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MIDDLE ARM TAILINGS RECOVERY PROJECT

HAZARD IDENTIFICATION AND KNOWLEDGE GAP ANALYSIS

Prepared For:

BCD RESOURCES (OPERATIONS) NL – TASMANIA MINE

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- Ms Monique Thompson, NRM North.

Glossary & Abbreviations

ANZECC	Australian & New Zealand Environment & Conservation Council
ARMCANZ	Agricultural & Resource Management Council of Australia & New Zealand
BCDR	BCD Resources (Operations) NL – Tasmania Mine
BMI	Blue Metal Industries
BMJV	Beaconsfield Mine Joint Venture
CAMBA	China Australia Migratory Bird Agreement
DEPHA	Department of Environment, Parks, Heritage and the Arts
DPEMP	Development Proposal and Environmental Management Plan
DPIWE	Department of Primary Industry, Water and Environment
ISQG	Interim Sediment Quality Guideline
JAMBA	China Australia Migratory Bird Agreement
NWQMS	National Water Quality Management Strategy
NOAA	National Ocean and Atmospheric Administration (USA)
PEV	Protected Environmental Value
RGAG	Rice Grass Advisory Group
TEER EHAP	Tamar River and Esk Rivers Ecosystem Health Monitoring Program
Anadromous	Fish species that spend most of their life in marine waters but migrate to freshwater to breed
Catadromous	Fish species that spend most of their life in freshwater but migrate to marine waters to breed
Bioturbation	Mixing of bottom sediments by biological organisms
Euryhaline	Organisms tolerant of a wide range of salinity e.g. estuarine species
Infauna	Organisms living within bottom sediments
Mixohaline	Waters of intermediate salinity between sea water and freshwater; estuarine waters 0.5 - <35 ‰ salt – divided into polyhaline, mesohaline and oligohaline waters.
Mesohaline	Waters of intermediate salinity in mid sections of estuaries; 5 – 18 ‰ salt
Oligohaline	Slightly salty waters in upper reaches of estuaries; nominally 0.5 – 5 ‰ salt
Al	Aluminium
As	Arsenic
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
Fe	Iron
Mn	Manganese
Ni	Nickel
Pb	Lead
Zn	Zinc
WAD CN	Weak Acid Dissociable Cyanide (CN_{WAD})

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1 Introduction

BCD Resources is currently examining the viability of reprocessing historical mine tailings to extract gold within Middle Arm, Tamar River estuary, in Northern Tasmania. Application has been made for an exploration licence EL6/2012 covering the historical tailings area. Following approval, a drilling program and metallurgical test work is planned for commencement in August 2012.

1.1 History

Gold was discovered at Beaconsfield in 1877 and the underground Tasmania Mine operated from 1877 to 1914 when mining ceased (BMJV, 1997). During that time, 26,578 kilograms of gold was produced from 1,085,000 tonne ore processed and treated, including roasting to remove sulphide (BMJV, 1997; BCDR, 2012). Over that period, mine effluent including mine waters from dewatering and tailings, was discharged to Middle Arm Creek and Middle Arm in the Tamar River. These discharges resulted in the contamination of a large section of Middle Arm with tailings, precluding access by shipping (BDC Resources, 2012). These deposits are exposed for extended periods at low tide (Figures 1 and 2). Consequently, the waters of Middle Arm Creek and Middle Arm have been highly disturbed in the past by mine discharges, resulting in the extensive sediment build up from tailings between Auburn Road and Kildare, as well as various tailings recovery attempts between 1914 and the 1970s (e.g. Blue Metal Industries - Port of Launceston Authority, 1975), and a major program of tailings recovery by dredging from 1983 to 1988 by Golconda. Between 1985 and 1988, Golconda recovered approximately 540,000 tonnes of tailings with an estimated 500,000 tonnes of variable grade tailings remaining (S. King, BCDR, *pers. comm*.).

From the time of their build up, the presence of these deposits have presented a range of threats to ecological and other values within Middle Arm, including:

- Sediment resuspension and transfer both downstream and to a lesser extent upstream.
- Smothering of a range of organisms normally occupying the Middle Arm Creek estuary.
- Alteration of normal tidal patterns, with the exposure of extensive mudflats for extended periods each day.
- The extension of the low salinity section of the Middle Arm Creek Estuary some 2 km downstream
- Alteration of natural ecological communities.
- Potentially, toxicity to fauna from metals found within the sediments.
- Loss of shipping access and recreational boating and fishing.
- Loss of visual amenity.

The Beaconsfield Gold Mine was rehabilitated over a period of about twenty years (BMJV, 1997) and recommenced production in September 1999. Until closure of the mine in July 2012, mine waters were treated by a series of settling dams and treatment wetlands prior to discharge to Middle Arm. Dewatering at rates up to 650L/s (~56ML/day) occurred during rehabilitation in the mid 1990's but the rate has steadied at approximately 70L/s (~6ML/day) over recent years.

Figure 1- Middle Arm tailings deposits, low tide from Scotchmans Point and Middle Arm Creek

Process waters, treated as necessary through the CN (cyanide) destruction circuit, are stored in two flotation tailings dams and, in the past, excess water was redirected to the mine water treatment system. In the event of a 1 in 100 year flood, excess water from the flotation tailings dams may be discharged to the Brandy Creek catchment through a series of treatment wetlands and ponds designed to trap sediment.

As part of the Beaconsfield Gold Mine Development Proposal and Environmental Management Plan (DPEMP) (BMJV, 1997), Protected Environmental Values (PEVs) were identified for the Brandy Creek catchment and Middle Arm, Tamar Estuary.

The proposed PEVs for the Middle Arm section of the Tamar Estuary in the vicinity of the discharge but outside an agreed mixing zone in the vicinity of Bowens Jetty were:

- *Maintenance of the existing aquatic biological communities, particularly invertebrates and fish.*
- *Maintenance of the existing potential of that section of the Tamar Estuary for human recreational use – both primary and secondary contact.*

Extensive water quality and biological monitoring programs were performed between 2001 and 2012 to monitor the impacts of mine and processing discharges; Brandy Creek biological monitoring continues.

Figure 2 – Middle Arm tailings deposits circa 2007 (Source: Google Earth).

1.2 Catchment Characteristics

The Middle Arm Creek catchment is relatively large, comprising Middle Arm Creek, Blyth Creek, Johnston Creek and Cobblestone Creek. The first three of these creeks flow from the south-west through agricultural land and state forest, between Cabbage Tree Hill and Salisbury Hill to the south of Beaconsfield, and enter Middle Arm from the south at Auburn Road. Cobblestone Creek flows from the south through the agricultural area east of the West Tamar Highway, joining Middle Arm Creek about 50 metres upstream of Auburn Road.

Middle Arm Creek is perennial and has its origins in groundwater flows of about 100 L/s from a limestone outcrop; it carries heavy flows during wet periods due to its large catchment area (BMJV, 1997). The minewater discharge point (B10) is a short distance downstream of Auburn Road and forms an additional source of flow. Monthly flow data are available for Middle Arm Creek for the 1981 – 1990 period (BCDR data – Middle Arm Creek gauge; originally provided by DPIWE (Peter Hills, *pers. comm.*), demonstrating both flow permanence and high variability. Over those years, flows were lowest in January – March and highest in July and August. The gauge is still present.

Middle Arm also receives flows from smaller catchments including an unnamed creek from the south-east opposite Scotchman's Point, from two sources between Scotchman's Point and Kildare - Clog Toms Creek to the east and Brandy Creek to the west (see Figure 1), and from Pease Creek to the west between Kildare and Beauty Point. All of these creeks are ephemeral.

All but Pease Creek enter Middle Arm within the area of mine tailing deposits south of Kildare. Middle Arm Creek, Clog Toms Creek and Brandy Creek all contain tailings in their estuarine sections (Koehnken, 2002; Walker, 2008). The tailings deposits contain well defined channels where flows occur during rising and falling tides and high freshwater flow events.

The nearby West Arm has been used as a control or reference location for biological monitoring as it is considered to be broadly similar in characteristics to Middle Arm prior to the formation of the tailings deposits, and hence possible condition following rehabilitation. However, it does differ in that all streams flowing into West Arm are ephemeral.

The York Town Rivulet enters the headwaters of West Arm from the west, Masseys Creek from the south-west and Andersons Creek from the south. Andersons Creek flows through a large catchment from its source near Kellys Lookout, draining mainly state forest to the west of Brandy Creek and Middle Arm Creek. The source of Andersons Creek is close to that of Middle Arm Creek and Johnston Creek that flow to Middle Arm. The York Town Rivulet flows through a smaller mainly forested catchment from its source in the foothills of the Asbestos Range. The Masseys Creek catchment is similar in nature to that of the York Town Rivulet but smaller. West Arm also receives flows along its length from several small, localised streams from the north and south.

As Middle Arm receives flows from the largest and only permanent stream in the area, it is likely to have been less marine dominated than West Arm, with a more extensive and dynamic estuarine region. This is also likely to be the case following the removal of tailings deposits.

1.3 Estuaries

Estuaries

The term estuary has been variously defined (e.g. Turner et al, 2004; Edgar, 2001; Edgar et al, 1999; Barnes, 1974; Reid, 1961) but, although somewhat simplistic, for the purposes of this report, an estuary will be considered to be a region where freshwaters from rivers meet and mix with saline waters from the sea. Where neither freshwater inflows or tidal influence are dominant, the estuarine section of a river may be long, with low salinity in its upper reaches (oligohaline waters), gradually increasing salinity through its middle reaches (mesohaline waters – sometimes known as the gradient zone) to marine waters where it enters the sea (euhaline) (Rochford, 1951; Anon, 1958; Segerstrale, 1958). Salinity variability is a key character of estuaries, with what may be defined as zones of salinity moving up and down estuaries with tidal cycles and freshwaters influxes such as rainfall and floods (Morrisey, 2000). In some cases, higher density saline water may underlie lower density fresh water, with saline water moving upstream along the bottom of an estuary on the incoming tide (salt wedge).

As a result of the transport of nutrients from their catchment rivers, estuaries are natural nutrient sinks collecting nutrients from their catchment rivers and hence, may be highly productive. Due to the interaction of these inflows with tidal water movements, sediment tends to accumulate in estuaries, although these accumulations are rarely stable, being continually resuspended and redistributed. The accumulation of sediments occurs naturally, but may be increased by anthropogenic activities such as land clearance or mining operations. The fauna within these sediments generally occupies a relatively thin surface layer of up to 10 cm (Inglis, 2000).

Sediment particle size affects the rate of water exchange within sediments, their chemical properties and hence the organisms that live in them, although these organisms in turn, may also modify sediment characteristics by various processes, such as burrowing and bioturbation. Sediments are resuspended each tidal cycle and redeposited, although very fine sediments may not be redeposited within one tidal cycle (Morrisey, 2000). This periodic resuspension of sediment may produce high turbidities, especially in estuaries with fine sediments and high tidal flows.

Many of the estuaries of northern Tasmania are subject to tides of high amplitude, with extensive scouring and high tidal flows. The Tamar River estuary, including Middle and West Arms, has a tidal amplitude typically around 3 m, and hence is a very dynamic system.

The assessment of anthropogenic environmental impacts on the ecological communities of estuaries is often difficult since a natural gradient of community change occurs along these waterways. In addition, the effects of the discharges and other human activities may be heavily influenced by the mixing characteristics within the estuary in question, which itself is determined by a range of factors including freshwater inflows (amount and location), topography, catchment characteristics, tides (amplitude, tidal currents) and the presence of other anthropogenic impacts. Impacts may extend some distance from a discharge both downstream (freshwater flows) and upstream (tidal flows). Because their natural habitat is dynamic and strongly dominated by abiotic factors such as salinity, estuarine communities may be very tolerant of some forms of anthropogenic disturbance (Edgar *et al*, 1999).

In the case of Middle Arm, the situation is complicated further by the presence of the extensive historical tailings deposits with marked impacts on the habitat available to the communities present.

It is assumed that prior to the presence of the tailings deposits the Middle Arm estuary would have been more similar to that of West Arm than it is today. Nevertheless, both systems have been impacted by anthropogenic disturbance in their catchments and due to the nature of their catchments, historical freshwater flows into the headwaters of Middle Arm would always have been greater than those into West Arm.

1.4 Middle Arm Tailings Recovery Project

The construction of a cofferdam across Middle Arm in the vicinity of Kildare is proposed, to allow access for a floating barge allowing the removal of tailings. This will permit tailings removal at all parts of the tidal cycle, including low tide when the sediment deposits are usually exposed. This section of Middle Arm is narrow and located near the seaward extent of the main deposits, rendering it the most effective location for the dam. The tidal amplitude within the Tamar Estuary is large, up to 3.5 m (lowest low tide to highest high tide), but generally between 2.5 and 3 m, resulting in the exposure of the deposits for extended periods at low tide. Without the dam to maintain sufficient water level to float the barge, removal of the tailings would not be possible except near high tide. The barge will utilise state of the art technology to remove the tailings as a slurry, which will be pumped to the current processing plant for metal extraction, remote from the estuary. Reprocessed tailings will be returned to the underground mine at Beaconsfield.

The project has the advantage of not only providing economic returns and employment in the area, but will substantially rehabilitate Middle Arm.

Providing gold levels are sufficient for reprocessing to be economically viable, the proposed reprocessing project will require EPA approval and a DPEMP (Development Proposal and Environmental Management Plan).

The latter will be prepared by BCD Resources with the assistance of specialist consultants where this is required.

