

**DESKTOP STUDY ON AVAILABLE SEDIMENT
INFORMATION FOR MIDDLE ARM BAY AND
ASSOCIATED LOWER TAMAR ESTUARY,
NORTHERN TASMANIA**

**BCD RESOURCES NL
BEACONSFIELD, TASMANIA**



DESKTOP STUDY ON AVAILABLE SEDIMENT INFORMATION FOR MIDDLE ARM BAY AND ASSOCIATED LOWER TAMAR ESTUARY, NORTHERN TASMANIA

Prepared for:

BCD Resources (Operations) NL
5 West Street, Beaconsfield TAS 7270

August 2012

CR 6720_1_v1



Coffey Environments Australia Pty Ltd ABN 65140765902
2 Melville Street Hobart 7000 Australia
T (+61) (3) 6108 0100 F (+61) (3) 6108 0199
coffey.com

© Coffey Environments Australia Pty Ltd August 2012

Project Director	Francisco J. Neira		
Project Manager	Elizabeth Pietrzykowski		
Author	Ana Lara-Lopez, Francisco J. Neira		
Reviewer	Samantha King – BCD Resources		28 August 2012
Version:	Details:	Approved:	Date:
CR 6720_v1-1	Initial draft to client	S. King	29 August 2012
CR 6720_v1-1	Final copy to client	F. J. Neira	30 August 2012

30 August 2012

Mrs Samantha King
Environmental Engineer
BCD Resources (Operations) NL – Tasmania Mine
PO Box 58 - 5 West Street
Beaconsfield TAS 7270

Dear Sam,

RE: Desktop Study on Available Sediment Information for Middle Arm Bay and Associated Lower Tamar Estuary, Northern Tasmania

The attached Final Report is provided in response to BCD request issued on the 6 July 2012 to carry out a desktop study on existing sediment data undertaken to date at Middle Arm Bay and the associated lower reaches of the Tamar Estuary. The report has been prepared by Coffey Environments Australia.

Please do not hesitate to contact me and should you have any queries on the contents of this technical report.

For and on behalf of Coffey Environments Australia Pty Ltd.



Dr Francisco J. Neira
Senior Associate

cc Dr Elizabeth Pietrzykowski
Dr Ana Lara-Lopez

CONTENTS

ABBREVIATIONS	VI
EXECUTIVE SUMMARY	VIII
1 INTRODUCTION	1
1.1 Project Background	1
1.2 Scope of Work and Objectives	2
2 BACKGROUND INFORMATION	3
2.1 Study Area	3
2.2 Infrastructure	4
2.3 Existing Information in Middle Arm Bay and Tamar Estuary	4
2.3.1 Field Data	4
2.3.2 Analysed Data	7
2.4 Information Requirements and Recommendations	10
2.4.1 Additional Field Data	10
2.4.2 Additional Data Analyses	11
2.5 Potential Impacts and Benefits of Removing Tailings from Middle Arm Bay	12
3 SUMMARY AND CONCLUSIONS	13
4 REFERENCES	15

Tables

1	Number of sites and sample type collected in Middle Arm Bay by Koehnken as part of the Environmental Protection Notice requirements. Environmental refers to samples of temperature, salinity, dissolved oxygen and pH; water quality refers to samples of heavy metal concentrations, TDS etc. Blanks indicate no data available.....	7
2	Studies with relevant analyses available for the Tamar Estuary system and/or Middle Arm Bay	7
3	Summary of raw data available for Middle Arm Bay showing which metals exhibited the highest concentrations at the different locations. Abbreviations: d, dissolved; t, total, * trigger values not yet established; x,data unavailable or not reported for that month. Refer to abbreviations table for metal symbols.....	9

Figures

1	Section of lower Tamar Estuary of showing the different sampling locations within and outside Middle Arm Bay.....	14
---	---	----

ABBREVIATIONS

Al	Aluminium
ANZECC	Australian and New Zealand Environment and Conservation Council
As	Arsenic
Ba	Barium
BMJV	Beaconsfield Mine Joint Venture
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
DO	Dissolved Oxygen
DHHS	Department of Health and Human Services
DPEMP	Development Plan and Environmental Management Plan
DPIWE	Department of Primary Industries, Water and Environment
EPA	Environment Protection Authority
EPN	Environmental Protection Notice
Fe	Iron
Hg	Mercury
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
MRT	Mineral Resources Tasmania

Ni	Nickel
Pb	Lead
Sb	Antimony
SO4	Sulphate
TDS	Total Dissolve Solids
TEER	Tamar Estuary and Esk Rivers
THCN	Thiocyanate
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
WADCN	Weak Acid Dissociable Cyanide
Zn	Zinc

EXECUTIVE SUMMARY

Early mining operations at the Beaconsfield Gold Mine between 1879 and 1914 involved the discharging of tailings into Middle Arm Creek and Middle Arm Bay, located in the lower Tamar Estuary in northern Tasmania. Approximately 540,000 tonnes of these tailings were processed for gold by Golconda during the period 1986 -1988 using cyanide-based extraction, but the low gold price coupled with cyanide leaks caused the company to shut down its operations. Recently BCD Resources NL has proposed to recover gold contained in the remaining tailings by pumping a layer of existing seabed sediments in Middle Arm Bay back to the Beaconsfield mine for reprocessing. However, the potential impacts of the sediment extraction process on the flora and fauna of Middle Arm Bay and lower Tamar Estuary need to be understood before such operation can commence, particularly from suspended sediments and pollutant dispersal following dredging operations.

BCD Resources NL therefore commissioned Coffey Environments Pty Ltd. to prepare a desktop study on the existing sediment and water quality data for Middle Arm Bay and lower Tamar Estuary, and to identify the information gaps that would need to be addressed regarding sediment data and analysis. Such baseline information is required to underpin future environmental impact assessments from extractive operations in Middle Arm Bay.

A number of available studies containing information on sediment and water quality data of Middle Arm Bay and the Tamar Estuary were reviewed. However, while most studies covered the entire estuary, the only data specific to Middle Arm Bay derived from monitoring carried out by the BCD Resources between 2001 and 2008 under EPN conditions.

