Centre of Excellence for
Sustainable Mine Lakes

CSML

# FINAL REPORT TO STATE GOVERNMENT
## January 2002 to March 2007

Inclusive of annual reporting information for the final year of the Funding Agreement (April 2006 to March 2007)

Fostering the creation of mine lakes of value to the community, environment and economy, through collaborative research, education and training.

water quality prediction
remediation strategies
beneficial end uses

smart mine lakes

Executive Director
Professor Louis Evans


Images courtesy of Wesfarmers Premier Coal

# REPORT FROM CHAIR

The Centre for Sustainable Mine Lakes (CSML) has had a very productive five years of research. The ten research projects began slowly, gained momentum and a number of the projects are still operating.

The majority of the Centre's research has advanced the knowledge-base of water in final mine voids; these advances have, and will continue to, contribute to the creation of sustainable mine lakes.

The CSML collaboration between mining companies and universities has kept the focus of the Centre's research efforts directed towards the beneficial end uses for mine lake water.

Research, particularly research activities in the field takes a considerable time, with many of the Centre's projects requiring the full five years to achieve scientifically rigorous results. Up-scaling the trials to full-scale operations are continuing.

Issues surrounding acidic water, just like the salt water issues, will not go away. Here in Western Australia we must continue to research and evaluate trials in the management, remediation and usage of mine lake water.

CSML is one stage in the development of beneficial end uses for mine lake water. Research arising from the Centre has contributed scientific knowledge which can be applied to the development of recreation areas, aquafarms, industries and wetlands which will demonstrate that we can use our valuable water resources in a sustainable manner.

Despite the vigorous efforts by Professor Louis Evans (CSML Executive Director) and Mr Peter Ashton (formally Environment and Compliance Manager, Wesfarmers Premier Coal) it was not possible to attract sufficient financial backing from the four universities and the mining industry to continue the operation of CSML as a multi-institutional research centre.

For the duration of CSML's operation, mining companies across Australia have developed an increasing awareness of the obligation to plan for final mine closures and include a social legacy for the community. These companies will continue to seek out and contract researchers for assistance in applying the findings of the CSML research to their unique mining operations.

On behalf of the mining communities of Western Australia I would like to thank:

- The Western Australian Government, the mining companies, the Australian Coal Association Research Program, Collie based local government and community organisations and the four universities for the financing and support of the Centre for Sustainable Mines Lakes.
- The Research Project Leaders, post graduate students, research officers, assistants and volunteers for their dedicated work towards achieving project goals.

In particular I would like to thank Professor Louis Evans and Mr Peter Ashton, for their passion and leadership in the development of CSML, and the operation of the Centre throughout its five years of operation.

Dr Hilda Turnbull

Chairperson, Advisory Board, Centre for Sustainable Mine Lakes

## CSML research programs and corresponding research projects:

- **MINE LAKE WATER QUALITY PREDICTION**
  - Prediction of long-term water quality in mine lakes, with and without remediation
- **OFF TAKE WATER TREATMENT SYSTEMS**
  - Biological remediation
  - Mine lake water quality assessment using bioassays and chemical analyses
  - Construction and evaluation of a Fluidised Limestone Reactor (FLR) treatment system
- **BENEFICIAL END USES**
  - Polyculture as a beneficial end-use for mine lakes
  - Inland saline aquaculture
  - Environmental management system for mine lake aquaculture
  - Aquaculture health management
  - Mining for Country
  - World's best practice closure outcomes

# EXECUTIVE SUMMARY

## OVERVIEW

The Centre of Excellence for Sustainable Mine lakes (CSML) was established in June 2002 out of an urgent need for research and education on the sustainable use of mine lakes.

Following the cessation of mining activities below the water table, water levels recover to form a pit or mine lake in the mine void. The final water quality is dependent on a host of factors affecting water quality that can ultimately lead to the lake being affected by dissolved contaminants, high alkalinity, high acidity, and high salinity. Mine lakes affected by salinity or acidity have the potential to impact on local groundwater resources, as well as the broader natural environment[1].

Industry and regulators alike agree that of critical importance is the need to develop the science underpinning mine closure criteria so as to ensure ecologically sustainable closure plans that are achievable and realistic. Indeed, the State Government has indicated it is no longer viable for WA to exploit its natural resources without taking into account sustainable development principles[2].

A proposal to establish a Centre of Excellence for Sustainable Mine Lakes was developed in close consultation with the Australian Coal Association Research Program (ACARP) and submitted to the WA State Government in late 2001. A revised proposal with a reduced budget was submitted in January 2002, and WA State Government approval for the Centre of Excellence was announced in May 2002.

As per the State Government and CSML Funding agreement, this report serves as both the Annual Report for the final year of the Agreement (April 2006 to March 2007) and as an overview of the entire period of the Agreement (January 2002 to March 2007).

## THE PROJECT

Addressing the performance and management of final mine lakes to inform the development of regulatory guidelines and final-void management strategies have been the major challenges faced by CSML. With a focus on fostering the creation of smart mine lakes of value to the community, environment and economy, the Centre aimed to develop innovative solutions to the prediction of water quality changes in mine lakes over time, technology to improve mine lake water quality, and identification and assessment of various beneficial uses of mine lakes.

During the five year funding period, 2002-2007, CSML concentrated its efforts in three core areas – research, education and community service. The aims of CSML research were focussed around three core themes: 1) predicting the evolution of water conditions in mining lakes over time; 2) developing technological solutions to poor water quality conditions; and 3) identifying and evaluating opportunities to use mine lake water for community benefit or commercial enterprises. The education program mainly comprised undergraduate and post graduate research projects conducted by students from the four university partners but also included a bridging course for Aboriginal students wishing to study university undergraduate science or business degrees. The community service program concentrated on the facilitation of cultural, education and enterprise development initiatives by Aboriginal mining communities in Collie, Leonora and Laverton and by remote Aboriginal communities in NT and SA. Some of this latter work was funded by the Desert Knowledge CRC through a joint CSML/DKCRC project, Plants for People.

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[1] Johnson, S.L and Wright, A.H (2003) Mine void water resource issues in Western Australia: Western Australia, Waters and Rivers Commission.

[2] Gallop G, Premier's media statement, July 17, 2001.

## PEOPLE AND RESOURCES INVOLVED

CSML brought together the research and teaching resources of Western Australia's four public universities involved in the diverse fields that are encompassed in the study and management of mine lakes. Core partners included Curtin University of Technology, The University of Western Australia, Edith Cowan University and Murdoch University, Wesfarmers Premier Coal Limited, Griffin Coal Mining Company Limited, Sons of Gwalia, and AngloGold Ashanti Limited. The Australian Coal Research Program provided substantial financial support and further financial support came from the Collie community through the Shire of Collie and the Coal Miners' Welfare Board. The headquarters of the Centre was based in Collie with research and education programs conducted at other sites in Western Australia and North Queensland.

## MAJOR FINDINGS AND OUTCOMES

Throughout the five year funding period CSML attracted a total of $2 million in external grants and contracts beyond the initial funding support by industry and the State Government. The ratio of total sponsorship funding and income earned ($3,697,921) to government funding provided ($1,679,000) of 2.2 was within the normally accepted range of 2-3 and represented a very good outcome for the Centre and State.

A total of nine honours and four PhD student projects were completed, a further nine PhDs are in the final stages of completion, and two Aboriginal students successfully completed the Curtin University UniReady bridging course.

When the last submitted and accepted research paper is printed, a total of 103 research output materials will have been published by CSML researchers, and a further 100 presentations delivered, for the benefit of industry and future mine lake research.

Two Aboriginal communities provided with mentoring and project planning advice by CSML staff are now in the process of developing rural enterprises based on natural resources.

The CSML team contributed three chapters to an international workbook on the management of metal mine and metallurgical processes, towards an international effort to synthesise current knowledge on mine lakes. The manual is intended for use as a worldwide handbook for the mining industry on pit lakes and the issues surrounding them.

Significant research outcomes by the CSML team were as follows:

- An existing numerical model that had been developed for the prediction of algal blooms in drinking water reservoirs (DYRESM-CAEDYM) was extended to include ecological parameters and applied to the prediction of evolution of water quality of a mine lake in Collie, WA. The model was ground-truthed and found to accurately predict spatial and temporal water quality parameters in the lake. The new model includes user-defined aqueous species, calculation of aqueous speciation, gas phase and mineral equilibrium. Importantly, it also includes descriptions of sediment diagenetic processes. This is a new tool for investigating the impact of suggested mine lake remediation strategies, such as addition of organic carbon and/or nutrients and is now available for analysis of in-lake controls on water quality, particularly pH.
- The efficacy of treatment of adverse water quality in old and new acidic mine lakes using biological remediation approaches was trialled in Collie, WA. A conceptual model of the ideal passive remediation system was scoped-out based on the results of the approaches trialled to treat acid mine drainage in the lakes. The system is currently on trial at the City of Stirling's Spoonbill Lakes which have low pH ~2 waters derived from acid sulphate soil contaminated groundwater. An in-lake remediation trial to clean up toxic and acidic mine water at the Collinsville Coal Project (Xstrata Pty Ltd), North Queensland, using sewage and green waste, has also commenced following the project's results. Both projects show positive initial results, with the Xstrata initial results leading to Collinsville winning the Ergon Energy Tidy Towns 2006 Award for Environmental Innovation.

- Acute and chronic bioassays have been developed using the freshwater microalga *Chlorella protothecoides*, the rotifer *Brachionus calyciflorus* and the water flea *Daphnia magna* and used in a range of applications including the assessment of efficacy of various water treatment approaches including a wetland treatment system, and an analysis of the major causes of adverse water quality in Collie mine lakes.
- The Collie Aquafarm hatchery was used to produce silver perch fry, effectively closing the life cycle of silver perch in acid-remediated mine lake water for the first time. Polyculture production demonstrated greater increases in biomass than monoculture ponds in all production trials, which supported previous research into aquatic polyculture and the factors governing production in multi-species environments. The prospect of conducting commercial-scale aquaculture in remediated mine lake water was greatly encouraged as all participating species survived in aquaculture ponds that were supplied with mine lake water. Further, marron reproduced in all ponds at some point during the project, an indication that conditions were near optimum. Silver perch were also spawned during the project, presenting an attractive proposition to proponents of a commercial operation.
- An innovative fluidised limestone reactor (FLR) used to raise the pH of off-take acidified mine lake water from pH 3 to pH 6.5 has been developed and a semi-commercial scale prototype tested at the Griffin mine site. This technology is now being proposed for use in treating acidic leachates at a mine site in Queensland and acid water resulting from acid sulphate soils in WA, as well as producing water that is suitable for aquaculture and horticulture enterprises.
- For the first time a comprehensive summary of beneficial end uses of mine lakes and mine lake water from throughout the world has been undertaken. The study has also identified the general environmental impacts associated with these different end uses and developed a detailed assessment of the potential environmental impacts from different aquaculture production systems using mine lakes and mine lake water.
- A PhD project has examined best practice mine closure outcomes and will inform regulators and mining companies seeking to develop a policy framework for mine void closure that addresses the current gaps that exist in mine closure legislation in Australia. The economic modelling being performed in this project has the potential to be applied by mining companies considering mine closure outcomes. This model will provide both financial and non-financial values for mine void closure (using Lake Kepwari as an example), with the future aim of any company using the application when developing options for mine closure.

## FUTURE PROSPECTS

An expression of interest for a new Centre of Excellence in Mine Closure and Sustainable Resources was submitted to the State Government in October 2005, however was not approved to go to the full project application phase.

Alternative approaches to maintaining CSML as a functioning and vibrant research organisation post Centre of Excellence funding period were explored. New sponsorship arrangements for CSML research and administrative activities were pursued, as were opportunities to collaborate with other research centres in developing major research proposals. Unfortunately, these efforts did not result in a firm commitment by possible sponsors and it was decided to wind down the operations of the Centre at the completion of the State Government sponsored research. However, commercialisation of the outcomes of CSML research has been a high priority and commercialisation of the environmental and social science research conducted by CSML researchers is underway through new contracts and consultancies with mining companies and other clients.

Knowledge gaps in mine lake research have been identified and priorities for mine lake research established. Researchers in WA universities, that have been integral to the CSML research platform of fostering the creation mine lakes of value to the community, environment and economy, will continue to work in partnership with government and industry to deliver scientific information towards these areas that need urgent attention.

# CONTENTS

# 1. INTRODUCTION

## MOTIVATION FOR THE CENTRE

Collie is home to a number of abandoned mines that have filled with water over time, and had the potential for new mine lakes being created when current mining at Wesfarmers Premier Coal and Griffin Coal Mining Company ceases.

However, the water quality in the lakes has been affected by mining operations and the lakes are generally acidic due to exposure of pyritic coal seams to the atmosphere. Over the period 1996 – 2001 a series of research projects were performed through sponsorship of the Australian Coal Association Research Program (ACARP) to identify the source of acidity in the lakes and evaluate the opportunities that the lakes might present for beneficial end uses such as aquaculture. These projects were strongly supported by the local mining industry and the local community.

During this time Wesfarmers Premier Coal commenced a community development project focussed on the rehabilitation of a 103 Ha mining void into a recreational lake – the Lake Kepwari project. Relinquishment of the site for this purpose however required investigations into the prediction of the long-term water quality in Lake Kepwari.

Concurrently, Griffin Coal Mining Company had built an artificial wetland next to their Chicken Creek mine lake. The wetland was designed to treat acidic Chicken Creek Lake water to a standard suitable for aquaculture. The next step was to initiate science-based research to evaluate and improve the performance of this wetland.

With Wesfarmers' and Griffin Coal's research needs identified, the concept of forming a centre focused on much needed research in the overall area of mine lakes was developed.

Discussions were held between the four public universities, and support gained for a centre from leading Western Australian mining companies, ACARP, the Shire of Collie and the Collie Coal Miners Welfare Group. A funding submission for CSML was developed in consultation with these stakeholders, submitted and later revised with a request to match the $1.679M pledged by these stakeholders to provide vital infrastructure and research support required to achieve the stated objectives of the Centre.

The opening of the Centre was officially announced in May 2002 by then Minister for State Development, Clive Brown.

## CSML KEY OBJECTIVES

The Centre established the following key objectives to be achieved within the term of the Centre's research plan:

- Recruit a champion to lead the centre, with the right skills and networks and then provide support through quality staff, PhD students, Research Fellows and International Visitors.
- Establish an appropriate supporting structure including the Advisory Board and Management Committee and necessary staff (research and administrative).
- Attract the support and ongoing commitment of industry, the universities and the Department of Industry and Technology.
- Ensure certainty of funding for the first four years of operation.
- Develop the intellectual capital by the Centre through its academic staff, graduate students and networks.

- Deliver real benefit to the industry from the research conducted by the Centre, acting as a catalyst for change.
- Establish and maintain credibility with the mining industry.
- Establish self-funding mechanism in the medium term through scholarships, industry funds, and university support.
- Develop and enhance inter-disciplinary and international linkages.

## CSML KEY OUTPUTS

Key outputs from the Centre, as articulated in the research proposal, were to include:

- Local graduates at the undergraduate and postgraduate level with expertise in mine lake management and downstream uses;
- A research and education presence in Collie and potentially in other regional centres;
- Research reports and papers that lead to an enhanced understanding of mine lake management;
- Conferences, case studies and seminars on mine lake management;
- Improved market and research networks;
- An enhanced reputation for the State as a manager of mine lakes and for approaches to mine closure.

# 2. SCIENCE

## HIGHLIGHTS AND BREAKTHROUGHS

A snapshot of highlights and breakthroughs by CSML researchers during the 2006 funding period is presented below and principally covers successes in obtaining grants, awards, contracts and new partnerships. For an overview of the competitive research grants, industry funding and consultancies successfully obtained by CSML researchers since 2002 refer to section 7 Grant Funding. About 30% of CSML's additional income through competitive grants, contract research and consulting assignments was gained during the 2006/2007 funding period.

SWDC

| KEY INFORMATION | A REVIEW TO COMPLETE TRANSFORMATION |
|---|---|
| **Project Title:** Review of CSML research of Lake Kepwari and recommendations for water quality management<br><br>**Period:** 2007<br><br>**Funding Body:** South West Development Commission<br><br>**Amount:** $40,750<br><br>**CSML Recipients:** Evans L., Tsvetnenko Y. Neil L., Curtin; Oldham C. & Salmon U., UWA; McCullough C.D., ECU | The South West Development Commission (SWDC) works in partnership with business, industry, the community and government, striving to help improve regional communities and small towns, and to boost economic growth. Accordingly, the SWDC has a vested interested in advancing Wesfarmers Premier Coal's vision to see former mine void WO5B, now Lake Kepwari, complete its transformation from a mine to a recreational lake development of 103 hectares. In late 2006, CSML was contracted by SWDC to undertake a synthesis and summary of all literature regarding water quality monitoring and modelling completed to date on Lake Kepwari, along with a gap analysis on this literature. The request was initiated by the WA Department of Environment and Conservation (DEC), to provide information regarding the scientific knowledge of the water body and expected water quality trends over time. CSML was identified as the most appropriate organisation to perform this review and was specifically requested by the DEC, through the SWDC, to make recommendations for managing risks in identified areas of uncertainty. Lake Kepwari is now being opened up as a recreational centre in Collie. The final decision to relinquish the site to the State Government was strongly influenced by information provided to decision makers by CSML researchers. |

Indicative of the high reputation WA researchers have in mine lakes and mine closure, in 2006 CSML researchers across all three research programs were invited to contribute to an international workbook on the management of metal mine and metallurgical process drainage. Three chapters have been accepted for publication that relate to regulatory requirements and planning required to develop successful beneficial end uses, successfully rehabilitated pit lake examples, and mine lake water quality modelling. Research outcomes relating to mine lake research at Wesfarmers Premier Coal features strongly in these chapters. This book is an international effort to synthesise current knowledge on pit (mine) lakes, and is intended for use as a worldwide handbook for the mining industry on pit lakes and the issues surrounding them. The acceptance of CSML researchers' chapters for inclusion in the Society for Mining Engineering publication is a strong indication that CSML is leading the way internationally in mine lake research.

# ACARP

| KEY INFORMATION | ONE STEP CLOSER – COMMERCIALISATION OF INNOVATIVE WATER TREATMENT SYSTEM |
|---|---|
| **Project Title:** Fluidised Limestone Reactors for the Remediation of Acidic Drainage<br><br>**Period:** 2006-2007<br><br>**Funding Body:** Australian Coal Research Ltd<br><br>**Amount:** $121,430<br><br>**CSML Recipients:** Evans L., Tade M. & Tsvetnenko Y., Curtin | The potential benefit of design refinement for optimum performance of the conical Fluidised Limestone Reactor (FLR), developed and trialled through CSML research undertaken between 2002 and 2005, led to CSML researchers being awarded an ACARP grant in 2006 of $121,430 for a 14-month project titled 'Fluidised Limestone Reactors for the Remediation of Acidic Drainage Waters'. The Project, headed by Professor Louis Evans from Curtin, aimed to design a cost efficient commercial sized conical FLR, and to develop design guidelines for FLRs that efficiently utilise limestone and are capable of raising the pH above 6 in waters rich in iron and aluminium. Based on results achieved in this ACARP project, steps are now being taken to assess the commercial potential of this innovative treatment system. Refer to section 3 (CSML Research – Commercial, Scientific and Industrial Value) for further details. |

In October 2006, CSML hosted a two-day visit by Alcoa Anglesea and Alcoa Australia representatives to start considering how CSML's research focus might be adapted to the Alcoa Anglesea location and mine closure challenges. During the visit, Alcoa representatives toured CSML R&D sites to gain a better understanding of CSML's research programs and projects relevant to their operations. Mine lake potential end-uses, vital to a regulator acceptable closure plan, which capitalise on the Anglesea location was discussed and considered. This visit resulted in A/ Professor Carolyn Oldham from the UWA team visiting the Alcoa Anglesea operations in February 2007, where discussions were held on priority areas for effective mine closure in 10 years; mine lake configuration, catchments, and ecological impact on a nearby estuary.

# RIRDC

| KEY INFORMATION | IN SIGHT – RURAL APPLICATIONS FOR AGRI-AQUACULTURE SYSTEMS |
|---|---|
| **Project Title:** Integrating inland saline aquaculture and livestock production<br><br>**Period:** 2006-2009<br><br>**Funding Body:** Rural Industries Research and Development Corporation<br><br>**Amount:** $93,428<br><br>**CSML Recipient:** Lymbery A., Murdoch | Results from the final-year of CSML project *Environmental management system for mine lake aquaculture* were integral to achieving further funding success for CSML's Dr Alan Lymbery from Murdoch University. Dr Lymbery applied for funding in 2006 to the Rural Industries Research and Development Corporation (RIRDC) for a three-year project titled 'Integrating inland saline aquaculture and livestock production'. Management and utilisation of aquaculture effluents, a core focus of the CSML environmental management system project led by Dr Lymbery, forms the basis of the project. The RIRDC Environment and Farm Management program grant funding of $93,428 will support the further investigation of the potential for utilising crops and forage plants to filter aquaculture effluent in an agricultural setting. This project, to be completed by 2009, has the potential to provide a basis for integrated agri-aquaculture systems in rural areas of Australia. |

# WESFARMERS

| KEY INFORMATION | 'WORLD FIRST' AS SILVER PERCH SPAWN AND THRIVE |
|---|---|
| **Project Title:** Mine lake aquaculture interim project<br><br>**Period:** 2006-2007<br><br>**Funding Body:** Wesfarmers Premier Coal<br><br>**Amount:** $34,000<br><br>**CSML Recipients:** Whisson G. & Storer T., Curtin | Silver perch have been successfully spawned and reared using mine lake water, representing a 'world first' for closing the life cycle of silver perch using ameliorated mine lake water. Following extensive research conducted at Wesfarmers Premier Coal's Collie Aquafarm which demonstrated successful polyculture of marron and caged silver perch in ameliorated mine lake water, Wesfarmers committed funding in late 2006 of $34,000 for a 'mine lake aquaculture interim project' to breed silver perch fingerlings at the Aquafarm, adjacent to Wesfarmers' WO5H mine lake. This project was developed in anticipation of a successful FRDC funding application that would see the last five years of mine lake aquaculture research at Wesfarmers move into a development phase and demonstrate commercial viability of treated mine lake water in aquaculture. Silver perch larvae were raised across a three-week period in large nursery tanks and then stocked into ponds at the Collie Aquafarm, filled with ameliorated mine lake water treated by the CSML FLR system, where they were reared for a further 11 weeks. Three nursery tanks were installed, operating consumables covered, and the salaries of two full-time staff supported. The mine lake aquaculture interim project successfully supported the required silver perch spawning and associated fry-rearing across a 14-week period in early 2007. |

A CSML Scientific Review Seminar was held in March 2007 at Wesfarmers Premier Coal, Collie WA, which showcased research conducted by CSML across the previous four years. The seminar attracted 34 delegates from the mining industry, government, and Indigenous community, and had a particular focus on research outcomes in mine lake aquaculture, acidic water remediation technologies, Aboriginal enterprise development and the Lake Kepwari study.

