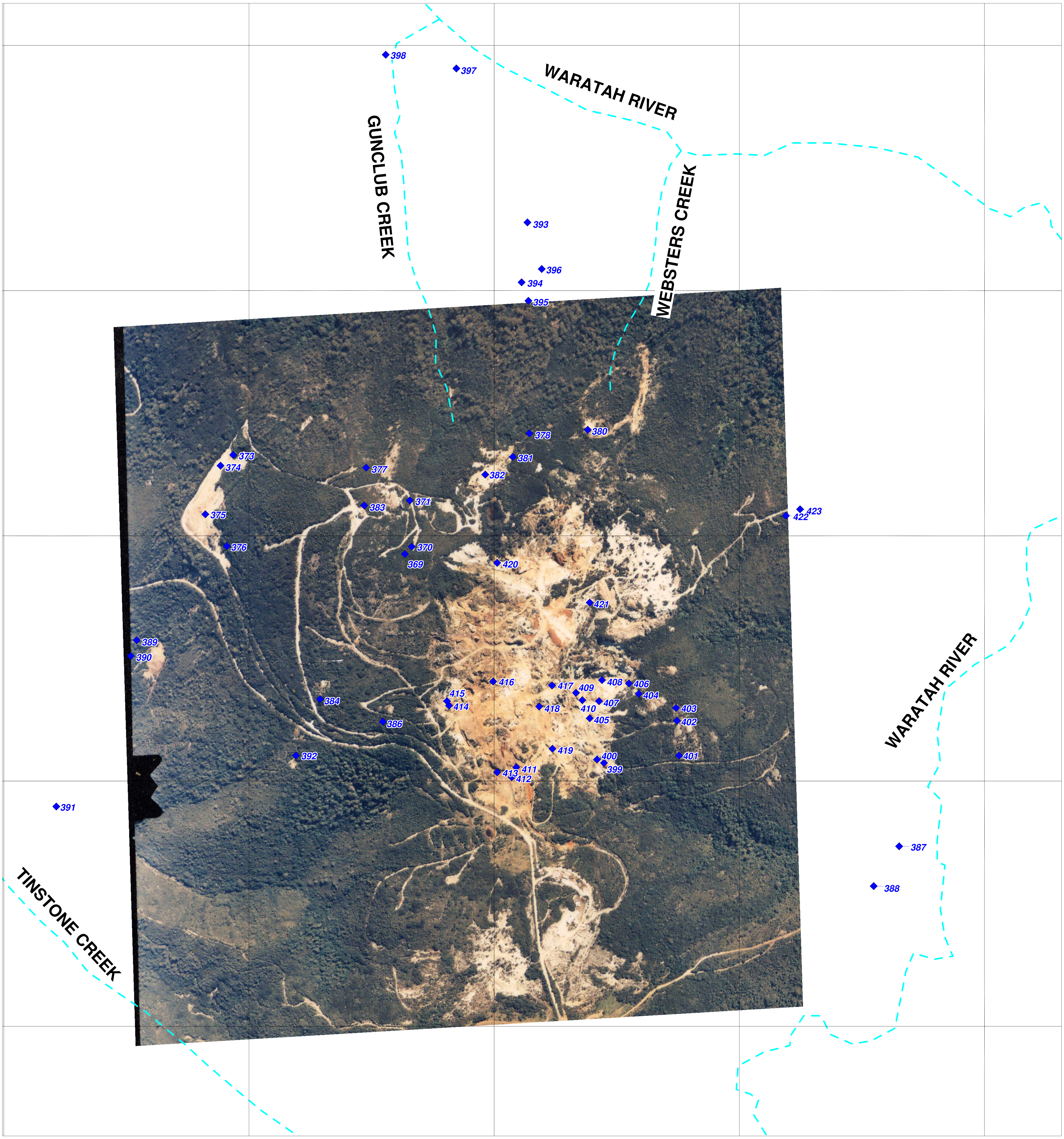