The project may be divided into a number of phases. Initially, assessment of the potential hazards and threats the project may present to ecological and other values will be required, and the measures required to manage and avoid these determined. The consolidation of knowledge of the Middle Arm ecosystem will also be required and an analysis of what additional information may be required to evaluate risks to the system and to ensure the management proposed is appropriate and effective.

From this information, any additional baselines studies required can be designed and water, sediment and biological monitoring programs planned and implemented. These will be integrated across the life of the program from initial baseline monitoring, through the tailings removal phase to the recovery phase following the cessation of tailings removal. Any additional baseline studies and pre-recovery monitoring programs will need to be completed or implemented prior to the submission of the DPEMP.

2 Objectives and Scope

The overall aim (scope) of this report is to identify and examine the potential threats posed by the Middle Arm Tailings Recovery Project to the flora and fauna of Middle Arm.

The specific objectives include:

- Literature review and collation of available information on Middle Arm flora and fauna and water and sediment quality.
- Identification of the potential hazards to flora and fauna by the project, including:
  - Ecological
    - Subtidal Infaunal communities
    - Intertidal invertebrate fauna
    - Saltmarsh communities
    - Bird communities
    - Fish communities
  - Ecotoxicological
  - Bioaccumulation
- Introduced pest species
- Knowledge gap analysis and identification of additional information/baseline studies required to assess the risks to Middle Arm ecological values and monitor the effectiveness of future management measures.

3 Beaconsfield Mine Monitoring Program

The Beaconsfield Mine Monitoring Program (Beaconsfield Mine Joint Venture) provides the most information specifically relevant to Middle Arm. Between 2002 and 2012, the following surface water/sediment elements have been included:

- Sediment quality investigation (2002)
- Sediment leachate investigation (2002)
- Bathymetric survey of Middle and West Arms, and Port Dalrymple (2003)
- Water quality
  - Middle Arm and treatment wetlands (including the tailings dam) (2001 - 2008)
  - Brandy Creek ponds (2002 - 2012)
- Biological monitoring
  - Middle Arm and West Arm (infaunal and intertidal fauna) (2002/2003, 2008)
  - Brandy Creek ponds (2003 – 2012)

The locations of sites used for sediment and water quality water within Middle Arm are provided in Figure 3, and those used for biological monitoring in Figure 4.

Bioaccumulation of metals in oysters was also examined in December 2001, based on information collected from within Middle arm by the Department of the Environment (1980). Groundwater testing has also been performed.

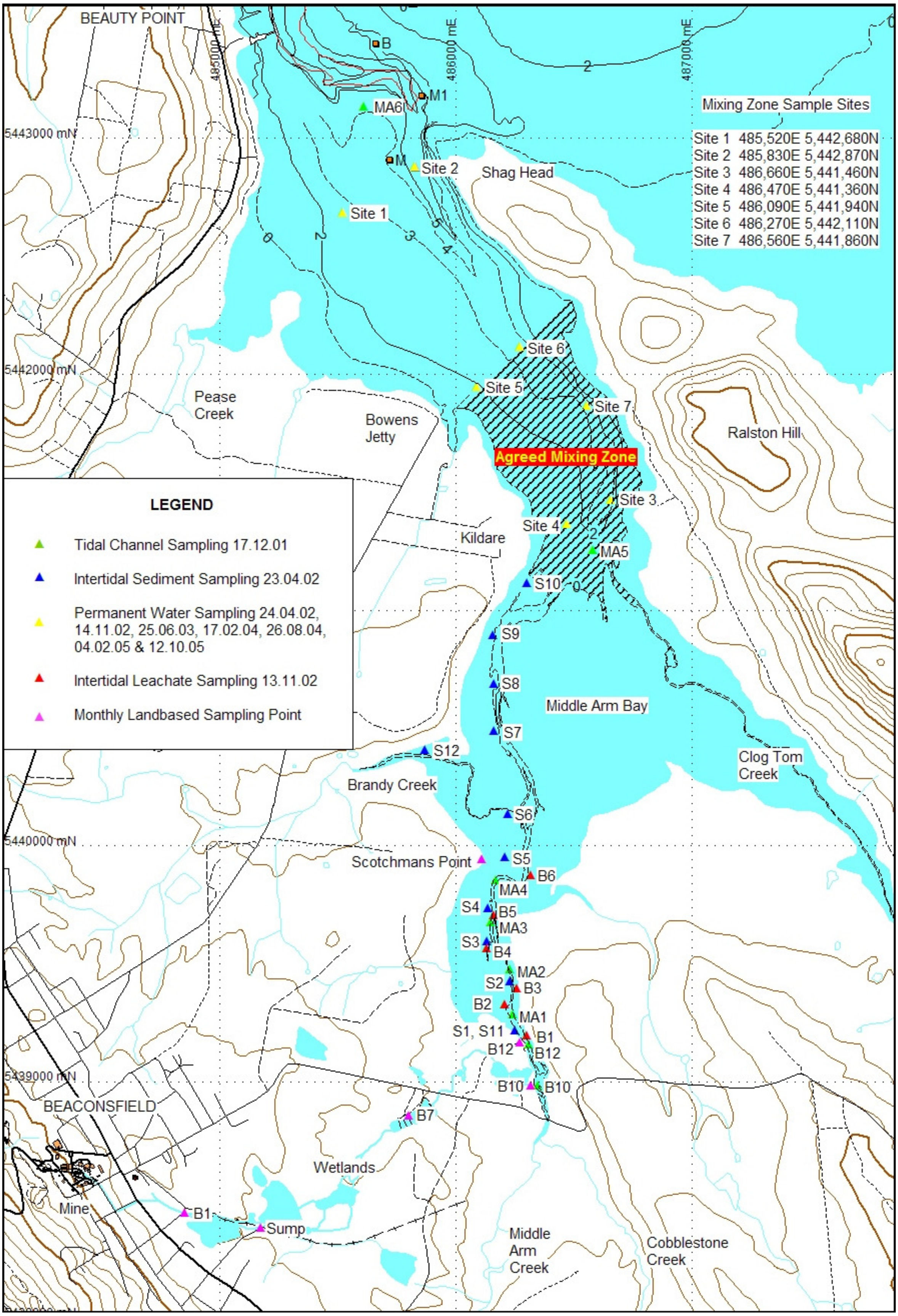

Figure 3: Beaconsfield Mine Monitoring Program. Middle Arm monitoring sites (Source: BCD Resources)

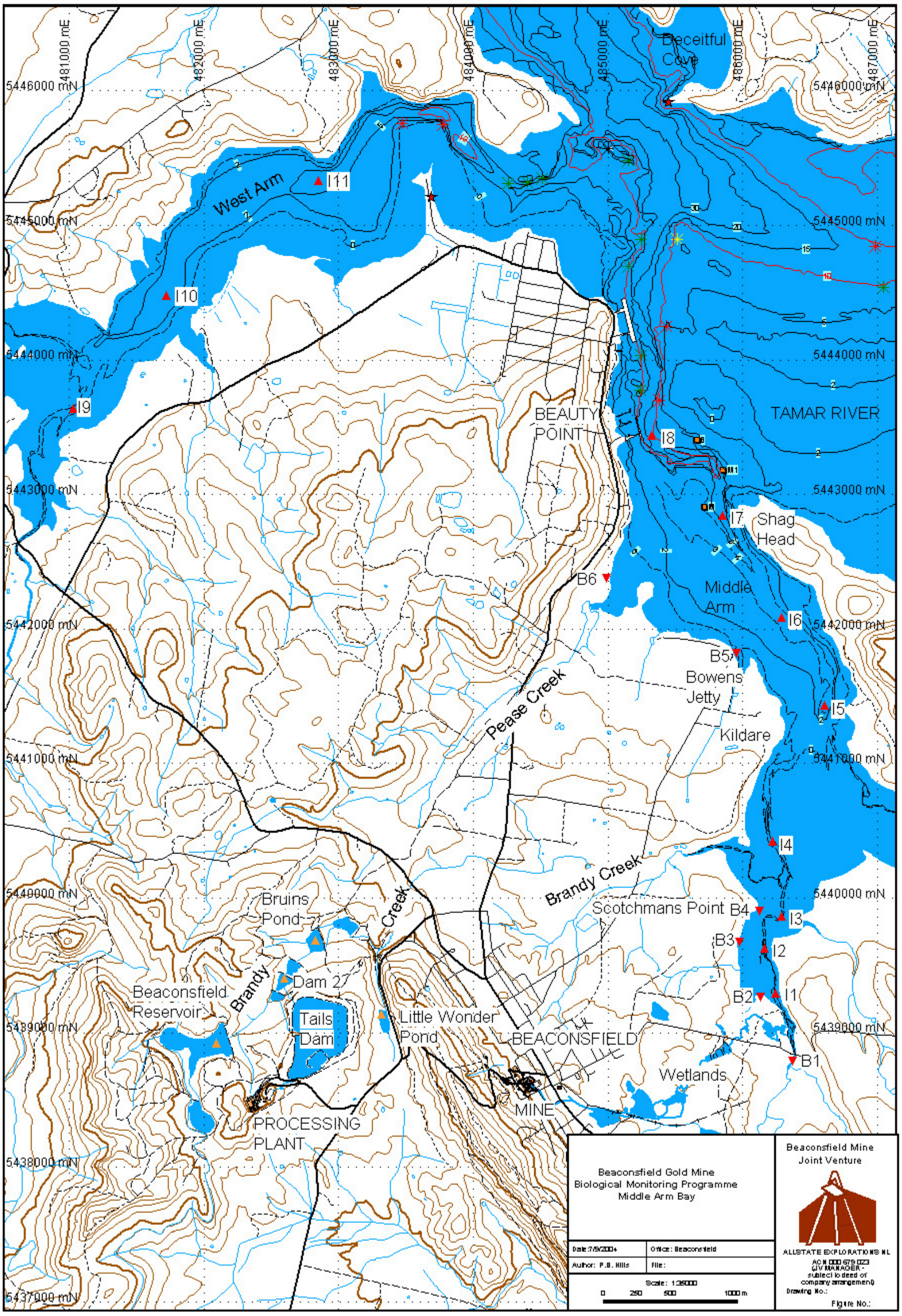

Figure 4 – Middle & West Arm biological monitoring sites and bathymetry

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4 Desktop Study

A literature search was completed to identify the water and sediment quality, ecological and faunal information currently available relating to Middle Arm. Additional information was also sourced concerning other nearby sections of the Tamar Estuary, which may be applicable to Middle Arm.

4.1 Information Available

4.1.1 Water Quality

Koehnken, L.: Water Quality Monitoring in Middle Arm Estuary – Biannual Reports 2002 – 2008.

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4.1.3 Ecological - Macroinvertebrates

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Gawne, K., and Richardson, B. (1992b). An investigation into the distribution and accumulation of selected chemical species in the waters, sediments and biota of Deceitful Cove. Prepared for TEMCO and Comalco.

4.1.7 Other

Range of aerial photos and maps from 1972 to approx. 2010.

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Environment Australia (2002). National Ocean Disposal Guidelines for dredged Material.

4.2 Summary of Available Information

4.2.1 Sediment

The available sediment quality data specifically relating to the tailings deposits and Middle Arm seems limited to that of Koehnken (2002a,b), although some information relating to the Blue Metal Industries and Golconda recovery programs in the 1970s and 1980s is available, particularly that relating to settling times and the depth of the sediment deposits. Detailed information on gold content and recovery is also provided, but not relevant to potential biological impacts.

Sediment particle size distribution data were provided by Walker (2004, 2009) for each of the infaunal biological monitoring sites located in the channels of Middle and West Arms, since this can have marked impacts on the nature of the biological communities present (Figure 5).

These analyses revealed:

- In 2003, the sediments of the Middle Arm channels were poorly sorted, consisted principally of finer sediment fractions and were not uniformly distributed. Down the length of Middle Arm (from Middle Arm Creek), there appeared to have been a number of discontinuities in sediment distribution patterns i.e. points where rises or falls in specific sediment fractions for sites down the length of the estuary were interrupted. These appeared to exist principally in the area of the historical tailings and at site I6 just downstream; each occurred in the vicinity of where creeks entered Middle Arm.
- In general, finer sediment such as silt was more common in the vicinity of entering streams and at I6 in mid-estuary, a deeper area where sediment, flushed from the historical tailings deposits may accumulate.
- There were a number of differences noted in sediment makeup between 2008 and 2003. Coarser sediment fractions were more common at all sites in 2008, particularly at the upstream sites, and silt/clay levels were much higher at Site I6 in Middle Arm than in 2003. Sediments were better sorted in 2008. These differences

were attributed to lower freshwater inflows due to drought prior to the 2008 sampling event.

These data indicate that flows into Middle Arm are important for the sorting of surface sediments, particularly those within the historical tailings area.