The present review found that the existing gaps in the information currently available for Middle Arm Bay precludes the appropriate assessment of the risks that the removal of historical tailings may pose to Middle Arm Bay, and the subsequent development of suitable mitigation measures. It is therefore suggested that the following actions be carried out in order to fill up the existing gaps:

- Collection of additional environmental, water quality and sediment samples within and immediately outside Middle Arm Bay;
- Analysis of spatio-temporal distribution of heavy metals and their relationship with key environmental variables; and
- Development of a hydrodynamic current model of Middle Arm Bay.

Information from suggested actions will enable the assessment of any adverse environmental effects from the removal of tailings and highlight the benefits to Middle Arm Bay and lower Tamar Estuary in general.

1 INTRODUCTION

BCD Resources NL engaged Coffey Environments to carry out a desktop study on existing sediment data at Middle Arm Bay and associated lower reaches of the Tamar Estuary. Coffey Environments was also requested to outline any information gaps which needed to be addressed in order to compile the baseline information, detect likely risks this project may pose and determine management actions necessary to address these risks. Information from this desktop study will also help identify potential benefits of removing tailings and associated contaminants to the site and surrounding areas and the overall Tamar Estuary.

1.1 Project Background

The Beaconsfield Gold Mine is located in the town of Beaconsfield, approximately 40km north of the city Launceston in northern Tasmania, along the western bank of the Tamar Estuary. Mining operations at the Beaconsfield mine started in 1879, following the discovery of gold in 1877. However, difficulties with the continuous flooding of the shafts and production costs escalating above the value of gold at the time, forced the closure of the mine in 1914. During that period, a total of 1,085,000 tonnes of ore was processed, and mine waters and tailings were discharged into Middle Arm Creek and Middle Arm Bay in the Tamar Estuary. Such tailing management option resulted in extensive sediment build up between Auburn Road and Kildare (BMJV, 1997; Walker, 2004), and have since contributed to degradation in water quality and reduced boating access to Middle Arm Bay. Between 1986 and 1988, 540,000 tonnes of these tailings were re-processed by Golconda using cyanide-based extraction, but the low gold price coupled with cyanide leaks caused the company to shut down its operations.

Recently, BCD Resources NL proposed to recover the gold by pumping these historical mine tailings from Middle Arm Bay to an existing processing plant located 3 km away via a purposely-built pipeline. Such re-processing operation will in turn allow the rehabilitation of Middle Arm Bay and facilitate its return to its natural form and depth.

The proposed extraction and re-processing of mine tailings from Middle Arm Bay is set to be evaluated through the following steps:

- Exploration Licence application
- Test drill holes to determine depth and gold grade
- Assessment of likely environmental impacts from dredging
- Engineering and metallurgical studies
- Public consultation and submissions
- Preparation of a Development Plan and Environmental Management Plan (DPEMP) for EPA and MRT
- Mining Lease application

1.2 Scope of Work and Objectives

The proposed desktop study will evaluate and summarize existing sediment information for Middle Arm Bay and the lower Tamar Estuary, and address the information gaps regarding sediment analysis and available data. The information is ultimately intended to provide a better understanding of the significance of the likely impacts that the tailing extraction process may pose to the flora and fauna of Middle Arm Bay and the overall lower Tamar Estuary. It is understood that a local consulting company has been engaged by BCD Resources NL to assess the existing environment of Middle Arm, both in terms of water quality as well as flora and fauna (predominantly fishes).

The objectives of this desktop study are to:

- Review background information on the proposed project operations, including any new and existing infrastructure that will be required to undertake it.
- Locate studies and information available of sediment dynamics, sediment contamination and water quality in Middle Arm Bay and/or Tamar Estuary.
- Collate existing sediment, contamination and water quality data of Middle Arm Bay from local authorities, research institutions and BCD Resources.
- Assess existing sediment and water quality studies, and address information gaps needed to prepare a baseline representation of the area.
- Formulate recommendations to address information gaps.
- Identify potential risks to water quality, flora and fauna of Middle Arm Bay and surrounding areas resulting from re-suspension of sediment and contaminants during and after tailings removal.

2 BACKGROUND INFORMATION

2.1 Study Area

The Tamar Estuary is one of the largest estuarine systems in temperate Australia, and constitutes a major environmental, economic and social asset for Tasmania. The estuary corresponds to a highly-flushed mesotidal drowned river valley, and is characterized by one major navigable channel and a winding course comprising a series of shallow and extensive bays covering a large catchment area (Phillips, 1975; Bell, 1996; Edgar *et al.*, 1999). Tides are semidiurnal with a moderate diurnal inequality that has an approximately 6-hour flood and 7-hour ebb tide, and a tidal range of 3 m at Georgetown and 3.5 m at Launceston (Phillips, 1975; Pringle, 1982; Bell, 1996; Lara-Lopez, 2006). The estuary has been classified as a Type 2a or partially-mixed estuary (Hunter, 1991; Lara-Lopez, 2006), a quantitative classification based on the ratio of salinity contrast and the ratio of surface velocities and depth average currents (Hansen and Rattray, 1966). Vertical stratification of temperature and salinity along the main channel of the lower estuary is weak with considerably strong current velocities ($\pm 2 \text{ m s}^{-1}$), which suggests the absence of a two-layered circulation pattern (Lara-Lopez, 2006). Diffusion (i.e., tidal mixing) appears to be the main force driving the upstream salt flux, having an estimated exponential flushing time along the main channel of the lower estuary of approximately 10 days during moderate freshwater runoff ($75 \text{ m}^{-3} \text{ s}^{-1}$) (Lara-Lopez, 2006).

Industrial activities along the banks and catchment area of the Tamar Estuary have contributed significantly to the degradation of the estuary, including in the lower reaches of the estuary from historical, unregulated gold, iron and chromate mining in Beaconsfield as well as gold dredging activities in Middle Arm Bay (Wood, 2000).

Middle Arm Bay, in the lower Tamar Estuary is an embayment subjected to freshwater discharge via the Middle Arm Creek as well as several smaller, ephemeral streams draining at different points along the bay, and it is influenced by the same tidal forces that prevail along the entire Tamar Estuary. The catchment area of Middle Arm Creek is large and perennial, and covers agricultural land and State forests before entering Middle Arm Bay at its southern end.