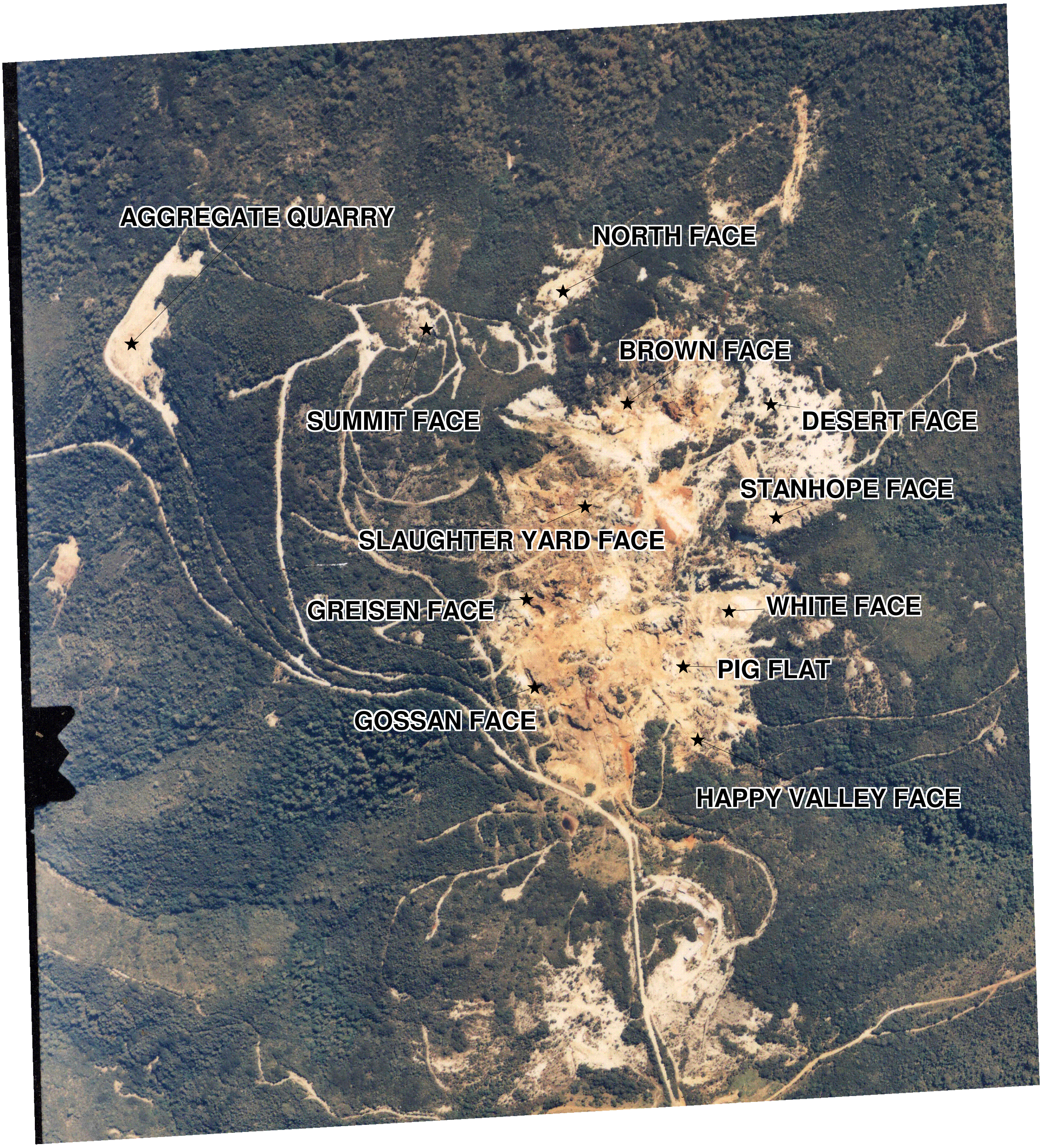
Figures