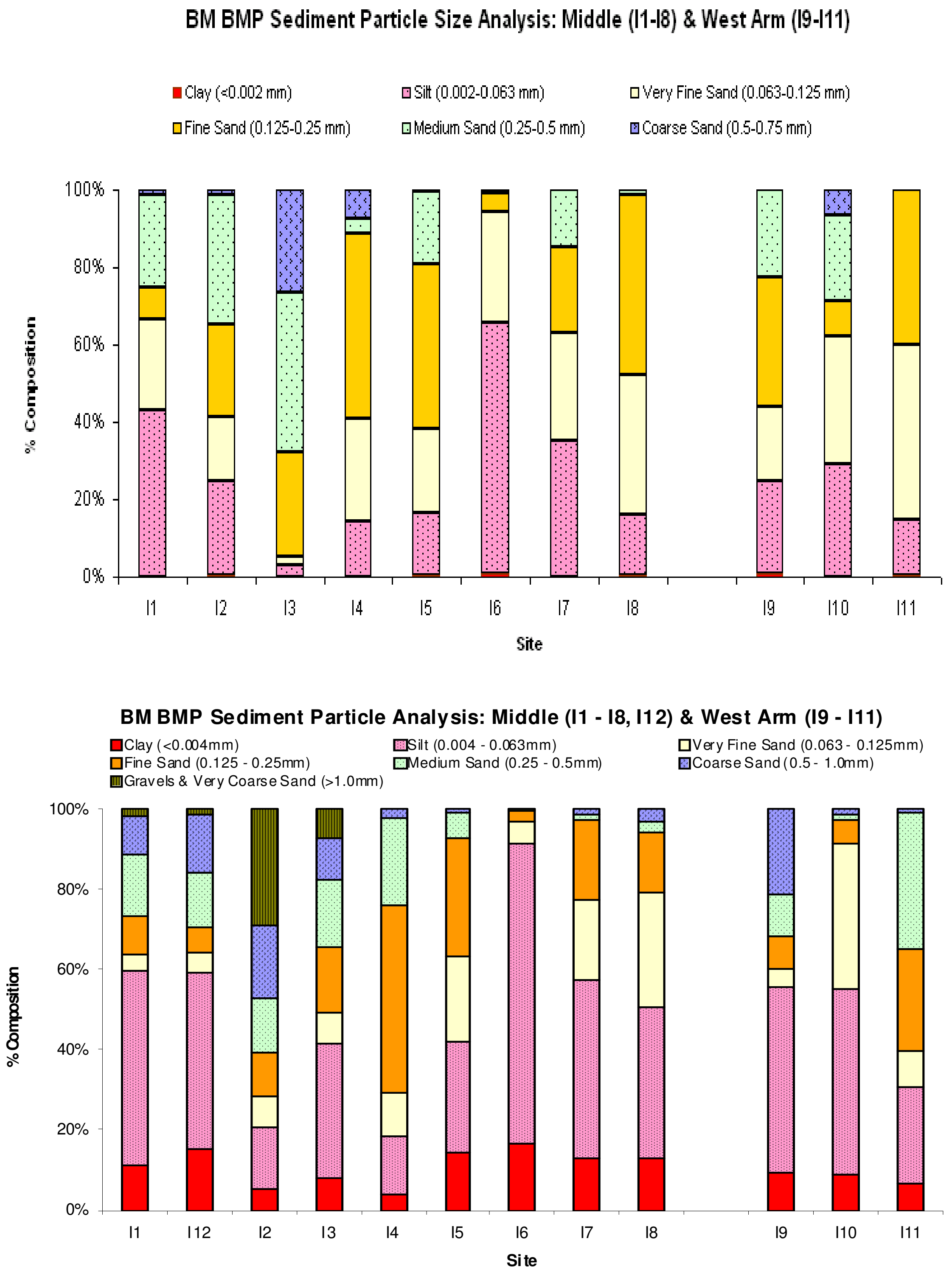


Figure 5 – Sediment particle size distribution, Middle & West Arms, 2003 (top) and 2008 (bottom)

Koehnken (2002a) examined metal levels in 11 surface samples and one sub-surface sample

(0.3 m) (Sites B1 – B12) on 23 April 2002. These sites were located along the channel from Middle Arm Creek (B1, B11) to Kildare (B10), and an additional site (B12) at the mouth of Brandy Creek.

This study revealed the following:

- A range of metals or metalloids were found to exceed the ANZECC/ARMCANZ 2000 Interim Sediment Quality Guidelines (ISQG) for the protection of aquatic ecosystems, including arsenic, copper, nickel, lead and zinc (See Table 1 and Figure 3).
- In most cases, metal levels fell with distance from the head of Middle Arm (near the "Battery", the original Tasmania Mine processing site and historical stockpiles) downstream. Nonetheless, arsenic and copper levels exceeded both the ISQG-Low risk and ISQG-High risk values at all sites.
- Zinc levels exceeded both the ISQG-Low and High at the most upstream sites (S1-2, S11), the ISQG-Low for sites further downstream (S3 - 6), but neither at sites closer to Kildare.
- Lead and nickel levels exceeded ISQGs only in the most upstream sites.
- The levels of arsenic, copper, lead and zinc (slightly) were higher in the sub-surface sample (30 cm) than the surface sample at the same site, suggesting these metals were leached from surface layers by oxidation processes into the waters of Middle Arm. This also suggests that metal levels are not only variable with position within Middle Arm, but also with depth within the deposits.
- Iron levels were very high at all sites (33,200 – 82,900 mg/kg), although falling with distance from the head of Middle Arm as with other metals. There is no ISQG for iron, due to its low toxicity, nor for aluminium, which was also present in high levels, especially at the mouth of Brandy Creek.

One test report (TR20) for BMI Mining presented assay results for a suite of metals (expressed as % by weight), apart from gold. The sample tested was a composite head sample from 4 drill samples. When converted to mg/kg, metal levels (Table 2) were similar to those reported for the sub-surface sample of Koehnken (2002a). Sulphur levels were elevated.

Metal	**Arsenic**	**Copper**	**Lead**	**Zinc**	**Sulphur**
Level (mg/kg)	1,600	1,200	200	500	6,800

Table 1 – Assay results for BMI Mining; TR20 (Austin & Wellington)

The exceedence of the ANZECC/ARMCANZ (2000) ISQGs, for some potentially toxic metals and especially the ISQG-High, indicates there is a risk of adverse effects on the fauna of Middle Arm from these contaminants if they become biologically available or remobilised, especially in the case of arsenic and copper, and for sites closest to Middle Arm creek.

None of the above studies incorporated reference sites outside Middle Arm, such as West Arm.

As part of the BMI recovery program, in 1973, holes were drilled by auger along a series of transects across Middle Arm to ascertain the depth and gold content of the tailings deposits. These extended from Middle Arm Creek along Middle Arm to just north of Scotchmans Point. Tailings depths ranged from (converted from feet to metres) 30 cm at the edges to around 2.7 m. Deposits up to 3 m in depth were also noted around Middle Arm Creek and upstream of Auburn Road.

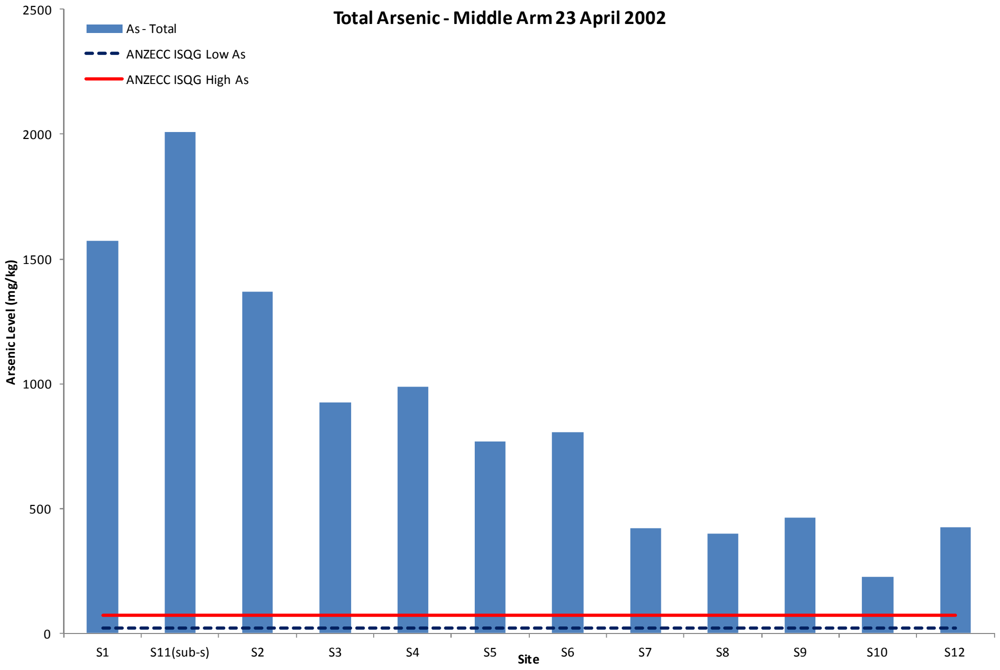
Two further transects were sampled in 1993 (MRT, 1995). These were located further to the north between Brandy Creek and Clog Toms Creek, with holes drilled at 50 m intervals across Middle Arm. Tailings depth was ascertained for all holes along the southern of the two transects (Line B). Depths of up to 3.75 m were recorded, somewhat deeper than shown further upstream by the BMI transects.

Turbidity testing performed between Middle Arm and Scotchmans Point in 1975 (Port of Launceston Authority, 1975), revealed that sediment samples with high tailings content, contained 6 – 8 % fine silt and took 20 minutes to fully settle after agitation; samples with less tailings contained 20 – 25% fine silt and took up to 60 minutes to fully resettle. Significant surface sediment resuspension on incoming and outgoing tides was also noted during biological monitoring within Middle Arm Creek and at Scotchmans Point (Dr Terry Walker, Ecosure, *pers. comm.*) and appears to be a feature of the current impacted environment.

The State of the Tamar Estuary Report (Aquenal & DEPHA, 2008) and Wood *et al* (2002) provide data concerning sediment metal levels within the Tamar River Estuary. For the middle sections of the estuary, it was noted that arsenic and copper levels were elevated in Middle Arm and lead and zinc in Deceitful Cove, relative to other sites tested. This suggests that the sources of the elevated copper and arsenic levels in Middle Arm are contained within the arm itself and probably associated with historical and/or current mining operations. However, Wood *et al* (2002) noted that current releases from mining operations were inadequate to account for the sediment levels found, suggesting other 'natural' sources. He also noted that little of the arsenic present (approx. 1%) was likely to be biologically available, and hence unlikely to cause adverse impacts on ecological communities. Wood *et al* (2002) also found that, apart from arsenic, copper and zinc, mercury levels were elevated and exceeded "the standard for sediments".

Metal/metalloid (units: mg/kg)	**ANZECC/ARMCANZ ISQG-Low**	**ANZECC/ARMCANZ ISQG-High**	**Surface Samples (Range)**	**Sub-surface Sample**
Arsenic	20	70	**227 - 1,570**	**2,010**
Copper	65	270	**344 - 1,100**	**1,670**
Nickel	21	52	9 - 51	30
Lead	20	220	46 – 163	**224**
Zinc	200	410	143 - **589**	**598**

Table 2 – Sediment metal levels in Middle Arm, 23 April 2002



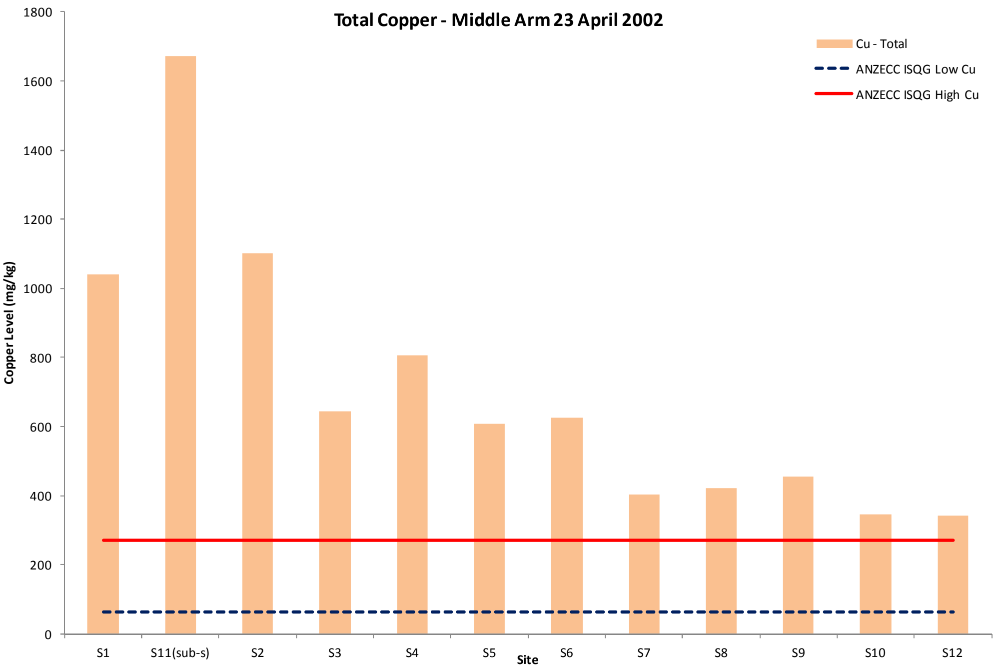


Figure 6 – Sediment arsenic and copper levels along Middle Arm, 23 April 2002

4.2.2 Water Quality

The most appropriate water quality information relating to Middle Arm is provided by the BMJV Water Quality Monitoring Program and the reports produced by Koehnken (2002 – 2008). Other information exists for the Tamar River estuary as a whole *e.g.* Aquenal & DEPHA (2008) and Attard *et al* (2011), but not specifically Middle Arm, apart from a single site at Beauty Point where the arm enters the Tamar Estuary at Port Dalrymple. In this case, elevated zinc levels were noted (Aquenal & DEPHA, 2008). However, this site is also close to Deceitful Cove, which is known to have elevated metal levels (Pirzl & Coughanowr, 1997).