The main body of Middle Arm Bay has been affected by the Beaconsfield mining operations, particularly as a result of the extensive deposits of fine sediment in the upper reaches and mine water discharge into the bay. Mining operations in Beaconsfield took place during two different periods; the first between the 1870's to 1914 when mine tailings were deposited directly into Middle Arm Bay; and from 1998 to 2012, during which time tailings storage facilities and a system of wetlands were purposely built to neutralize and decant mine water before draining into Middle Arm Bay (Parnell, 2008).

Water management operations between 1998 and 2012 were carried out as follows (Figure 1):

- Mine water was pumped to the highest point of the wetlands for de-watering (site B1);
- Mine water was combined with surface water runoff from Beaconsfield Township and flow through the first wetland to the Sump;
- 30% of the water was used for ore processing, with the remaining water flowing into the rest of wetlands system and discharged into Middle Arm Bay (point B10);
- Water collected at the Sump was used for ore processing, and tailings directed to storage facilities;

- Water from tailings storage facilities was then pumped via a decant (T4) to the wetlands system where it joined the rest of the mine water and surface runoff, and subsequently discharged into Middle Arm Bay (pointB10).

Under Environmental Protection Notice (EPN) conditions, it was required that BCD Resources (BCD) carried out monthly water quality monitoring at sites B1, B10 and T4, and bi-annual monitoring in Middle Arm Bay to ascertain if its operations were causing any additional environmental damage to bay and/or Tamar Estuary.

A proposal was made by BCD to re-process the historical mine tailings deposited in Middle Arm Bay and recover the gold, through an operation that consisted of pumping tailings from the bay to an existing processing plant at Beaconsfield.

2.2 Infrastructure

It is proposed that the removal of the mine tailings be carried out by pumping these as slurry through a purposely-built pipeline to the existing processing plant at Beaconsfield where gold and other minerals will be extracted. Consequently, no new infrastructure will be required for the purpose of pumping and re-processing tailings for mineral extraction. However, the construction of a small coffer dam is planned for a narrow section of Middle Arm Bay near Kildare, to maintain water levels for the tailing removal operations and to minimise the movement of any disturbed sediment and associated contaminants downstream into the main body of the Tamar Estuary.

2.3 Existing Information in Middle Arm Bay and Tamar Estuary

Information on hydrodynamics, sediment dynamics, pollution and biota of Middle Arm Bay is sparse. Instead, most studies have focused on the entire Tamar Estuary or are limited to the upper estuary reaches of the Tamar (e.g., Phillips, 1975; Barrenger *et al.*, 1986; Foster *et al.*, 1986; Hranisavljevic *et al.*, 1994a,b; Sinclair Knight LPH, 1995; Bell, 1996; Smith, 1997; Wood, 2000; Seen *et al.*, 2004; Lara-Lopez, 2006; GHD, 2009; BMT WBM, 2010). While some of these studies involved collection of data in Middle Arm Bay, none focused specifically on that location.

Information available on water quality and sediments exclusively from Middle Arm Bay derives mainly from water quality monitoring carried out bi-annually in the area by BCD to comply with EPN conditions.

2.3.1 Field Data

This section outlines information available on sample type and sampling techniques used in studies in Middle Arm Bay and/or Tamar Estuary.

Environmental Variables

Environmental variables such as water temperature, salinity, pH, DO, and current speed and direction, have been collected along the entire Tamar Estuary and within Middle Arm Bay. Information on the above parameters is contained in the following studies:

DPIWE Monitoring (1971-1996): Ongoing monitoring carried out by the Tasmanian DPIWE at several sites along Tamar Estuary since 1971. Data collected include temperature, salinity, pH, light penetration and DO; these data are not publicly available except in the form of summary reports and is therefore uncertain if there were data collected in Middle Arm Bay.

Wood (1992): Study provides salinity and temperature profiles at 14 sites along Tamar Estuary, along with drogues to calculate current velocities; no data were collected in Middle Arm Bay.

Koehnken (2001-2008): Monitoring surveys focused exclusively on Middle Arm Bay, with results reported in bi-annual reports. Variables encompassed pH, temperature, salinity and DO through the water column at 6 different sites during ebb tide within the bay. Most reports only provide salinity profiles, with only a couple of reports showing some results of temperature, pH and DO. Table 1 shows the number of sites and data type collected for these reports; raw data of these variables may no longer exist to be utilized.

Lara-Lopez (2006): Multidisciplinary study incorporating monthly salinity and temperature data along Tamar Estuary between October 2001 and November 2002; intensive sampling regime included three 24-hour sampling surveys in the lower estuary to examine tidal and diurnal cycles. Variables measured included current velocity data during spring and neap tides at three locations (lower, middle and upper estuary) in 2005; study did not include sampling within Middle Arm Bay.

Attard *et al.* (2011): Study reported monthly temperature, salinity, DO, pH, turbidity, light penetration (Secchi disc) and chlorophyll *a* data collected from October 2009 to September 2010 at 20 sites along Tamar Estuary; no data were collected within Middle Arm Bay except the nearby Beauty Point.

Water Quality

Water quality information such as concentration of heavy metal and other pollutants, as well as nutrients, is included in the following studies:

DPIWE Monitoring (1971-1996): Ongoing monitoring carried out by the Tasmanian DPIWE at several sites along Tamar Estuary; it is uncertain if surveys included Middle Arm Bay. Data includes chloride, total suspended sediments, SO₄, fluoride, pesticide compounds and faecal indicators. Data on heavy metal concentrations also collected along Tamar Estuary in 1986. Summary of the results are available in Pirzl and Coughanowr (1997).

Gawne and Richardson (1992): Study examined heavy metal concentrations at several sites in the lower Tamar Estuary and Deceitful Cove during four surveys. Analysed metals included Al, Ba, Fe, Hg, Mn, Pb and Zn; a summary of the results is provided in Pirzl and Coughanowr (1997).

Koehnken (2001-2008): Monitoring surveys focused exclusively on Middle Arm Bay, with results reported in bi-annual reports encompassing information on heavy metal concentrations at 6 sites within the bay and at key sites where mine water was processed before being discharged into the bay (Table 1). Reports include information on total and dissolved concentrations of Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sb and Zn, as well as SO₄, TDS, THCN and WADCN. The report from November 2002 also includes additional sediment leachate samples.

BMT WBM (2010): Monitoring surveys undertaken by the Tasmanian DPIWE at a number of locations within the TEER catchment, as well as turbidity records from Hydro Tasmania; data derive mostly from the catchment area as opposed to the estuary. Data on TSS, TN and TP are available from Brandy Creek which drains into Middle Arm Bay.