# DAFF

| KEY INFORMATION | INDIGENOUS AQUACULTURE TOWARDS RURAL ENTERPRISE |
|---|---|
| **Project Title:** CSML Collie Aboriginal integrated aquaculture project<br><br>**Period:** 2007<br><br>**Funding Body:** Department of Agriculture, Fisheries and Forestry<br><br>**Amount:** $27,200<br><br>**CSML Recipient:** Evans L., Curtin; Ngalang Boodja Council | Linking Indigenous capacity development with CSML research outputs to extend the Centre's flow-on benefits was a key factor behind an Aboriginal integrated aquaculture project based at the Collie Aquafarm. The project facilitated training in fish husbandry, plant cultivation and marketing for Aboriginal students who will ultimately complete a one-year certificate course in Indigenous Aquaculture at the Collie TAFE. The Department of Fisheries, Forestry and Agriculture supported project is expected to contribute to the establishment of a viable Aboriginal aquaculture enterprise at Collie, and employment of trained Aboriginal people in the aquaculture industry in the South West of Western Australia. |

NHT

| KEY INFORMATION | WORKING TOGETHER – COLLIE FLORA PROJECT |
|---|---|
| **Project Title:** Sustainable weed control and habitat restoration in the Collie region<br><br>**Period:** 2006-2007<br><br>**Funding Body:** NHT Envirofund<br><br>**Amount:** $41,210<br><br>**CSML Recipient:** Evans L., Curtin; Collie Weed Action Group; Ngalang Boodja Council | Developing a management plan for weed control in State forests and other public areas of high conservation value, along with raising awareness of the devastation weeds can cause to our natural environment, is the dual focus of a community-based project running in Collie. On behalf of the Collie Weed Action Group and the Ngalang Boodja Council Aboriginal Corporation, CSML successfully applied for an NHT Envirofund grant of $41,230 in the 2006-2007 application round. The one-year project titled 'Sustainable weed control and habitat restoration in the Collie region' will also build the capacity of local people to carry out natural resource management and mine site rehabilitation activities. CSML's involvement as administrator of the project was a direct result of the Centre's past and present Collie-based community development, education, and research initiatives in partnership with local community groups. The project will specifically link in with activities conducted by Collie school groups involved a CSML DEST-funded ASISTM project aimed at using traditional Aboriginal knowledge about plants to encourage primary and secondary school children to excel in maths and science. |

Research conducted by Dr Geoff Woodall and Professor Louis Evans for CSML's Mining for Country project has demonstrated successful propagation and cultivation techniques of native plant species that could lead to Aboriginal business enterprises based around native plants of cultural significance. Cultivation studies were conducted on a total of eleven native plant species, nearly all of which have reported uses by Aboriginal people as either bush food or bush medicine plants. Major studies were conducted by Dr Woodall on tuberous plants found in the South West (*Haemodorum spicatum*, blood root), and in the North East Goldfields (*Ipomoea calobra*, a yam species) involving propagation investigations and growth trials under hothouse and field conditions. Both studies demonstrated the horticulture potential of these two native tuberous plants.

ACARP

| KEY INFORMATION | INNOVATIVE RESEARCH LEADS TO ENVIRONMENTAL AWARD |
|---|---|
| **Project Title:** Remediation of acid coal mine lakes using biological processes and organic material<br><br>**Period:** 2005-2006<br><br>**Funding Body:** ACR Ltd<br><br>**Amount:** $134,974<br><br>**CSML Recipients:** Lund M., McCullough C.D., ECU | An innovative ECU project funded by ACARP to clean up toxic and acid mine water at the Collinsville Coal Project (Xstrata Pty Ltd), North Queensland, has led to Collinsville winning the Ergon Energy Tidy Towns 2006 Award for Environmental Innovation. In collaboration with the Bowen Shire Council, the project is investigating whether municipal sewage and green waste is able to stimulate microbially-mediated sulphate reduction sufficiently to remediate a highly acidic pit lake. While sewage and green waste additions to the mine lake only commenced in July 2006, results to date indicate that bacteria feeding on the organic matter are reversing the process that caused the acidity to develop in the first place. Monitoring is planned until the end of 2007. |

As Executive Director of CSML, Professor Louis Evans was invited to present at the US EPA Pit Lakes conference in Reno, Nevada in 2004 and also to join the organising committee for the 10th International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production (SWEMP 2007), Bangkok, Thailand, December 2007. Considered acknowledgements of expertise, these invitations follow a total of 102 research output materials published by CSML researchers for the benefit of industry and future mine lake research, and close to 100 presentations delivered by CSML researchers since the establishment of the Centre.

GRIFFIN

| KEY INFORMATION | REVIEW ASSISTS IN PROJECT PLANNING |
|---|---|
| **Project Title:** Review of water quality limits for Collie industrial saline water discharge into the ocean<br><br>**Period:** 2006<br><br>**Funding Body:** Devereaux Holdings Pty Ltd<br><br>**Amount:** $11,022<br><br>**CSML Recipients:** Tsvetnenko Y. & Evans L., Curtin; Oldham C., UWA | Griffin Coal is considering options for discharge of waste water resulting from different ongoing and planned projects. One option is to use an existing pipeline constructed for ocean disposal of saline waste water of the Collie Power Station for discharge. However advances in technology for power station cooling operations and new projects for water desalinisation and carbonisation may well change the current water composition and increase the volume of waste water discharged into the ocean. In turn this could breach conditions of the current Department of Environment licence limits and national marine water quality guidelines. CSML was contracted by Devereaux Holdings Pty Ltd on behalf of Griffin Coal to prepare a review of the current concentration limits for Collie Power Station saline water discharged in the ocean pipeline; determine water quality parameters of current and prospective effluents; estimate water quality parameters in a composite effluent, and toxicant concentrations in a mixing zone of the ocean outfall, with and without desalinisation; and review available data on environmental impacts of the toxicants to marine organisms. The review determined the proposed scheme of disposal of saline water from new industrial developments in Collie, through the existing saline waste water discharge pipeline, may require further consideration. |

In May 2007, Professor Louis Evans was invited to present a public lecture within the 2007 Australian Innovation Festival program of events. Professor Evans' lecture 'Aboriginal Empowerment through Partnerships and Knowledge' outlined an innovative approach to teaching maths and science using traditional bush knowledge currently being carried out in a CSML project funded through the Australian School Innovation in Science, Technology and Mathematics (ASISTM). More than 50 people attended the public lecture held at Curtin University, with an article on the lecture appearing in the Canning Examiner. The Department of Education and Training's School Matters publication and Curtin's CITE magazine both profiled the ASISTM project as a direct result of the lecture.

# ACMER

| KEY INFORMATION | TAKING THE GUESS WORK OUT OF MINE LAKE WATER QUALITY PREDICTION |
|---|---|
| **Project Title:** Protocols for monitoring mine lakes for improved prediction of water quality<br><br>**Period:** 2006<br><br>**Funding Body:** ACMER<br><br>**Amount:** $79,000<br><br>**CSML Recipients:** Oldham C., UWA | CSML research has been vital in developing technical information to inform recommended guidelines to assist the mining industry in addressing issues related to proposed and existing developments below the water table. Now a collaborative project will produce a publication that provides mining companies and regulators with extensive standard protocols for the long-term prediction and monitoring of mine lake water quality. The CSML UWA team was successful in receiving an ACMER grant of $79,000 for a project that has the objectives of (1) establishing standard protocols for the monitoring of physical, chemical and biological characteristics on mine lakes, (2) aligning sampling protocols with data requirements of predictive modelling tools, and (3) improving efficiency of scenario testing for mine lake closure options. An important outcome will be a manual that describes the drivers and requirements for mine lake monitoring, the links to existing guidelines and detailed sampling protocols, and the pre-filling, during-filling and post-filling protocols which define the monitoring requirements to effectively take the mine to closure and relinquishment. A/Professor Carolyn Oldham is leading this project which involves collaboration with eight scientists from around Australia, and six industry representatives. |

The first student to receive a PhD relating to CSML research into mine lake management issues graduated in 2006, and is now applying his expertise in aquatic ecosystems impacted by acid sulphate soils to the estuarine environment. To date, four students have completed postgraduate degrees relating to CSML research, with a further nine in progression. Nine final-year undergraduate projects (Honours) have also been completed.

# DEC

| KEY INFORMATION | ONE MINE LAKE TO SOLVE NUMEROUS WATER CHALLENGES |
|---|---|
| **Project Title:** Simple prediction of water quality in Chicken Creek mine lake<br><br>**Period:** 2006<br><br>**Funding Body:** WA Department of Environment and Conservation<br><br>**Amount:** $25,000<br><br>**CSML Recipients:** Oldham C., Salmon U., UWA | One of Collie's most acidic mine lakes could play a key role in addressing water resource management challenges in the State's southwest. Chicken Creek Lake, a five-year old ground water filled mine lake with a pH of between 2.5 and 3 located at Griffin Coal Mining Company's operations in Collie WA, is at the centre of a plan that could see the lake temporarily store agricultural saline run-off. This follows results stemming from a $25,000 WA Department of Environment and Conservation funded project headed by UWA that used mass balance estimates to predict future water quality in the Chicken Creek Lake under a variety of different filling (and emptying) scenarios. Saline run-off from agricultural operations, a dedicated water supply for the Collie Power Plant, and the clean-up of the Wellington Dam are being addressed in the catchment scale water resources management plan. |

Three CSML researchers were invited to present at the Interact 2006 Air, Water and Earth Conference held in Perth, September 2006, under the themes of Mining and Environment, and Acidity and Salinity. This major international event enabled CSML researchers to transfer CSML research outcomes to the scientific, mining, and environmental management community that related to; toxicity assessment of limed and phosphorous amended mine lake water, mine lake water quality assessment using bioassays and chemical analyses, and the chemical profile of inland saline water and its effect on the aquaculture potential of selected marine species.

BHP

| KEY INFORMATION | BRINGING OCEAN LIFE TO THE PILBARA |
| --- | --- |
| **Project Title:** Cultivation of seaweed in inland saline water<br><br>**Period:** 2006-2009<br><br>**Funding Body:** BHP Billiton<br><br>**Amount:** $30,000<br><br>**CSML Recipients:** Fotedar R., Curtin | The ocean may soon give rise to a new environmentally sustainable industry in central and north-west WA when the cultivation of seaweed in inland saline water is put to the test. A BHP Billiton funded scholarship of $30,000 is supporting a Curtin-based PhD project exploring the possibility of cultivating seaweed in inland saline water and ionically modified inland saline water, such as that resulting from open cut mining activity in the State's Pilbara region and salinity caused by the mobilisation of geologically stored salt through rising water tables. Salinity is a major problem in Western Australia with serious damage occurring to aquatic and terrestrial ecosystems, affecting the profitability of agricultural land. Hydrogeological connection of mine voids with important wetlands or groundwater resources in the Pilbara region is also a major consideration, as there is potential for mine lakes to become point sources of hypersaline water. However inland saline water-bodies have an ionic composition similar to ocean water and have the potential to be productively used for cropping appropriate macroalgae such as seaweeds. Because seaweed absorbs heavy metals a crop can mitigate the cost of land rehabilitation by making profitable use of saline wastewaters through bioremediation. Extensive laboratory and in-situ trialling will provide information that can be used to determine the suitability of inland saline water in WA for commercial seaweed culture. This PhD project is an extension of CSML project 3.2, led by A/Professor Ravi Fotedar, which considered aquaculture as a potential beneficial end-use of mine lake water affected by salinity. |

Strong industry connections presented an opportunity for CSML's on the ground R&D activities to feature in the program of events for ACMER's 5th Annual Workshop on Acid Drainage in August 2005. Delegates were given the opportunity to visit CSML R&D sites at Wesfarmers Premier Coal and Griffin Coal Mining Company in the Collie Coal Basin, where open cut mine voids are mostly below the water table and resulting mine lakes are affected by acidity and dissolved contaminants. Supporting material and background information provided to delegates outlined water issue challenges at Wesfarmers' Collie Aquafarm and Lake Kepwari, and Griffin Coal's Chicken Creek, and the CSML projects taking place to help the companies to plan for optimal closure outcomes, with real benefits to the Collie community.

| KEY INFORMATION | SUCCESS IN INDIGENOUS ENGAGEMENT OPENS DOORS TO WATTLE-FOCUSED ABORIGINAL DEVELOPMENT PROJECT |
|---|---|
| **Project Title:** Scoping project for Dalwallinu Shire wattle feasibility study<br><br>**Period:** 2007<br><br>**Funding Body:** Wheatbelt Development Commission<br><br>**Amount:** $10,000<br><br>**CSML Recipient:** Evans L., Curtin | Previous successes in Indigenous engagement by the CSML Plants for People team led to a small but highly important consultancy project funded through the Wheatbelt Regional Development Scheme. Dalwallinu contains the largest number of Wattle species (186+ to date) in the world and is seeking to establish an Environmental Interpretive Centre based around the Wattle. The $10,000 'Scoping project for Dalwallinu Shire wattle feasibility study' was instigated to address one aspect of the Dalwallinu Wattle project – the involvement of Aboriginal people from the Shire of Dalwallinu in the Environmental Interpretive Centre initiative. The consultancy was carried out by a project team from Curtin University and was led by the CSML's Professor Louis Evans. The project team engaged with Aboriginal people from the Dalwallinu Shire and discussed traditional knowledge about Wattles as well as working with a local project team to develop a project proposal for an Aboriginal Enterprise Development project based on Wattles and Wattle seeds. This consultancy also provided information on the commercial viability of Wattle Seed production and generated information and resources that could contribute to the establishment of the Environmental Interpretive Centre at Dalwallinu. |

## FINAL YEAR ANNUAL RESEARCH PROJECT REPORTS AND FULL RESEARCH PROJECT REPORTS

## Project 1.0: Prediction of long-term water quality in mine lakes, with and without remediation (including sub-project: Sensor strings for the monitoring of the water quality of mine void lakes)


- Oldham C.E., Salmon U.S., Ivey G.N., Wake G.
- School of Environmental Systems Engineering
- University of Western Australia
- De Marco R. (sub-project Leader)
- School of Applied Chemistry
- Curtin University of Technology


### Final Year Annual Research Report

The following research activities were undertaken during the final year of CSML project *Prediction of long-term water quality in mine lakes, with and without remediation*:

- Microbial characterisation of littoral and deep sediments was conducted. Neither sulfate reducing nor iron reducing bacteria could be cultured, however the activity of these microbes was evident.
- Rates of iron and sulfate reduction in WO5B sediments, under varying doses of organic carbon and oxidant was quantified.
- WO5B and Chicken Creek sediment responses to organic carbon additions were compared to the responses of German ML111 sediment.
- Water and chemical mass balances were conducted for WO5B.
- Acidity balances indicated that the pH in WO5B (Lake Kepwari) may be dominated by the inflowing groundwater rich in Fe(II). As this enters the oxygenated lake waters, Fe(II) is oxidised to Fe(III) and a drop in pH results.
- The developed model, DYRESM-CAEDYM.v3 has been tested on Lake Kepwari and the project team is satisfied with its ability to describe key geochemical and water quality dynamics.

In March 2007, the project team initiated work on an ACMER funded project on the establishment of Protocols for Monitoring Mine Lakes for Improved Prediction of Water Quality. A/Prof Oldham is leading this project which involves collaboration with eight scientists from around Australia, and six industry representatives.

A Lake Diagnostic System (LDS) measuring in real-time the hydrodynamic response of Lake Kepwari, Collie, to wind and solar radiation.

The (F-Probe) measures at high resolution, physical and geochemical properties of mine lakes against the lake depth.

# Executive Summary

An intensive field program was conducted on Lake Kepwari, formally mine lake WO5B, to ascertain the controls on existing water quality, and provide data for developing the prediction model. The major water quality parameter of concern has historically been pH; during periods of riverine diversion pH of the lake water typically increased, but decreased again between diversion periods. CSML ACARP Project 1 sought to understand what was driving the continued decrease in pH.

While there are a number of processes within the lake maintaining the lake waters around pH 4.5, field data and subsequent mass balance estimates indicated an ongoing source of acidity to the lake via iron-rich groundwater. When this groundwater enters the oxic waters of the lake, Fe(II) is oxidized to Fe(III) resulting in a decrease in pH. While the iron-rich groundwater continues to flow into the lake, there is unlikely to be a sustained increase in lake pH.

The pH of Lake Kepwari continues to decrease during periods of no riverine inflow. There is minimal water quantity or quality data available for riverine, surface, sub-surface and groundwater inflows into this lake. Lake Kepwari undergoes summer density stratification, lasting from October until April. Surface and bottom lake water remain oxic throughout the year. There is little pH trend with depth, even during stratification. Primary productivity levels are very low in the lake; chlorophyll a levels remain less than 3 μg/L at all times, though deep chlorophyll maxima are observed.

In parallel to the field investigation, a numerical model was developed to allow testing of possible remediation scenarios. Rather than creating a new model a significant extension was undertaken of an existing numerical model that had been developed for the prediction of algal blooms in drinking water reservoirs. This freely available model (DYRESM-CAEDYM) is currently used around the world for this purpose. The new extended version of DYRESM-CAEDYM includes user-defined aqueous species, calculation of aqueous speciation, gas phase and mineral equilibrium. Importantly, the new model also includes descriptions of sediment diagenetic processes. The extended model provides a new tool for investigating the impact of suggested remediation strategies, such as addition of organic carbon and/or nutrients.

The extended model was validated against the two years of field data collected as part of this project. Most water quality parameters were well described by the model, including DO, nutrient concentrations, major cations/anion concentrations and pH. The model is now available for analysis of in-lake controls on water quality, particularly pH.

With respect to the program 1 sub project *Sensor Strings for the Monitoring of the Water Quality of Mine Void Lakes* led by Prof. Roland De Marco from Curtin University of Technology's Department of Applied Chemistry, the project explored the opportunity of deploying submersible pH and redox chemical sensors (purchased from Idronaut in Italy) in the in-situ field monitoring of water quality in mine void lakes, especially the stratification of the water body as a function of depth.

As these sensors are prone to drift on continuous exposure to real samples, it was necessary to undertake a rigorous laboratory study of their response to variations in temperature, pressure as well as continual exposure to the solution, since these are key physicochemical factors that influence the reliability of the sensors during deployment in the field. Accordingly, it was found that pressure alters the response and reliability of the sensors due to a liquid junction potential effect at the sensor reference electrode; however, conditioning of the sensors at the deployment pressure for a period of 1-2 days enabled pressure equilibration of the reference sensors and stability in the sensor readings. Furthermore, as expected according to the laws of electrochemical thermodynamics, the sensors displayed sensitivity to temperature, and an empirically derived temperature sensitivity function may be used to correct the sensor response for variations in temperature as a function of depth in the water body. Last, the sensors were shown to be prone to long-term drift on continuous exposure to a mine void sample. With the pH sensor, this was ascribed solely to a drift in the reference sensor, and this error may be rectified by periodically checking the reference sensor (say once a fortnight) against a standard

laboratory reference. On the other hand, the redox sensor showed a drift that was partly ascribed to the reference sensor, but also to poisoning of the sensor on continual exposure to mine void water. In this instance, it will be necessary to periodically polish the redox sensor surface (say once a fortnight) to rid the sensor of sample fouling.

The sub-project team also explored the influence of long-term exposure of the pH and redox sensors to mine void water using a fundamental electrode technique called electrochemical impedance spectroscopy, and the results clearly demonstrated the pH sensor is not susceptible to electrode fouling in samples, whereas the redox sensor is indeed poisoned on continuous exposure to mine void water.

Finally, three field trials were conducted at the W05 mine void at Collie. The first trial entailed a reconnaissance field study with the sensors using a Vandron sampling device to collect samples for ex-situ analysis in the laboratory, and the Centre for Water Research's F-probe in in-situ analyses. Additionally, the sensor response as a function of depth was correlated with the water chemistry by using atomic absorption spectrometry (AAS) to probe the iron levels associated with pyrite oxidation, and a dissolved oxygen (DO) probe to detect the oxygenation of the water body that is influenced by the oxidation of pyrite in the lake floor. Subsequent studies examined the mine void during the winter and summer periods, and demonstrated that stratification of the water body arises from the oxygen-based oxidation of pyrite at the lake floor leading to diminished DO and elevated iron levels, as well as concomitant low pHs and redox potentials at the base of the water body.

In summary, the sensor characterization and field research demonstrated that the submersible pH and redox sensors may be used with confidence in in-situ studies of mine voids, as long the sensors are properly conditioned and maintained.

## Introduction

The evolution of water quality in pit lakes, including master state variables such as redox potential and pH, is initially determined by the quality of surface and sub-surface inflows and how the inflow waters interact with pit mineralogy. However as the volume of inflows relative to the lake volume decreases (as would be expected as the pit fills), the physical, chemical and biological processes in the lake itself begin to impact, or even dominate, lake water quality. For example, lake physical processes, such as energy transport in the water column, affect stratification and mixing, which in turn control the transport of many species to different regions of the lake; biological and microbially mediated lake processes include primary production and the metabolism of organic matter; lake geochemical processes include the buffering of pH, in circum neutral waters by the bicarbonate system, or under the acidic or alkaline conditions often found in pit lakes, by precipitation and dissolution reactions of mineral phases.

There are many feedbacks between these different processes. For example, diagenesis in sediments involves microbially mediated inorganic redox reactions driven by the availability of organic matter; the resulting release of nutrients to the water column drives further primary production (organic matter production), and the release of alkalinity may neutralise water column acidity. Another example of feedback is the sorption of $PO_4$ to surfaces of amorphous Al and Fe minerals (solubility of which is pH-dependent) that may limit $PO_4$ concentrations and hence autochthonous organic matter production. External forcing, such as climate, combines with the interactions between the internal processes and lake bathymetry to result in lake water quality, including the generation, distribution, and fate of contaminants. The impacts on water quality of all of these lake processes must be balanced against the impact of inflowing waters; for example the geochemical characteristics of inflows may counteract alkalinity generation within the lake. Alternatively, we can consider that lake processes may ameliorate poor water quality of inflowing water.