Attard *et al* (2011) identified that the historical tailings from the Beaconsfield Mine are a source of metal contamination to the Tamar River, and that current mine operations are also a potential source. Over the period of the report (September 2009 – October 2010), metal testing was only performed in Zone 1 (upper Tamar Estuary) and Zone 4 (lower – mid estuary around Middle Arm and the industrial area of Bell Bay), where historical data suggest contamination was most likely. In zone 4, only lead exceeded the ANZECC/ARMCANZ (2000) guideline for the protection of marine ecosystems. This zone included a site between Beauty Point and Shag Point (T14), but none within Middle Arm itself.

The majority of the BMJV water quality monitoring to 2008 occurred within and downstream of the defined mixing zone between Kildare and Bowens Jetty (Sites 1 – 7), except in 2001 when channel samples were collected from Middle Arm Creek down Middle Arm to near Beauty Point. Samples were collected twice yearly, and on several occasions during each event between two successive slack tides, in both the channel and on the "flats" to the west. Two samples were collected at each site on each occasion, sub-surface at 1 m and near the bottom (using a Van Dorn sampler). Depth profiles for salinity, pH, temperature and dissolved oxygen were collected at each site for each run. Water quality at other sites was also examined including at the treatment wetland complex release point in Middle Arm Creek (B10), Middle Arm Creek downstream of the discharge point (B12), mine water (B1), and the tailings dam discharge (T4), allowing the calculation of contaminant loads from the then current mining operations.

The basic tends in water quality shown by these data are summarised below:

- Most total metal levels were below the relevant ANZECC/ARMCANZ guideline threshold value (GLTV) for ecosystem protection over the period of monitoring.
- Arsenic, copper and zinc levels (total and dissolved) exceeded the ANZECC/ARMCANZ GLTVs at most sites at various times, particularly in bottom samples. Manganese levels were also elevated at some sites.
- The site at Shag Head was taken to represent baseline levels for Middle Arm, but was found to be impacted by elevated copper and arsenic levels from upper Middle Arm.
- Several tidal cycles may be required to flush metals out of Middle Arm to the Tamar River.
- Samples collected in 2002 in Deceitful Cove showed lower metal levels than at the Middle Arm Site 3 near Kildare nearest the tailings deposits.
- Water quality downstream of Kildare was best during high tide, when relatively 'clean' water entered the estuary, but metal concentrations increased during outgoing tides due to inputs from the upper reaches of Middle Arm.
- Zinc and manganese (as well as nickel and cobalt) in the water column were primarily attributed to treatment wetland discharges from B10, and fell during the extended period of reduced mill production 2006 – 2008.
- The major sources of copper and arsenic (as well as cadmium, lead and chromium) were diffuse sources, probably the historical tailings deposits and also the Brandy Creek catchment.

- In November 2002, sediment leachate samples (water draining from intertidal sediment as the tide falls) were collected between Middle Arm Creek and Scotchmans Point. These showed high metal levels (Table 3), with arsenic, copper, zinc, manganese and nickel, exceeding the relevant ANZECC/ARMCANZ guidelines (or low-reliability guidelines) at all sites. Lead levels exceeded the guideline at all but one site. Cadmium exceeded the guideline markedly at one Site (B2). These levels generally exceeded those found at the estuarine sites sampled further down Middle Arm on the same date and were representative of the levels to which benthic organisms are likely to be exposed at those sites.
- Higher levels of some metals at depth in open water relative to the surface suggest these are mobilised from bottom sediments to the water column.
- During periods of higher rainfall, freshwater flows from upper Middle Arm as a surface layer over higher salinity water near the bottom (salt wedge). At these times, elevated metal levels in the channels appeared to be associated with the upper layer, with lower salinity.

Units: µg/L	**B10 Discharge**	**B12 MA Creek**	**B2**	**B3**	**B4**	**B5**	**B6**	**ANZECC Guideline**
As (total)	23	55	162	44	133	344	147	4.5*
Cu (total)	40	33.2	88.6	31.8	56.7	19.0	77.0	1.6
Mn (total)	21,500	4,350	5,000	5,020	2,500	4,210	3,950	*80
Zn (total)	6,600	1,700	1,820	1,930	843	1,570	1,330	15

*Not established – low reliability guideline value

Table 3 - Sediment leachate metal levels (µg/L), Middle Arm (Koehnken, 2002)

Since 2008, water quality sampling has only occurred at a single site at Scotchmans Point, which is sampled monthly at high tide. Sampling has occurred at this site from approximately 1997 and continues today (data provided S. King, BCDR). Although the parameters tested have varied over time, it is clear that sulphate levels at times exceed those typical of seawater (2,700 mg/L; Collier, 1970) and the levels of several metals exceed ANZECC/ARMCANZ (2000) toxicity threshold values (Figures 7 & 8), including zinc, copper and, at times, total lead. Lead levels have generally been below the guideline value since 2009.

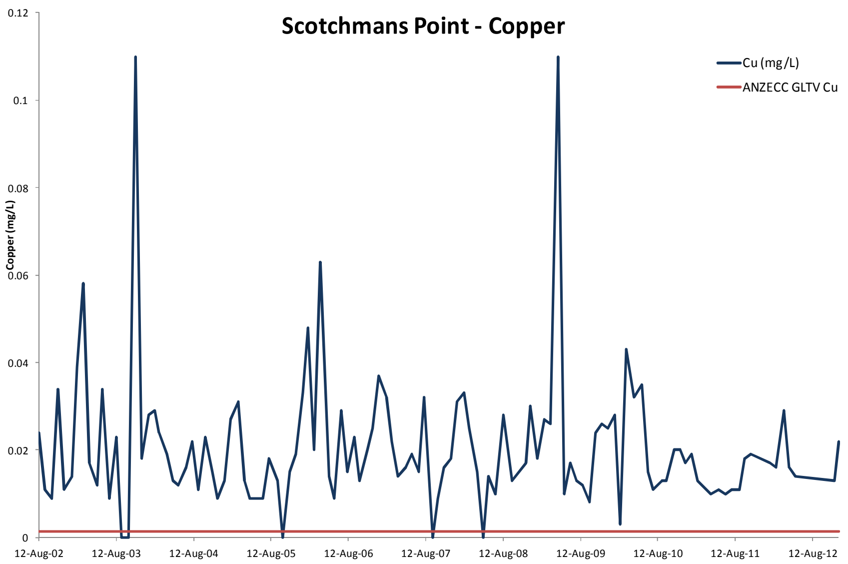


Figure 7 – Copper levels at Scotchmans Point, 2002 - 2012

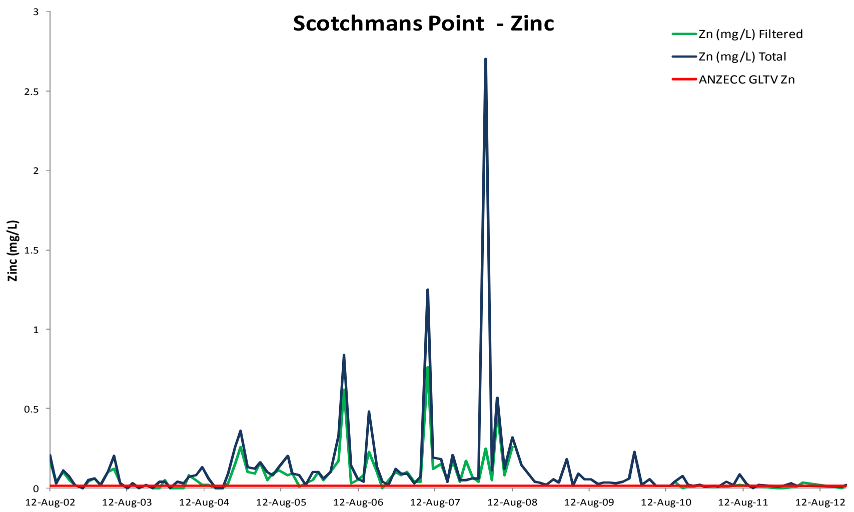


Figure 8 – Zinc levels at Scotchmans Point, 2002 – 2012

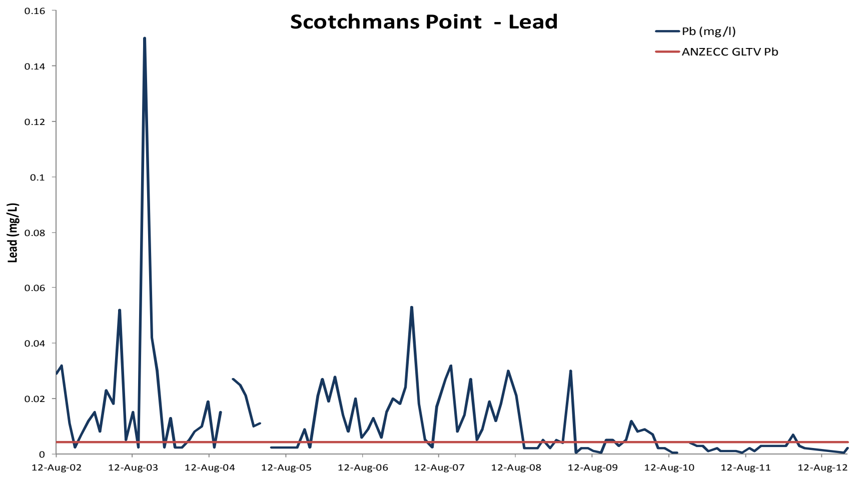


Figure 9 – Lead and sulphate levels at Scotchmans Point, 2002 – 2012

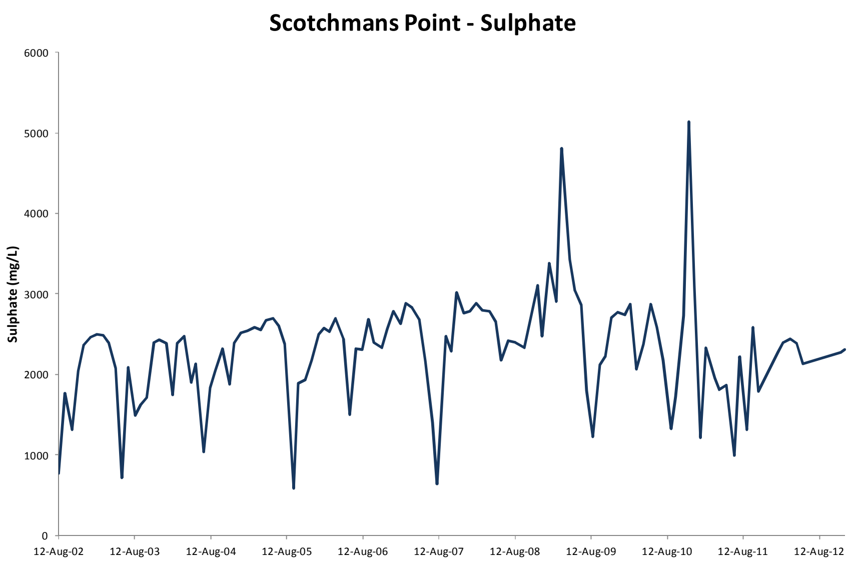


Figure 10 – Sulphate levels at Scotchmans Point, 2002 - 2012

4.2.3 Ecology and Fauna

Invertebrates

Two detailed ecological studies have been performed within Middle Arm, in 2003/04 and 2008 (Walker, 2004; 2009). During both studies, the subtidal infaunal communities along Middle Arm were examined quantitatively as well as those of West Arm, which was selected as a control or reference location. In 2003, a series of 8 sites (I1 – I8) were selected along the length of Middle Arm (within the channel) from the mouth of Middle Arm Creek (I1) to Beauty Point (I8); 5 of these I1 – I4) were within the historical tailings deposits, and another two (I5, I6) were located near the edge of the deposits. An additional 3 sites were selected within West Arm from the York Rivulet (I9) to Redbill Point (I11) where the arm enters the Tamar Estuary, north of Beauty Point. Three replicate samples were collected from each site using an Allstate Explorations boat and a 15 X 15 cm Eckman Grab sampler. In addition, intertidal fauna was qualitatively sampled intensively at 6 sites (B1 – B6) along the western shoreline of Middle Arm from the mouth of Middle Arm Creek (B1) to Pease Creek near Beauty Point (B6).

In 2008, this study was repeated but with two additional intertidal sites, one within Middle Arm Creek (B0) upstream of the B10 minewater discharge point and another within Clog Toms Creek (B12). In addition, in an attempt to separate current from historical mine impacts, three further sites were quantitatively sampled within Middle Arm Creek (MA1 - 3) and compared to three others within Clog Toms Creek CT1 - 3). Two replicate samples were collected at each site. Although differences were detected between these two sets of samples, they could not be definitively attributed to current mining discharges.

Once identified and enumerated in the laboratory, the data collected were subjected to a range of analyses to examine community structure. Most taxa were identified at least to Family level, and many to species level.

Thus a detailed record of the infaunal and intertidal invertebrate communities of Middle Arm, exists. This extends along its entire length, including the tailings deposits, forming a baseline for further studies. Similar, though less comprehensive, information has also been collected for West Arm nearby, unaffected by the Beaconsfield Gold Mine.

These two studies revealed:

- Middle Arm contains well developed infaunal and intertidal invertebrate communities. For example, approximately 110 family or higher taxa were found in Middle Arm and West Arm in 2008, containing more than 150 species (not all groups were speciated, and hence this number is an underestimate).
- These communities change in structure along the estuary, principally in response to the presence of the tailings deposits, sediment types and salinity. The number of taxa present (diversity) increased down the estuary.
- The communities present were divided into two main groups.
  - The communities of the historical tailings deposits and Middle Arm Creek (Sites I1-I4, I12).
  - Mid-estuarine and lower estuarine communities (Sites I5 and I6; Sites I7 and I8).
- The communities within Middle Arm Creek differed from those within the tailings deposits:

- Those found in Middle Arm Creek, upstream and near the B10 discharge and Clog Tom's Creek consisted of forms adapted to low and variable salinity. Although sediment was common, it was resuspended each high tide and extensive deposits were prevented by freshwater flushing in the constrained creek channel. Hard substrates were common. The fauna found was similar to that in the upper sections of other Tasmanian estuaries.
- Those within the tailings deposits were dominated by burrowing species, especially crabs and polychaete worms, and near Brandy Creek small molluscs.