Attard *et al.* (2011): Study collected monthly data on dissolved nutrients, dissolved metals, and TSS from October 2009 to September 2010 at 20 sites along Tamar Estuary; no data were collected in Middle Arm Bay except off the nearby Beauty Point.

Sediments

Most sediment dynamic studies focus in the upper reaches of the Tamar Estuary due to concerns of siltation in this area of the estuary. A number of studies included sediment sampling within Middle Arm Bay, in addition to the bay monitoring commissioned by BCD. Information on sediments is contained in the following studies:

Foster (1986): Study examined suspended sediments and currents in the upper reaches of the Tamar Estuary to understand siltation problems in that section of the estuary. Results of this study were summarised by BMT WBM (2008).

Koehnken (2002): Study examined sediment surface samples collected in April 2002 at 10 sites within Middle Arm Bay and at a single site at Brandy Creek, which drains into Middle Arm; one subsurface sample was also obtained at a key site where mining operations take place. Analysed metals included Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn.

Wood (2002): Study carried out to investigate level of heavy metals in shellfish and fishes along Tamar Estuary; it also includes information from Middle Arm Bay. Surface sediment samples from 9 sites within the low water mark region were also obtained as part of this study. A minimum of 5 separate locations within each site were sampled. Sediments were also obtained with mid-water sediment traps to investigate the presence of re-suspended sediments.

Walker (2004): Study aimed to provide baseline information on biological communities in Middle Arm Bays, and to assess impacts from historical and on-going mining activities. Sediment samples were obtained at 11 sites within Middle Arm Bay to examine particle size; no replicas were taken during this study.

Other Important Information

Heavy metal concentrations have been measured in oysters and fishes along Tamar Estuary. Information on bioaccumulation of metals in oysters and/or fishes along the estuary and/or Middle Arm Bay is contained in the following studies:

Ayling (1974): Study assessed heavy metal concentrations in oysters following health concerns about consumption of oysters from Tamar Estuary, and included information on Middle Arm Bay. Analysed metals comprised Cd, Cr, Cu, Pb and Zn.

Wood (2002): Study commissioned by the DHHS to investigate concentrations of heavy metals in oysters and fishes, and included data from Middle Arm Bay. Analysed metals comprised Al, As, Ba, Be, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Mo, Ni, Se, Sn, V and Zn.

Thomson (2012): Report prepared for the TEER program on concentrations of heavy metals in oysters and fishes along Tamar Estuary. Study did not include samples from Middle Arm Bay except same obtained off nearby Beauty Point.

Table 1 Number of sites and sample type collected in Middle Arm Bay by Koehnken as part of the Environmental Protection Notice requirements. Environmental refers to samples of temperature, salinity, dissolved oxygen and pH; water quality refers to samples of heavy metal concentrations, TDS etc. Blanks indicate no data available

Month/year	Sediment		Water quality		Environmental	
	Lease Site	Sites Middle Arm	Lease Site	Sites Middle Arm	Lease Site	Sites Middle Arm
Dec-01			B10, B12	6	B10, B12	6
Apr-02	B12	10		6		6
Nov-02			B10, B12	11	B10, B12	10
Jun-03			B1, B10, T4	6	B1, B10, T4	6
Feb-04			B1, B10, T4	6	B1, B10, T4	6
Aug-04			B1, B10, T4	6	B1, B10, T4	6
Feb-05			B1, B10, T4	6	B1, B10, T4	6
Oct-05			B1, B10, T4	6	B1, B10, T4	6
Apr-06			B1, B10, T4	6	B1, B10, T4	6
Oct-06			B1, B10, T4	6	B1, B10, T4	6
Apr-07			B1, B10, T4	6	B1, B10, T4	6
Oct-07			B1, B10, T4	6	B1, B10, T4	6

2.3.2 Analysed Data

This section includes information available from studies incorporating analyses of sediment dynamics, hydrodynamics and/or heavy metal concentrations along Tamar Estuary and/or Middle Arm Bay. Most studies focus on the estuary as a whole, and include some data from Middle Arm Bay (Table 2).

Table 2 Studies with relevant analyses available for the Tamar Estuary system and/or Middle Arm Bay

Analyses	Tamar Estuary	Middle Arm Bay
Hydrodynamics	YES	NO
Sediment dynamics	YES	NO
Metal distribution studies	YES	YES
Metal dispersion dynamics	YES	NO

Foster (1986): Study focused on hydrodynamics and sedimentation processes in the upper reaches of the Tamar Estuary employing water levels, currents, temperature and salinity at different sites along the estuary. Study concluded that the tidal wave propagated asymmetrically upstream affecting current speed and sediment transport, i.e., a dominant flooding tide transports sediments upstream during dry conditions, and its asymmetry amplifies the tidal ranges in the upper estuarine reaches. While this study focused in the upper Tamar Estuary reaches, some of the findings could be applied to Middle Arm Bay

since this embayment connects directly to the main body of the estuary implying that the bay is affected by the same tidal forces.

Hunter (1991): Study commissioned by DPIWE to develop a hydrodynamic model that could explain observed values of salinity, nutrients and sediment concentrations in the Tamar Estuary, as well as to predict pollutant concentrations along the estuary. River flow data and salinity were used to develop that model. The study used a sectionally averaged model suited to partially mixed estuaries, and concluded that tidal mixing was the main force contributing to the horizontal salt flux along the estuary. While this study did not contain information or data from Middle Arm Bay, this shallow embayment is strongly influenced by the same diffusive forces found along the whole estuary. Findings of this study are essential to understand the processes that control sedimentation, as well as pollutant dispersal and distribution in the area.

Koenhken (2001-2005): Bi-annual reports of monitoring surveys focused on Middle Arm Bay include analyses of environmental variables, water quality and sediments. However, analyses are limited to qualitative descriptions variations in concentrations of heavy metal between sites, and very crude analyses of median and 95 percentile metal concentrations (from October 2006). Salinity data are represented as depth profiles for each site; results from temperature, DO and pH data are seldom reported.