An essential method to test our understanding of what drives the overall water quality in pit lakes, and to quantify the relative contribution of inflows versus lake processes, is the use of numerical models that adequately map our conceptual models, and most importantly, allow the multitude of processes to progress at the appropriate time and length scales. Such models may also be used to investigate the response of pit lake water quality to remediation measures, such as nutrient or organic carbon addition to stimulate alkalinity generation from sediments (e.g., Wendt-Pothoff et al., 2002) or to remove metals from the water column (e.g., Crusius et al., 2003). A comparison of numerical simulation results with carefully conducted field and laboratory observations allow our conceptual models to be rigorously tested under controlled scenarios. However, while the connectivity between inflowing water and pit lakes, particularly with respect to lake water quality, is undeniable, there has long been a disconnect between sub-surface water quality prediction and lake water quality prediction.

Sub-surface water quality is typically assumed to be dominated by geochemical processes and models such as PHREEQC have been used successfully to predict water quality in the sub-surface environment (Prommer et al., 2000). In contrast, drinking water reservoir and lake water quality has been successfully modelled over the last few decades using a variety of stratification and/or nutrient-phytoplankton-zooplankton (NPZ) models. However, these models pay scant attention to geochemical cycling occurring in lakes (Ramsay et al., 2006). When modelling the long-term water quality of pit lakes, we simply cannot ignore the significance of this geochemical cycling. Up to now there has been no available model that combines geochemical process descriptions with the limnological process descriptions of the classic lake stratification and NPZ models.

The sensor characterisation work was carried out in the Electrochemistry Research Group of De Marco at Curtin University, while the instrumentation development component of the research was to be undertaken by the Centre for Water Research (CWR) at The University of Western Australia (UWA).

Given the stratification of acidic water in mine void lakes in Collie is a consequence of the oxidation of the underlying pyrite minerals of the region, along with segregation of the waters associated with the underlying hydrodynamics of the water body, the sensor characterisation sub-project aimed to develop an in-situ sensor instrument that could be used to continuously monitor the pH and Eh of mine void lakes.

These sensors are prone to long-term drift, as well variation in response as the pressure and temperature changes as a function of depth, and it is essential to mathematically characterize these phenomena so they may be compensated using an appropriate empirical correction function.

In addition, it is necessary to study mechanistically the origin of these effects so an appropriate methodology may be employed with the sensors during long-term deployment, e.g., regular cleaning of the probes to remove fouling media, conditioning of the probes under ambient conditions, etc.

Accordingly, this project aimed to characterise the pressure and temperature sensitivity, along with long-term drift of commercially available Idronaut submersible pH and redox sensors with a view to employing them in long-term deployment in sensor string instrumentation.

## Methodology

### *Model description*

Under the CSML Project 1 conducted from 2003 – 2006, an existing sophisticated NPZ model for lake aquatic ecology, CAEDYM.v2 (see e.g. Romero et al., 2004) that can be coupled to 1D or 3D lake, or 2D river, hydrodynamic models, was significantly revised to include a geochemical equilibrium solver and kinetic representations of water column geochemical processes and sediment diagenesis. The equilibrium solver allows calculation of aqueous speciation and user-defined control of concentrations of aqueous species (including pH) through equilibrium with gas phase or solubility equilibrium (ie by mineral precipitation/dissolution, as is often the case under acidic or alkaline conditions). Importantly, feedback between geochemical, ecological and diagenetic processes was incorporated into the new CAEDYM.v3. The conceptual description of these processes, including feedback between components, is shown for the water column (Figure 1) and the sediment (Figure 2). CAEDYM.v3 was coupled to the 1D stratification model DYRESM to allow application to Lake Kepwari.

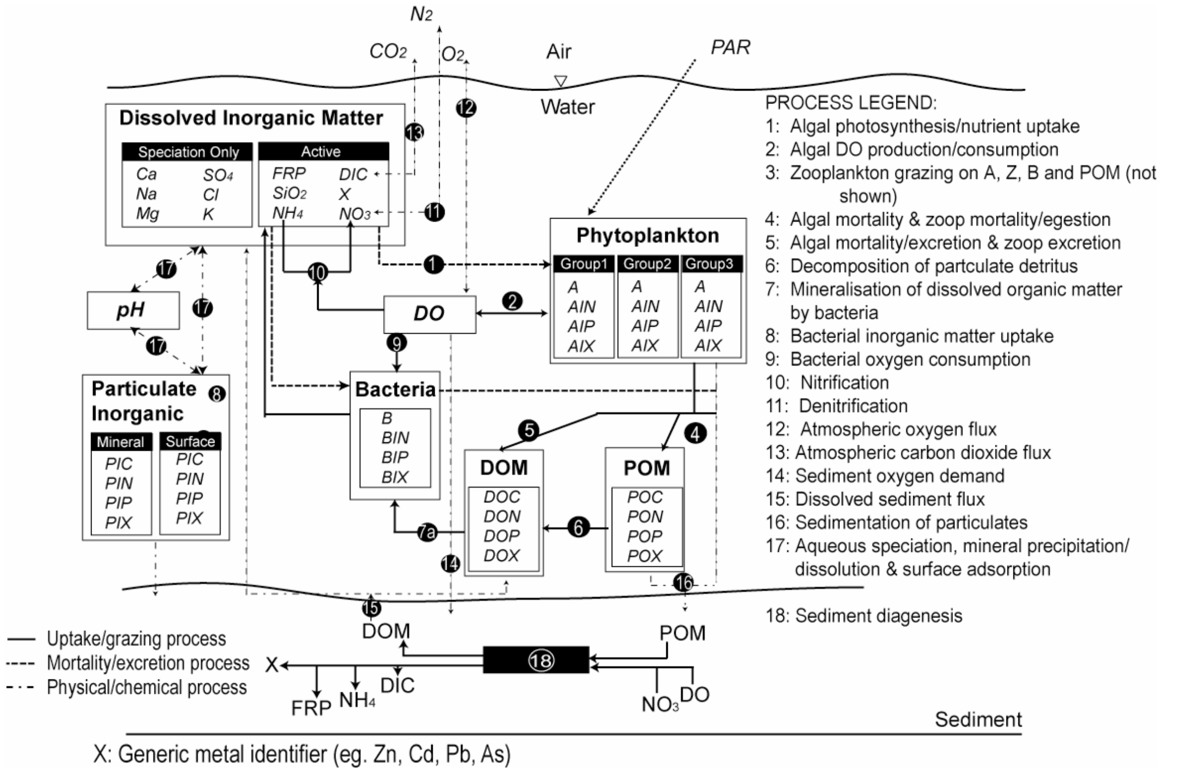


**Figure 1.** Schematic of the revised Computational Aquatic Ecological Dynamic Model, CAEDYM.v3, indicating interactions between the geochemical, nutrient and biological cycles. Note that the sediment module shown is simplistic; details of the sediment module are given in Figure 2.

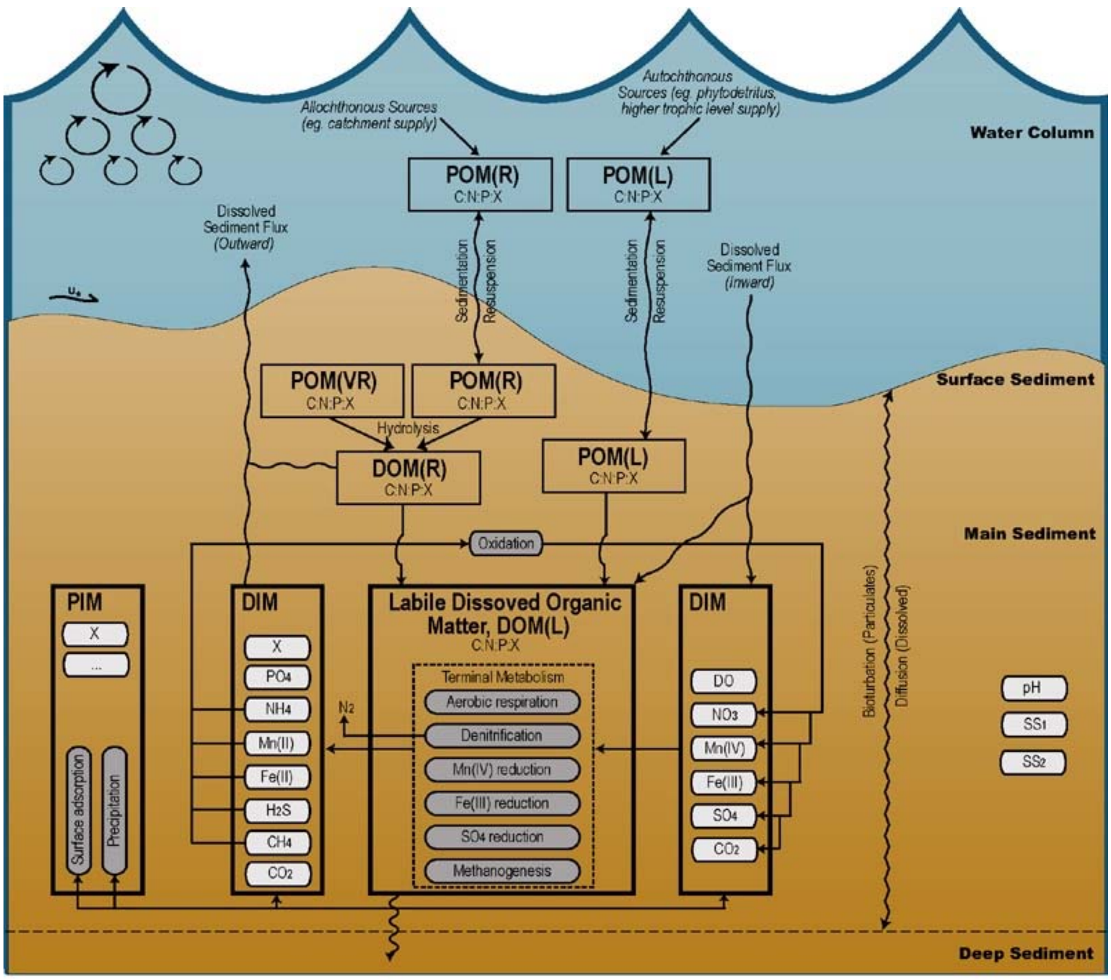


**Figure 2**. Schematic of the revised Computational Aquatic Ecological Dynamic Model, CAEDYM.v3, indicating sediment process description. Note that connectivity between sediment processes and lake ecology or inflow inputs, is predominantly via the supply of organic matter, of varying labilities, to the sediments.

### *Site Description*

Parallel to model development, the same CSML funding allowed data collection from a case study site, Lake Kewpari (pH ~5), a coal pit lake in Western Australia (Salmon et al., submitted). Lake Kepwari, formerly known as Mine Lake WO5B, is a pit lake located in the Cardiff Sub-basin of the Collie Coal Basin, 160 km south-southeast of Perth, Western Australia (Figure 3). The Collie Basin has a complex hydrogeology due to the prevalence of faults throughout the many geological formations, extensive underground and open cut mining, and the large volumes of groundwater abstraction, both historically and ongoing today (Varma, 2002). Prior to mining of the Lake Kepwari pit, the largely unsaturated Cretaceous Nakina Formation, made up of claystone, sandstone and conglomerate, formed the surficial soils. This formation was extensively excavated to access the underlying Permian Muja Coal Measure, made up of sandstone, siltstone and numerous black, sub-bituminous coal seams (Varma 2002). The aquifer underlying Lake Kepwari is confined by extensive coal seams and the lower sandstone aquifers; the hydraulic properties are irregular and anisotropic, leading to the formation of preferential groundwater flow paths. Since the cessation of mining in the pit in 1997, the slopes and overburden piles surrounding the pit have been landscaped and revegetated; coal seams exposed during mining were covered and/or submerged.

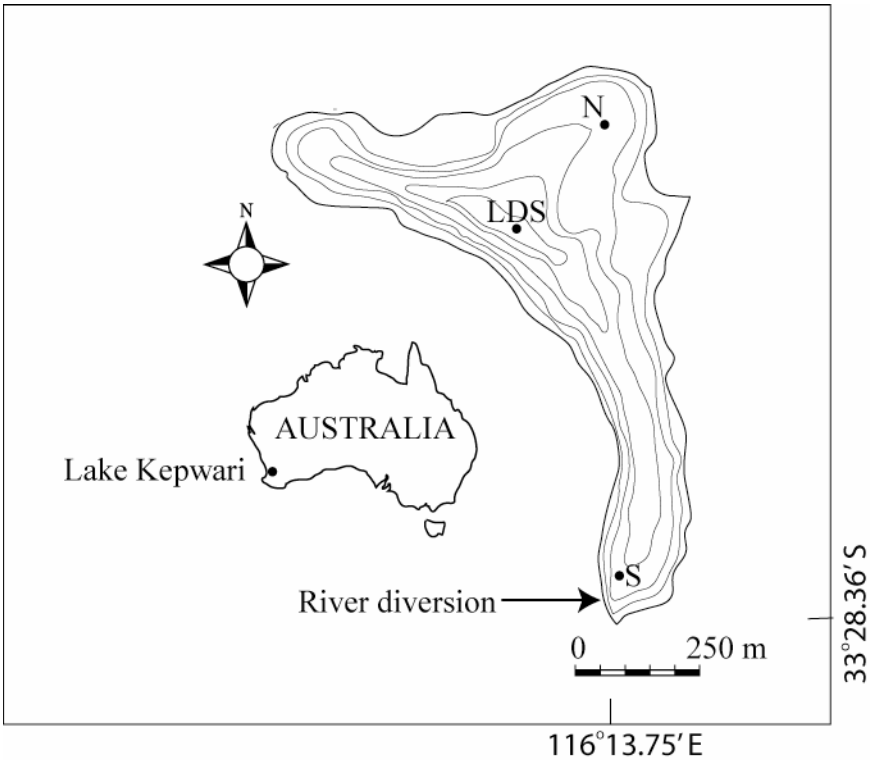


**Figure 3.** Lake Kepwari, in the south west of Western Australia, showing bathymetry using 10 m depth contours. The Lake Diagnostic System (LDS) was located at the centre of the lake; water samples were typically collected close to the LDS and from station S.

The region has a Mediterranean climate with hot, dry summers (12 to 29°C) and cool, wet winters (4 to 15°C). The annual average wind speed at the centre of the lake is around 3 m s-1, with peaks of up to 9 m s-1. The 100-year average annual rainfall for the Collie Basin is between 730 and 950 mm, although this has decreased to an average of 690-840 mm over the past 20 years. The majority of the rainfall occurs between May and September and the average annual potential evaporation is estimated to be between 1450 and 1650 mm.

Once dewatering of the WO5B pit ceased in 1997, the void started to fill with groundwater and precipitation. Between 1999 and 2005 the lake was rapidly filled by annual winter diversion of the adjacent ephemeral Collie River South Branch, with the exception of 2001, when low rainfall resulted in insufficient river levels to satisfy diversion licence requirements (Figure 4). Monitoring of the lake level by the mining company, indicated that in 1999 (immediately prior to the first river diversion), the lake volume was approximately 10% of the final lake capacity of approximately 24 GL. Since 2005, the lake has been at capacity volume; ongoing annual river diversion is planned only to replace water loss due to evaporation.

An earlier water balance with forward prediction (Varma, 2002) estimated a groundwater discharge (ie inflow into the lake) of up to 0.6 GL per year if the lake volume was below ~20 GL, groundwater recharge if the volume was above this, and annual surface runoff to the lake of 2 to 50 ML. The current volume of annual groundwater discharge or recharge to the void is not monitored, nor is surface water inflow.

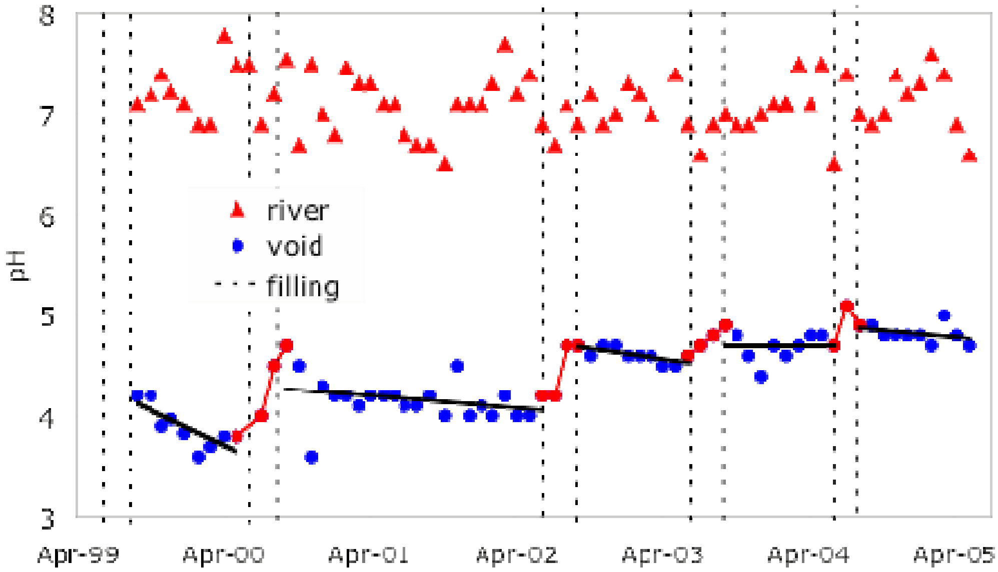


**Figure 4**. The Lake Kepwari void was filled with a diversion of the Collie River South Branch. The riverine diversion was ~ pH 7, and the lake pH increased during diversion periods. However after diversion was completed each year, the lake pH gradually dropped until the following winter diversion. (Data supplied by Wesfarmers Premier Coal Ltd).

### *Field sampling*

A Lake Diagnostic System (LDS, Precision Measurement Engineering) was installed at the deepest point of the lake (Figure 1) from March 2004 - March 2006. The LDS measured wind speed, wind direction, air temperature, relative humidity and short wave and net radiation, at a sample rate of 15 seconds. The LDS also sampled water column temperature, via 20 thermistors over a depth of 60 m. Water column profiles of temperature, conductivity, dissolved oxygen (DO) and pH, with depth resolutions ranging from 2 cm to 2 m, were measured approximately every 2-3 months from May 2004 – May 2005, with a probe mounted with Seabird sensors until Feb 2005, and a Hydrolab Datasonde 4A probe for the May 2005 sampling. On all occasions, 2-point calibration was performed on pH, DO and conductivity sensors. Profiles were measured at multiple sites across the lake to characterise any horizontal heterogeneity. In May and July 2004, oxidation-reduction potential (ORP) profiles were measured using a Yeokal 611; in May 2005, profiles of ORP were measured using a Hydrolab probe. Profiles of photosynthetically active radiation (PAR) were measured using a Licor LI-193SA underwater quantum sensor in May and July 2004 and May 2005, and light extinction coefficients were calculated. In situ profiles of fluorescence were measured in February 2005, at the deepest part of the lake using a multispectral BBE Fluoroprobe™.

### *Sample collection – lake water column*

Data presented here were collected in May 2004 at the end of the stratification period, one year later in May 2005, and during mixed conditions in July 2004. Geochemical sampling was also performed in March and September, 2004, and February and July, 2005; data from the additional sampling occasions supported the interpretations presented here. On each sampling trip, water samples were collected in duplicate from 4 – 7 depths at the deepest point of the lake, and in May and June 2004 also at 1-2 additional locations in the lake (Figure 1). Water samples were collected by hand from immediately below the surface and from depth using a van Dorn sampler, with separate drops for depth duplicates. Each water sample was transferred to a 1L high density polyethylene bottle (acid soaked in 10% hydrochloric, repeatedly soaked in fresh de-ionised water and rinsed 3 times with sample water), filled to minimise airspace. The bottles were kept shielded from ambient light and as close as possible to constant temperature until sub-sampling as soon as possible after collection (always within six hours).

A subsample (125 mL) was filtered through 0.45 $\mu$m cellulose acetate single use syringe filters into low density polyethylene (LDPE) bottles; syringes and bottles were acid washed as above. The filtered sample was acidified to pH <2 using p.a. grade concentrated nitric acid, for later analysis by inductively coupled plasma-atomic emissions spectroscopy (ICP-AES; Varian Vista AX) of Ca, Mg, Na, K, Al, Fe, Mn, Zn, and S (and in May 2004 for Ag, As, B, Ba, Cd, Co, Cr, Cu, Mo, Ni, Pb, Xb, Se, Sn, Sr, Ti, and V). Additional subsamples (10 mL) were filtered into nutrient tubes for analysis of filterable reactive phosphorus (FRP), NOx, NH4, SO4, Cl and Si (and in May 2004 for F and Br) by ion chromatography (Lachat Automated Flow Injection Analyser). Additional unfiltered water samples were collected for total nitrogen (total N) and total phosphorous (total P) analysis by ion chromatography after autoclave digestion, for acidity determination by titration to pH 8.3 with NaOH (with and without addition of hydrogen peroxide), and, in May 2004 and July 2005, for ICP analysis of total (unfiltered) concentrations of major cations and sulfur, with sample acidification as for other cation samples and aqua regia digestion prior to analysis. Sample were stored at 4°C or below until analysis.

Water samples were collected for analysis of total and dissolved organic carbon (TOC/DOC) and dissolved inorganic carbon (DIC) from three depths in May 2004 and from all depths in July 2004 and May 2005. Amber glass bottles were rinsed 3 times with sample and filled to minimize airspace. These samples were stored on ice for analysis by combustion – non-dispersive infrared method (NDIR; Shimadzu Corporation TOC 5000A) after filtration as required. Discrete samples were also collected for chlorophyll a analysis from depths of 5 and 10 m in March and July 2004.

In May 2005 additional water samples were collected for spectrophotometric analysis of Fe(II) and total Fe. Immediately after being brought to the lake surface, water samples were immediately transferred into an acid washed syringe and 50 ml was filtered through 0.45 $\mu$m cellulose acetate filters into acid washed 125 ml LDPE bottles that contained 2.5 ml of p.a. grade 0.1M $H_2SO_4$ and stored on ice until analysis within eight hours. Immediately prior to analysis, samples were allowed to attain room temperature and returned to pH 3-5 by addition of 1.5 ml 0.1M NaOH. Samples were analysed for Fe(II) (method 8146) and total Fe (method 8008) using a HACH spectrophotometer (DR/2000).

Sampling, travel, and analytical blanks were collected and analysed on all sampling occasions. Analyses of duplicate samples collected from the same depths generally showed agreement to well within 10%, with the main exception of dissolved Fe in May 05 (15%). The charge balance of cations and anions for all samples was generally within 5 %.