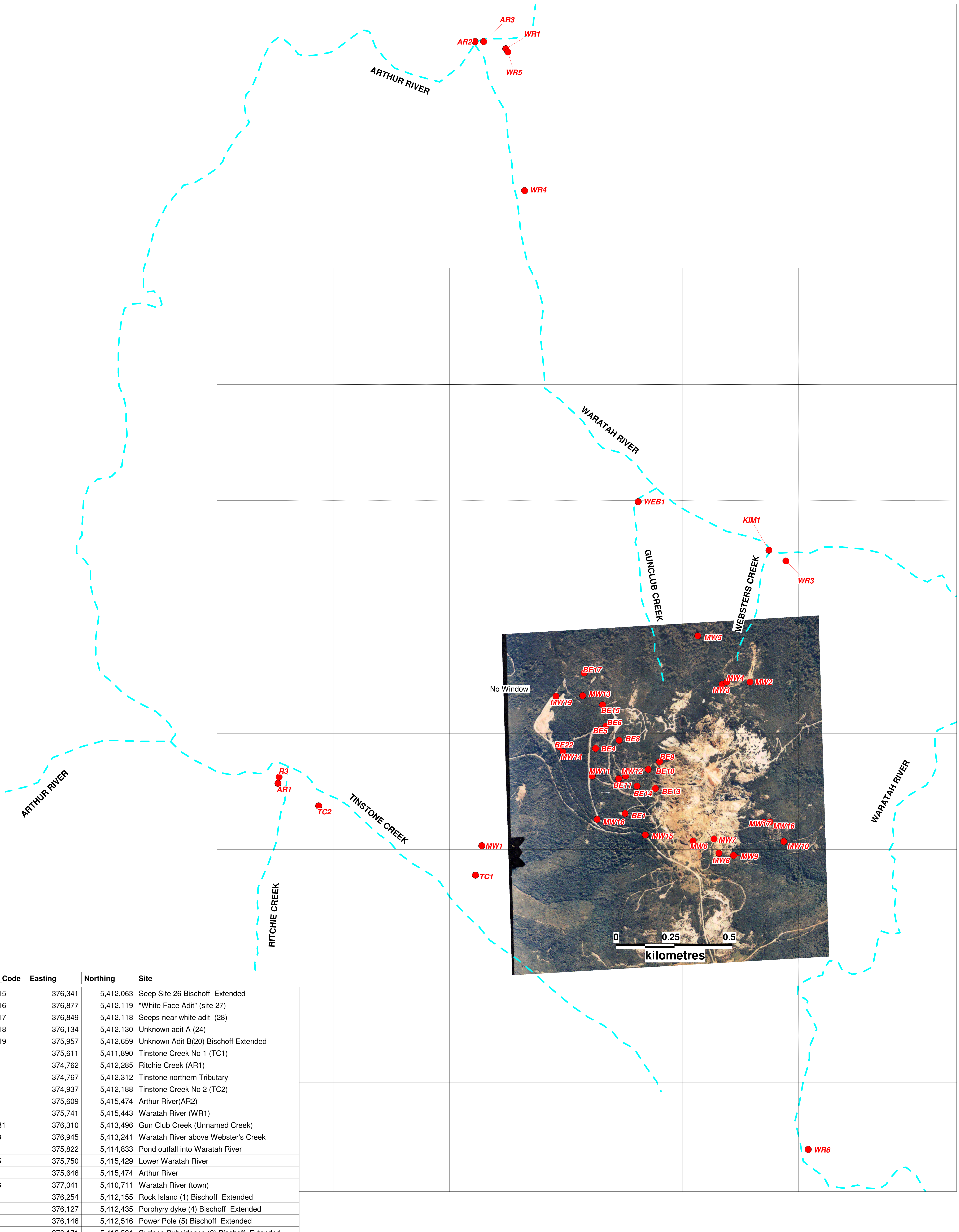


GEO-CHEMICAL INVESTIGATIONS

(Sampled by K. Morrison 2002)