Monitoring studies found that variations in salinity and temperature within Middle Arm Bay are influenced by a combination of tidal currents and freshwater discharge into the bay. Salinity and temperature decreased upstream showing little vertical stratification. Oxygen saturation in 2001 increased from 90% to 104% and was linked to a sea breeze, while pH varied from 7.7-8.0 in 2001 to 8.0-8.1 in 2005. Concentrations of Cd, CO, Cu, Hg, Mn, Ni, TDS, SO₄, WADCN and Zn derived mostly from the tailings dam (site T4), while Al, As, Cr, Fe, Pb, and Sb derived from mine water (site B1). However, consistently higher concentrations of As and Cu found in Middle Arm Bay suggest an additional source within the bay which could be related to leaching from the deposited tailings. Concentrations of As, Cu, Zn and were frequently above trigger limits in Middle Arm Bay. Studies also found that variability in metal concentrations and expansion of the mixing zone appears to be related to weather conditions such as precipitation and high winds. Table 3 summarises some of the metal concentration data obtained during the 2001-2005 monitoring period.

Lara-Lopez (2006): Main objectives of this multidisciplinary study included to describe the hydrography of Tamar Estuary, and classify the estuary according to its circulation and stratification; and to investigate the influence of tidal currents on the transport and retention of larval fishes in the lower estuarine reaches. The study included a one-dimensional box model to estimate flushing time in the lower reaches of the Tamar Estuary, through simulation of passive particles. The model estimated an exponential flushing time along the lower estuary's main channel of ~10 days in moderate freshwater runoff conditions. While the study did not include data from Middle Arm Bay, the residence time estimated for the lower estuary may also apply to this shallow bay.

BMT WBM (2010): Report estimated annual flows and loads of TSS, TN and TP into the Tamar Estuary using a modelling framework known as WaterCAST. This framework has the ability to simulate current catchment characteristics and responses, and evaluates the impacts of land use and supports a limited range of pollutant generation. It also facilitates the use of a range of rainfall/runoff models for individual subcatchments and land uses within subcatchments, and some water quality generation models. Reported outputs from the WaterCAST model cover the entire Tamar Estuary, and include data from the Middle Arm Creek catchment area.

Table 3 Summary of raw data available for Middle Arm Bay showing which metals exhibited the highest concentrations at the different locations. Abbreviations: d, dissolved; t, total, * trigger values not yet established; x, data unavailable or not reported for that month. Refer to abbreviations table for metal symbols

Month/Year	Mine water (B1)	Wetland (B10)	Tailings damn (T4)	Middle Arm	Elements higher in Middle Arm (MA) compared to B10	Elements above ANZECC trigger values in MA
Dec-01	-	Fe, Mn, Zn, Cd, CN, WADCN	-	Al, Cr, As, Ni,Cu	Al, Cr, As, Ni,Cu	Cr, CN, WADCN, Cu, Zn, As*, Mn*
Apr-02	-	Zn, Cu, Pb (?) taken from Nov 02 report	-	x	x	Cu, Zn
Nov-02	-	All except Cr	-	Cr	Cr	Cu, Zn, As*
Nov-02 L	-	Fe, Al, Mn, Ni, Zn	-	As, Cu, Cr, Cd, Pb, WADCN	As, Cu, Cr, Cd, Pb, WADCN	As*, Cr, Mn*, Ni, Zn, Cd, Co*, Cu, Pb, WADCN
Jun-03	Fe, Sb, As, Pb	Mn	Ni, Zn,Mn,Cd, Co, Cu,THCN,WADCN	TDS,SO4, Cr(d)	SO4, As, Cr, Cd, Cu, Pb, THCN	Zn, Cu, As*
Feb-04	Fe(d)	As(t), Fe(t)	SO4, Cd, Co, Cu, Mn, Ni, Sb, Zn, Pb	TDS,Hg, As(d), Al, Cr	SO4, Hg(t), As(d), Cu, Al(t), Cd(t), Cr(t), Pb(t)	Al*, Mn*, Zn(t), As, Cu, Pb(t), Cr(t), Hg(t),
Aug-04	Al, As, Cr, Fe, Pb, Sb		SO4, Co, Cu, Mn, Ni, Zn, Cd(t), WADCN	TDS, Cd(d)	SO4, Al, As, Pb, Cr(t)	Al*, Mn*, Zn, Cu, Cd, As*
Feb-05	Al, Pb, Sb, As(t), Cr(t), Fe(t)	Fe(d)	SO4, Cd, Co, Cu, Mn, Ni, Zn, THCN, WADCN	TDS, Al(d), As(d)	SO4, Al, As, Cr(t), Fe(t), Pb(t), THCN	Al*, Mn(t)*, Zn(t), Cu, Pb(t), As*
Oct-05	Sb, As(t), Cd(t), Cr(t), Pb(t)		SO4, As(d), Cd(d), Co, Cu, Fe, Mn, Ni, Zn, WADCN	TDS, Al	SO4, Al, As, Cd, Fe, Cr(t), Pb(t)	Al*, Mn*, Zn, Cu, Cd, As*
Apr-06	Sb, As(t), Cr(t), Pb(t)	WADCN	SO4, Cd(d), Co, Cu, Fe, Mn, Ni, Zn	TDS, As(d), Al(t), Cd(t)	SO4, As, Cu, Sb, Al(t), Cd(t), Cr(t), Fe(t), Pb(t)	Cu, As*, Mn, Zn, Pb(t)
Oct-06	Al, Fe, Mn, Ni, Pb(d), Co, As, Sb		Zn, Cu(t), Cd(t), Pb(t), Cr(t), Hg(t), WADCN	TDS, SO4	SO4, Al, Fe(t), Cd(t), Pb, Cr, As	Al*, Mn*, Zn, Cu, As*
Apr-07	Al(d), Fe(t), Mn(d), Ni, Pb(t), Co, As(t)	Cu(d)	SO4, Al(t), Fe(d), Mn(t), Zn, Cu(t), Cd(t), Cr(t), Hg(t)	TDS, Cd(d), Pb(d), As(d), Sb	SO4, Al, Fe(t), Cd, Pb, Cr(t), As, Sb	Zn, Cu, As*
Oct-07	Al(t),Fe, Pb, Cr, As, Sb(t)		SO4, Mn, Zn, Ni, Cu, Cd, Co, Hg(t), WADCN	TDS, Al(d)	SO4, Al, Fe, Pb, Cr, As, Sb	Zn, Cu, As*
May-08	Al(t), Pb, Cr(t), As(t)		SO4, Fe, Mn, Zn, Ni, Cu, Cd, Co, WADCN	TDS, Al(d), Cr(d), As(d), Sb	So4, Al, Fe(t), Pb, Cr, As, Sb	Mn*, Zn, Cu, As*

2.4 Information Requirements and Recommendations

Middle Arm Bay is likely to be influenced by the same tidal regime governing the dynamics along the lower Tamar Estuary. As such, information already available from the estuary could be utilized to assess the factors controlling sedimentation rates, and metal distribution and dispersion within the bay. However, since the morphology, bathymetry and sediment type of Middle Arm Bay differ from those in the lower estuary, both hydrodynamics and sediment dynamics may vary to some extent.