Water samples in duplicate were also collected from the river immediately adjacent to the diversion culvert on 9 occasions during the 2004 river diversion into to the lake. Surface runoff from the slopes surrounding the lake occurred only during rain events; replicate samples were collected during a rain event in July 2004, 1 week prior to lake sampling. The samples were processed as described above, and analysed for the same parameters as the water column samples.

Samples were also collected in July 2001 from 1 m below the surface of the lake for analysis by similar methods as those described above.

### *Saturation indices and calculations*

Acidity was calculated based on free protons and measured concentrations of Al, Fe redox species and Mn (cf. Kirby and Cravotta 2005).

In order to investigate the possibility of solubility equilibrium control of aqueous concentrations and pH in the lake, aqueous speciation and saturation indices were calculated using the geochemical equilibrium program PHREEQC (Parkhurst and Appelo 1999) in conjunction with the WATEQ4F database (Ball and Nordstrom 1991) and additional thermodynamic data for schwertmannite (Yu et al. 2002). Total Fe and redox values were used as inputs to the modelling, as these data were available for all sampling occasions; calculations based on the measured Fe redox species gave very similar results. As the concentrations of DOC in the lake were very low, DOC complexation was not included in the saturation indices calculations.

In order to quantify deviations from conservative behaviour, a simple mixing model was applied to the lake over the period between the May and July sampling occasions in 2004. The model was used to predict solute concentrations in the lake at the time of water column sampling in July, $C_L\big|_{July}$, using solute mass in the lake before diversion and mass fluxes input to the lake from the river diversion:

$$C_L\big|_{July} = \frac{\overline{C}_E\big|_{May} V_E\big|_{May} + \overline{C}_H\big|_{May} V_H\big|_{May} + \overline{C}_R\big|_{May} V_R^{May-July}}{V_L\big|_{July}} \qquad (1)$$

where $\overline{C}_E\big|_{May}$ and $\overline{C}_H\big|_{May}$ are the average measured solute concentration in the epilimnion and hypolimnion of the stratified lake in May, respectively, and $\overline{C}_R\big|_{May}$ is the average measured solute concentrations in the diverted river. $V_E\big|_{May}$ and $V_H\big|_{May}$ are the volumes of the epilimnion and hypolimnion, respectively, of the stratified lake in May, $V_R^{May-July}$ is the cumulative volume of river water diverted in 2004 up to the July sampling (approximately half the total 2004 diversion volume), and $V_L\big|_{July}$ is the volume of the lake in July 2004.

A second simple mixing model was used to quantify deviations from conservative behaviour over the three years of riverine diversion from 2001 to 2004, during which time the lake volume approximately doubled. In this case, the mixing model was used to predict lake solute concentrations in July 2004, $C_L\big|_{July}$, using solute mass in the lake before diversion in 2001 and mass fluxes into the lake from the total river diversion from 2001 to 2004:

$$C_L\big|_{July} = \frac{\overline{C}_L\big|_{2001} V_L\big|_{2001} + \overline{C}_R\big|_{May} V_R^{01-04}}{V_L\big|_{July}} \qquad (2)$$

where $\overline{C}_L\big|_{2001}$ is the average measured solute concentration in the fully mixed lake in July 2001 (a year in which there was no river diversion) and $\overline{C}_R\big|_{May}$ is the average measured solute concentrations in the diverted river in May 2004. Note that we assumed solute concentrations in the river in 2002 and 2003 to be the same as measured in 2004. The river drains an agricultural catchment and, while there are known temporal variations in dissolved solids, the main concentration spikes occur early in the wet season prior to river diversion. Thus it is reasonable to assume constant solute concentrations across years for the diversion periods. $V_L\big|_{2001}$ is the volume of the lake in May 2001 and $V_R^{01-04}$ is the total diverted river volume, as estimated by the difference between lake volumes in 2001 and 2004. For this simple calculation, evapoconcentration and groundwater recharge are considered to have negligible impact on lake volume over this period relative to the effect of the river diversion, which doubled the volume of the lake.

*Sub-project methodology*

The proposed methodology of this project was:

1. source the commercially available submersible pH and redox sensors from Idronaut in Milano Italy;
2. characterise their long-term drift characteristics using standard potentiometric techniques;
3. study their temperature and pressure sensitivity using potentiometry;
4. study the mechanistic aspects of sensor response using electrochemical impedance spectroscopy;
5. undertake parallel in-situ and ex-situ sensor field studies of the water quality in Mine Void Lakes using comparative sensor and chemical analyses;
6. long-term deployment of the characterised sensors in mine void lakes using custom-designed sensor string instrumentation.

In 2003, the sensors were sourced, and their long-term drift in mine void water was studied. This study that was undertaken in parallel with all other studies over 2003 and 2004.

In 2004, the Project also studied the influence of temperature and pressure on the response of the sensors. In this work, the experiments were repeated on a number of occasions, so as to provide a statistical confidence in the results, and the exact reason for the alteration in response (e.g., reference liquid junction drift, and/or fouling of the sensors) was rigorously evaluated.

In 2005 and 2006, the sub-project team used the sensors in field trials of Collie WO5 mine void water. In this work, we studied the behaviour of sensors in-situ using the CWR's F-probe instrument, and we also undertook ex-situ analyses using the sensors and independent chemical assays (e.g., dissolved oxygen, iron levels by AAS, acidity, etc.).

## Results

*Field sampling*

### Temperature, conductivity and pH

In both 2004 and 2005, thermal stratification in the lake began in late September, peaked in February (maximum surface temperatures of 25 °C) and began breaking down in May (Fig 5a), although stratification was still in place at the time of sampling in both years. By June due to seasonal cooling the lake was fully mixed and remained isothermal over the winter months; the minimum water temperature was 13 °C. Note that the river diversion period was when the lake was isothermal.

On all sampling occasions there was little horizontal variability in temperature, conductivity, pH, DO or ORP, except in July 2004 when a signature of the river inflow was observed in the southern end of the lake, in the bottom 2-3 m of the ~17 m profile (Figures 5a, b, c). As the lake was well mixed at the time of inflow, the signature is weak and not apparent in the other parts of the lake.

In both years, salinity was higher in the epilimnion than in the hypolimnion by the end of the summer, likely due to evapoconcentration of the surface waters (Figure 5b). The pH in the lake was between 4.5 and 5, with no clear temporal trend over the period of investigation (Figure 5c).

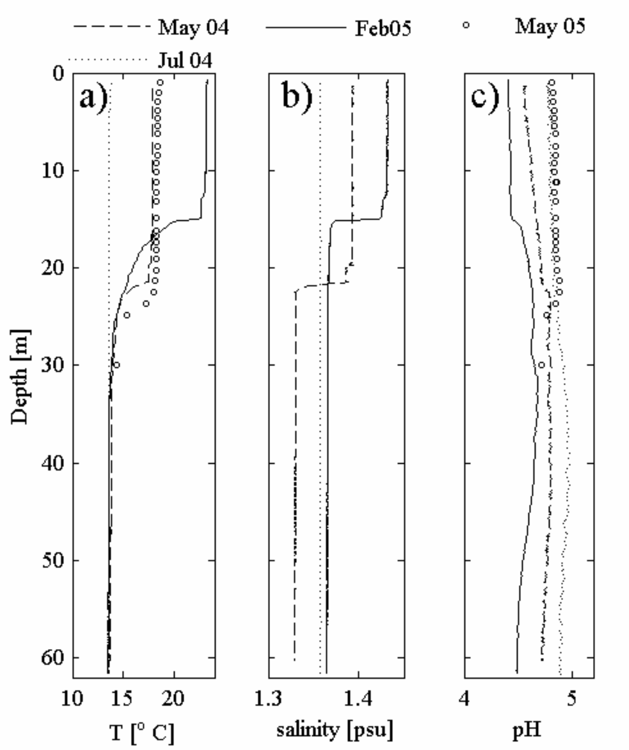


**Figure 5** Water column profiles of a) temperature, b) salinity, and c) pH, measured at the LDS site on 12 May 2004, 28 July 2004, 15 February 2005, and, for temperature and pH, 11 May 2005.

## PAR, dissolved oxygen, ORP and chlorophyll a

Dissolved oxygen concentrations in the lake were close to saturation in the upper region of the lake on all sampling occasions (Figure 6a). Undersaturation was generally observed in the hypolimnion during stratified periods, however supersaturation was observed just below the thermocline in February 2005, presumably a signature of a deep photosynthesising layer. This is supported by the observation in February 2005 of a deep chlorophyll maximum (0.2 $\mu$g $L^{-1}$) located between 18-32 m, with values at other depths otherwise under the detection limit (Figure 6b). Chlorophyll a concentrations were highest in discrete samples in July 2004, at 2-4 $\mu$g $L^{-1}$; at all other times, concentrations were < 1 $\mu$g $L^{-1}$. Light levels varied across seasons; extinction coefficients ranged from 0.2 to 0.7 $m^{-1}$, indicating photic depths of 22 m and 6 m in May and July, respectively. The higher July chlorophyll a concentrations agree with the shallower photic depths observed at that time, however, the lower photic depth during the winter may also be due to fine inorganic particles, as substantial transport of particulate matter from the surrounding slopes into the lake was observed during the rain event one week prior to sampling. Even the maximum chlorophyll a concentrations measured in this lake were very low relative to most aquatic systems (Wetzel 2001). During periods of stratification (May 2004 and May 2005) ORP increased with depth below the thermocline (Figure 6c).

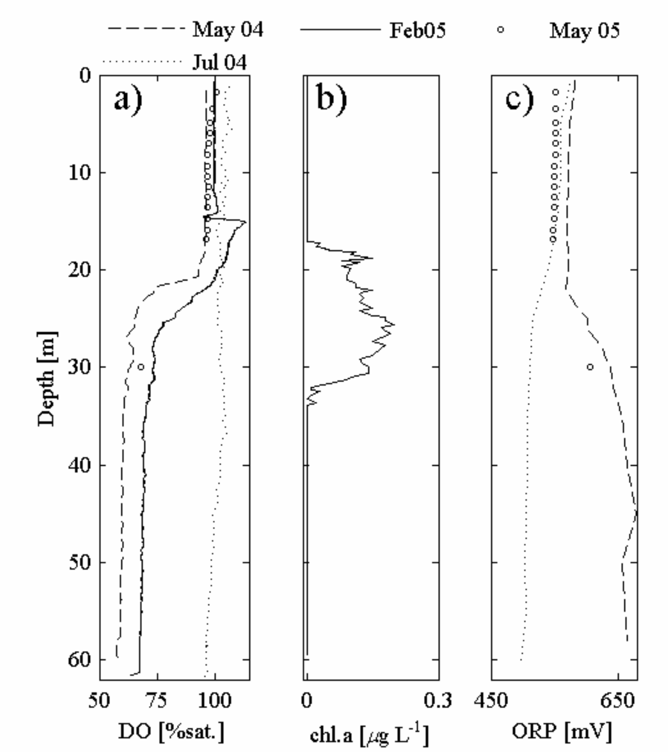


**Figure 6** Water column profiles of a) dissolved oxygen, b) chlorophyll a, and c) oxidation-reduction potential (relative to the standard hydrogen electrode), measured at the LDS site on one or more of 12 May 2004, 28 July 2004, 15 February 2005, and 11 May 2005.

### Inorganic and nutrient species

Average solute concentrations in the lake in July 2004 are presented in Table 1. The major dissolved ions were Cl and Na, followed by $SO_4$, Mg, and Ca; other elements were low or below the detection limit. Acidity was measured to be 12-20 mg $CaCO_3$ $L^{-1}$, which agreed fairly well with the calculated ~10 mg $CaCO_3$ $L^{-1}$, of which approximately 80% was due to Al, 10% to free protons, and the remainder to Fe and Mn. Total dissolved Fe concentrations, as measured by ICP and by spectrophotometry, showed good agreement (Figure 5). Measured Fe(II) concentration was 30 - 40 % of the total dissolved Fe, which agreed with the iron redox speciation predicted by PHREEQC, using total dissolved iron concentrations and ORP. This suggested that the iron redox couple controlled ORP in the lake, as has been observed in other acidic systems (Nordstrom et al. 1979).

**Table 1.** Average water quality in Lake Kepwari, July 2004.

| Specie | Concentration[a] | |
|---|---|---|
| Cl | 769 ± 7 | mg $L^{-1}$ |
| Na | 329 ± 2 | mg $L^{-1}$ |
| Mg | 77.2 ± 0.5 | mg $L^{-1}$ |
| $SO_4$ | 107 ± 4.2 | mg $L^{-1}$ |
| Ca | 28.2 ± 0.4 | mg $L^{-1}$ |
| K | 4.86 ± 0.08 | mg $L^{-1}$ |
| Al | 1.1 ± 0 | mg $L^{-1}$ |
| Total Al | 1.3 ± 0.2 | mg $L^{-1}$ |
| Zn | 0.468 ± 0.005 | mg $L^{-1}$ |
| Mn | 0.211 ± 0.002 | mg $L^{-1}$ |
| Fe | 0.15 ± 0.01 | mg $L^{-1}$ |
| Total Fe | 0.3 ± 0.1 | mg $L^{-1}$ |
| Silicate | 3.87 ± 0.7 | mg Si $L^{-1}$ |
| DOC | 1.9 ± 0.1 | mg C $L^{-1}$ |
| TOC | 2.1 ± 0.1 | mg C $L^{-1}$ |
| Total N | 1370 ± 60 | $\mu$g N $L^{-1}$ |
| $NO_3$+$NO_2$ | 972 ± 9 | $\mu$g N $L^{-1}$ |
| $NH_4$ | 239 ± 5 | $\mu$g N $L^{-1}$ |
| Total P | 7.0 ± 1.6[b] | $\mu$g P $L^{-1}$ |
| ortho-P | < 2 | $\mu$g P $L^{-1}$ |

[a]Average concentration ± standard deviation of all samples from 3 locations with collection replicates from 2-4 depths, with the exception of total Al and total Fe, which are the average of 2 single samples, from 0 and 49 m, at the LDS. [b]Average of samples from locations S and N; all samples at the LDS were below the detection limit (5 $\mu$g P $L^{-1}$).

Total concentrations of most inorganic elements were the same as dissolved concentrations, with the exception of slightly higher total Fe and Al concentrations on some sampling occasions (Table 1). Saturation index (SI) calculations indicated that precipitation/dissolution of iron hydroxide likely controlled Fe(III) concentrations at all depths ($-0.5<SI<0.3$). Aluminium concentrations were possibly controlled by solubility equilibrium between solution and a hydroxysulfate ($-0.6<SI<-0.4$) or hydroxide ($0.2<SI<0.9$) phase. The saturation index for strengite (Fe(III) phosphate) was also close to zero. Note that the solid phases, as measured by the difference between total and dissolved concentrations, were small to negligible for nearly all species, however such synoptic sampling is unlikely capture mineral precipitation and sedimentation out of the water column. Solution was undersaturated with respect to other phases commonly reported to control aqueous concentrations in mine lakes or other waters affected by acid mine drainage (Nordstrom and Alpers 1999), for example gypsum.

Concentrations of major ions Cl and Na exhibited low horizontal variability (Figure 7a and b) and little variation with depth. During periods of stratification, slightly higher concentrations were observed in the epilimnion, as was consistent with the salinity profiles and is attributed to evapoconcentration (Figures 7a and 7c). Similar profiles were observed for Ca, K, Mg, Mn, Zn, Si, and $SO_4$ (not shown), indicating largely conservative seasonal behaviour of these species.

During periods of stratification, the dissolved Fe concentrations in the epilimnion, relative to those in the oxic hypolimnion, were greater than expected due to evapoconcentration (Figures 7d and 7f). In contrast, the depth profile of aluminium did not display higher concentrations in the epilimnion during stratified conditions (Figure 6d and 6f). Concentrations of all species, including those that exhibited non-conservative behaviour during stratification, were constant with depth during non-stratified periods (Figures 7b and 7e).

Total N and Total P were composed predominantly of dissolved inorganic forms and TOC consisted predominantly of DOC (Table 1). During periods of stratification, ammonium, DOC, and DIC concentrations were higher below the thermocline (Figure 8). In contrast, NOx concentrations displayed the typical conservative behaviour (not shown). High concentrations of ammonium are unusual in the oxic hypolimnion of a natural water body, however this is commonly observed in acidic waters (e.g., Schindler et al. 1991) and may be attributed to the disruption of the nitrogen cycle due to, for example, altered equilibrium of the $NH_4/NH_3$ couple under acidic conditions and inhibition of nitrification under acidic conditions (Villaverde et al. 1997). During stratification, the DIC concentration below the thermocline reached up to 1.5 mg C $L^{-1}$ (Figure 8b), however it was below the detection limit (0.5 mg C $L^{-1}$) in the epilimnion and throughout the water column when the lake was fully mixed. Under the lake conditions of pH 4.5-5 and 13-25 °C, the aqueous concentration of $CO_2$ in equilibrium with the atmospheric partial pressure is below the detection limit of the analytical method (0.5 mg C $L^{-1}$). Degassing of $CO_2$ from the surface layers after the breakdown of stratification would thus explain the lack of measurable quantities of DIC throughout the water column when the lake is mixed and also in the epilimnion during stratification. Total phosphorus concentrations were relatively constant with depth (5–10 $\mu$g P $L^{-1}$) and FRP was under detection limit (< 2 $\mu$g P $L^{-1}$) on most sampling occasions (not shown).

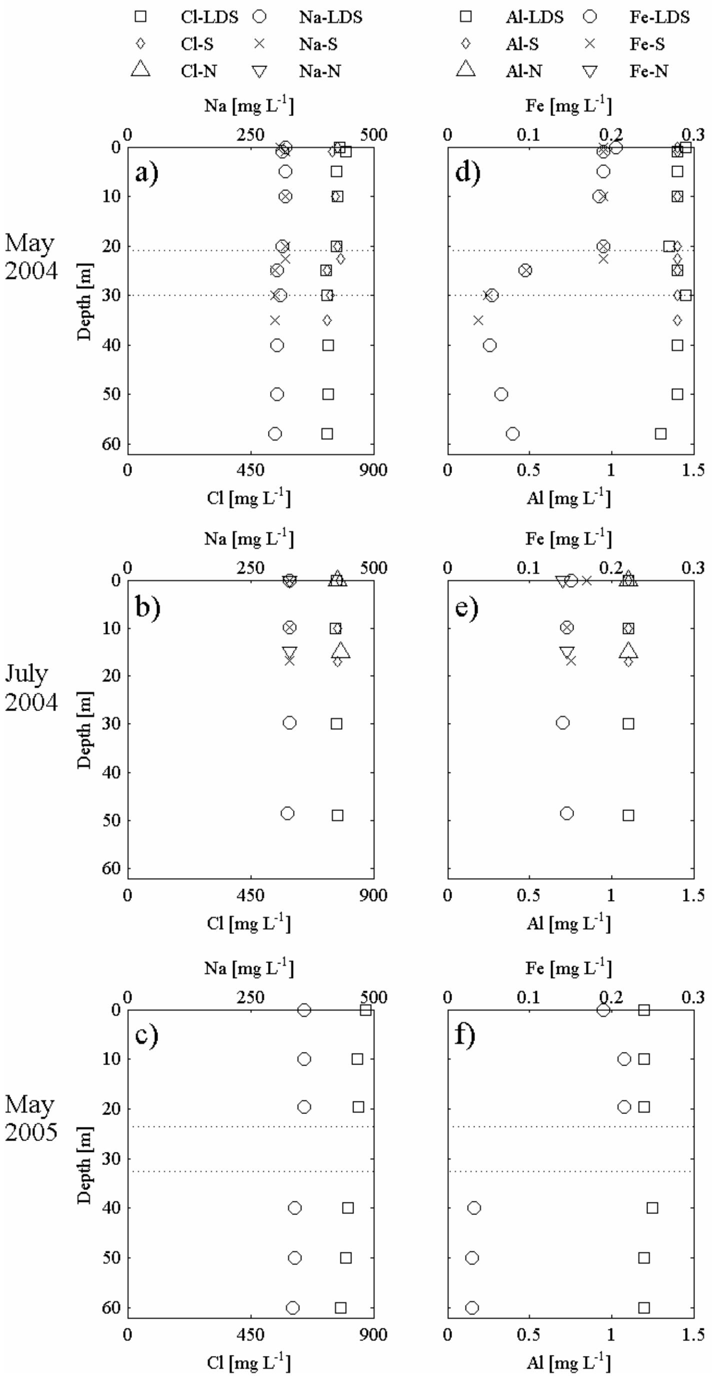


**Figure 7** Water column concentration profiles of Cl and Na in a) May 2004, b) July 2004, c) May 2005; and Fe and Al in d) May 2004, e) July 2004 and f) May 2005. Different symbols are used for different sampling locations (cf. Figure 1) and highlight the lack of horizontal heterogeneity in the lake. The dashed lines indicate the extent of the thermocline during stratification periods.