- Although nearly 5 years apart, community differences between the two studies at each site were relatively small and generally less than differences between sites.
- The communities of the tailings deposits were very different from those within the rest of Middle Arm and also those in West Arm.
- Mid estuarine communities in Middle Arm (Sites I5 and I6) were similar to those in the upper and mid estuarine parts of West Arm (I9 and I10).
- Lower estuarine communities were similar in both water bodies (I7, I8 and I11).
- It was found that any impacts from current mine operations could not be separated from natural factors and the impacts from the historical tailings i.e. they were smaller.
- It was concluded that the primary determinants of the infaunal communities present in Middle Arm and West Arm were salinity, habitat availability and sediment characteristics. Based on the communities present, it appeared that freshwater influences extended much further down Middle Arm than West Arm. Although the higher freshwater influxes from both Middle Arm Creek and mine discharges to the headwaters of Middle Arm relative to those to West Arm would have accounted for some of this difference, most appears to have been due to the presence of the historical tailings deposits. The presence of the tailings deposits has resulted in the infilling of the upper estuary, the exposure of extensive areas of the upper Middle Arm estuary to the air at low tide, and the penetration of freshwater stream influxes and mine discharges, mixed with runoff from the mudflats, through channels all the way to Kildare. Thus the oligohaline or low salinity region of the Middle Arm estuary has been expanded physically for over 2 km downstream with consequent changes to the infaunal communities present and hence their similarity. This was coupled with major habitat modification due to the presence of the mudflats over the region from the mouth of Middle Arm Creek to Kildare. The mid-estuarine communities of Middle Arm (Site I5 and to a lesser extent I6) were also impacted although they were similar to those of the upper West Arm estuary (Site I9).

A range of other studies of Tamar River invertebrate communities have been completed as part of various monitoring programs (Aquenal & DEPHA, 2008). These include that of Smith (1993) which examined the intertidal invertebrates of Deceitful Cove and compared them to those of other nearby areas including East, West and Middle Arms, and a range of studies of Donovans Bay by Aquenal between 2001 and 2004 as part of the monitoring of the Bell Bay Power Station (Aquenal & DEPHA, 2008). Edgar et al (1999 – Appendix B) provides valuable information on the infaunal communities present in a range of Tasmanian estuaries, including 4 sites on the Tamar River – Low Head, Paper Beach and Long Reach. Identification was to species level. These data are summarised in Aquenal & DEPHA (2008) with totals of 116 species at Low Head, 32 species at Paper Beach and 43 at Long Reach. It is clear that the infaunal communities in Middle Arm are diverse with 47 species at Site I8, 36 at Site I7 in the lower estuary, and in excess of 83 species over all sites (Walker, 2008).

Aquenal (2006) have also examined infaunal communities much further upstream in the Tamar River at the outskirts of Launceston.

Fish

The Tamar Estuary supports over 100 species of finfish, largely comprised of estuarine and marine species (Pirzl & Coughanowr, 1997; Aquanel & DEHP, 2008). The estuary is an important nursery and breeding ground for a large number of these species. Surveys undertaken in 2001-2002 revealed that the Estuary provides spawning habitat for over 30 fish families (Lara & Neira, 2003). Additionally the Tamar Estuary supports a substantial recreational fishery.

Fifteen native and three introduced fish species have been recorded from the freshwater streams of the north-east of Tasmania (incorporating the Tamar River) with all but three of these species known to exhibit obligatory or facultative movements into estuarine environments (Chilcott & Humphries, 1996; Koehnken, 2001).

No detailed surveys of fish assemblages specifically in the Middle Arm were identified in the literature review. Records of fish have been taken during macroinvertebrate sampling (Walker 2004, 2008 and *pers. comm*.) in the Middle Arm estuary were largely comprised of estuarine goby species (*Favonigobius tamarensis, Arenigobius bifrenatus, Arenigobius frenatus, Tasmanogobius lordi, Tasmanogobius* sp 3 and *Pseudogobius olorum*), although Common Galaxids (*Galaxias maculatus*), Congolii (*Pseudaphritis urvilli*) and an unidentified specimen of the family Atherinidae (hardyheads and silversides) were recorded in the upper estuarine reaches of Middle Arm. These records represent general aquatic ecosystem sampling and were not targeted fish surveys.

The Tamar Estuary includes species protected under state, national and international instruments. Several threatened fauna species visit or inhabit the Tamar Estuary. A desktop search for threatened species within five kilometres of Middle Arm identified the following listed species that could potentially be impacted by the hazards listed in Section 4.

- Australian grayling (*Prototroctes maraena*) – Vulnerable (Tasmanian Threatened Species Protection Act 1995) and vulnerable (Commonwealth Endangered Species Protection Act 1992)
- Eastern Dwarf Galaxias (*Galaxiella pusilla*) – Vulnerable (Tasmanian Threatened Species Protection Act 1995) and vulnerable (Commonwealth Endangered Species Protection Act 1992)

Australian Grayling is found in small to large streams and rivers close to the coast and spends part of its life at sea. Larval fish are swept by the river current downstream to the sea and juveniles return to freshwater at four to six months of age. It is the juvenile phase in their life history that is most susceptible to impacts from this project. In Tasmania this species is widespread but uncommon. Threats to this species include structures such as dams, weirs and culverts which prevent dispersal and migration, changes in river flows, loss of riparian vegetation, extensive stream siltation, damage to stream channels caused by sand and gravel extraction, changes in food resources (*i.e.* macroinvertebrate communities) particularly due to siltation, and possible predation by brown trout (*Salmo trutta*) (Wager & Jackson, 1993; Bryant &Jackson, 1999).

Eastern Dwarf Galaxias have a cycle that is completed entirely in freshwater and if present in sites above Middle Arm are unlikely to be adversely affected by the project.

Other species of conservation concern which occur in the Tamar Estuary include school shark (*Galeorhinus galeus*), gummy shark (*Mustelus antarcticus*), and members of the family Syngnathidae such as spotted pipefish (*Stigmatopora argus*), wide-bodied pipefish (*Stigmatopora nigra*), pug-nosed pipefish (*Pugnaso curtirostris*) and Port Phillip pipefish (*Vanacampus phillipi*) (Aquenal & DEPHA, 2008).

Birds

The literature search failed to reveal any information concerning birds specifically within Middle Arm. However, the Tamar Estuary as a whole contains more than 60 bird species and is considered an area of international and national importance for shorebirds (Watkins, 1993; Department of Sustainability, Environment, Water, Population and Communities, 2012). Aquenal and DEPHA (2008) note that there are a number of resident and migratory wading birds utilising the Tamar Estuary. Resident birds include white-faced herons, pied oyster catchers, red-capped plovers and sandpipers that feed on the intertidal flats. A range of the migratory species are protected by the CAMBA and JAMBA international bird agreements.

The George Town/Tamar Estuary region is a priority site for nesting and migratory shorebirds, although, Cooper et al (2012) provide evidence that migratory shorebirds within the estuary are declining in abundance.

No bird surveys have been completed within Middle Arm, and although a range of water and other birds have been observed in the lower estuary during biological sampling, few water birds have been observed in the region of the tailings deposits, mostly in flight and not feeding (Dr Terry Walker, *pers. comm*.). These included a few Silver Gulls (*Larus novaehollandiae*) and a White Faced Heron (*Egretta novaehollandiae)* observed in the salt marsh at the edge of the arm.

A desktop search for threatened species within five kilometres of Middle Arm identified the following listed species that could potentially be impacted by the hazards listed in Section 4.

- Fairy Tern (*Sterna nereis*) – Rare (Tasmanian Threatened Species Protection Act 1995) and Vulnerable (Commonwealth Endangered Species Protection Act 1992)
- White-bellied Sea-eagle (*Haliaeetus leucogaster*) – Vulnerable (Tasmanian Threatened Species Protection Act 1995)

Estuarine Flora

The majority of the tailings deposit region of Middle Arm is surrounded by farmland, with patches of open eucalypt forest along sections of the eastern shoreline. It is unlikely any of the latter will be affected by the proposed tailings recovery program, which will be restricted to the tailings area within Middle Arm.

However, saltmarsh is common at the edge of the tailings area, and in some areas near Middle Arm Creek, where it extends onto the tailings as patches (Figures 11, 12 and 13). The major species noted during biological monitoring were *Juncus krausii* - sea rush, *Sarcocornia* *quinqueflora* - beaded glasswort, *Samolus repens* - creeping brook weed and, less commonly, *Suaeda australis* – seablite (Dr Terry Walker, *pers. comm*.). These saltmarsh plants are commonly found at the edge of Tasmanian estuaries (Saintilan, 2009). The introduced pest species *Juncus acuta* (spiny rush) was also found and common in areas such as Middle Arm Creek and Middle Arm to Scotchmans Point, generally mixed with *Juncus krausii*.

Figure 11 – Saltmarsh, near mouth of Middle Arm Creek, March 2008

Figure 12 – Saltmarsh species: *Sarcocornia quinqueflora* and *Samolus repens,* March 2008

Aquenal and DEPHA (2008) identified seven estuarine plant species in the Tamar Estuary region listed as rare or endangered. Although these have been recorded within the Tamar Estuary, none have been recorded from Middle Arm. If any of these are present within the proposed tailings recovery area, they would be at the edge of the tailings deposits, probably in isolated patches, and easily avoided.

Middle Arm also contains infestations of two estuarine pest plant species, rice grass *Spartina anglica*, and spiny rush *Juncus acuta.* Spiny rush has been observed along of Middle Arm Creek, and at various points along the western shoreline of Middle Arm (Figure 13) from Middle Arm Creek to at least Bowens Jetty (Dr Terry Walker, *pers. comm*.). Romanowski (2011) notes this species has been introduced from Europe and can be a serious environmental weed that is difficult to eradicate. Lane (2008) also reported the presence of spiny rush in Middle Arm.

Figure 13 – *Sarcocornia quinqueflora*, *Juncus krausii* and introduced *Juncus acuta* (right), mouth Middle Arm Creek, March 2008

The English rice grass species *Spartina anglica* was introduced at Windemere in the Tamar Estuary in 1947 and at other sites up to 1964 to stabilise and raise the mudflats (Pringle, 1993). Since then it has become a major pest and has spread to mudflat areas along the estuary. When Pringle (1993) surveyed the estuary the seaward limit was at Ruffins Bay, but since then has invaded areas further downstream, including Middle Arm (RGAG, 2002).

Figure 14 – Rice Grass, north Scotchmans Point in 2003 (left) and 2008 (right)

Rice grass is now established in seven of Tasmania's coastal regions and has been become a major invasive weeds species displacing native vegetation and the other organisms associated with these, including invertebrates and birds (RGAG, 1998). A detailed strategy has been formulated and implemented for the management of rice grass infestations in Tasmania (RGAG 1998, 2002).

Rice grass has spread along Middle Arm all the way to near the mouth of Middle Arm Creek, although it is patchy between this area and Scotchmans Point (Figure 14 and 15). At the latter site, the area of infestation increased over the period between the biological surveys of 2003 and 2008 (Dr Terry Walker, *pers. comm.*).

Figure 15 – Rice grass, south Scotchmans Point, March 2008 (absent in 2003).

4.2.4 Ecotoxicity

The literature search did not reveal any toxicological studies within Middle Arm or on waters or sediments within the historical tailings deposits.

However, two acute toxicity studies were found on species known to occur in the upper estuarine sections of Middle Arm Creek and Middle Arm, or closely related species. These were the effects of copper, cadmium and zinc on larvae of the crab *Paragrapsus quadridentatus* from Western Port (Ahsanullah and Arnott, 1978) and copper on the estuarine amphipod *Paracorophium excavatum* (Marsden & Wong, 2001) in New Zealand.

Although *Paragrapsus quadridentatus* was rare in Middle Arm (mainly found south of Scotchmans Point), the closely related *P. laevis* was common at most sites, including near the mouth of Middle Arm Creek.

The 96 hr LC_{50} (the concentration required to kill 50% of the test animals in 96 hours) for *P. quadridentatus* larvae was found to be 0.17 mg/L for copper and 1.23 mg/L for zinc. Larvae were found to be 29 times more sensitive to dissolved copper than were adult crabs, making them a sensitive test animal for toxicity. Given the abundance of the related *P. laevis* in the tailings are of Middle Arm, toxic effects from the elevated copper and zinc levels they are presently exposed to seem unlikely.

Although there is taxonomic uncertainty whether the Tasmanian *Paracorophium excavatum* is identical to that in New Zealand, it is very closely related and occupies the same environments.

This species was abundant in the estuarine section of Middle Arm Creek in the vicinity of the B10 wetland discharge, and the channels within the tailings deposits, as it is in many other Tasmanian estuaries (Walker, 2004, 2008). The Marsden & Wong (2001) study found that tissue copper concentrations increased with sediment copper concentration and concluded that *P. excavatum* was a suitable indicator species for use in ecotoxicological tests for marine sediments. Again, given the very high abundance of this species all over the Middle Arm tailings deposits, adverse toxicological effects to current exposures seem highly unlikely.