The following additional information will be required in order to assess the likely effects of removing the remaining tailings from Middle Arm Bay:

2.4.1 Additional Field Data

Environmental Variables

A sound understanding of sedimentation, geochemical and pollutant dispersion processes, and their linkages with environmental factors, is essential to assess the potential impacts that tailings removal may pose to the Middle Arm Bay and nearby lower estuary region, and to prepare appropriate mitigation measures. While a suite of environmental variables were collected in Middle Arm Bay by Koehnken (2001-2005), such data may no longer be available. Furthermore, these data were collected only during ebb tides and did not include spring-neap tidal cycles which may have a strong effect on the processes within the bay (Vale *et al.*, 1998; Eggleton and Thomas, 2004). It is therefore suggested that the following additional data be collected:

- pH, DO, temperature and salinity at the existing water quality monitoring sites through a complete tidal cycle at spring and neap tides (Figure1).
- Current velocity data at different sites across Middle Arm Bay through a complete tidal cycle during spring and neap tides, coupled with temperature and salinity measurements.
- Water levels and freshwater input information from the different tributaries that discharge in Middle Arm Bay; these data may be available from the Bureau of Meteorology or Hydro Tasmania.

Water Quality Parameters

Contaminants partition between aqueous and solid phases within estuaries and their spatial distribution depends largely on the hydrodynamics, biogeochemical process and environmental conditions (Eggleton and Thomas, 2004). Furthermore, their degree of bioavailability and toxicity depends on factors such as salinity, temperature, presence of other chemicals, pH, oxygen and reactivity of the contaminant (Eggleton and Thomas, 2004). While water quality monitoring of Middle Arm Bay was conducted bi-annually between 2001 and 2008, the results were never analysed in terms of the effects of environmental factors on concentrations and/or spatial distribution. Given that environmental data collected at that time may no longer be available it is suggested that additional water quality samples be collected, with replicas at the same monitoring sites used by Koehnken at spring and neap tides (Figure 1). These samples should be collected in conjunction with environmental samples for further analyses.

Sediment Information

Sediment data obtained in Middle Arm by Koehnken (2002) and Walker (2004) came from samples with no replication, and these were limited to surface samples and one sub-surface sample. Wood (2002) included a surface sediment sample from Middle Arm Bay with 5 replicas and a sample from a sediment trap from an unknown sampling location within Middle Arm Bay. It is therefore suggested that:

- Additional replicate samples of surface sediments be taken from the historical tailings at the same locations sampled by Koehnken (2002) (Figure 1). Sediment samples collected from tailings will provide information on geochemistry and particle size of the sediment. This information is necessary because accumulation of contaminants is dependent on particle size, and sediment disturbance can result in changes in the geochemistry of sediments making them bioavailable or toxic (Eggleton and Thomas, 2004). Results from these samples should be compared with Koehnken (2002) samples and analysed temporally.
- Suspended sediment samples are collected in the main channel of Middle Arm Bay using a mid-water sediment trap, and be analysed for sediment re-suspension, suspended particle size and metal concentrations in suspended particles. This is important to understand sediment distribution and dynamics.
- Core sediment samples are collected from tailings to obtain a sediment profile along with associated contaminants. It is important to obtain a sediment profile to examine horizon-specific chemical data since contaminant concentrations may vary with depth, and the removal of tailings is likely to expose some of these contaminants thereby affecting the surrounding environment (Spencer and MacLeod, 2002).
- Additional surface sediment samples to be taken at a pre-selected control site in order to evaluate natural variation as well as baseline metal concentrations prior to mining (i.e., background concentrations) for remediation measures.

2.4.2 Additional Data Analyses

A spatial analysis of metal concentrations and suspended sediments will provide important information on the spatial extent of metal distributions, and identify the areas of high risk. The data collected by Koehnken (2001-2005) could also be used in conjunction with any new data on heavy metal concentrations to analyse temporal variation.

Spatial and temporal analyses of metal concentrations from surface and core sediment samples will allow the evaluation of sediment chemistry at various depths, a step which is considered as necessary given that the pumping of tailings is likely to disturb deeper sediments that were previously undisturbed and exposed these to oxygen.

Statistical analyses of metal concentrations and variables such as temperature, salinity, pH and DO are regarded as an important step to understand the relationship between these variables and heavy metal concentrations, and help to better understand the processes taking place from sediment re-suspension during the removal of the tailings.

Furthermore, environmental data such as freshwater input, water level, salinity, wind regime and current direction and speed velocities may be necessary to develop a small-scale, localised hydrodynamic model of Middle Arm Bay to help the assessment of sediment dynamics, distribution, dispersion and residence time of heavy metals within the bay, and the extent of the mixing zone. Such model is considered as essential to plan mitigation measures should the removal of tailings be carried out.

2.5 Potential Impacts and Benefits of Removing Tailings from Middle Arm Bay

The proposal to remove and re-process historical gold mining tailings from Middle Arm Bay will remobilise sediments that were previously undisturbed, thus changing the chemical properties of the sediment-contaminant complexes and releasing previously trapped heavy metals (Eggleton and Thomas, 2004). The potential impacts of removing large quantities of tailings are:

- Release of metals trapped in deep, previously undisturbed sediments
- Greater exposure of released metals to oxygen and increased concentrations in the water column.
- Change of chemistry of heavy metals due to oxygen exposure, thus becoming available to bioaccumulation.
- Transport and dispersal of heavy metals into other areas of the Tamar Estuary.