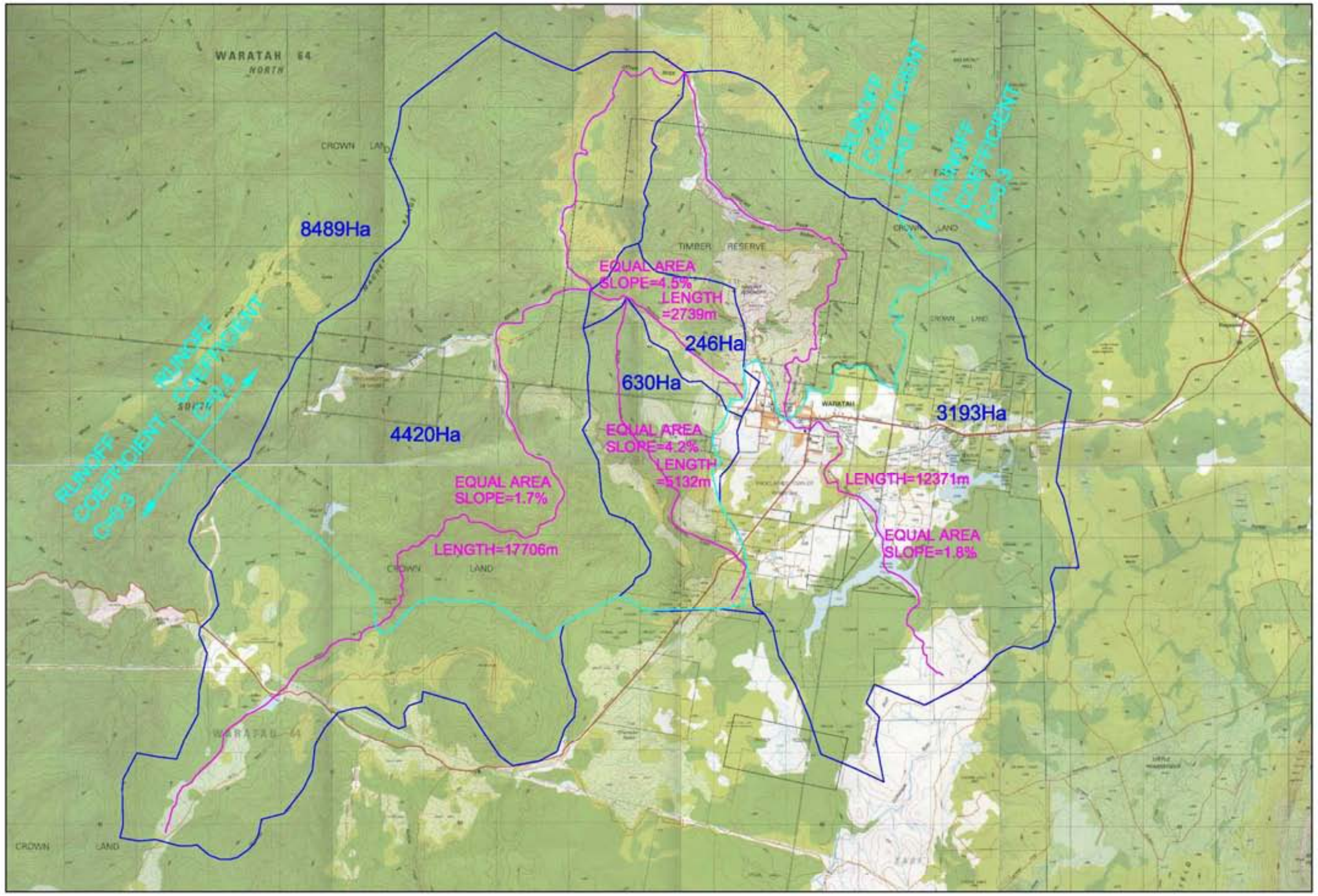


SURFACE WORKINGS



Site_Code	Easting	Northing	Site
MW15	376,341	5,412,063	Seep Site 26 Bischoff Extended
MW16	376,877	5,412,119	"White Face Adit" (site 27)
MW17	376,849	5,412,118	Seeps near white adit (28)
MW18	376,134	5,412,130	Unknown adit A (24)
MW19	375,957	5,412,659	Unknown Adit B(20) Bischoff Extended
TC1	375,611	5,411,890	Tinstone Creek No 1 (TC1)
AR1	374,762	5,412,285	Ritchie Creek (AR1)
R3	374,767	5,412,312	Tinstone northern Tributary
TC2	374,937	5,412,188	Tinstone Creek No 2 (TC2)
AR2	375,609	5,415,474	Arthur River(AR2)
WR1	375,741	5,415,443	Waratah River (WR1)
WEB1	376,310	5,413,496	Gun Club Creek (Unnamed Creek)
WR3	376,945	5,413,241	Waratah River above Webster's Creek
WR4	375,822	5,414,833	Pond outfall into Waratah River
WR5	375,750	5,415,429	Lower Waratah River
AR3	375,646	5,415,474	Arthur River
WR6	377,041	5,410,711	Waratah River (town)
BE1	376,254	5,412,155	Rock Island (1) Bischoff Extended
BE4	376,127	5,412,435	Porphyry dyke (4) Bischoff Extended
BE5	376,146	5,412,516	Power Pole (5) Bischoff Extended
BE6	376,171	5,412,531	Surface Subsidence (6) Bischoff Extended
BE8	376,228	5,412,470	Surface Subsidence (8) Bischoff Extended
BE9	376,402	5,412,378	Surface subsidence (9) Bischoff Extended
BE10	376,353	5,412,345	Quartz porphyry dyke (10) Bischoff Extended
BE11	376,226	5,412,305	Road below mine workings (11)
BE13	376,384	5,412,263	Open cut behind Bischoff (13)
BE14	376,306	5,412,273	Porphyry dyke (14) Bischoff Extended
BE15	376,157	5,412,623	Old workings (15) Bischoff Extended
BE16	376,072	5,412,662	Porphyry dyke (16) Bischoff Extended
BE22	375,971	5,412,442	Dolomite (22) Bischoff Exended
BE17	376,078	5,412,759	Bischoff Tramway (17) Bischoff Extended
BE25	376,341	5,412,063	Possible Costine (25)
KIM1	376,872	5,413,287	WEBSTERS cREEK (KIM1)