This is not to say that other, more sensitive species have been affected, but the presence in Middle Arm of most of the species commonly found in other Tasmanian estuaries, suggests that toxicity effects are not significantly affecting community structure.

4.2.5 Bioaccumulation

A range of studies have been performed examining the levels of metals and various other pollutants within organisms from the Tamar Estuary (Ayling, 1974; Department of Environment, 1973; Thompson, 2012; Gawne & Richardson, 1992a, b and Wood & Associates, 2002), or in species that are found in the Tamar Estuary (Ashanullah *et al*, 1978). Koehnken (2001) examined bioaccumulation in oysters using the information provided by Department of Environment for 1980, including oysters from Middle Arm. She reported that oysters within Middle Arm had higher tissue metal levels than those at the mouth at Beauty Point, particularly zinc, copper, iron and, to a lesser extent, cadmium.

Ayling (1974) found that copper, cadmium and zinc were concentrated in oyster tissues in the Tamar Estuary 10 – 40 times, relative to sediment levels, in contrast to the much higher levels generally accepted, which were based on levels in filtered water. Ayling also found that sediment metal levels could be used to predict the likelihood of metal contamination in oysters, but not the level.

The study revealed there were three distinct patterns of accumulation in Tamar River oysters:

- Accumulation up to a maximum weight, related to the size of the oyster and independent of the amount of metal in the sediment – copper and chromium.
- Randomly incorporated at sites with high sediment levels – lead.
- Accumulated based on sediment concentrations – zinc and cadmium

Importantly, this study examined sediments and oysters from Middle Arm and noted particular concern at the “phenomenally” high lead levels of 1,400 ppm in sediments as well as elevated copper levels of 220 ppm. Elevated copper and lead levels were linked to the vicinity of Devils Elbow and Middle Arm.

Other studies have also examined metal levels in sediments and oysters within Middle Arm including Department of Environment (1973), Wood *et al* (2002) and Koehnken (2001), but the precise location of sites are uncertain and the results variable. This may partly be due to the influences of other contaminated sediments in the vicinity for sites located at the mouth of Middle Arm and variability within the arm itself. It is apparent, from the studies available, that metals do bioaccumulate in oysters within Middle Arm, principally zinc, copper and cadmium (levels below food standards). Arsenic, copper, zinc and in some studies, lead and selenium reach levels within oysters exceeding FSANZ maximum limits (MLs) or Generally Expected Levels (GELs), sometimes referred to as food standards. In the mid Tamar Estuary, Middle Arm seems to be the major source of copper and arsenic, whilst Deceitful Cove appears to contribute most zinc. Other nearby sites were also found to contribute.

The latest study of the Tamar Estuary is that of Thompson (draft report 2012), on metal levels in Pacific Oysters (*Crassostrea gigas*) and a range of fish species. This study included a single site at Beauty Point at the mouth of Middle Arm, but none within the arm itself. The study revealed that metal levels in the fish examined were not in excess of FSANZ MLs or GELs and that in oysters:

- Copper and zinc levels were generally elevated in oysters along the estuary, but especially in the industrialised mid estuary around Deceitful Cove, Bell Bay and Middle Arm.
- Although elevated, zinc levels in oysters from Beauty Point were less than at other nearby sites.
- Total arsenic levels were exceeded the FSANZ ML in some replicate samples from Beauty Point. However, as a number of authors have indicated (*e.g.* Philllips *et al* 1992; Jain & Ali, 2000; Neff, 1997; Thompson, 2012; Fabris *et a l*, 1999), the majority of arsenic present in the marine environment is present as nontoxic forms and the levels at Beauty Point were likely to be much lower than the FSANZ ML.
- Metal levels in commercial oysters were lower than in Tamar River oysters.
- Lead levels were found to be low, in contrast to previous surveys.
- Metal levels recorded in this study were lower than those noted in 2002 by Wood & Associates (2002).

It should be noted that the current study is based on sites located along the Tamar Estuary, and included only 1 site at Beauty Point at the mouth of, but not within, Middle Arm. Hence, it is quite possible that earlier studies may be more indicative of levels within Middle Arm.

5 Hazard Identification& Risk Assessment

The potential hazards from the project are considered below as well as possible consequences and their likelihood of occurrence (Table 4). General mitigation measures are noted. Although not a formal risk assessment, a preliminary risk score is ascribed to each hazard, based on current knowledge, to highlight the hazards of most concern. This assessment assumes that the mitigation measures discussed are effective. The simple risk matrix below has been used for this purpose as per Standards Australia/Standards New Zealand (2004).

Likelihood		**Consequences**: *Minor*	**Consequences**: *Major*
	Probable	Medium Risk	High Risk
	Improbable	Low Risk	Medium Risk

Figure 16 – Simple risk matrix

A more formal risk assessment will be possible when further details of the project are known and knowledge gaps identified in Chapter 6 are addressed. Key issues are identified and discussed in more detail.

Although the precise details of methodology for tailings recovery remain to be decided, the hazards identified are based on the following assumptions:

- A cofferdam will be constructed across Middle Arm, probably at the narrowest point, near Kildare. The usual construction related impacts will need to be managed during this phase, including sediment remobilisation, fuel spills from machinery and so on. A wide range of construction guidelines exist for this purpose.
- The dam will maintain water levels upstream sufficient to allow a barge to operate at all tidal phases to remove tailings as a slurry. The precise height of the dam is not known at this point, but it is likely that some tidal exchange will be required for environmental purposes and that flooding from the catchment streams may require water releases.
- The hydrology of the resultant system and the interplay of freshwater influxes, reduced tidal exchange, currents and evaporation are unknown at this time.
- Tailings will be removed and pumped as a slurry by pipeline to the current processing plant, remote from Middle Arm. Reprocessed tailings disposed of either underground or into a suitable storage facility.
- Tailings removal will proceed for approximately 2 years until completion.
- At that time the cofferdam will be removed and normal tidal exchange will resume within Middle Arm. Some redistribution of the remaining sediment is expected.

Table 4 – Hazard identification and risk assessment

Hazard	Consequences	Likelihood and Mitigation	Ecological Risk
Construction of cofferdam	Raised water levels, particularly at low tide; altered salinity regime; altered period of exposure at low tide; disturbance of foraging birds	Changes are inevitable and discussed in more detail below. Level of impact depends on height of the dam and degree of change of factors such as salinity and salinity variability. Adverse impacts most likely with a rapid rate of change. However, much of the fauna currently colonising the tailings deposits will be removed when the deposits are recovered to be replaced by fauna more similar to that found prior to the presence of the tailings; birds appear rare and disturbance temporary.	Moderate
	Resuspension of contaminated sediment from construction activities.	See below.	Low - medium
Sediment suspension/resuspension	Resuspension of sediment bound contaminants, especially Zn, Cu and As, and with a more oxidising environment increases in dissolved forms, which are more biologically available; especially the case for deeper sediments where some contaminants appear to be present at higher levels than in surface sediments and locked in place by reducing conditions.	Technology is available to greatly minimise the escape of resuspended sediment during mining operations; existing evidence suggests that even fine sediment will resettle within 1 hour under still conditions. Tidal movements will resuspend sediment from the bottom of mined areas as is currently the case, but tidal current velocities are likely to be reduced during mining due to the presence of the cofferdam and resultant higher water levels at low tide. Turbidity should be monitored in the vicinity of operations, and points of tidal exchange.	Low
	Resuspension of sediment causing smothering of organisms, habitat modification and reduction in habitat complexity.	As noted, with appropriate technology, most sediment resuspension should be localised. Sediment resuspension from tidal and other currents is unlikely to be greater than that currently experienced. Organisms currently present are adapted to this. Habitat complexity is currently limited to fine sediment deposits and unlikely to be reduced.	Low
	Resuspension of sediment and smothering of fish breeding habitat and /or eggs.	Seems unlikely as sediment resuspension is already high; attached eggs are more likely in the freshwater reaches and most estuarine spawners (or larval drift) is pelagic; little change to this is expected.	Low
	Barrier to fish passage along estuary particularly anadromous and catadromous species migrating to breed	Cofferdam will provide a barrier to fish migration along Middle Arm. Adverse effects may be minimised by allowing adequate tidal exchange at specific points, which fish are likely to utilise.	Moderate - low

Hazard	Consequences	Likelihood and Mitigation	Ecological Risk
	Increased turbidity and lowered light penetration	For reasons above, increased turbidity is likely to be highly localised to the site of removal. Following sediment removal, light penetration is likely to increase. Turbidity is currently high and no macroalgae or seagrasses have been noted on the historical deposits, presumably due to unstable substrate and high turbidity. Filamentous microalgae exist within the MAC estuary near Auburn Road, but turbidity is currently very high and unlikely to increase. This site is removed from the prospective area of sediment removal.	Low
	Resuspension of cyanobacterial cysts with increased risk of toxic blooms. This risk would be increased if salinity is allowed to fall over extended periods. Resuspension of toxic algal cysts e.g. the dinoflagellates *Gymnodinium catenatum* and species of *Alexandrium*. Cyanobacterial/algal blooms present risks of toxicity to humans, pets and animals, aesthetic impacts, odours and fish kills on degeneration due to oxygen depletion. There is also the danger of the bioaccumulation of cyanobacterial toxins in shellfish and fish (Stewart et al 2012) in Middle Arm, and potentially human health.	There is no historical record of blooms within Middle Arm. Sediment resuspension minimisation technology would also minimise cyst resuspension. Providing tidal exchange is permitted, the salinity regime should not freshen to the extent that brackish species such as *Nodularia spumigena* would proliferate, as was the case when Orielton Lagoon in south-eastern Tasmania was dammed; in the latter the re-establishment of tidal exchange mitigated the problem (Jones *et al*, 1994; DEWHA, 2005). Tidal exchange should be maintained, albeit reduced as freshening and the addition of treated sewage from the Beaconsfield STP would increase the likelihood of eutrophication and cyanobacterial/algal blooms. Increased light penetration is possible as tailings removal progresses due to increased water depth and resuspension by tidal movements; this may exacerbate the likelihood of blooms in the short term. Algal monitoring to provide advance warning of blooms.	Low -medium
Maintenance of elevated water levels by cofferdam	Alteration to existing channel structure	Will occur as recovery progresses, but maintenance of existing channels may act to minimise sediment mobilisation. Location of water exchange points along cofferdam where channels currently exist would help to maintain existing water flows and channels.	High Low

Hazard	Consequences	Likelihood and Mitigation	Ecological Risk
	Freshening of upper estuary	If tidal exchange is limited, constant influxes from Middle Arm and Clog Toms Creeks will lower salinity upstream of the dam with a range of potentially adverse effects detailed below. Flooding will overtop the dam in any event. Can be mitigated by maintaining water levels sufficient to float and operate machinery but allowing tidal exchange over the higher parts of the tidal cycle. Once recovery and tailings removal commences, water level will be increased, even at low tide. May be possible to modify water levels over time to allow more exchange as recovery progresses, since removal will create deeper water. Water quality monitoring required.	High Low - moderate
	Changes in water chemistry and loss of buffering effects of seawater, including pH and salinity, if conditions become markedly less saline; increases in turbidity and dissolved metal levels	Most likely if tidal exchange substantially reduced. Biologically available metal levels may increase to toxic levels. Remobilisation of nutrients also possible. Unlikely if cofferdam allows adequate tidal exchange over part of tidal cycle. Water quality monitoring to confirm.	Low - moderate
	Increased metal loads downstream to Middle Arm; increased toxicity effects and/or bioaccumulation.	Unlikely if freshening and sediment resuspension minimised. Ecotoxicological monitoring of flows from recovery site and bioaccumulation monitoring downstream would confirm the presence or absence of these effects.	Low
	Increased risk of cyanobacterial blooms and eutrophication from freshening.	Likely if tidal exchange significantly impaired; adverse effects due to lowered salinity, sediment nutrient mobilisation, trapping of STP inputs and agricultural inputs from catchment. Cyanobacterial/algal blooms may cause fish kills on degeneration. Adequate tidal exchange would allow normal nutrient flushing and exchange along the estuary at high tide.	Low - moderate

Hazard	Consequences	Likelihood and Mitigation	Ecological Risk
	Stratification	With the formation of a large, shallow, saline water body with freshwater influxes, temporary stratification is possible at times of low flows and still conditions. This may occur as a result of freshwater flowing over denser saltwater, or due to heating of surface layers. Stratification may induce anoxia near bottom sediments facilitating the remobilisation of sediment bound metals and nutrients. Windy periods are likely to remix bottom and surface waters as well as any remobilised contaminants. Turbulent mixing by wind/waves would also prevent stratification. Mixing characteristics under conditions reduced tidal exchange are unknown as are those associated with influxes from catchment streams such as Middle Arm Creek. Hydrological modelling may be required.	Moderate - At times High
	Increased predation of invertebrates that normally feed at low tide when aquatic predators cannot reach them.	This will occur to some extent due to higher water levels. Faunal composition will alter in areas not normally flooded for long periods. However, these organisms will be removed with the tailings they occupy in any case. They will persist intertidally near the edges of Middle Arm similar to what would have been the case prior to the presence of the tailings.	Low
	Changes in infaunal community composition due to increased water levels and less exposure at low tide, particularly the oxypodid crabs occupying burrows in the tailings deposits.	This will occur. However, as noted above, these organisms will be removed with the tailings they occupy in any case. They will persist intertidally near the edges of Middle Arm similar to what would have been the case prior to the presence of the tailings. Providing sufficient tidal exchange occurs, the increase in nutrient levels due to the death of some organisms from increased inundation is likely to be insignificant.	Low
	Freshening of current upper estuarine areas and loss of important fauna	The upper estuarine areas of Middle arm Creek, for example, contain essentially normal estuarine fauna relative to other Tasmanian estuaries; inadequate tidal exchange could result in the loss of this fauna due to deceased salinity and freshwater influxes. Reduced but adequate tidal exchange would minimise this effect; some movement of fauna is likely but not its loss. Communities would re-establish on completion of the recovery process and the removal of the dam. Biological monitoring to confirm.	Moderate