The construction of a coffer dam near Kildare is likely to greatly reduce the transport and/or dispersal of sediments and contaminants into the lower reaches of Middle Arm Bay and the lower Tamar Estuary, thereby confining the effects to the upper reaches of the bay. The tailings deposited within Middle Arm Bay are fully exposed during low tide periods, thereby restricting boating access to the bay. Moreover, these tailings appear to contribute to the overall sediment load of the Tamar Estuary and are thought to be partly responsible for the high concentrations of As, Cu, Cd and Pb in the area. While the removal of these tailings may result in short-term localized adverse environmental effects, the long term benefits may outweigh these effects with the potential returning of the bay to its pre-tailing, natural form.

3 SUMMARY AND CONCLUSIONS

Information on sediments and water quality is currently available for the Tamar Estuary as a whole and, to a much lesser extent, Middle Arm Bay. The only data source with specific focus on Middle Arm Bay derived from monitoring requirements by BCD. Consequently, environmental information currently available for Middle Arm Bay is insufficient to fully understand the potential impacts that the removal of tailings may have on the bay and associated lower Tamar Estuary, and to identify the appropriate mitigation measures.

Results of the present desktop study support the additional collection of environmental, water quality and sediment data within Middle Arm Bay, and the subsequent analyses of these data at various temporal and spatial scales. These additional analyses should focus on heavy metal concentrations and sediments, and their relationship with other physical variables, as well as the development of a hydrodynamic model for the bay.

It is understood that the removal of historical gold tailings may have some adverse effects to the biodiversity of Middle Arm Bay. However, it would be necessary to assess if these effects may be outweighed by the benefits of returning the bay to its pre-tailing natural state.

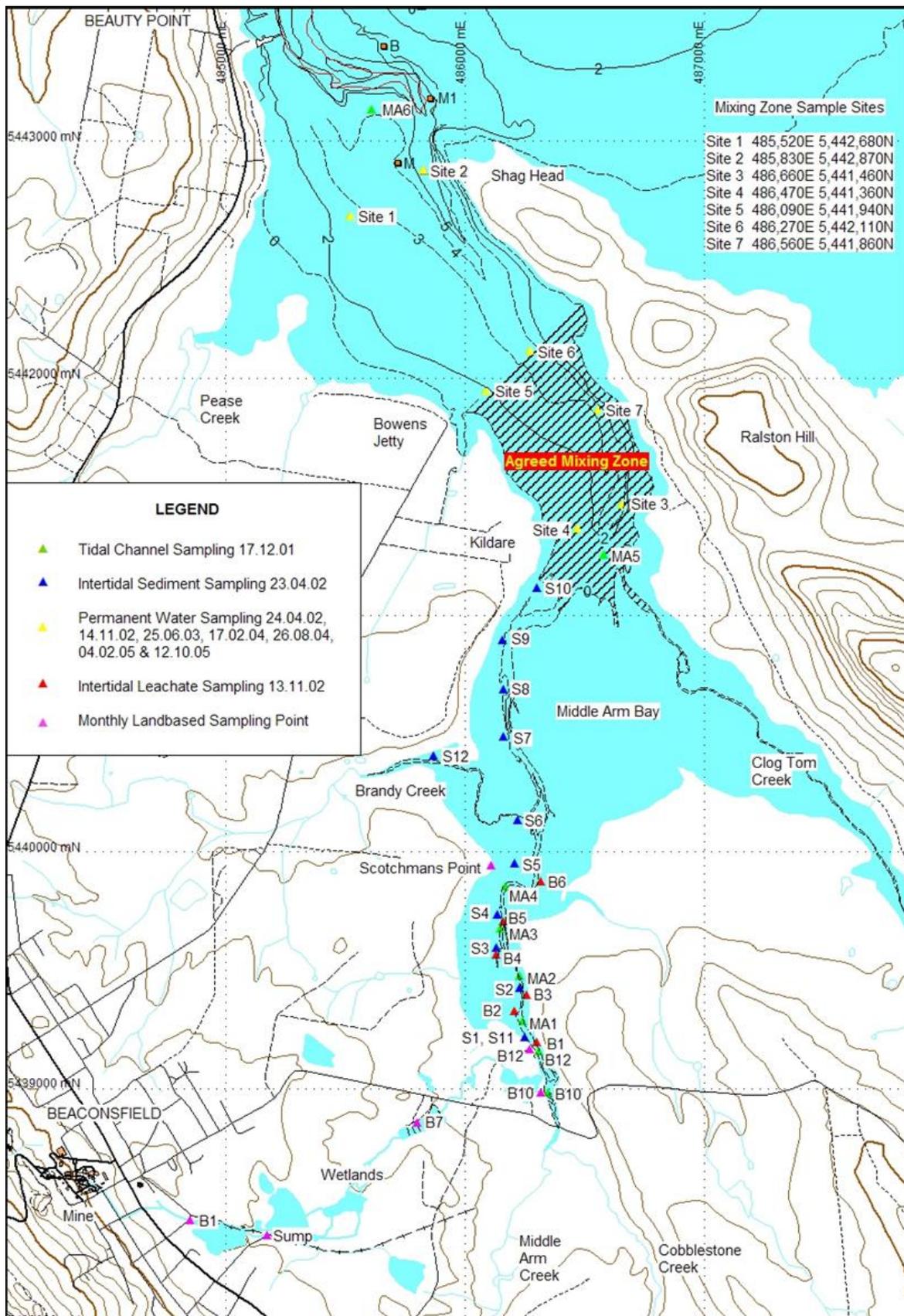


Figure 1 Section of lower Tamar Estuary of showing the different sampling locations within and outside Middle Arm Bay.