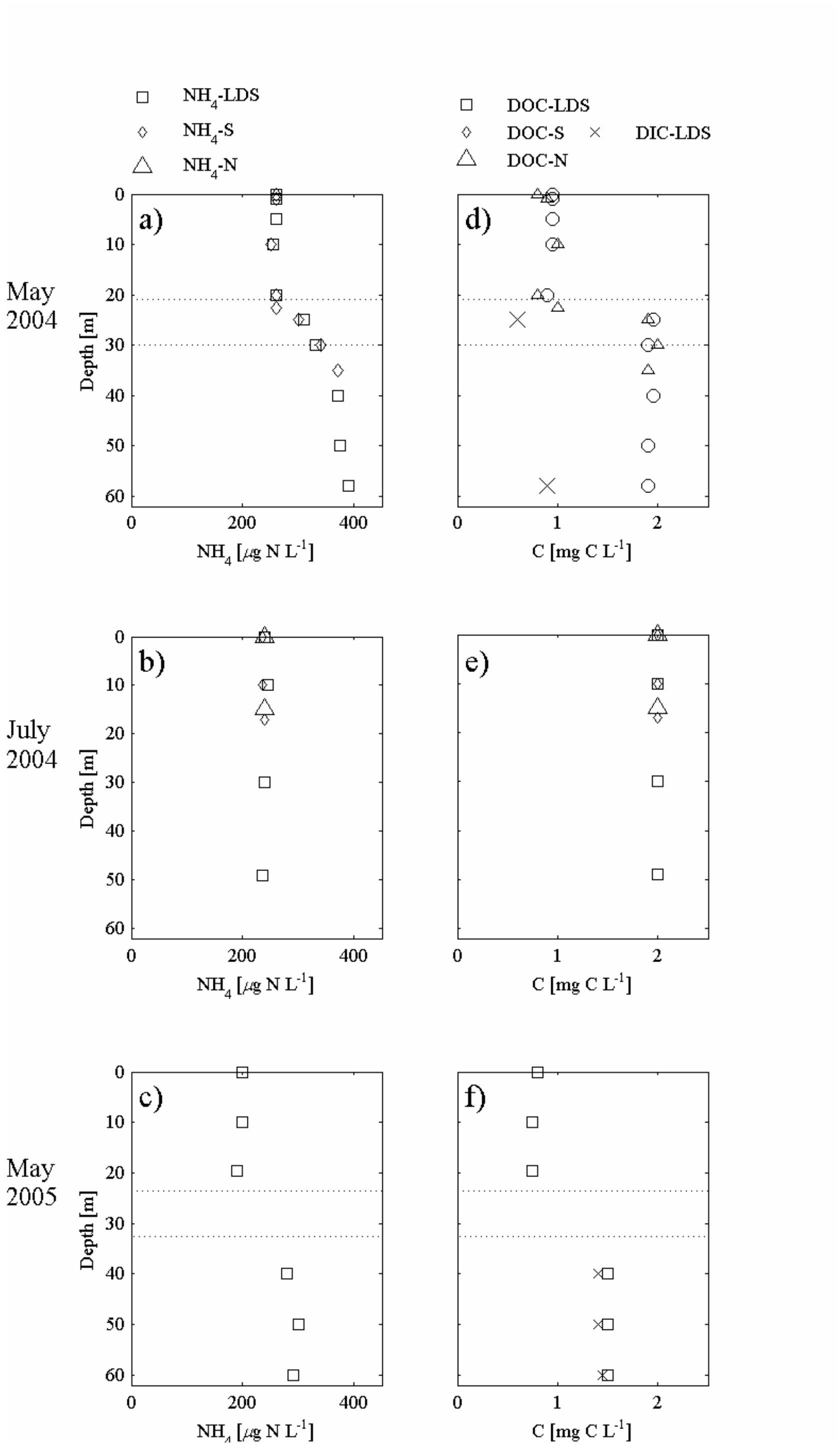


**Figure 8** Water column concentrations profiles of $NH_4$ in a) May 2004, b) July 2004, c) May 2005; and dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) in d) May 2004, e) July 2004 and f) May 2005. Different symbols are used for different sampling locations and highlight the lack of horizontal heterogeneity in the lake. The dashed lines indicate the location of the thermocline during stratification periods. Note that DIC was above the detection limit only during stratification, in or below the thermocline (see text).

### Inflows and temporal trends

During the river diversion period in 2004, the pH of the Collie River South Branch as measured on 9 occasions varied from 6.5-7, and DIC concentrations ranged from 6.2-7.9 mg C $L^{-1}$. Concentrations of the major inorganic "conservative" ions were similar in the lake and river (Figure 9a), which is consistent with 95% of the volume of the lake originally being river water. Of the species that differed by more than a factor two, concentrations of Al (dissolved and total), Zn, Mn, and $NH_4$ were lower in river water, whereas TOC, DOC, TP, FRP and dissolved Fe were higher in the river water. The conservative mixing model, as applied to the May-July 2004 riverine diversion period, predicted most July 2004 concentrations to within a factor of two (Figure 9b).

In contrast, estimation of the July 2004 lake water quality from conservative mixing of July 2001 lake water (pH 4.4) with river water led to an over-prediction of concentrations of Al, Fe, DOC and P (Figure 9b), indicating probable loss of these species from the lake water column over time. Note that while differences between concentrations in May 2004 and May 2005 were not great enough to be significant, trends were consistent with the longer-term conservative mixing model in that concentrations of most non-conservative species were slightly lower in May of 2005 than in May 2004, for example, even in the case of DOC, despite the higher concentration in July 2004 that resulted from river inflow (Figure 8d-f). In contrast, concentrations of conservative species increased slightly from May 2004 to May 2005 (e.g., compare Figures 7a and c), which is consistent with evapoconcentration over the summer 2004-2005. The lack of signature of evapoconcentration in the conservative mixing calculations from 2001-2004 is probably due to the effect being small relative to the large volumes of river diversion over this period.

As the lake has now reached maximum capacity and river diversion is currently planned only to be used to "top up" the lake each year, the annual contribution of the river to the water column will be less in future. Other inflows that may influence the future evolution of the water quality in the lake, particularly over a longer time period, include surface runoff and groundwater. Groundwater samples from 1998 (Varma 2002), collected from 2 bores on different sides of the lake, showed relatively disparate pH (4 and 6) and concentration levels (for those elements measured, Figure 8c), but in general did not differ greatly to concentrations in the lake.

The sample of surface water runoff collected in July 2004 was fairly dilute relative to the lake water, however, the concentration of dissolved Al was as high as in the lake, concentrations of particulate Al, Fe and P were much higher, and pH was much lower at 3.5 (Figure 9d). As the volume and flowrate associated with the surface and groundwater inflows is unknown, as is any spatial or inter- and intra-annual variation in concentrations in these inflows, forward calculations of long-term lake water quality evolution are limited.

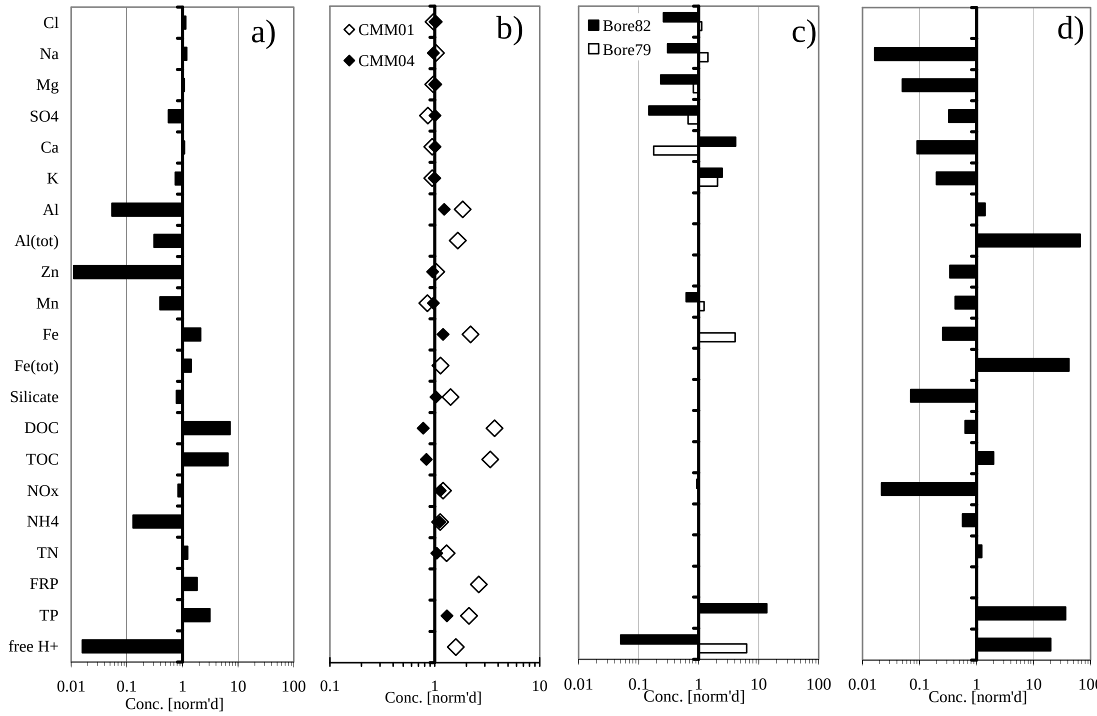


**Figure 9** a) Solute concentrations measured in the river water; b) solute concentrations predicted by the conservative mixing model as applied to the 2004 diversion period (CMM04), and also as applied to the 2001 – 2004 diversion period (CMM01); c) solute concentrations measured in two groundwater bores close to Lake Kepwari (Varma 2002; Note that not all parameters were measured in either bore); and d) solute concentrations measured in the surface run-off. Note the logarithmic scale. All values are normalized to lake solute concentrations in July 2004 (cf. Table 1).

### *Modelling*

Largely without calibration, the numerical model prediction of Lake Kepwari water quality over an annual cycle closely reproduced the patterns of stratification and overturn observed in the lake (Figure 10), as well as evapoconcentration (Figure 11, chloride as a conservative tracer). The model also reproduced major temporal and spatial patterns for non-conservative species, such as $NH_4$ and DOC (Figure 11) and pH and Al (Figure 12), and a sensitivity analysis indicated that even though the lake is now at full capacity, surface and groundwater inflows may still be important factors in the long-term evolution of the lake water quality. The model also allowed us to test the importance of geochemical processes for lake water quality, for example solubility equilibrium control of pH by Al hydroxide phases (Figure 12). The modelling study of Lake Kepwari thus demonstrated the capability of the model to reproduce the main features of the current water quality in the lake, and highlighted the need for testing against data sets which include e.g. well-constrained water and mass balances over the lake.

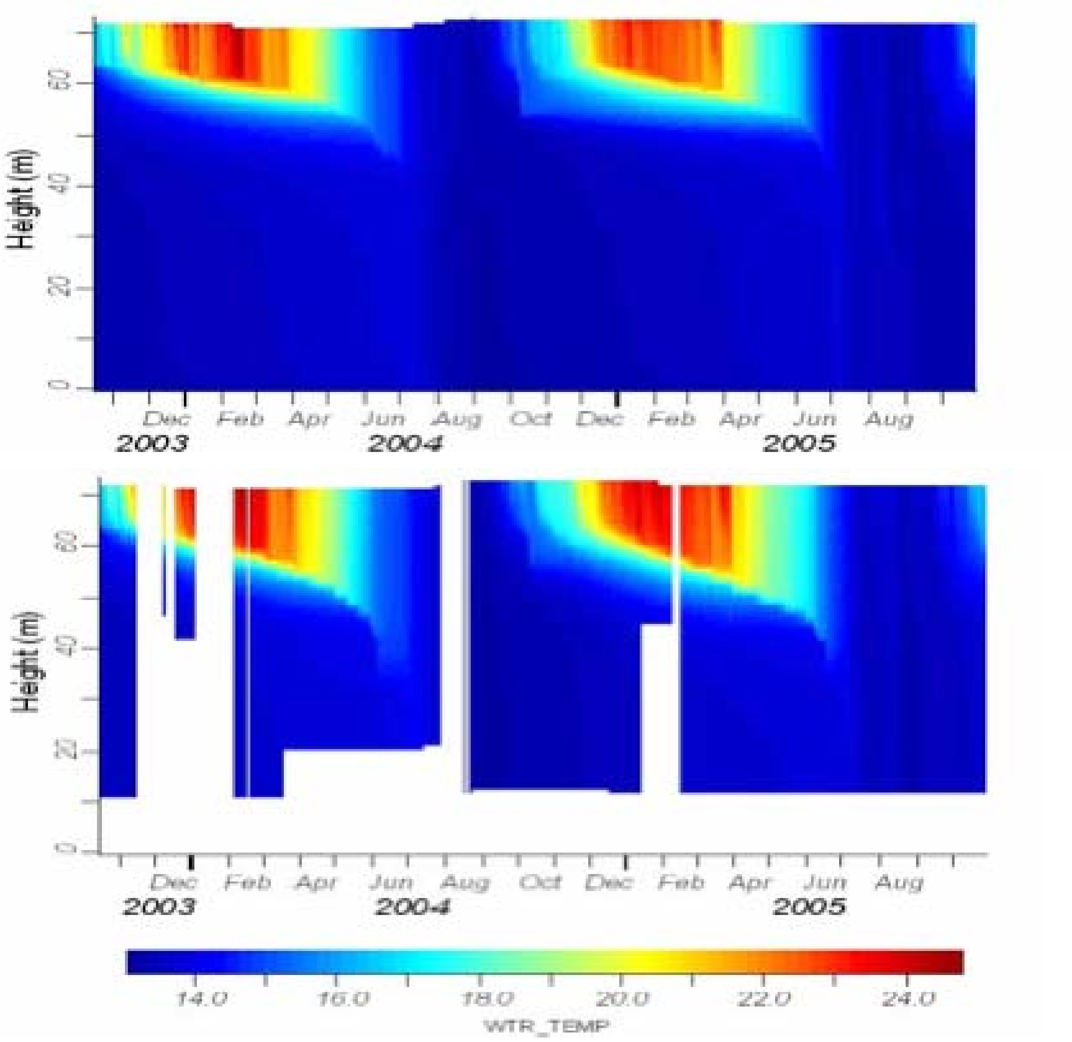


**Figure 10**: Temperature stratification cycles in Lake Kepwari from October 2003 – October 2005. The top panel shows DYRESM output, and the bottom panel shows LDS field data. Temperature stratification occurs from October to May each year. Note that the riverine diversion occurs in June-July when the lake is isothermal, and therefore its signature is rarely detectable.

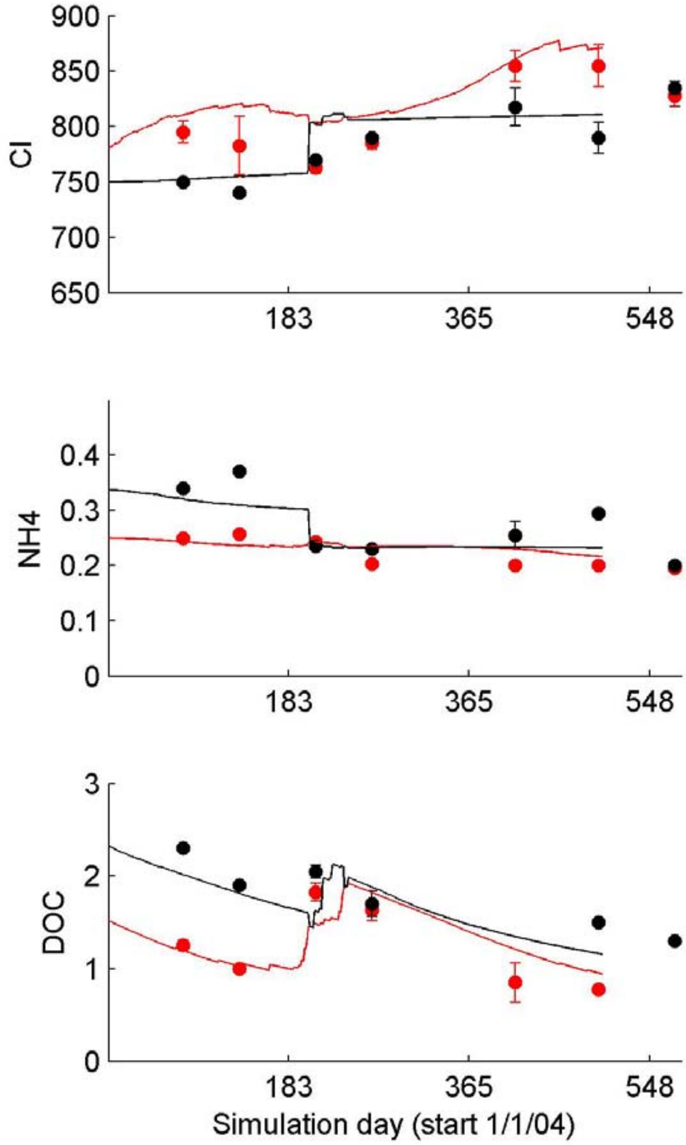


**Figure 11**: Model output (lines) compared to field data (symbols) for Cl, NH4, and DOC. Red lines indicate depth and volume averaged surface water concentrations, black lines indicate depth and volume averaged bottom water concentrations. Red dots show measured bottom water concentrations, and black dots show measured surface water concentrations.

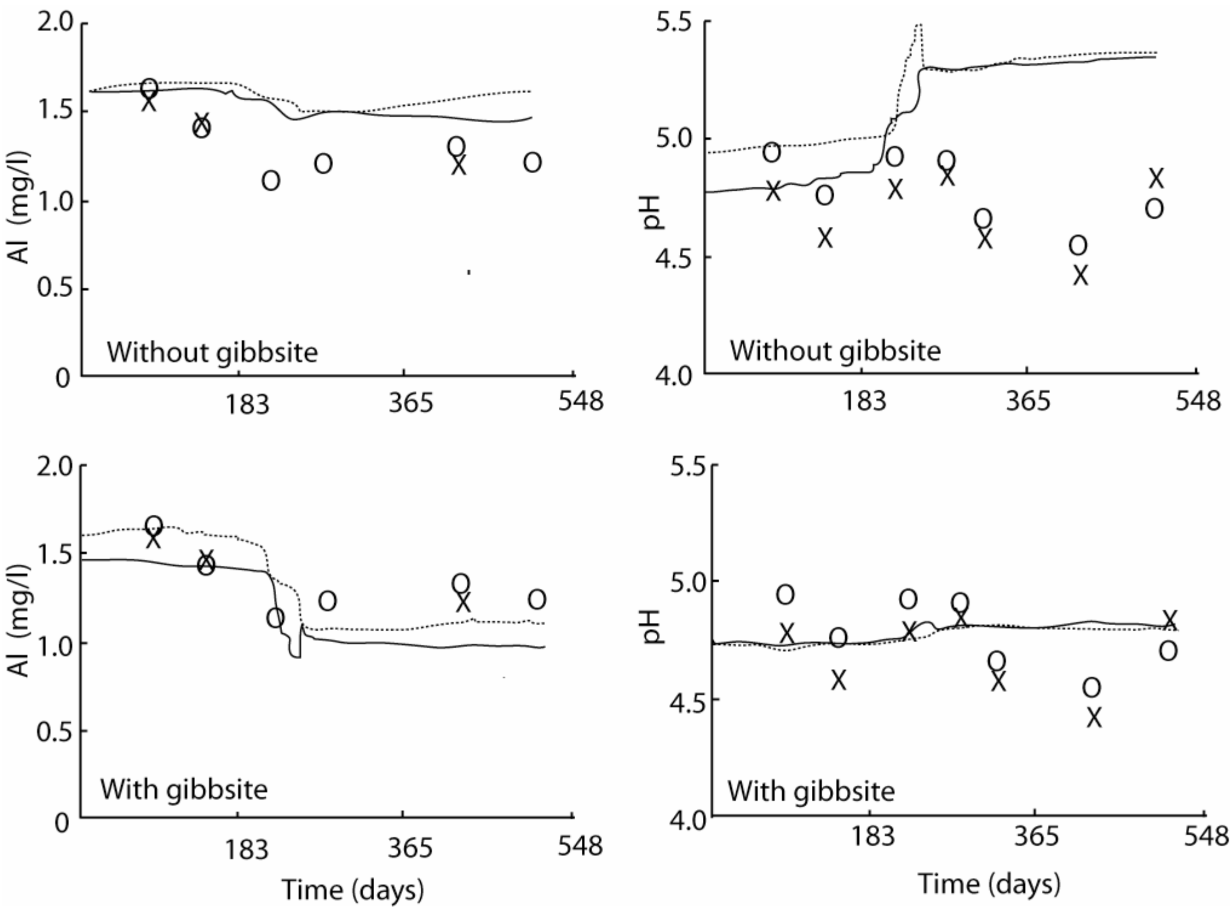


**Figure 12**: Model output (lines) compared to field data (symbols). Dashed lines indicate depth and volume averaged surface water concentrations, solid lines indicate depth and volume averaged bottom water concentrations. Crosses show measured bottom water concentrations, and circles show measured surface water concentrations. The addition of gibbsite solubility equilibrium control to the model improved its ability to simulate the response of Al concentrations and pH to riverine inflow.

## Discussion

The precipitation/dissolution reactions of Al and Fe are commonly reported to control pH in pit lakes (e.g., Geller et al. 1998). Despite consisting of 95% river water, Al comprised approximately 80% of the calculated total acidity in Lake Kepwari and saturation index calculations suggested that aqueous aluminium concentrations were controlled by solubility equilibrium with a hydroxide or hydroxysulfate phase. Inflow of alkalinity with the river diversion has thus been insufficient to overcome acidity originally present in the void when filling began, and/or ongoing acidity inflow. Long-term improvement of the pH in Lake Kepwari therefore requires the generation of sufficient alkalinity to lead to removal of Al and Fe, both that already present in the water column and from current and future inflows.

Ideally, the inflow of alkalinity and/or natural or internal alkalinity generation (IAG) in the lake itself would suffice to both neutralise the acidity present in the water column and also maintain a natural buffering system against any ongoing acidity source. Potential internal alkalinity sources in lakes include anaerobic, microbially mediated oxidation of organic matter in conjunction with the reduction of $NO_3$, Fe(III) or $SO_4$ (e.g., Kelly et al. 1982). Laboratory and mesocosm experiments demonstrating stimulation of the alkalinity generating sediment processes in acid mine lake sediments in response to the addition of organic carbon (e.g., Wendt-Potthoff et al. 2002; Frömmichen et al. 2003, 2004) indicate that alkalinity generation in such lakes may be limited by the supply of organic carbon. Sources and sinks of DOC in Lake Kepwari may thus have an important influence on how the acidity, and general water quality, in the pit lake will evolve, both with and without riverine diversions.

It should be noted that the generic process descriptions in the developed model can be applied to almost any aquatic system, irrespective of the pH. Examples of systems which can now be modelled, include the effect of artificial destratification on algal blooms associated with Fe reduction and $PO_4$ release; treatment of eutrophic waters or drinking water by addition of Al or Fe salts to remove organic matter and/or phosphorous; and the removal of heavy metals through addition of nutrients to stimulate primary production (organic matter scavenging) and/or sulphate reduction (metal sulphide precipitation). The model also allows us to study the response of water quality to altered groundwater and surface water inflow under various climate change scenarios.

It should be particularly noted that while the initial test field site was a coal mine pit lake, the model is based in sophisticated process description and parameterisation; this allows immediate application to pit lakes of widely varying water quality. We now require a comprehensive validation exercise of model predictions against high quality datasets from pit lakes; it is essential to increase our confidence in the simulation results. In particular, there is a need for testing model performance against long-term data sets from systems with well constrained groundwater inflow, sediment fluxes and aquatic food web data, as well as hydrodynamic and geochemical state variables. As with all models, there is also the need to quantify, given the available data, the uncertainty in model simulation results, and alternatively, the minimum data required to obtain a result to within a given degree of certainty. The result will be an improved tool for management and remediation of acidic mine lakes, including design optimisation for future field and laboratory sampling campaigns.