Hazard	Consequences	Likelihood and Mitigation	Ecological Risk
	Reduction of sediment flushing in Middle Arm Creek estuary and other catchment stream estuaries.	Elevated water levels would reduce sediment flushing on outgoing tides, but would also reduce sediment entry on incoming tides; uncertain outcome, but fauna adapted to high sediment levels. Reduced but adequate tidal exchange would result in a situation more similar to current processes.	Low
	Increased access of pest species to catchment streams e.g. Mosquito Fish, *Gambusia*	With higher water levels over the lower part of the tidal cycle and reduced salinity, species such as *Gambusia* may have greater access to streams entering Middle Arm. The maintenance of some level of tidal exchange so that salinity levels are not reduced significantly would minimise this. The presence of *Gambusia* has not been investigated in these steams to date; it is not certain if it is present or not currently.	Low
	Potential increase in water bird numbers	The presence of an extensive, permanent body of water, especially if salinity is reduced, may attract water birds such as ducks. Their presence may increase their exposure to metal contamination if present. Their presence may also increase nutrient loads and the risks of eutrophication and algal/cyanobacterial blooms. It is uncertain if these birds would occupy the area for extended periods as there is no aquatic vegetation for them to feed on. Again, the minimisation of freshening by allowing adequate tidal exchange would reduce these risks.	Low
	Removal of foraging habitat for shorebirds	Elevated water levels at low tide will potentially remove foraging habitat, but area small relative to the available Tamar Estuary habitat. No formal bird survey data, but few birds noted foraging during other monitoring surveys.	Low
Removal of the dam Return to Full Tidal Exchange	Release of stored nutrients and contaminants such as metals to the lower regions of Middle Arm	This would mainly occur if levels of nutrients, metals or other contaminants were allowed to build up. Adequate tidal exchange and good management should prevent this. Staged reinstatement of full tidal exchange, coupled with adequate water quality monitoring, would also reduce the impacts of sudden remixing.	Low

Hazard	Consequences	Likelihood and Mitigation	Ecological Risk
	Impairment of organisms adapted to salinity and reduced tidal regime with dam in place Impacts from altered salinity regime	Salinity related impacts greatest if freshening has occurred from inadequate tidal mixing during recovery operations or as a result of recent flooding. Adequate management of tidal exchange across period of recovery would allow saline water to enter and mix; may get more saline bottom layers where benthos exist and less saline surface layers. This would minimise changes due to salinity. Organisms present would already have been exposed to variable salinity and be adapted to some extent. However, increases in salinity and changes in mixing characteristics in short term are unavoidable due to the removal of tailings deposits and increased depth by 2 -3 metres within the upper area of Middle Arm. This can be considered part of the process of rehabilitation of Middle Arm to a state more similar to that pre tailings. Staged removal may reduce impacts by minimising the rate of changes. Monitoring important prior to and during this phase.	Moderate
	Impairment of organisms adapted to salinity and reduced tidal regime with dam in place Impacts from altered tidal levels, especially low tide	These impacts would again be greatest if tidal exchange during tailings recovery was limited. Impacts would be greatest in the intertidal areas that were submerged during tailings removal, but become exposed at low tide during normal tidal exchange. A greater level of tidal exchange prior to dam removal would minimise this. Some impact is inevitable and considered part of the process of rehabilitation of Middle Arm to a state more similar to that pre tailings. Staged reinstatement of full tidal exchange may reduce impacts due to sudden changes.	Moderate
	Changes of aquatic faunal communities	This is an inevitable but positive consequence of removing the tailings and returning the upper Middle Arm physical environment to a condition more similar to that prior to that before tailings were dumped into its waters. It is expected that mid estuarine (mixoeuhaline) organisms will penetrate further up Middle Arm, with upper estuarine (oligohaline) restricted to less saline waters in streams such as Middle Arm Creek. Ecological monitoring to confirm this	

Hazard	Consequences	Likelihood and Mitigation	Ecological Risk
	Loss of saltmarsh communities on deposits	Intertidal saltmarsh communities along the shoreline should be relatively unaffected as tidal levels should be similar to those before tailings recovery, although salinity will increase within the upper reaches of Middle Arm. Depending on the extent of recovery, some or all of the patches of saltmarsh that had colonised patches of the tailings deposits offshore from the intertidal margins will be lost. Again, this is seen as this is an inevitable consequence of removing the tailings and rehabilitation of Middle Arm. Ecological monitoring would confirm this.	Low
	Spread of pest species	It is likely that with the reinstatement estuarine conditions and more solid substrate that pest species such as Pacific Oysters found in the middle sections of Middle Arm will spread into the upper estuary. Although not recorded in Middle Arm, other pest species such as *Carcinas maenas* (European Shore Crab) and *Musculita senhousia* (Asian Mussel) recorded in the Tamar River Estuary may also invade Middle Arm; this will be more a consequence of the spreading of these species through the Tamar Estuary as a whole than a consequence of tailings removal. Although this is undesirable, it is seen as minor in relation to the re-establishment of healthy communities similar to those found historically in Middle arm and the removal of much the potentially toxic tailings deposits. In addition, the removal of the tailings may reduce the spread of other pest species such as Rice Grass (*Spartina anglica*) which are currently established and spreading.	Low

The major hazards from the project to ecological communities are summarised as:

- Potential toxicity from metal contaminated sediments resuspended by recovery operations and increased levels of bioaccumulation within organisms.
- Significant freshening of the waters above the proposed cofferdam, resulting in a reduction of the buffering effects of seawater, and increased risks of contaminant and nutrient mobilisation, algal/cyanobacterial blooms and adverse ecological community changes.
- Potential adverse ecological effects from sudden changes in salinity and other factors on removal of the cofferdam.

As noted in Table 4, a range of technologies exist to substantially reduce sediment resuspension during the tailings recovery process and are used for a range of applications such as sediment removal in drinking water storages. The application of these technologies should adequately manage this issue and the aim should be to keep sediment disturbance highly localised. Water quality monitoring and auditing are required to ensure this is the case, permitting adaptive management where required. In addition, reduced tidal flows to Middle Arm below the cofferdam will minimise the movement of sediment further down Middle Arm. Flow regulation by the dam will form a component of sediment management when higher flows of sediment laden water occur during flood events in Middle Arm Creek and associated catchment streams. The presence of a semi-permanent lake above the dam for the duration of recovery, will enhance sediment settlement at these times, and minimise movement downstream.

The disturbance of deeper sediments with higher contaminant levels has the potential to increase contaminant levels within the waters above the cofferdam and also in flows to Middle Arm below, and thus resuspension of these sediments should be minimised.

Residual sediment build up near the cofferdam can be expected following recovery operations and this will be redistributed when the dam is removed. Care will be required to minimise this build up and control the rate of redistribution to prevent sudden smothering of faunal communities.

Monitoring of parameters such as turbidity and suspended solids levels at and near the site of operations will provide evidence of the success of measures to minimise sediment resuspension and allow adaptive management if required. Metal levels in ambient waters should also be monitored to demonstrate that they have not increased as a result of the disturbance of currently stable sediment deposits. Flows to the lower sections of Middle Arm should also be monitored at the dam and further downstream.

The presence of Pacific Oysters downstream of the proposed dam site presents an opportunity to use the phenomenon of bioaccumulation as an indicator of increased metal pollution loads. Oysters within Middle Arm are known to be contaminated with metals. The levels of selected metals in oysters at sites downstream of the cofferdam site can be ascertained prior to the commencement of the recovery project, forming a baseline. However, it may be difficult to control other variables such as changes in other sources of metals downstream to establish whether changes are attributable to tailings recovery operations.

The presence of the cofferdam will reduce current tidal flows. The level of reduction will be dependent on the levels of the dam (or flow passages), which in turn will depend on the level of water required at low tide to operate floating machinery. The saline waters currently present have several important characteristics in relation to the sequestration of metal contaminants into sediments including, pH buffering, flocculation of fine clays, metal complexation and the latter's effects on toxicity. Adequate tidal flows should be maintained over/through the dam to prevent freshening to the extent that these features are lost or significantly reduced. Freshening will also increase the risks of eutrophication and cyanobacterial/algal blooms, as well as other adverse ecological effects on fauna adapted to more saline conditions. Fish passage also needs to be maintained, particularly for species that migrate through the estuary to breed (anadromous and catadromous species).

Once tailings are removed at a particular location to the original bottom of Middle Arm, the depth of water available for floating machinery will be increased. Thus it should be possible to maintain a degree of tidal exchange while maintaining adequate depth of water for the recovery process, and sediment settlement during flood events. It is likely that denser saline water will flow along the bottom, under less dense fresher water on the incoming as a tidal wedge once a sufficient depth of water is available.

The presence of the dam will also affect the salinity regime below the dam, by regulating flows from the regions above in both extent and timing, although to a lesser extent than upstream. Water quality monitoring will define these changes, which are unlikely to impact substantially on the aquatic ecosystems of these waters.

Following tailings recovery, the removal of the dam, will be associated with additional changes to the hydrological regime of Middle Arm, to one resembling that present prior to the presence of the tailings. There will be a period of adaptation for ecological communities following this. Sediment remaining on the bottom will also be redistributed. Periods of sudden change may have deleterious effects on faunal communities. The major impacts will probably be associated with alterations in water levels at low tide, changes in the salinity regime and the contaminant levels in residual sediment present. The severity of these changes should be minimised to reduce these effects, for example, by staged removal of the dam, coupled with water and sediment quality monitoring.

As part of the Beaconsfield Gold Mine Development Proposal and Environmental Management Plan (DPEMP) (BMJV, 1997), Protected Environmental Values (PEVs) were identified for the Brandy Creek catchment and Middle Arm, Tamar Estuary. The proposed PEVs for the Middle Arm section of the Tamar Estuary in the vicinity of the discharge but outside an agreed mixing zone were:

- *Maintenance of the existing aquatic biological communities, particularly invertebrates and fish.*
- *Maintenance of the existing potential of that section of the Tamar Estuary for human recreational use – both primary and secondary contact.*

Although the PEVs for Middle Arm for the tailings recovery project have not yet been determined, the above PEVs form a useful guideline in the interim. The mixing zone would be a limited area below the cofferdam. For the remainder of Middle Arm downstream of the dam, the above PEVs would indicate that existing aquatic biological community condition should be maintained or improved and recreational access maintained during the project.

6 Knowledge Gaps

The information currently available has been listed and summarised in Chapter 4 of this report and the potential hazards to faunal values within Middle Arm posed by the Tailings recovery project are identified and discussed in Chapter 5. Although valuable information exists concerning sediment quality, water quality, and the biological communities within Middle Arm, a range of information not available is identified that would enhance the management of the hazards identified. This is detailed below.

6.1 Sediment

Although it has been established that the sediment within the tailings deposits are contaminated with various metals, the information is based principally on work performed by Koehnken (2002) nearly ten years ago, and a range of conflicting information from other studies. It is clear that sediment arsenic and copper levels are elevated and probably zinc, at least at some sites. With less certainty, mercury, manganese, nickel and lead may also be elevated, at least at isolated sites. Additionally, sulphur appears to be elevated. It has been concluded that most arsenic is probably not present in biologically available forms. It is also likely that metals are not uniformly distributed within the sediment deposits either vertically or horizontally, and evidence exists for the leaching of metals from surface sediments.

There is little doubt that the presence of these metals potentially presents a risk of toxicity to organisms within Middle Arm if they are or become biologically available. It is uncertain if these metals currently adversely affect the aquatic communities of Middle Arm or not.

It may be assumed that, as is typical in most estuarine sediments, nutrient levels in at least surface sediments would be high, particularly near Brandy Creek, but no quantitative information was found.

The following information would assist in the management of the hazards identified:

- Current sediment metal levels across a range of sites covering the area to be recovered and their significance for aquatic communities.
- Sites also located along the length of Middle Arm as a baseline for future monitoring and to examine the contributions from other sources not located within Middle Arm.
- The sediment parameters examined should include at least physico-chemical parameters such as pH, electrical conductivity, redox potential, turbidity, total suspended solids, dissolved oxygen and metals.

6.2 Water quality

More detailed information exists for water quality than sediment, but apart from Koehnken (2001), principally for the lower sections of Middle Arm, where detailed physico-chemical depth profiles were completed for over ten years as well as metal levels. Arsenic, copper and zinc appear to present the greatest risk to aquatic fauna, but manganese, nickel and cadmium were also found to be elevated in leachate from the tailings (Koehnken, 2002). Water quality monitoring data for Middle Arm are limited to one site at Scotchmans Point after 2008; these data suggest zinc, copper and possibly lead levels are elevated.

Further water quality sampling will be required to manage the hazards identified, including:

- Current water quality at sites along the length of Middle Arm to form a baseline for future monitoring during the recovery project; the sites used by Koehnken should form the basis for site selection, with additional sites selected across the region of the tailings deposits.
- Water quality sampling and analysis should be similar to that performed by Koehnken in the past, including at least physico-chemical parameters such as pH, electrical conductivity, turbidity, total suspended solids, dissolved oxygen and metals.