4 REFERENCES

- Attard M., Thompson M., Kelly R. and Locatelli A. 2011. Ecosystem Health Assessment Program, Monitoring Report 2011. Prepared for the Tamar Estuary and Esk Rivers Program.
- Ayling, G.M. 1974. Uptake of cadmium, zinc, copper, lead and chromium in the Pacific oyster *Crassostrea gigas*, grown in the Tamar River, Tasmania. *Water Research* **8**: 729-738.
- Barrenger, T.A., Laughlin, M.R., Jordan, P., Edwards, J.K., Steane, J.D., Hepburn, K., Kremer, H. and Joyce, H.K. 1986. Improvements to the upper reaches of the Tamar River. Tamar River Improvement Committee, Launceston.
- Bell, K.N. 1996. Foraminiferan faunas of the River Tamar and Port Dalrymple, Tasmania: A preliminary survey. *Records of the Queen Victoria Museum* **102**: 1-25.
- BMJV. 1997. Beaconsfield Gold Mine Development Proposal and Environmental Management Plan. Prepared by the Beaconsfield Mine Joint Venture, Beaconsfield Tasmania.
- BMT WBM. 2010. Tamar Estuary and Esk Rivers Catchment Model Final Report. Prepared for NRM North through the Tamar Estuary and Esk Rivers Program.
- Edgar, G.J., Barrett, N. and Graddon, D.J. 1999. A classification of Tasmanian estuaries and assessment of their conservation significance using ecological and physical attributes, population and land use. Tasmanian Aquaculture and Fisheries Institute, Tasmania.
- Eggleton, J. and Thomas, K.V. 2004. A review of factors affecting the release and bioavailability of contaminants during sediment disturbance events. *Environment International* **30**: 973-980.
- Foster, D.N., Nittim, R. and Walker, J. 1986. Tamar River siltation study. The University of New South Wales, Water Research Laboratory, Manly Vale, NSW.
- GHD. 2009. Report for upper Tamar River sediment evaluation study. Options for siltation management. Prepared for the Launceston City Council.
- Hansen, D.V. and Rattray, M., Jr. 1966. New dimensions in estuary classification. *Limnology and Oceanography* **11**: 319-326.
- Hranisavljevic, R., Nittim, R. and Cox, R.J. 1994a. Launceston flood protection scheme. North Esk assessment. The University of New South Wales, Manly Vale, NSW.
- Hranisavljevic, R., Nittim, R. and Cox, R.J. 1994b. Launceston flood protection scheme. Re-assessment. The University of New South Wales, Manly Vale, NSW.
- Hunter, J.R. 1991. Modelling of the Tamar Estuary, Tasmania. CSIRO Division of Oceanography, Hobart.
- Koehnken, L. December 2001. Mixing zone investigation in Middle Arm, Tamar Estuary. Prepared for Allstate Explorations.
- Koehnken, L. April 2002. Water quality monitoring in Middle Arm Estuary. Prepared for Allstate Explorations.
- Koehnken, L. November 2002. Water quality monitoring in Middle Arm Estuary. Prepared for Allstate Explorations.
- Koehnken, L. June 2003. Water quality monitoring in Middle Arm Estuary. Prepared for Allstate Explorations.
- Koehnken, L. February 2004. Water quality monitoring in Middle Arm Estuary. Prepared for Allstate Explorations.
- Koehnken, L. August 2004. Water quality monitoring in Middle Arm Estuary. Prepared for Allstate Explorations.

- Koehnken, L. February 2005. Water quality monitoring in Middle Arm Estuary. Prepared for Allstate Explorations.
- Koehnken, L. April 2006. Water quality monitoring in Middle Arm Estuary. Prepared for Allstate Explorations.
- Koehnken, L. October 2006. Water quality monitoring in Middle Arm Estuary. Prepared for Allstate Explorations.
- Koehnken, L. April 2007. Water quality monitoring in Middle Arm Estuary. Prepared for Allstate Explorations.
- Koehnken, L. November 2007. Water quality monitoring in Middle Arm Estuary. Prepared for Allstate Explorations.
- Koehnken, L. April 2008. Water quality monitoring in Middle Arm Estuary. Prepared for Allstate Explorations.
- Koehnken, L. October 2005. Water quality monitoring in Middle Arm Estuary. Prepared for Allstate Explorations.
- Lara-Lopez, A.L. 2006. Hydrodynamics and zooplankton ecology in the Tamar Estuary, northern Tasmania, with special emphasis on larval fishes. PhD Thesis, University of Tasmania.
- Parnell, J. 2008. Annual Environmental Report for Allstate Explorations. Balance Consulting Australia Pty Ltd.
- Phillips, A.W. 1975. The establishment of *Spartina* in the Tamar Estuary, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **109**: 65-75.
- Pirzl, H.R. and Coughanowr, C. 1997. State of the Tamar Estuary: a review of environmental quality data to 1997. Supervising Scientist, Natural Heritage Trust, Barton, ACT.
- Pringle, A.W. 1982. Tidal immersion of the Tamar Estuary *Spartina* marsh, Tasmania Australia. *Papers and Proceedings of the Royal Society of Tasmania* **116**: 143-152.
- Seen, A., Townsend A., Atkinson B., Ellison J., Harrison, J. and Heijnis, H. 2004. Determining the history and sources of contaminants in sediments in the Tamar Estuary, Tasmania, using ²¹⁰Pb dating and stable Pb isotope analyses. *Environmental Chemistry* **1**: 49-54.
- Sinclair Knight LPH. 1995. Launceston flood protection scheme. Status report. Sinclair Knight LPH Consulting Engineers, Launceston.
- Smith, B.J. 1997. Invertebrate fauna of the Tamar Estuary, Northern Tasmania. *Memoirs of the Museum of Victoria* **56**: 475-482.
- Spencer, K.L. and MacLeod, C.L. 2002. Distribution and partitioning of heavy metals in estuarine sediment cores and implications for the use of sediment quality standards. *Hydrology and Earth System Sciences* **6**: 989-998.
- Thomson M. 2012. An investigation of metal contaminant in wild oysters and fish from the Tamar River estuary. NRM North's Tamar Estuary and Esk Rivers Program.
- Vale C, Ferreira A.M., Micaelo C., Caetano M., Pereira E., Madureira E. and Ramalhosa, E. 1998. Mobility of contaminants in relation to dredging operations in a mesotidal estuary (Tagus Estuary, Portugal). *Water Science and Technology* **37**: 25– 31.
- Walker, T. 2004. Biological monitoring program baseline survey report for Beaconsfield Mine Joint Venture. Water ECOscience Pty Ltd.
- Wood, W.F. 1992. Report on the Tamar Estuary physical study. Prepared for the Department of Environmental and Land Management, Northern Regional Office, Launceston.
- Wood, W.F. 2000. Tamar Estuary fish and sediments study. First year report. Prepared for the Tasmanian Department of Health and Human Services.

Wood, W.F. 2002. Tamar Estuary fish and sediments study. Final report. Prepared for the Tasmanian Department of Health and Human Services.