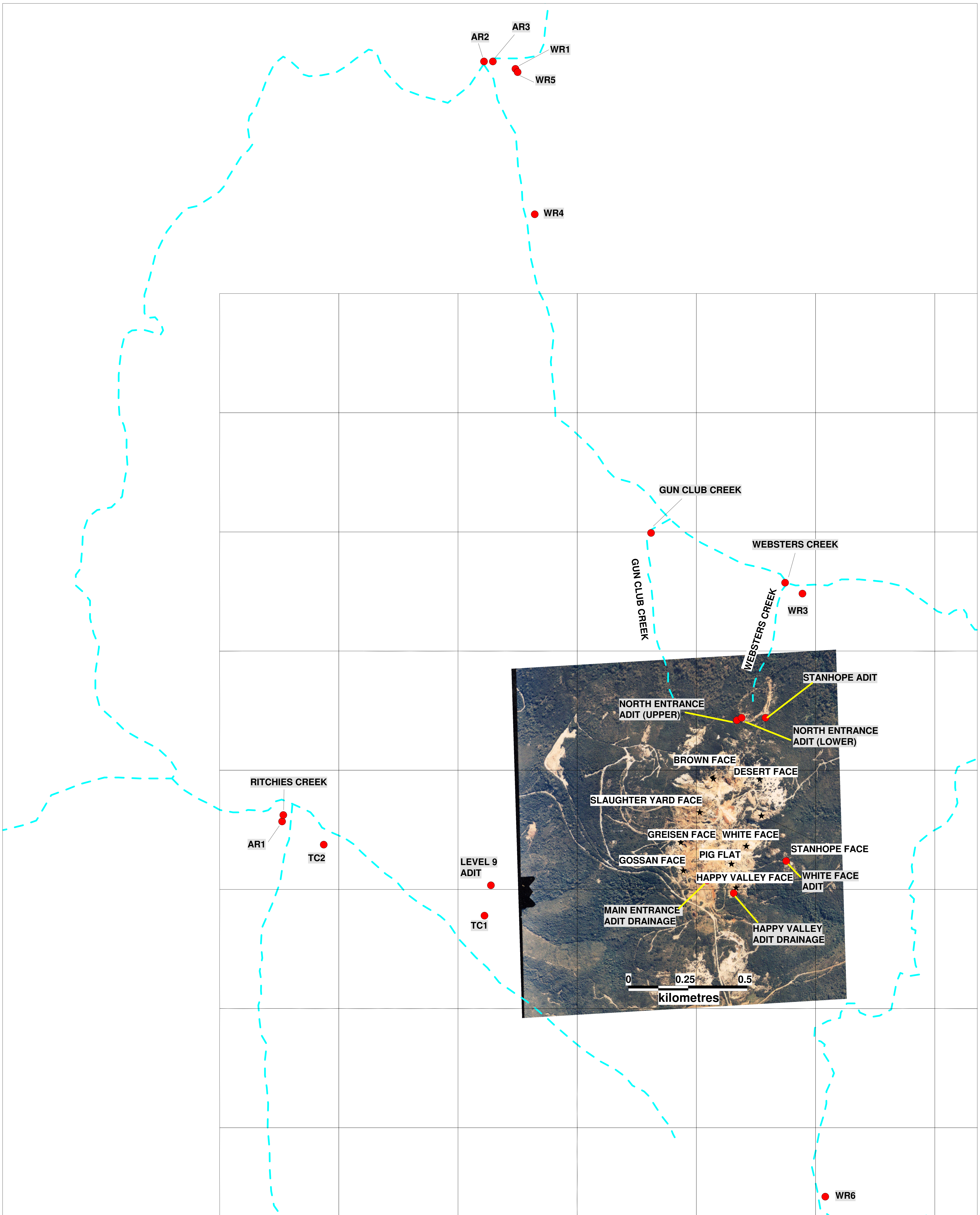
FIELD INVESTIGATION SITES



MOUNT BISCHOFF MINE

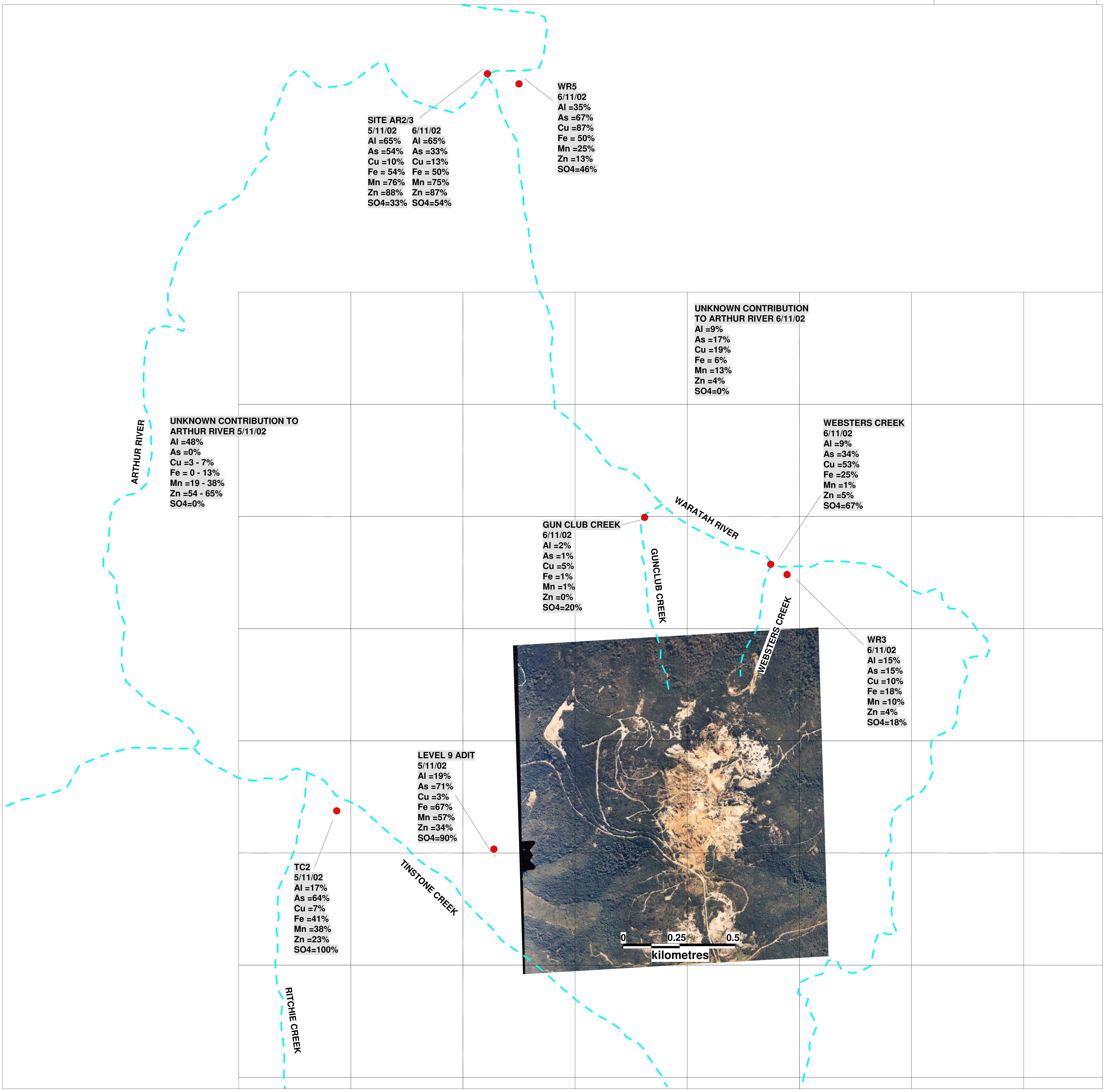
CATCHMENT DETAILS

Dec 18, 2002 - 10:17:37 DWG Name: H02212-P1.dwg DWG Updated By: ajensen



Site_Code	Easting	Northing	Site	Site_Type
AR1	374,762	5,412,285	Ritchie Creek (AR1)	Riverwater
AR2	375,609	5,415,474	Arthur River(AR2)	Riverwater
AR3	375,646	5,415,474	Arthur River	Riverwater
KIM1	376,872	5,413,287	WEBSTERS cREEK (KIM1)	Riverwater
MW1	375,638	5,412,017	Adit 9	Mine Surface Water
MW16	376,877	5,412,119	"White Face Adit" (site 27)	Mine Surface Water