With respect to the sub-project, the long-term drift of Idronaut pH and redox sensors were fully characterised. It was shown that the long-term drift of the pH sensor is only due to a drift in the reference sensor, while the redox sensor drift is also ascribable to fouling of the electrode. Ultimately, these results signalled that it is essential to periodically check the reference sensor for drift (say once a fortnight) and recalibrate the pH sensor as necessary, and that the redox sensor requires periodic polishing (say once a fortnight) to remove any surface fouling acquired during long-term deployment in the field.

For the influence of temperature, the sensors obeyed the laws of electrochemical thermodynamics, and the research showed that the temperature sensitivity of the sensors was around 0.5-1.0 mV per degree centigrade. This linear response to temperature may be used in a temperature compensation of the sensor response as a function of depth during the deployment of the sensors in the field.

Pressurisation of the sensors led to a considerable change in the response of the sensors, and rigorous evaluation of the response showed that this behaviour is ascribable solely to a liquid junction potential error for the reference sensor. Nevertheless, the experimental studies also showed that the sensors adapted to pressurisation eventually providing a stable reading after approximately 24 hours exposure to mine void water at elevated pressure. Clearly, it is essential to condition the sensors for at least 24 hours at each pressure applicable to field deployment at depth, so as to provide reliable data that is free of pressure related experimental artefacts.

The mechanistic aspects of long-term ageing of the sensors in mine void water were studied using the electrode kinetic technique of electrochemical impedance spectroscopy. Clearly, the pH sensor is insensitive to ageing, and any observed drift may be compensated by periodic checking of the reference sensor against a standard reference sensor. Alternatively, ageing of the redox sensor is due to poisoning of the sensor, and may be rectified by periodic polishing of the redox probe. As shown above, these actions need to be performed about once every fortnight, if reliable field data is to be obtained.

The sub-project team has employed these sensors in both field trials of water quality at the W05 mine void at Collie during both the dry and wet seasons. Furthermore, the measurements of pH and redox potential were correlated against independent chemical analyses of the acidity of the waters, along with the redox capability of the waters obtained using dissolved oxygen and iron assays of the waters. Clearly, the field data showed that the sensors are functioning reliably since stratification of the water is due to the oxygen-based oxidation of pyrite leading to elevated acidity and iron levels at the lake floor, as well as diminished DO levels in this part of the water column. These results are very reassuring, giving great confidence in the ability of the sensors to monitor reliably the changes in the water chemistry that reflect variations in the water quality.

The project provided a reliable measurement protocol for use with the Idronaut pH and redox sensors in the monitoring of mine void water in sensor strings. Furthermore, this methodology has been validated against the CWR's commercially available F-probe.

Due to restrictions with resources, the CWR were unable to build the custom-designed sensor string instrumentation to be used in the in-situ field studies. Hence, this component could only be completed using comparable sensors attached to the CWR's commercially available submersible F-probe instrument. Furthermore, only a limited amount of work was undertaken using the F-probe due to equipment downtime with this submersible instrument.

## Conclusions

The pH of Lake Kepwari remains below 5, and continues to decrease during periods of no riverine inflow. There is minimal water quantity or quality data available for riverine, surface, sub-surface and groundwater inflows. Lake Kepwari undergoes summer density stratification, lasting from October until April. Surface and bottom lake water remain oxic throughout the year. There is little pH trend with depth, even during stratification. Primary productivity levels are very low in the lake; chlorophyll levels remain less than 3 $\mu$g/L at all times, though deep chlorophyll maxima are observed.

Most of the dominant aqueous species can be considered conservative. Iron, aluminium, DOC, FRP and $NH_4^+$ behave non-conservatively in the lake waters. Acidity in the lake is dominated by Al, which buffers the pH to around 4.5. Fe also contributes to acidity but to a lesser extent, however higher Fe(II) concentrations in the bottom waters suggest an ongoing source, possibly from groundwater. This may explain the decreasing pH over periods of no riverine inflow.

Very low levels of FRP most likely result from complexation with Fe and Al species, and likely limit primary productivity in the lake. Internal alkalinity generation in the lake is controlled by very low levels of organic carbon. On addition of organic carbon to the lake sediments, $NH_4^+$, FRP and Fe are released into the water column, and there is evidence of sulfate reduction deeper in the sediments. Ultimately this would be a potential source of internal alkalinity generation.

Numerical modeling results highlight the importance of geochemical equilibrium control on pH within the lake.

The outcomes of the sub-project research have demonstrated that it is necessary to regularly repolish the redox probe to remove electrode fouling, if reliable measurements are to be obtained during the long-term deployment of this sensor. Furthermore, the temperature sensitivity of the sensors, as expected, is ascribable to the underlying chemical thermodynamics of the cell, viz., the temperature coefficient is underpinned by the cell entropy. On the other hand, the influence of long-term deployment and pressure is ascribable to a variation in the liquid junction potential of the associated reference electrode, and this may be compensated by using a conditioning regime (e.g., allow equilibration at the measurement depth overnight) prior to deployment of the sensor in the field.

Field studies have demonstrated that the Idronaut pH and redox sensors can reliably monitor and depict chemical events in the water body that lead to stratification of the water, and a diminution in the water quality of the mine void. Clearly, this is a significant outcome, as it provides a methodology for monitoring in-situ the water quality of mine void lakes.

Finally, Ms. Phub Gyem, an AusAid sponsored student working on this project, has submitted her Master of Science thesis for examination, and returned to her home of Bhutan.

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## Project 2.1: Biological remediation


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### Final Year Annual Research Report

The following research activities were undertaken during the final year of CSML project *Biological remediation* (note the majority of research work was completed by December 2006):

- A mesocosm experiment established to test the effectiveness of P additions and liming on remediation of waters from Lake Kepwari was complemented with a co-supervised ecotoxicological appraisal of the improvements in water quality undertaken by Luke Neil (ACARP Project 3).
- Further testing of a pilot scale remediation system installed at Spoonbill Lakes in City of Stirling, WA, to treat acid urban lakes, contaminated by nearby oxidizing acid sulphate soils.
- Treatment of AMD issues in Collinsville (Qld)[3] was initiated.
- Assessment began on the capacity for a sewage evaporation pond to treat acid pit lake water in Collinsville.
- The efficacy of sewage and greenwaste in microcosms to treat acidic pit lake waters in Collinsville was assessed.
- A lake scale treatment with sewage and greenwaste in an acidic pit lake in Collinsville was instigated.

The CSML Biological remediation team's in-lake remediation trial to clean up toxic and acidic mine water at the Collinsville Coal Project (Xstrata Pty Ltd), North Queensland, using sewage and green waste led to Collinsville winning the Ergon Energy Tidy Towns 2006 Award for Environmental Innovation.

Five refereed papers authored by the CSML Biological remediation team were accepted and published in 2006, with a further three major research reports written, and four conference papers presented that focused on biological remediation approaches developed from CSML research.

Macrocosms constructed at Ewington Mine Lake, Collie, to investigate whether complex organic matter can increase acidic mine lake water.

Acid Sulphate Soils impacts at Spoonbill Lakes, City of Stirling, WA.

Mesocosm experiment at ECU where twelve 1,200L tanks where filled with a 40mm layer of lake sediment from the bottom of the fast river-filled Lake Kepwari.

[3] The Collinsville work was funded directly by ACARP (Project number C14052). Therefore it is only briefly reported in this report. The ACARP report should be available by the end of 2007.

## Executive Summary

The original objective of Project 2.1 was to evaluate and improve the performance of an artificial wetland built next to Griffin Coal Ltd's Chicken Creek pit lake. The wetland was designed to treat acidic Chicken Creek Lake water to a standard suitable for aquaculture. The system makes use of a fluidized limestone reactor to neutralise the water followed by a 5 ha aerobic wetland to polish the water.

Our research shows clearly that the wetland did not substantially improve water quality following neutralisation and for some parameters increased concentrations. The wetland was undersized and lacked sulphate reduction capacity in its design. Low levels of nutrients (particularly P) might also have contributed to poor performance.

Expanding the project scope to look at biological remediation of acid pit lakes, the team examined four 45 year old (Ewington, Stockton, Black Diamond and Blue Waters) pit lakes in Collie and a new pit lake (Chicken Creek). This work highlighted that, after 45 years, the older lakes with minimal or little rehabilitation had generally changed little. Sites with large surface water inputs from old overburden dumps (Blue Waters) had changed the least, while sites with more neutral groundwater inputs and low surface inflows (Black Diamond) had improved significantly with pH >6. The pit lakes therefore represent a gradient in water quality from Chicken Creek through to Black Diamond. This highlights the importance of groundwater and surface water inputs in determination of water quality.

A macrocosm experiment was also conducted in Ewington Lake where experimental additions of organic matter (council mulch) and P were tested. Despite making very little difference to water quality, when analysed with multivariate statistics, the sites showed they were moving on a different trajectory to the old pit lakes. This indicates that adding organic matter and P fundamentally changed the lakes, moving them towards a profile more like a natural lake. However, the low sulphate concentrations (particularly in the old pit lakes) makes them unsuited to remediation strategies which focus on sulphate reducing bacteria. Although addition of P did not produce a significant water quality improvement, it was added in very low concentrations and was still able to produce a positive response in the pit lake overall.

As marron (edible Western Australian freshwater crayfish) are considered to be a potential aquaculture species for Collie pit lakes and are very popular as a recreational fishery, the team investigated what factors in the old pit lakes might be effecting the health and success of these animals. Marron were found to accumulate some heavy metals from the lakes to levels of concern for human consumption, they did not show significant health impacts of this body burden. Lack of habitat and food appeared to be the most important factors limiting growth rates and survival. It is speculated that remediation of these pit lakes with organic matter and P would enhance marron success.

A mesocosm experiment was established to test the effectiveness of P additions and liming on remediation of waters from Lake Kepwari. This was complemented with a co-supervised ecotoxicological appraisal of the improvements in water quality undertaken by Luke Neil (Project 2.2). The mesocosm experiment's results clearly show that liming is effective at increasing pH and removing most toxic metals, substantially reducing the toxicity of the water. The contraindications for liming remain the likely quantity of material required and associated costs, notwithstanding the future potential of liming systems outlined in Project 2.3, and the reductions seen in nutrients particularly P. Addition of P increased primary production slightly, and had some concentrations reductions of certain metals. However, only very low levels of P were added and the team remains optimistic that P addition possibly in conjunction with organic matter/liming remains an approach worthy of further consideration for remediating the Collie pit lakes.

The ECU team had the opportunity to test addition of organic matter additions in acid waters with substantial sulphate concentrations, when asked to build a pilot treatment plant for an acidity problem in an urban lake caused by oxidation of acid sulphate soils. This system incorporates a neutralisation stage (presently sodium hydroxide with the option of using fluidized limestone reactor), followed by mulch filled bioreactors. A key task for the system was removal of arsenic, which is associated with these acid sulphate soils. This experiment is ongoing and to date appears to be effectively treating pH and reducing metals and arsenic prior to discharge.

The team is also involved in an ACARP project (C14052) which involves application of technologies developed by the team in Collie to a severe AMD issue in Collinsville in Queensland. In a series of microcosm experiments, the team has tested additions of sewage and greenwaste to mine waters and successfully treated them from pH 2 to pH 7. A field trial to treat a 50 ML pit lake is currently underway and initial results are very encouraging. This incomplete work is not reported on detail here, but instead will be detailed in the ACARP Project Report for C14052 in late 2007.

## Introduction

Griffin Coal Mining Company Limited in Collie, (Western Australia), has constructed an artificial wetland to remediate acidified pit lake water and make it suitable for cultivating plants or fish. This 5 ha treatment wetland is located next to the Chicken Creek Mine Lake (pH 3, containing approximately 8 million $m^3$ of water). Although the wetland was originally designed to use compost ponds to increase pH through sulfate reducing bacterial action, this part of the wetland was replaced by a liming treatment. The liming treatment, utilising a fluidised bed of limestone, was developed by Griffin based on studies conducted in North America. This liming system has been further developed by CSML (and is detailed under ACARP Project 4). Initial results showed that the liming was very economical and successful in increasing pH of the void water to circum-neutral. It was originally proposed that this project team would examine the role played by the newly constructed wetland in polishing the limed water for use in a variety of end-uses (including return to the void).

A number of technical issues with the operation of the liming system limited water that could be supplied to the wetland. As a result the team did some initial sampling and then combined this with a literature review on wetland performance. This revealed the limitations of the wetland for polishing and the 2005 conversion of Chicken Creek Mine Lake to a sacrificial lake to contain saline waters from the Collie River (a river rehabilitation strategy) effectively halted this research. The team forthwith broadened their interests to all types of biological remediation of mine waters. This included work on the Collie pit lakes, lakes in Queensland and urban lakes impacted by acid sulphate soils. The aim was to develop and assess a range of technological approaches that could be used to remediate a range of pit lake waters.

The project team undertook the following projects:

- An evaluation of the Griffin Constructed Wetland.
- A brief survey of existing historical pit lakes in Collie and modern pit lakes.
- An assessment of the robustness of acidity measurements.
- An in-lake macrocosm experiment to evaluate the effects of organic matter and P additions on water quality.
- A study looking a marron health as an indicator of biological processes in the pit lakes.
- A mesocosm study examining the effectiveness of P and liming additions on water from Lake Kepwari (Collie).
- Construction of a treatment system to treat acid sulphate soil induced acidity in Spoonbill Lakes in the City of Stirling (Perth).
- Treatment of AMD issues in Collinsville (Qld)[4].
- Assessment of the capacity for a sewage evaporation pond to treat acid pit lake water in Collinsville.

[4] The Collinsville work was funded directly by ACARP (Project number C14052). Therefore it is only briefly reported in this report. The ACARP report should be available by the end of 2007.

- Assessment in microcosms of the efficacy of sewage and greenwaste to treat acidic pit lake waters in Collinsville.
- A lake scale treatment with sewage and greenwaste in an acidic pit lake in Collinsville.

## Griffin Wetland - Background

At Griffin Coal Mining Company Limited in Collie WA, an artificial wetland was constructed to polish mine lake water treated using fluidised limestone beds to remediate acidified mine lake water and make it suitable for cultivating plants or fish. This 5 ha treatment wetland is located next to the Chicken Creek Mine Lake (pH 3, containing approximately 8 million $m^3$ of water (Nguyen, 2004). Although the wetland was originally designed to use compost ponds to increase pH through sulphate reducing bacterial action, this part of the wetland has been solely replaced by a liming treatment. The treated water was then intended to be passed through a aerobic wetland for conditioning (polishing) before being available for a range of enduses, including return to the mine lake or aquaculture.

## Griffin Wetland - Methods

A desktop study was undertaken in 2004 to review current developments in the use of wetlands to treat acidic mine waters. This review formed the basis for an assessment of the wetlands predicted performance in polishing limed pit lake water. Water flow and liming treatment through the Chicken Creek wetland was inconsistent throughout 2004. However, water samples were collected in 2004 during a period of consistent flow through different steps of the liming filter and wetland treatment components. Samples were analysed for nutrients and metals. These sites were also utilised by Dr Yuri Tsvetnenko who determined the toxicity of the water at different points along the wetland to selected test animals (Reported in ACARP Project 3).

## Griffin Wetland - Results and Discussion

Phosphorus concentrations were very high in Chicken Creek pit lake, as has been evidenced from algal blooms following mixing events. The high concentrations of phosphorus seen here are likely to be due to groundwater influx from the agricultural areas inland of the void lake. Surprisingly, the liming treatment removed little phosphorus from Collie Wetland, other than to bind some of the dissolved form – filterable reactive P (FRP; Figure 2.1). This might have been due to dissolution of P from the lower-grade lime chip used in this filter or insufficient residence times within the filter to allow binding. Total (TP) and FRP increased slightly after passage through the wetland, and this was suspected to be due to fertilising of the wetland soils to assist plant establishment. Nitrogen trends are more difficult to explain. Although first liming appeared to increase total nitrogen (TN) concentrations, the second liming treatment appeared to decrease them. Loss of ammonia (NH3) throughout liming treatment is possibly due to both volatisation and also conversion to NOx (NO2/NO3) forms. The loss of NOx, ammonia and total nitrogen through the wetland was most likely due to biological assimilation.

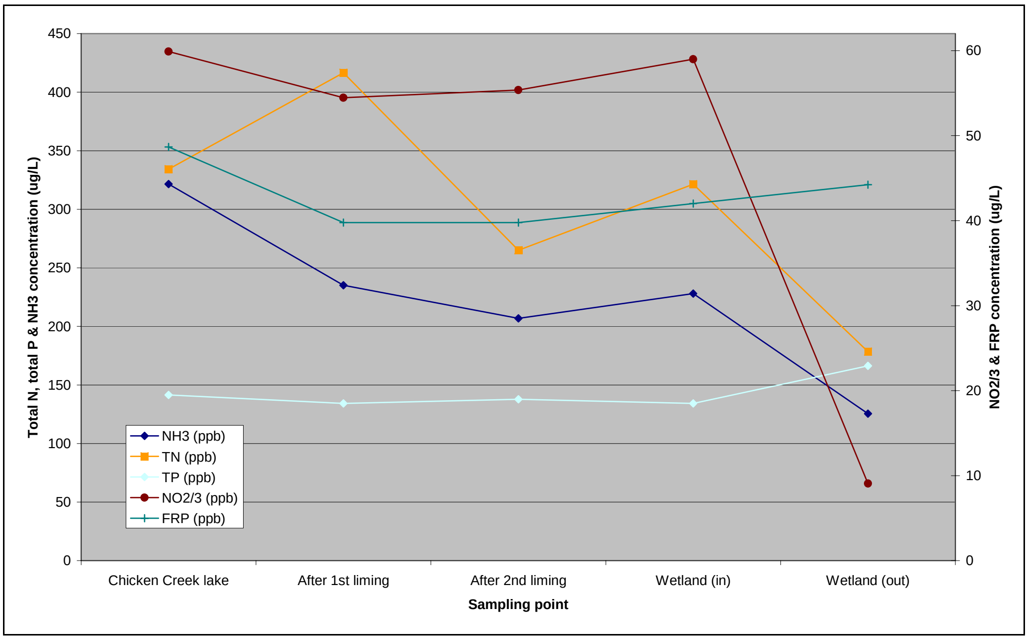



**Figure 2.1** Change in nutrient concentrations through fluidised liming treatment and Chicken Creek wetland.

Metal concentrations behaved as expected through the liming and wetland treatment system. The very low concentrations of particulate (total) forms of chemicals generally decreased throughout the process, whereas dissolved forms of some species, e.g., Ni, Zn, Cd, etc., conversely *increased* throughout the treatment system. Water hardness characteristics increased (magnesium and calcium ion concentrations), acidity buffering ions of aluminium and iron (iron especially after the first liming treatment) decreased through precipitation as oxyhydroxides. The total and filtered concentrations of many other metal remained largely unchanged, even throughout the wetland (Figure 2.2).

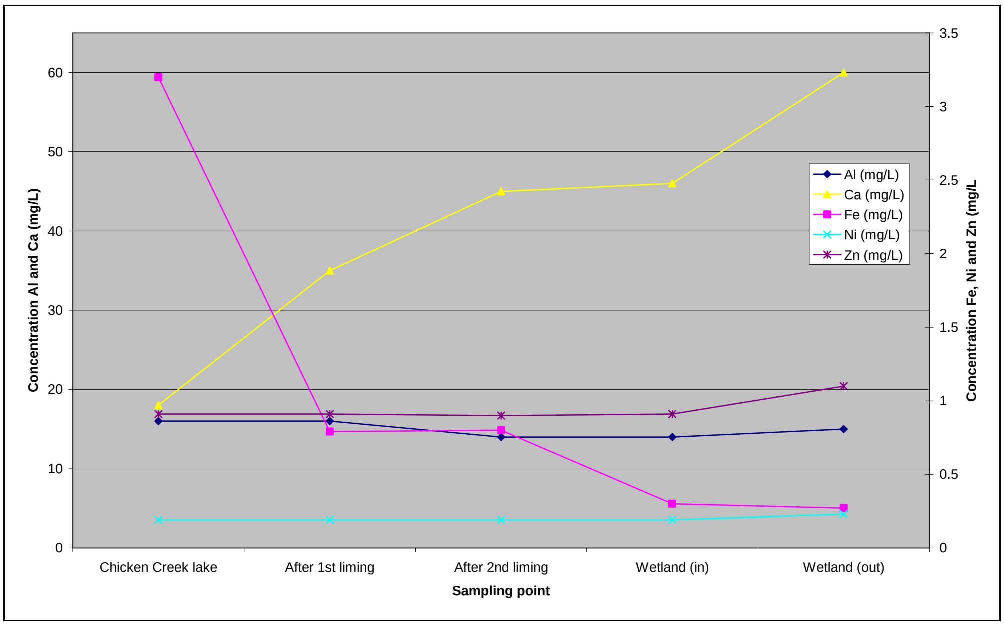



**Figure 2.2** Change in filtered metal concentrations through fluidised liming treatment and Chicken Creek wetland.

An extensive review of the literature revealed that these data largely fit with expectations as to how this wetland treatment system would act. Although liming was an effective treatment for remediating pH acidity and iron and aluminium concentrations, other metals and metalloids of concern such as cadmium and arsenic respectively, are left unchanged. There appeared to be no significant metal contribution through liming, although a sample of the lime chip used has also been taken to quantify this contribution.

Although totals of metals were generally reduced by the wetland, this appeared to be largely by a settling process as filtered concentrations often increased. These filtered forms are considered the more biological available, and hence more toxic forms of these chemicals (ANZECC/ARMCANZ, 2000). Data from CSML Program 2.2 also confirmed the inability of this system to remediate mine water, with final treatment water found to remain toxic in bioassays. This was most likely due to high metal concentrations remaining. These findings were not unexpected as the Chicken Creek Wetland is an aerobic design. Although aerobic wetlands are often 6 times cheaper than their anaerobic counterparts as is Chicken Creek Lake water (Syrinx, 2001) which treat acid water with high concentrations of ferric iron and aluminium (Ford, 2003) treatment in an aerobic wetland is only successful for net alkaline water.

The expected characteristics of an anaerobic wetland off-take system to treat acid water from the Chicken Creek lake were examined via the Pennsylvania Department of Environmental Protection's AMD Treat model (Pennsylvania Department of Environmental Protection *et al.*, 2004). A further desktop study evaluated the state-of-the-art of biological acid mine water remediation also. Scientific literature was examined for data suggesting lake acidity and sulfate concentrations (Syrinx, 2001), expected sulfate reduction rates (Eger, 1994) and organic matter required. This model estimated that around 50,700 $m^3$ of organic matter would be required, at a recent unit costing of $14 per $m^3$, this would lead to an expense of around $710,000 (Table 2.1). The anaerobic wetland surface area required for this would be expected to be 9 ha. The current aerobic wetland surface area is only 5 ha.