6.3 Ecology

Two detailed studies of intertidal and sub-tidal infauna have been completed, using West Arm as a reference location, although none since 2007/08 (Walker, 2004, 2009). Both studies used the same sites and methodologies and are hence comparable.

Some differences were found between the results of the two studies, especially within the tailings deposits, showing that communities alter over time in response to environmental conditions. It would be possible to use these studies as baselines for comparison with later studies during and following the tailings recovery, although a third round of sampling using the same study design would provide more recent baseline information.

Additionally, in view of the changes likely as a result of the construction of the cofferdam, a more focussed study design to specifically monitor changes in the waters above the dam would be pertinent, particularly those at risk such as the Middle Arm Creek estuary where a high diversity of estuarine species exist. In this case, as a focussed monitoring program, it would be appropriate to select specific organisms or groups of organisms as indicators of change rather than entire infaunal communities, if this is possible. This would save costs and allow more intensive monitoring, both in relation to sites and sampling frequency. A baseline study should be completed prior to the commencement of operations with sampling annually during the tailings removal phase. Another round of sampling would be completed after the cofferdam has been removed and communities have adapted to the new hydrological regime. Sampling sites should be carefully selected and used across all studies; initial selection should be based on the sites used in past studies (Walker, 2004, 2009).

The presence of any pest invertebrate species would also be detected and documented by these surveys.

6.4 Ecotoxicity

There is no information available on the toxicity of the tailings deposits of Middle Arm or the waters subject to metal contamination from these. Ecological evidence suggests that major toxicological effects are not present across Middle Arm. However, more localised or subtle effects are unknown.

Information concerning the potential toxicity of sediments and leachate from the tailings deposits to sensitive organisms would be very useful for the assessment of the risk of toxicity to fauna and the formulation of management tools.

Ideally, this would involve the exposure of known sensitive organisms from the receiving environment to a range of concentrations of contaminated water or sediment and the observation of a range of biological responses. Generally, such site specific assays are not possible, and as a result, a range of standardised laboratory based bioassays have been developed using organisms and responses known to be sensitive to various types of contamination, for both sediment and water samples (e.g. Simpson *et al*, 2005). The results of these may be used to assess the risk of toxicological impacts on natural ecosystems. If risks are significant, then appropriate management may be implemented and ecological studies performed to see if communities have been or are being adversely impacted.

Because these tests are based on whole samples, their advantage is that they examine the cumulative impacts of all contaminants present, rather than single toxicants. Water quality guideline values are based on single toxicants and do not take into account other factors present.

Ecotoxicological testing of sediments (or porewaters) and waters from the tailings deposits would reveal whether they are likely to be toxic and the likely degree of toxicity. Similar testing could also be used on waters (including suspended sediment) moving downstream from the tailings recovery area. Toxicity levels would be indicative of the risk to the communities of the lower regions of Middle Arm. For example, no or low toxicity indicated by the most sensitive bioassay would provide evidence that adverse ecological impacts would be unlikely, reduce the need for expensive ecological studies and indicate that risk mitigation measures are effective.

The bioassay(s) selected should be those known to be most sensitive to metal contamination in this case.

Appropriate ecotoxicological testing would include:

- Ecotoxicological testing of representative samples from the tailings deposits within Middle Arm prior to tailings recovery; should include deeper, potentially more contaminated sediments or their pore waters, since these may present a higher risk than leached surface sediments.

- Intermittent ecotoxicological testing of waters flowing to the lower sections of Middle Arm.

6.5 Bioaccumulation

Bioaccumulation is the phenomenon where certain organic and to a lesser extent metal contaminants present in the environment are concentrated to higher levels in the tissues of certain organisms. It is important because contaminants present in the environment in apparently "safe" levels can be concentrated to toxic levels within organisms. Some filter feeding molluscs such as oysters are known to be powerful bioaccumulators and form useful sentinels or indicator organisms for this type of pollution.

As noted earlier, the levels of various metals, including arsenic, zinc, copper, iron and possibly cadmium and lead, have been found to be elevated in Pacific Oysters within Middle Arm. However, the sites vary in location and evidence is at times contradictory. There are no recent data for metal levels in oysters close to the tailings deposits. As Pacific Oysters are present at intertidal sites close to these deposits, they represent a local species present in the receiving environment, albeit an introduced one.

Pacific Oysters would form a useful organism to assess the level and significance of the bioaccumulation of metals prior to and possibly during tailings removal operations. Wild and/or transplanted oysters could be used for this purpose. Transplanted mussels may also be useful as their abilities to accumulate pollutants are well understood, but they may not survive well in Middle Arm.

Initially, wild oysters should be examined to establish whether bioaccumulation is currently occurring. As metal levels in wild oysters appear to vary on a seasonal basis within the Tamar Estuary, sampling of these should occur at the same time of the year, preferably when levels are known to be highest.

The use of uncontaminated transplanted oysters has the advantage of removing confounding factors such as pre-existing contamination and non-uniform size distribution and condition, but when transplanted they need to survive and feed normally, which isn't always the case. Comparisons with oysters downstream of the dam may be inconclusive as other contamination sources may vary over time.

It may be possible to examine bioaccumulation in transplanted Pacific Oysters above the cofferdam immediately after construction as a baseline and then again during operations. If bioaccumulation is present, the trial could also be repeated after completion and removal of the dam, to ascertain whether the removal of the tailings had reduced metal availability as expected.

6.6 Saltmarsh communities

Saltmarsh communities within the upper sections of Middle Arm have not been formally surveyed, although their presence has been recorded at various locations during biological monitoring along with the presence of aquatic weed species such as *Juncus acutus* and *Spartina anglica*. Aerial photographs also provide some information as to broader distribution patterns.

Apart from some patches that have colonised the tailings deposits, it is unlikely that the saltmarsh communities present will be degraded. Nonetheless, as systems of high ecological value which are increasingly under threat (Adam in Saintilan, 2009), it would be useful to know the location of these communities and the presence of any rare, threatened or valuable species or especially well developed patches so that inadvertent damage these can be avoided during tailings removal in their vicinity.

Useful information:

- Basic survey of the location of saltmarsh communities within the tailings area; the location of major pest species should also be noted.

6.7 Fish

As with other biological communities, fish assemblages currently present in Middle Arm have been largely under studied. The limited studies that have been done suggest that the fish assemblages are largely dominated by goby species, with a few migratory species moving through Middle Arm to recolonise freshwater habitats upstream.

The existing conditions result from the mine tailings deposits in Middle Arm will have largely influenced the species that reside there and removal of the tailings will alter conditions towards pre-existing conditions. It is anticipated that fish assemblages will shift as a result and the more diverse habitat conditions will support a broader range of species.

If not properly designed and constructed the cofferdam may prevent fish passage into and from Middle Arm and upstream freshwater environments.

Useful additional information includes:

- Targeted surveys of current fish assemblages along the length of Middle Arm to form a baseline for future monitoring during the recovery project.
- A review of cofferdam options to maximise fish passage.
- Surveys of fish assemblages in freshwater streams upstream of Middle Arm to form a baseline for fish passage through Middle Arm and recruitment for species with an estuarine/ marine component in their life cycles.

6.8 Birds

No bird surveys have been performed specifically on the upper section of Middle Arm. However, during biological monitoring, the presence of various birds has been noted. Although water birds were recorded in the lower sections of Middle Arm during biological monitoring surveys in the past, only a few have been observed near the tailings deposits, and most of these were observed in flight rather than feeding (Dr Terry Walker, *pers. comm.*).

Despite this, at least a brief survey prior to the construction of the cofferdam may confirm the observations made during biological monitoring surveys, particularly if performed when migratory birds were present in the Tamar Estuary region, which includes Middle Arm. It would also provide a baseline for any surveys completed following the removal of the tailings when bird numbers may increase.

In addition, any wading or other water birds observed on or feeding above the cofferdam following construction should be recorded during other monitoring activities such as ecological and water quality surveys. Any build up of numbers should result in a review of the potential impacts of their presence as well as the potential impacts of the tailings recovery operation on the birds present. In addition, formal surveys of the species and numbers present may be required to assess potential impacts.

A bird survey would be desirable following the completion of the tailings removal and a period of 1 – 2 years to allow the recolonisation by aquatic fauna and stabilisation of their communities. An increase in bird numbers would confirm the successful rehabilitation of the area.

6.9 Hydrology

The impact of the cofferdam on the waters it will dam and also flows to Middle Arm downstream have been discussed in detail and a range of hazards identified. The water balance for Middle Arm upstream of the dam is a complex interaction of a range of factors including freshwater influxes, saline tidal influences, evaporation and mixing, which may change as tailings removal progresses. A hydrological assessment may be required so that the likely interplay of these factors is understood and to ensure the hazards identified are adequately mitigated or avoided.

7 Summary & outcomes

The major hazards from the Middle Arm Tailings Recovery project to flora and fauna are summarised as:

- Potential toxicity from metal contaminated sediments resuspended by recovery operations and increased levels of bioaccumulation within organisms.
- Significant freshening of the waters above the proposed cofferdam, resulting in a reduction of the buffering effects of seawater, and increased risks of contaminant and nutrient mobilisation, algal/cyanobacterial blooms and adverse ecological community changes.
- Potential adverse ecological effects from sudden changes in salinity and other factors on removal of the cofferdam.

With the use of appropriate technology, good management and adequate focussed monitoring the risks to ecological health within Middle Arm can be mitigated.

A useful, but incomplete body of information currently exists for water quality, sediment quality and biological characteristics of Middle Arm. Much of this was provided by various Beaconsfield Mine monitoring programs. A range of additional studies will be useful in providing baseline information for the management of risks and future monitoring of potential impacts. The general nature of these has been determined, including investigations within the areas of:

- Sediment quality.
- Water quality.
- Aquatic Ecology.
- Ecotoxicity and bioaccumulation.
- Saltmarsh distribution.
- Water bird distribution.

These need to be prioritised as details of the project are refined and detailed study designs developed. These studies should be integrated with each other and focussed on the common aims of:

- Providing adequate baseline information to permit monitoring and management of the potential hazards associated with the tailings recovery project so that adverse effects are avoided or minimised.
- Documenting changes to upper Middle Arm aquatic ecosystems as a result of the recovery program.

The likely outcomes following tailings recovery will include:

- The majority of tailings will be removed and the original channel of Middle Arm re-exposed. Any remaining sediment will redistribute. Evidence suggests that originally, most of Middle Arm would have been sandy – cores will reveal whether this was the case or not.
- Some sediment is likely to remain present in the upper sections of Middle Arm as is the case with West Arm; in the latter case, this is due to anthropogenic activity within the catchment e.g. land clearance as well as natural sediment transport.

- Due to continuous flows, the majority of sediment currently in Middle Arm Creek estuary is likely to wash out and be redistributed. Further sediment from activities upstream will continue to enter as is the case with West Arm. Tidal flows may return some sediment to the estuary.
- Benthic algae currently present in the Middle Arm Creek estuary near Auburn Road and covered in sediment at low tide is likely to proliferate due to increased light penetration.
- Sediment deposits in other streams such as Clog Toms Creek and Brandy Creek are likely to become reduced in depth and extent over time, but over a longer period due to lower flows than in Middle Arm Creek.
- Saltmarsh communities will remain associated with the intertidal zone and edge of Middle Arm as well the mouths of creeks, as would naturally be the case; patches that colonised the historical tailings deposits may be removed, but this depends on the degree of tailings removal.
- Intertidal fauna will display a more natural composition, being limited to the edges of the arm; saline influence will be restored to the upper sections of Middle Arm. Mixohaline species will spread back up into the upper sections of Middle Arm, and oligohaline species will be restricted to the upper estuaries as would historically have been the case. Unfortunately, pest species such as Pacific Oysters Crasso*strea gigas* may colonise shorelines further up Middle Arm due to increased salinity and potentially more hard substrates.
- The salinity and hydrological regime of Middle Arm will be more similar to the pre-tailings situation than with the deposits; tidal flushing will increase.
- Crab populations and other fauna currently taking advantage of the tailings deposits will be restricted to soft sediments at the edges of the arm, more akin to their former distribution. The species mix may well alter as the salinity and sediment regime alters.
- Depending on the extent of tailings recovery, existing beds of the invasive rice grass may be removed. In any event, their extent of spread will be limited by a reduction in the amount of intertidal sediment available for colonisation.
- Habitat diversity will increase in the current area of the tailings deposits, providing additional habitat for invertebrate and fish species; an increase in faunal diversity is likely.

On completion of the tailings recovery, the following ecological benefits are identified:

- The substantial removal of metal contaminated and potentially toxic sediments in the upper section of Middle Arm and current effects of leached contaminants further downstream e.g. metal bioaccumulation in oysters.
- The removal of the physical impacts of the sediment deposits and substantial re-establishment of a pre-tailings hydrological regime in Middle Arm.
- The re-establishment of ecological communities along the length of the estuary similar to those pre-tailings.
- A reduction in sediment input to the lower leaches of Middle Arm and the Tamar River Estuary as a whole.
- The likely flushing of sediment originating from the tailings deposits from the Middle Arm Creek estuary, near Auburn Road.
- Slowing of the spread of Rice Grass within Middle Arm as a consequence of the removal of sediment suitable for colonisation.

Apart from these ecological benefits, other benefits include:

- Re-establishment of recreational access.
- Substantial removal of seafood contamination source and reduction of potential risks to human health.
- Improvement in aesthetic values.
- Provide a case study where mineral extraction has demonstrated positive ecological outcomes, in this case in line with the aims of the TEER program.
- Provide important sediment quality, water quality and ecological information on Middle Arm.
- Financial returns and employment in the local area.

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