MW2	376,790	5,412,720	Stanhope Adit ("Brown Face Adit")	Mine Surface Water
MW3	376,670	5,412,710	North Entrance Adit ("North Face Upper Adit")	Mine Surface Water
MW4	376,690	5,412,720	North Entrance Adit B (North Face Lower adit")	Mine Surface Water
MW6	376,545	5,412,037	Waterfall above front workings (above adit) drair	Mine Surface Water
MW8	376,657	5,411,984	Drainage from Happy Valley adit	Mine Surface Water
R3	374,767	5,412,312	Tinstone northern Tributary	Riverwater
TC1	375,611	5,411,890	Tinstone Creek No 1 (TC1)	Riverwater
TC2	374,937	5,412,188	Tinstone Creek No 2 (TC2)	Riverwater
WEB1	376,310	5,413,496	Gun Club Creek (Unnamed Creek)	Riverwater
WR1	375,741	5,415,443	Waratah River (WR1)	Riverwater
WR3	376,945	5,413,241	Waratah River above Webster's Creek	Riverwater
WR4	375,822	5,414,833	Pond outfall into Waratah River	Riverwater
WR5	375,750	5,415,429	Lower Waratah River	Riverwater
WR6	377,041	5,410,711	Waratah River (town)	Riverwater

OPTION ANALYSIS OPTIONS



INDICATIVE PERCENTAGE EMISSION CONTRIBUTION TO ARTHUR RIVER

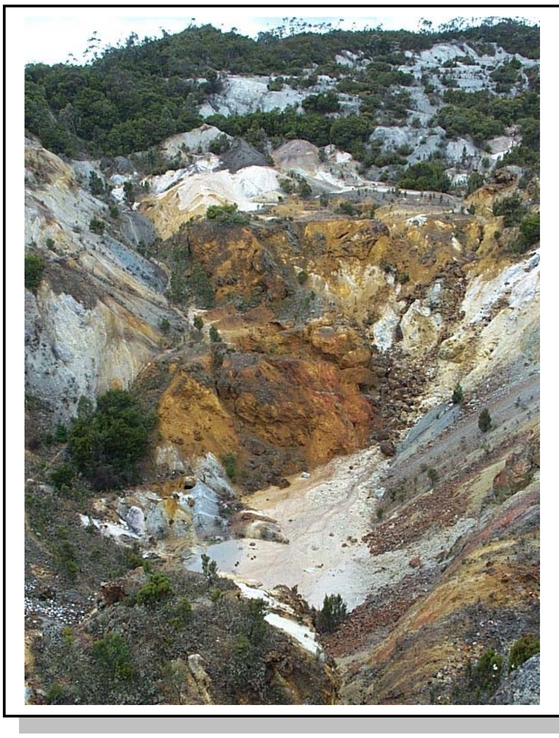
(EMISSIONS VARY DUE TO TEMPORAL HYDRAULIC FLOWS
HENCE NOT NECESSARARILY SUMMED TO 100 (SECTION 5.5)