**Table 2.1** Estimated and predicted physico-chemical parameters for Chicken Creek remediation by liming alone.

| Parameter | Value | Units |
|---|---|---|
| Influent sulfate concentration | 282 | (mg/L) |
| Flow rate | 30 | (L/s) |
| Sulfate loading | 731 | (kg/day) |
| Sulfate reduction rate | 11,016 | (mg/$yd^3$/day) |
| Organic matter required | 50,676 | ($m^3$) |
| Lake acidity | 171 | (mg/L $CaCO_3$) |
| Acidity loading | 443,517 | (g/day $CaCO_3$) |
| Wetland size Ψ | 9 | (ha) |
| Sulfate-reduction alkalinity produced* | 380 | (kg/day $CaCO_3$) |
| Lake volume | 6,817,435 | ($m^3$) |
| Time to neutralisation | 8.4 | (years) |

ΨAcidity loading factor of 5/g/$m^2$/d (Pennsylvania Department of Environmental Protection, 2005; Ford, 2003) *Assuming 50% conversion of $SO_4$ to $H_2S$

Alternatively, treatment by liming (as $CaCO_3$) alone, assuming no sediment buffering or ground water inflow, would require around 1,200 t of lime (more as lime chip) and around 12 years for neutralisation at the rate of treatment of 30 L $s^{-1}$ (Table 2.2).

**Table 2.2** Estimated and predicted physico-chemical parameters for Chicken Creek lake water remediation by liming alone.

| **Parameter** | **Value** | **Units** |
|---|---|---|
| Liming efficiency (% acidity removed)* | 0.96 | |
| Flow rate | 19 | (L $s^{-1}$) |
| Total lake acidity | 1,167 | (t $CaCO_3$) |
| Time to neutralisation | 11.9 | (years) |

*R. Desmier CSML, pers. comm.

The large scale of the problem relative to the scale of the remediation system, means that in many cases the initial investment and operational costs for active off-take systems are prohibitive (Koschorreck *et al.*, 2002).

## Limnology of pit lakes in Collie - Background

The aim of this survey is to determine what natural processes have led to some of historic mine lakes (e.g., Black Diamond) having lower acidity and high pH than their compatriots. Once the implications of these processes are known, these processes may then be accelerated to improve water quality of both low water quality historic void lakes and also of new mine lakes. To this end, March 2004 saw a summer survey of the physical, chemical and biological limnology of five old and new void lakes completed.

## Limnology of pit lakes in Collie - Methods

In March 2004, four old pit lakes (Stockton, Ewington, Blue Waters and Black Diamond), and one new pit lake (Chicken Creek) in Collie were sampled. Sampling involved measuring light attenuation (using a PAR meter (Li-Cor) and 4pi globe), benthic sampling by SCUBA of sediment for analysis of organic matter (measured as Loss on Ignition). Analyses of chemotrophic bacterial activity in lake sediments was measured through semi-quantitative "BART" tests which examined sulfate reducing bacteria (SRB) and iron-related bacteria (IRB) activity.

## Limnology of pit lakes in Collie - Results and Discussion

Attenuation of photosynthetic active radiation (PAR) has been found to be a limiting factor for benthic, and also for much pelagic primary production, in the deep Chicken Creek Lake. This lake has an epiphotic depth of 13 m, which is where there is approximately 1% of incident light and respiration equals photosynthesis. Below the epiphotic depth there is insufficient light for net primary production. The shallower or clearer nature of the other mine lakes suggests that there is sufficient light at the sediment to support benthic algae (Figure 3.1).

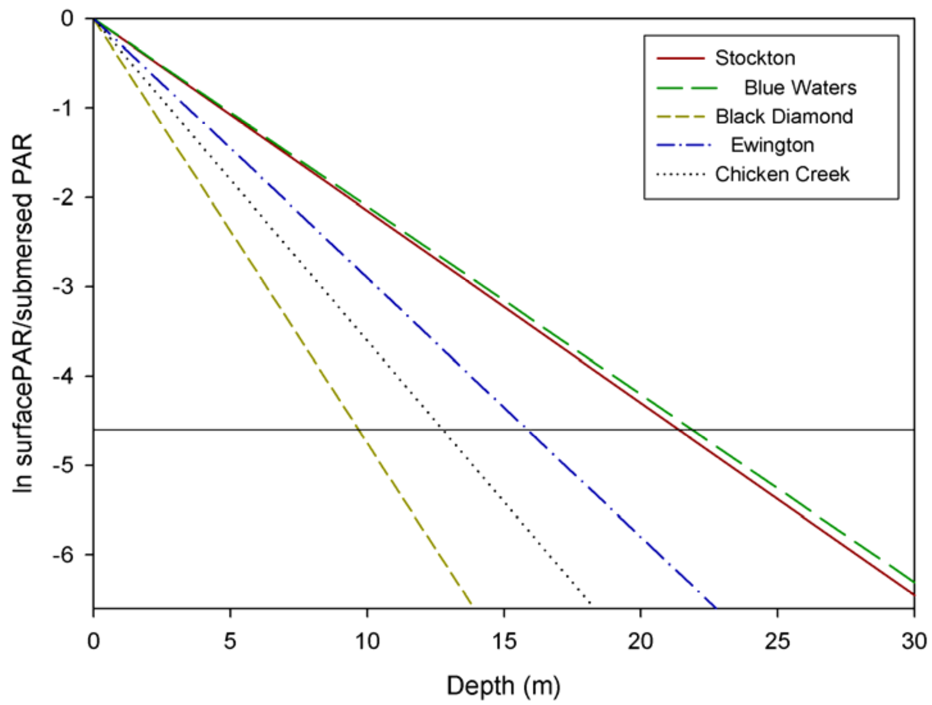



**Figure 3.1.** PAR attenuation as a function of depth in Collie mine void lakes. Reference line indicates epiphotic zone

Other findings include the discovery and collection of what appears to be the charophytes *Chara globularis* and an unidentified *Nitella* sp. in Black Diamond Lake. Further surveying during periods of fruiting is expected to resolve their taxonomic identity. Frequently the primary colonisers of recently disturbed aquatic habitats, the presence of these algae (the only aquatic macrophytes present in any of the mine lakes) has great significance both to the mechanisms of evolution of the void lakes, and also to other biological pathways available for their remediation.

Coexisting with previously recorded feral freshwater poeciliid mosquitofish (*Gambusia holbrooki*), western pygmy perch (*Nannoperca vittata*, formerly *Edelia vitta*) were also discovered in Black Diamond lake this year. Both fish are primarily surface feeders, therefore introduced *Gambusia* probably compete directly with pygmy perch for allochthonous invertebrate foods.

It can be seen in Figure 3.2, LOI of lake sediments was generally very low. This suggests that biota in the lakes are probably limited by the availability of organic matter for food.

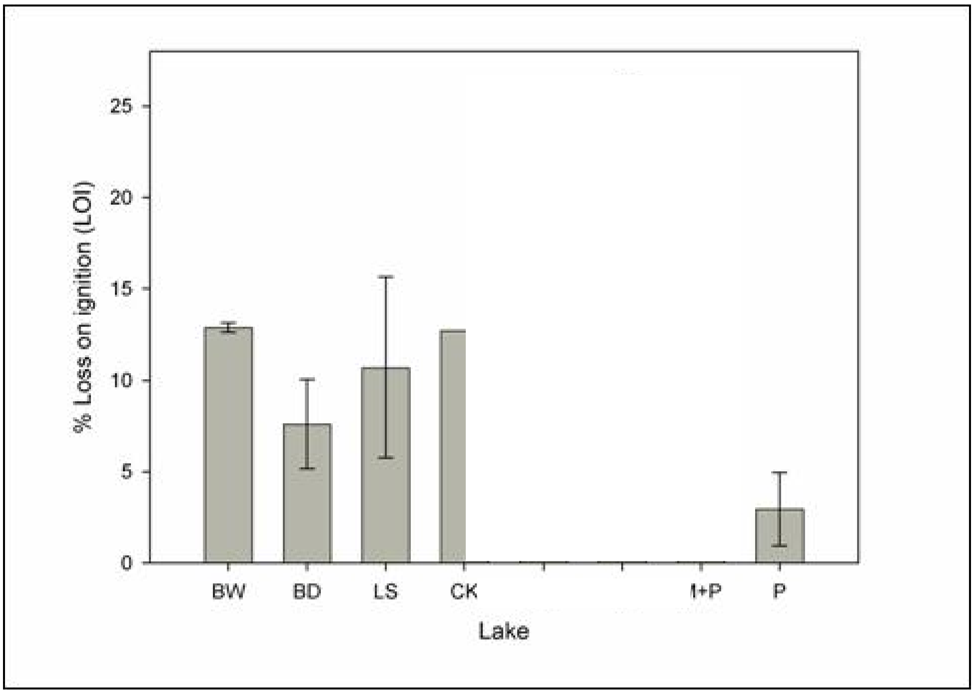



**Figure 3.2** Loss-On-Ignition (LOI) of sediments of Collie mine void lakes (April 2004). Bars represent single standard errors of the mean (BW = Blue Waters; BD = Black Diamond; LS = Stockton; CK = Chicken Creek; EW = Ewington).

Bacterial activity was also surprisingly patchy within lakes (Figure 3.3).


**Figure 3.3.** SRB samples from Ewington Lake mesocosm experiment (Day 12)

Iron-related bacterial activity was highest for Chicken Creek Lake. SRB activity was found in all lakes except for Chicken Creek, and was highest in Black Diamond and Stockton lakes (Table 3.1).

**Table 3.1.** Semi-quantitative bacterial activity of Collie mine void lakes (April 2004). More intense black indicates greater SRB activity; more intense red indicates greater IRB activity

| Lake | Replicate | SRB | IRB |
|---|---|---|---|
| Blue Waters | 1 | | |
| Blue Waters | 2 | | |
| Black Diamond | 1 | | |
| Black Diamond | 2 | | |
| Stockton | 1 | | |
| Stockton | 2 | | |
| Chicken Creek | 1 | | |
| Chicken Creek | 2 | | |
| Chicken Creek | 3 | | |
| Ewington | 1 | | |
| Ewington | 2 | | |

Furthermore, rank SRB activity was positively correlated with rank LOI ($n = 12$, $\rho = 0.55$, $p = 0.06$). This relationship strengthened when an outlier from Chicken Creek was removed ($n = 11$, $\rho = 0.75$, $p = 0.008$). However, rank IRB activity was not significantly correlated with rank LOI ($n = 12$, $\rho = -0.24$, $p = 0.46$), although this relationship was also strengthened when an outlier from Chicken Creek was removed ($n = 11$, $\rho = -0.34$, $p = 0.306$) (Figure 3.4).

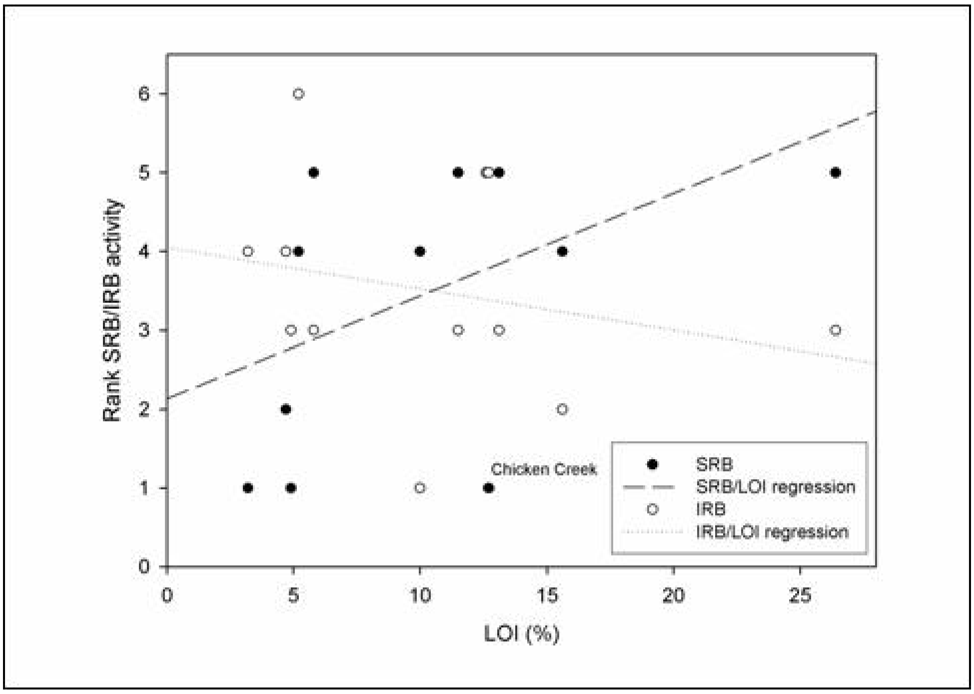



**Figure 3.4.** Relationship of rank semi-quantitative SRB and IRB activity to LOI

LOI from Chicken Creek may be an outlier due to the large coal component of this sample, as evidenced with the strong coal smell displayed during its combustion.

Although there were too few data for the rank correlation to be significant, lake dissolved iron concentration positively correlated well with mean sediment IRB activity ($n = 5$, $\rho = 0.78$, $p = 0.117$) (Figure 3.5).

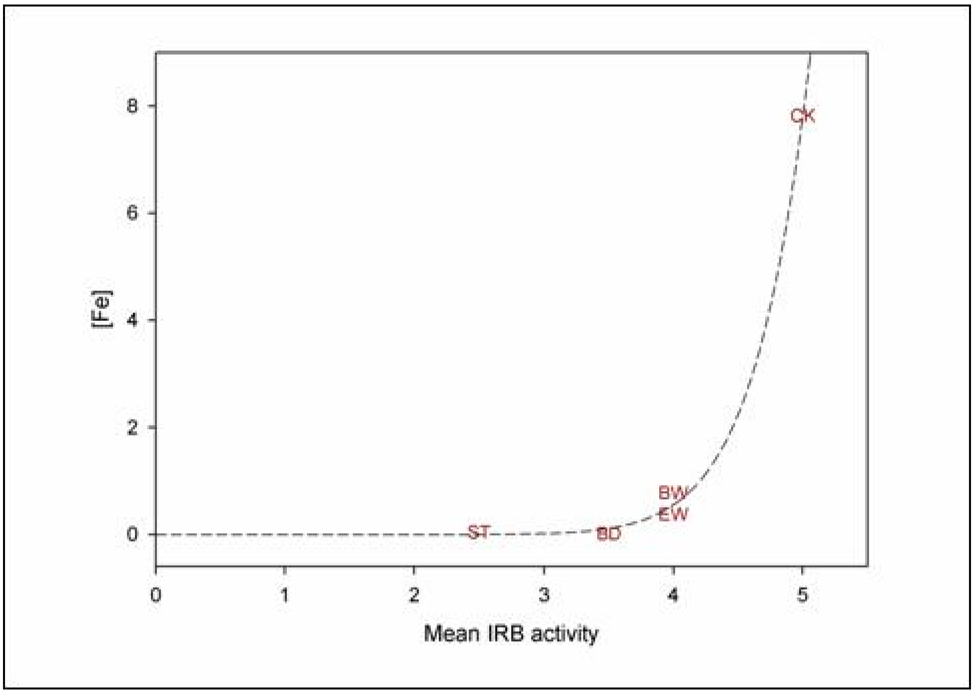



**Figure 3.5** Relationship between lake [Fe] and mean sediment IRB activity (BW = Blue Waters; BD = Black Diamond; ST = Stockton; CK = Chicken Creek; EW = Ewington).

*Temporal robustness of pit lake water acidity measurements*

An experiment challenging established practice that acidity measurements must be made within 24 hours of a water sample being taken was carried out as part of the CSIRO Student Research Scheme (SRS). Three replicate acidity titrations of Blue Waters lake water were made in the field with 0.10 mol NAOH solution. All except for a day 161 titration were then repeated at four other times back in the ECU laboratory, at days 3, 7, 21, 39 from water stored in a carboy at 3$^{o}$C. The day 161 titration was from water collected from 4 months earlier.

This experiment found a large and significant difference between immediate and delayed acidity measurements (Dunnett's test, all $p<0.01$). It was also observed that there was much greater precision in results when acidity titrations were made in a laboratory setting rather than in the field (day 0) (Figure 7).

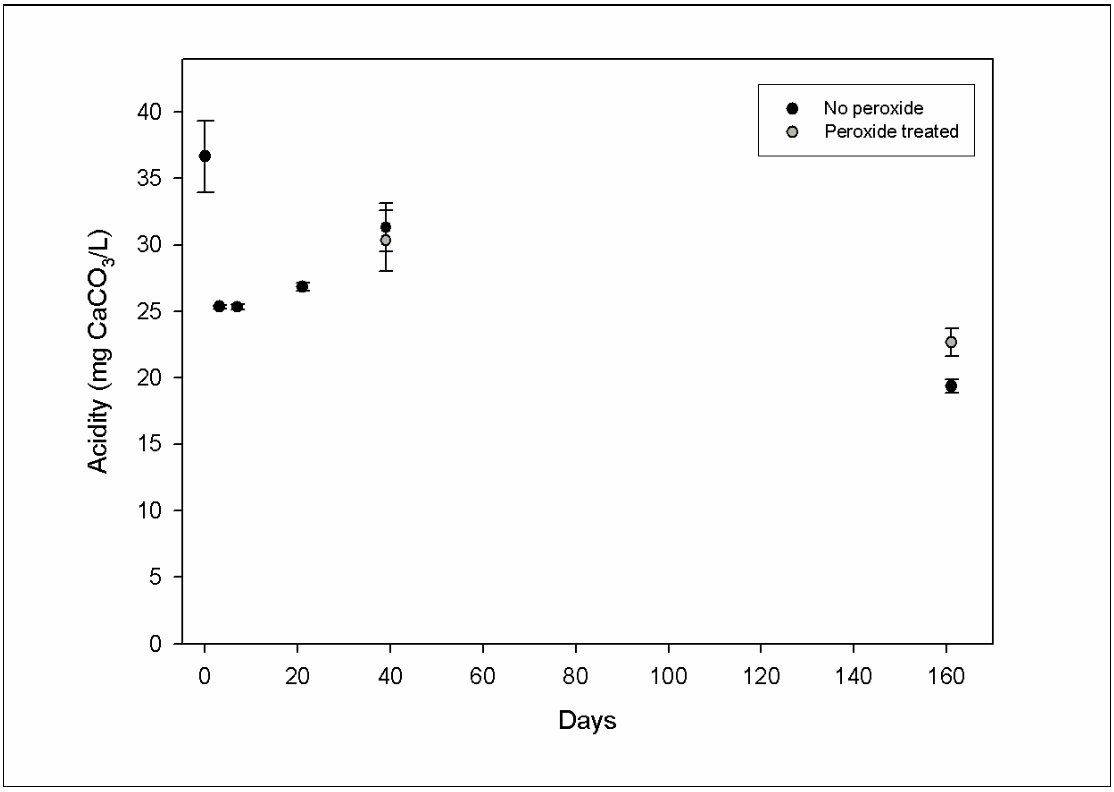



**Figure 4.1**. Change in Blue Waters lake water acidity over storage time

The recommendations from this study were that, where possible, field measurements of acidity should be made (this is of course not possible when these analyses are outsourced). Where acidity measurements do occur in a few days to weeks of collection, measurements are likely to underestimate acidity by as much as 30%. An even greater underestimation may occur at storage times of months. Hydrogen peroxide treatment slightly improved acidity measurements accuracy, however the improvement was still well below the value measured in the field and peroxide treatment also increased measurement variability.

## Mesocosm Experiment in Ewington Lake

This mesocosm experiment is published in:

Lund, M. A.; McCullough, C. D. & Yuden (2006). *In-situ coal pit lake treatment of acidity when sulfate concentrations are low.* Proceedings of the 7th International Conference on Acid Rock Drainage (ICARD). St Louis, Massachusetts, USA Barnhisel, R. I. (ed.) American Society of Mining and Reclamation (ASMR), 1,106-1,121 pp.

## Liming and nutrient enrichment mesocosm experiment - Introduction

The Kepwari mine pit started to fill with groundwater following the completion of coal mining and cessation of dewatering in 1999. As part of the rehabilitation of Lake Kepwari prior to filling, acid-producing overburden dumps and un-mined coal seams along the lake margin were covered, battered and revegetated with endemic flora by direct seeding. In order to further reduce wall exposure and rates of consequent acid production, Lake Kepwari was then rapid-filled by a diversion from the South Branch of the Collie River over three winters until 2005. The current volume of Lake Kepwari is 24 GL, with a maximum depth of the lake of 65 m and surface area of 10 ha. Lake Kepwari still maintains a seasonally low pH (pH *ca*. 4.8) and elevated metal concentrations.

Water filled abandoned mining pits are a common legacy of open cut mining worldwide (Castro & Moore, 1997). In Western Australia there are approximately 1 800 existing mine pits with more than 150 mines currently operating below the water table (Johnson & Wright, 2003). Unless backfilled, many of these mine voids will eventually fill with ground and surface water to create a pit lake. These pit lakes have the potential for a range of beneficial end uses including recreation, biodiversity conservation, stock and plant irrigation, aquaculture, extraction of industrial chemicals and as sources of potable and industrial water (McCullough & Lund, 2006). The water quality in mine lakes, in particular acidity, salinity, hardness and metal composition differ depending on the hydrology and geochemistry of the local and surrounding areas (Miller et al., 1996). However, the water quality of the pit lake typically determines viable end uses (Grünewald & Uhlmann, 2004). Given that water quality in these lakes rarely meets water quality guidelines for many end uses, pit lake water quality remediation may therefore be required, (McCullough & Lund, 2006).

A problem within some mine lakes is acidification of the mine lake and surrounding receiving water bodies. This acidification may cause toxicity to aquatic biota (Lopes et al., 1999a). Anthropogenic acidification largely results from the disturbance of pyritic ($FeS_2$) geologies, thus allowing for oxidation and hydrolysis, leaching acidic water and solutes into receiving environments. Acidification itself not only causes severe toxicity through lowered pH but also causes further toxicity through its effects on the increased bioavailability of other toxicants, particularly aluminium and heavy metals (Lopes et al., 1999a).