Plates

Plates A – I:	Surface Workings
Plates J – S:	Mine Water Drainage
Plates U - Z:	Receiving Water

SURFACE WORKINGS

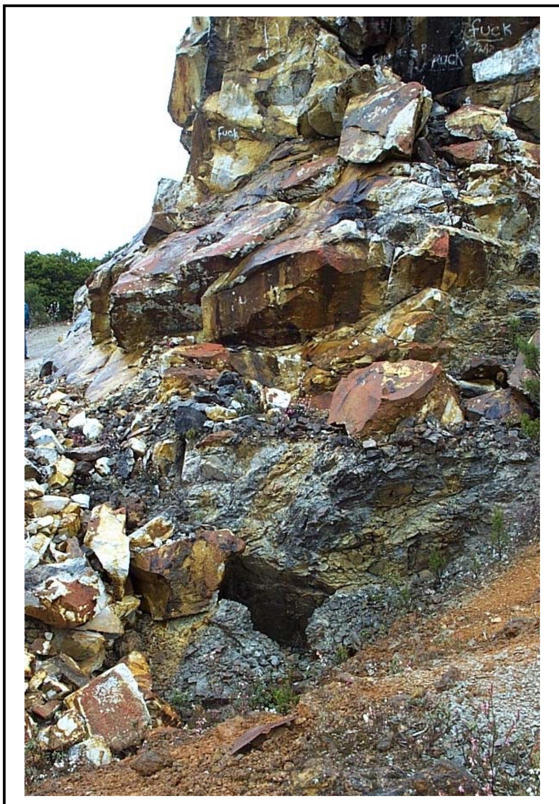
A. Mt Bischoff Surface Workings (7/11/2002)



B. Brown Face (5/11/2002)

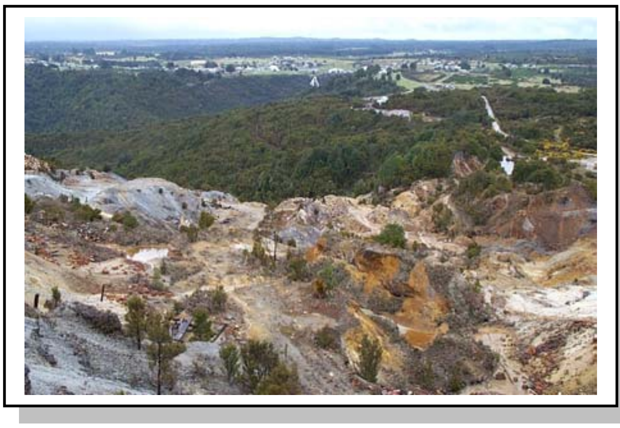
C. Stanhope Face & Mullock Dump (5/11/2002)

D. Stanhope Face (close-up) 5/11/2002



E. Slaughteryard Face (showing graffiti) 5/11/2002

F. White Face and Pig Flat 5/11/2002



G. Greisen & Gossan Faces 5/11/2002

I. Quarry – Bischoff extended 6/11/2002

H. Happy Valley Face with pyritic stockpiles 7/11/2002

MINE WATER DRAINAGE

J. Adit 9 5/11/2002

L. Stanhope Adit 5/11/2002

K.. "Yellow Boy" (Ferric hydroxide) precipitate from Adit 9 5/11/2002

N. Adit Drainage Ponds adjacent to Waratah River 6/11/2002

M. Northern Entrance Adit 5/11/2002

O. Main Entrance Adit Drainage Pond 5/11/2002

P. Main Entrance Adit Drainage Pond 5/11/2002

Q. Main Entrance Adit 7/11/2002

R. Happy Valley Adit 7/11/2002

S. White Face Adit 6/11/2002

RECEIVING WATER

T. TC1 – Tinstone Creek 5/11/2002

W. WR1/WR5 – Waratah River 6/11/2002

U. TC2 – Tinstone Creek 5/11/2002

X. Webster's Creek 6/11/2002

V. AR2/AR3 – Arthur River 5/11/2002

Y. WR3 – Waratah River 6/11/2002

Z. WR6 – Waratah River in Waratah 6/11/2002