Aluminium is generally thought to be responsible for the pH buffering and toxicity (directly or indirectly) of these moderately low pH lakes (pH 3–5) (Stephens & Ingram, 2006). Aluminium toxicity derives from its replacement of divalent metal complexes, specifically Ca and Mg (Amonette et al., 2003). Elevated Al concentrations in acidified lakes may also affect biota and nutrient cycling by reducing bioavailability of P which disturbs in-lake P cycling (Kopacek et al., 2000). Phosphorus is removed from the water column by co-precipitation with iron and aluminium oxyhydroxides (Lessmann et al., 2003), thus causing P nutrient limitation (Bittl et al., 2001). As a result of this P-binding, concentrations of P relative to other nutrients are especially low in acidic pit lakes (Schultze et al., 2003, Kopacek et al., 2000). Primary production in acidic lakes is therefore typically limited by disproportionately low concentrations of P relative to nitrogen (Schindler, 1980) as indicated by the “Redfield ratio” (Redfield et al., 1963).

Lake trophic status also has implications for internal alkalinity production. Primary production of organic carbon by *in situ* biological communities is a weak process that can contribute to both alkalinity production and heavy metal removal (Davison et al., 1995; Tittel & Kamjunke, 2004; McCullough, in press). Autotrophs may produce alkalinity *in situ* during carbon fixation when nitrate (often high in pit lakes as a result of leached blasting residues) is biologically assimilated into organic matter, as in the following equation after Davison et al. (1995).

**Equation 1.** $106CO_2 + 16H^+ + 16NO_3^- + H_3PO_4 + 122H_2O \rightarrow (CH_2O)_{106}(NH_3)_{16}$
$+16OH^- + 138O_2 + PO_4^{3-}$

When organic matter is anaerobically decomposed further alkalinity is also produced through denitrification (Davison et al., 1995; George & Davidson, 1998), as in the following equation.

**Equation 2.** $NO_3^- + CH_3OH + H_2CO_3 \rightarrow N_2 + H_2O + HCO_3^-$

Biogenic assimilation of heavy metals also occurs within cells of planktonic biota; either deliberately as trace minerals through metabolic uptake, or incidentally through uptake of non-essential cations as analogue ions (Akber et al., 1992; Markich & Jeffree, 1994). Metal removal by biota such as phytoplanktonic algae, requires conditions conducive to their growth and survival. Although low pH will modify algal community structure, actual phytoplankton biomass, through selection for smaller-celled species, may still be high given sufficient nutrient availability (Lessmann et al., 2000; Woelfl, 2000). Consequently, enhanced primary production and more natural ecosystem food-web functioning may occur even when only the low nutrient status of acid pit lakes is addressed. However, the size of these primary producer may limit their availability to larger organisms (fish, waterfowl, etc.) higher up the food-chain.

The potential impacts and remediation efficacy of acidification and metal contamination on aquatic environments are often studied using mesocosms (Tang, 1993; Fyson et al., 1998; Bortnikova et al., 2001; Collins et al., 2005; Totsche et al., 2006). Mesocosms allow for a large-scale measurement of remediation techniques and are easily replicated, an approach that is sometimes difficult to achieve in the field. Mesocosms can be used to assess water remediation techniques, conduct toxicity studies of effluents and to study other aspects or parameters of aquatic environmental effects (Odum, 1984). Such in-lake, biologically based treatment approaches have been suggested as practical techniques for remediation of these mine lakes (Tittel & Kamjunke, 2004; Lund et al., 2006; McCullough et al., 2006; Totsche et al., 2006).

This chapter reports on the preliminary results from an experiment attempting to remediate Lake Kepwari water in mesocosms. The aim of this study was to evaluate the efficacy of three different acid pit lake water remediation treatments. These treatments were: limestone chip (L), phosphorus (P) and limestone chip and phosphorus (L&P). These studies are aimed at remediation of lake water toxicity through reducing metal solubility at increased pH and through planktonic and benthic algal growth stimulation. Limestone was used to increase pH to levels suitable for biotic growth and survival through reducing proton ion, dissolved metal and other contaminant concentrations (Lopes et al., 1999). Pit lake water was phosphorus amended as phosphorus is known to be a limiting nutrient within freshwater systems, especially those affected by acidic conditions (Parent & Campbell, 1994; Kopacek et al., 2000; Bittl et al., 2001).

## Liming and nutrient enrichment mesocosm experiment - Methods

### *Mesocosm Treatments*

In August 2005, twenty-five fibreglass tubs (1.3 m diameter, 1.0 m high and 1 200 L volume) were filled with benthic sediment and water from Lake Kepwari. Sediment was pumped as a slurry from the littoral margin of the lake in approximately 5 m of water and then transported directly to the mesocosms at ECU before lake water was added on top.

Three treatments and an untreated control were replicated three times in twelve mesocosms arranged in a randomised block design. Water quality parameters of each mesocosm were measured prior to the commencement of the trial (month 0) and at two monthly intervals thereafter (months 2, 4, 6 and 8 respectively). The control (MC) contained un-treated Lake Kepwari water while treated mesocosms were 1) neutralised with limestone chip to pH neutral in two stages to prevent over-neutralisation (L); 2) amended with P (as $K_2HPO_4$) to increase filterable reactive phosphorus (FRP) concentration to around 20 µg $L^{-1}$ (P); and 3) neutralised and P amended as per 1) and 2) combined (L&P). Ongoing P additions to maintain a P concentration of around 20 µg $L^{-1}$ were made on days 2, 80, 161, 172, 189, 203, 219, 308 and 365. Following depletion of nitrogen from the water column, a single addition of 174 µg $L^{-1}$ $NO_3$ in the form of sodium nitrate ($NaNO_3$) was made on day 315.

### *Water quality analysis*

Water quality parameters of each mesocosm were measured on November 2005 (month 2) and at two monthly intervals thereafter on January 2006 (month 4), March 2006 (month 6) and May 2006 (month 8). Additional measurements of temperature, pH and DO were also made on mesocosm water samples at the commencement of each of the bioassay experiments. (reported in Project 2.2)

Water samples collected from mesocosms for analysis were immediately filtered to 0.5 µm and stored in acid washed high-density polyethylene bottles at <5°C before analysis. Measurements for temperature, pH, dissolved oxygen (% saturation and mg $L^{-1}$), specific conductance, chlorophyll *a* concentrations and ORP (platinum reference electrode) were collected *in situ* with a Hydrolab Datasonde 4a. A filtered mesocosm water sample was analysed for $SO_4$ and Cl on an ion chromatograph (Metrohm model 7961). Ammonium, $NO_x$ and filterable reactive phosphate (FRP) were analysed on a Skalar Autoanalyser after APHA (1998). The remaining filtered sample was then acidified with reagent grade HCl and selected metals analysed by Inductively Coupled Plasma Atomic Emission Spectrophotometry (ICP-AES) for Al, As, B, Ba, Be, Ca, Cd, Cr, Co, Cu, Fe, K, Mg, Mo, Mn, Na, Ni, Sb, Se, Sn, V and Zn. Unfiltered samples were digested using a persulfate digestion and then analysed as per FRP and $NO_x$ on a Skalar Autoanalyser to determine total P and total N respectively according to APHA (1998).

### *Biotic analyses*

At the end of the experiment, periphyton was scraped from eight 15 cm x 15 cm (total 0.18 $m^2$) replicate quadrats evenly spaced around the middle of the mesocosms, then pooled and homogenised. Ten replicates of the uppermost 10 cm of benthic sediment were collected with a plastic syringe with its tip removed. The top 10 mm of each sample was separated, then pooled and homogenised. Where deeper sediments showed a distinct horizon, a sample of these other sediments from each mesocosm was pooled and homogenised.

### *Data Analysis*

Statistical analysis of all biotic and water quality data were performed using the statistical programs SPSS (2004) and SigmaPlot (2004).

## Liming and nutrient enrichment mesocosm experiment - Results

Shortly after initiation of the experiment, pH increased markedly following the initial neutralisation of limed treatments from an initial mean of pH 4.8±0.1 to >7 before returning to circum-neutral after Day 100 (Figure 6.1). The control mesocosm also saw a gradual increase in pH to around 6.5. When P was added, this produced a consistently higher pH after Day 100 than the control in the order of 0.2 to 0.5 pH units.

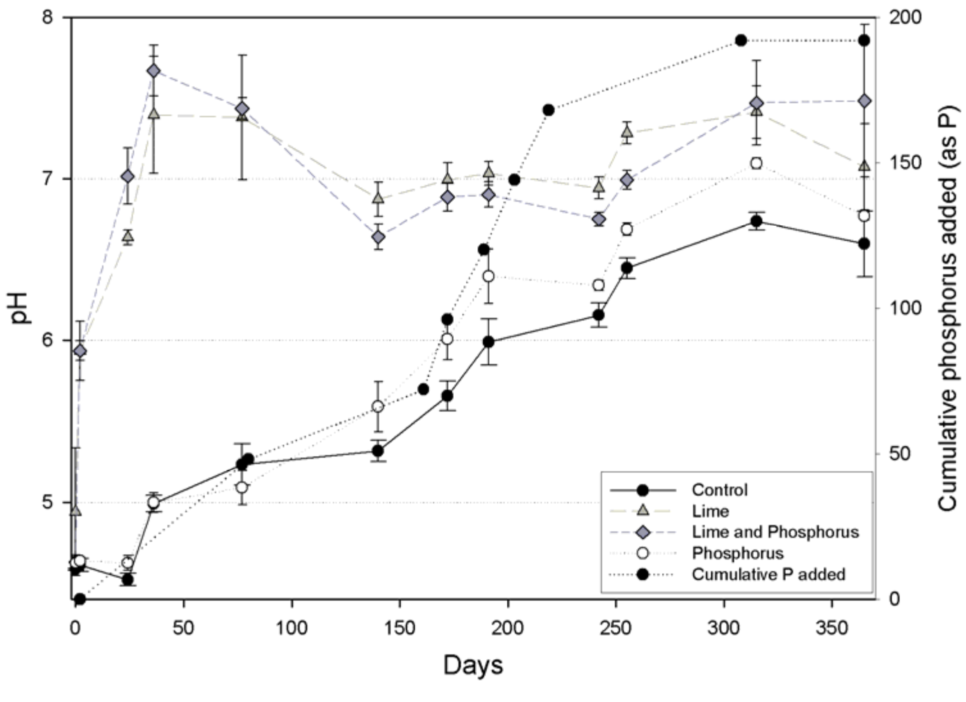



**Figure 6.1.** Mesocosm pH over time in response to liming and P amendment.

Electrical conductivity changed little over the course of the experiment or between treatments, ranging between 2.4 and 2.6 mS $cm^{-1}$, although it dropped in all treatments to between 2.1 and 2.2 mS $cm^{-1}$on the last sampling occasion reflecting input of and dilution by rainfall at this time. ORP of the water remained positive at between 91 and 205 mV which is a range suitable for denitrification and reduction of Mn and Fe (120 mV). The water was generally saturated with dissolved oxygen which ranged from 70–118 %.

Chlorophyll *a* was detected on occasion in individual mesocosms, but overall concentrations remained low at <5 µg $L^{-1}$.

### *Nutrients and other select anions*

Nutrient concentrations recorded at selected times during the experiment are shown in Figure 6.2. Near Day 255 there was a substantial input of rainwater directly into the mesocosms which probably accounts for the unusual responses in some anions at this time. Where P was added as a treatment there was a slight increase in total P. FRP however was similar between all the treatments on each occasion and higher than the control (except on Day 191). Up to Day 191 total N in the control increased from <250 to >400 µg $L^{-1}$ reflecting similar increases in $NO_x$ and $NH_4$.

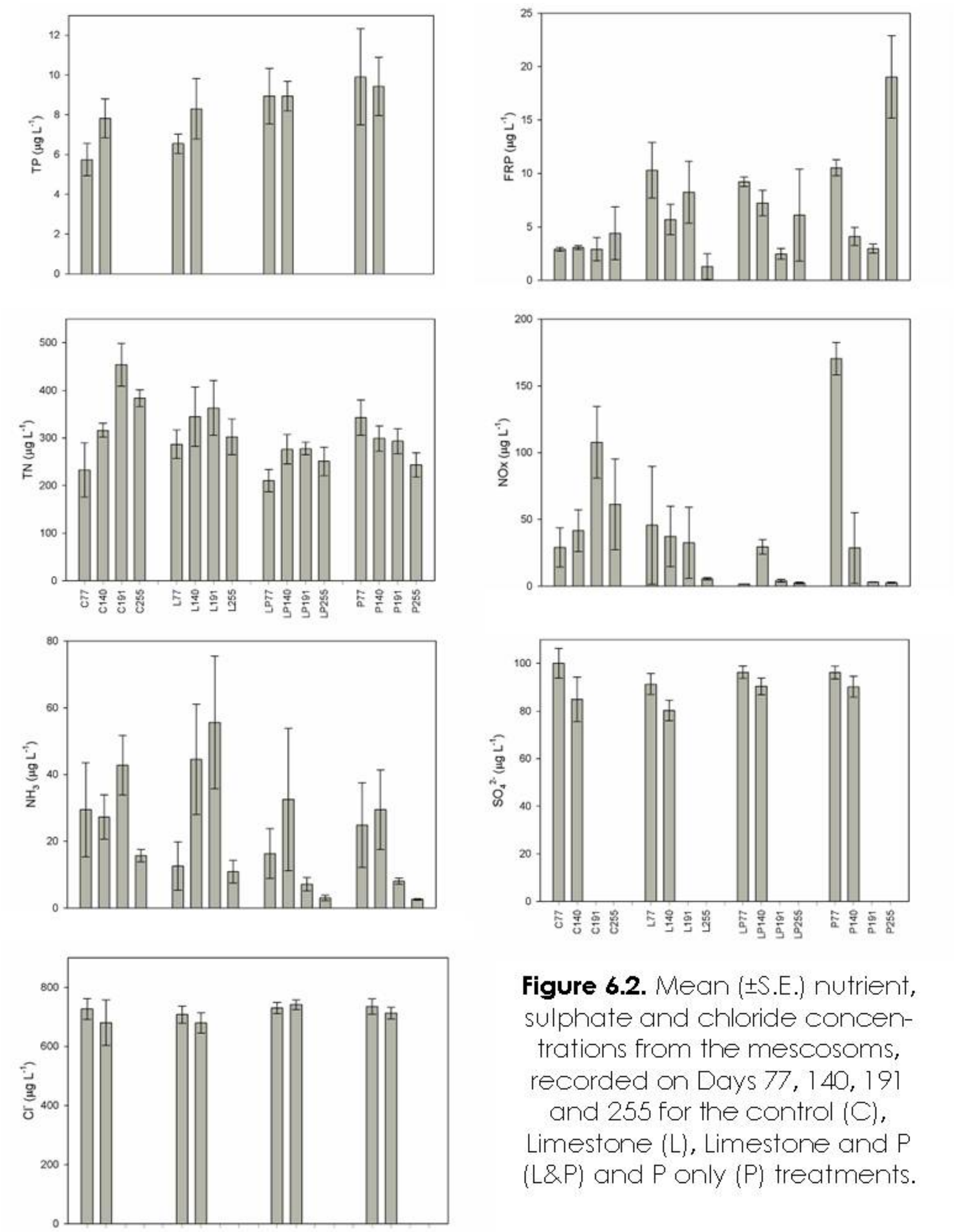



**Figure 6.2.** Mean (±S.E.) nutrient, sulphate and chloride concentrations from the mescosoms, recorded on Days 77, 140, 191 and 255 for the control (C), Limestone (L), Limestone and P (L&P) and P only (P) treatments.

This suggested that despite favourable redox potential denitrification was not significant. Limestone also showed a similar response with more variability between replicates. When P was added, there was very little change in Total N between occasions with similar levels to the control and limestone treatment. However, the concentrations of $NO_x$ were generally very low (exception being Day 77 for P treatment) while $NH_4$ concentrations were similar or lower than the limestone treatment and control. This suggests that $NO_x$ was being incorporated into organic matter either directly or indirectly. Combined assimilation and dissimilation of NOx by biological processes is known to generate alkalinity and this process is probably responsible for the elevated pH in the P treatment compared to the control. From the limited $SO_4$ data there appears to be a small and not significant decline between days 77 and 140.

### *Metals*

Ca concentrations for un-neutralised treatments were around 30 mg $L^{-1}$, and for neutralised treatments were around 35 mg $L^{-1}$. Na concentrations increased slightly on Days 191 and 255 in all treatments, however there were no differences between treatments. Al, Cu, Co, Fe, Mn, Ni, and Zn all showed a similar pattern with strong similarities between control and P treatment, with typically high concentrations declining over time. However, liming initially substantially reduced concentrations of these metals, which then continued to decline slightly over time. B concentrations were similar between all treatments and control and increased slowly over the course of the experiment. Presumably the addition B was released from the sediments. Cr was slightly higher in the treatments compared to the control for Days 77 and 140. However by Day 191 levels were generally the same or lower than the control. The cause of the increase in Cr is not known.

Metals and metalloid concentrations on Day 191 are compared to in situ Lake Kepwari water and ANZECC/ARMCANZ Water Quality Guidelines for the Protection of Aquatic Ecosystems (95% of species) in Table 6.1. Lake Kepwari water has metal concentrations that exceed the guidelines for Al, Co, and Zn. After 191 Days concentrations of Al, Co, and Zn although greatly reduced still exceed the guidelines. P addition had minimal effect on metal levels but did substantially reduce Mn and Co compared to the control, although Co still remained higher than guideline levels. Liming appeared to increase concentrations of Al, although due to the higher pH these fell below the guideline. Liming also successfully brought levels of Zn down compared to control and P alone but not below the guideline level.

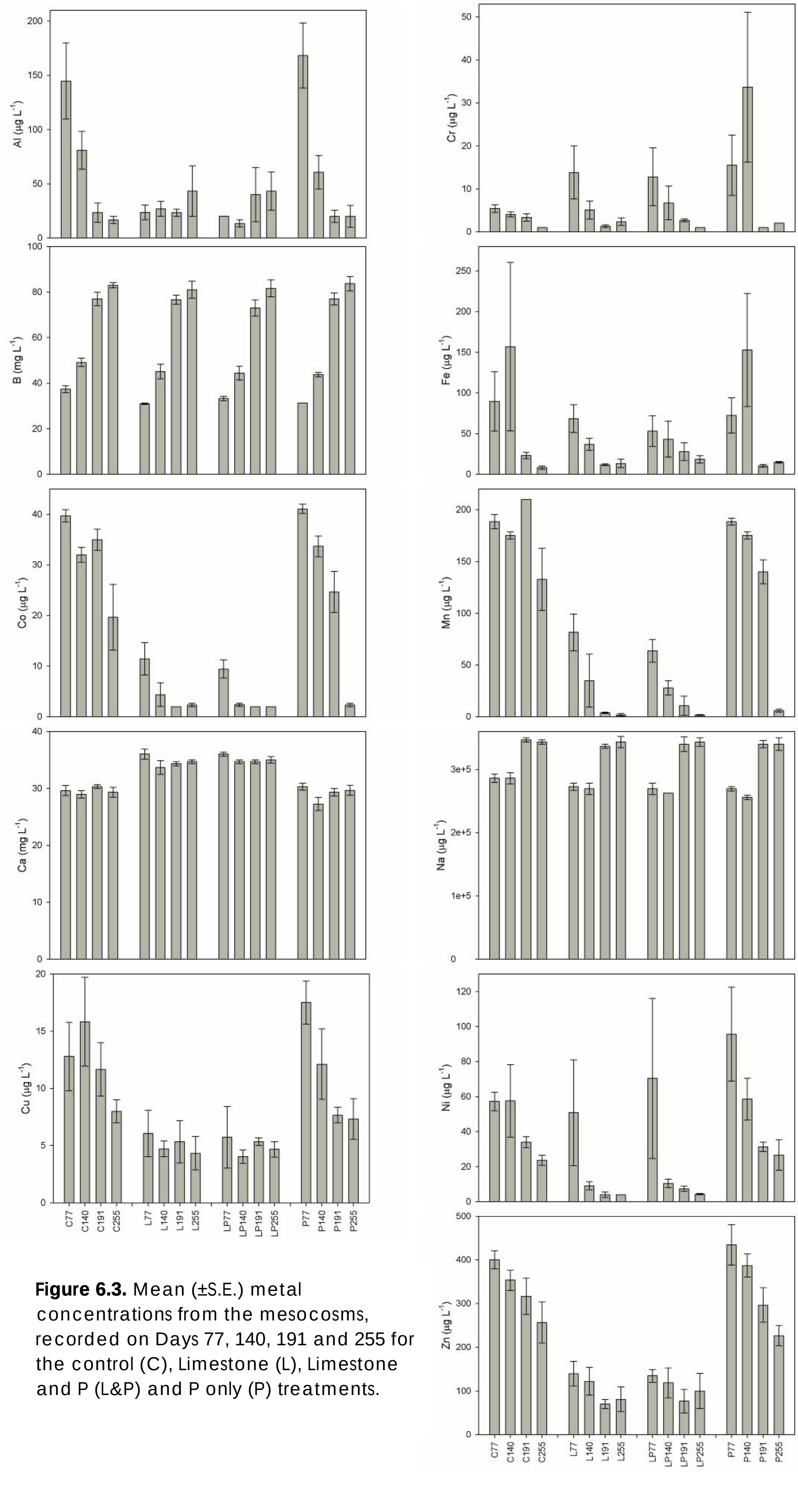



**Figure 6.3.** Mean (±S.E.) metal concentrations from the mesocosms, recorded on Days 77, 140, 191 and 255 for the control (C), Limestone (L), Limestone and P (L&P) and P only (P) treatments.

**Table 6.3.** ANZECC/ARMCANZ (2000) metal and metalloid concentration guideline values for the protection of 95% of species in aquatic ecosystems and concentrations in Lake Kepwari prior to water collection and in mesocosms on day 191. Parentheses indicate standard errors of the mean.

| | **Al (μg/L)** | **As (μg $L^{-1}$)** | **B (μg $L^{-1}$)** | **Cd (μg $L^{-1}$)** | **Co (μg $L^{-1}$)** | **Cr (μg $L^{-1}$)** | **Cu (μg $L^{-1}$)** | **Fe (μg $L^{-1}$)$^{\omega}$** |
|---|---|---|---|---|---|---|---|---|
| Guideline value | 0.8–55* | 13–23 | 370 | 2.18** | 1.4 | | 13.7** | 300^ |
| Lake Kepwari | **1 125** | <10.0$^{\psi}$ | 15 000 | <0.6$^{\psi}$ | **61.3** | <10 | <10 | 180 |
| C | **16.7 (3.3)** | <10.0$^{\psi}$ | 83.0 (1.2) | <0.6$^{\psi}$ | **19.7 (6.5)** | 1.0 (0.0) | 8.0 (1.0) | 8.0 (2.0) |
| L | 43.3 (23.3) | <10.0$^{\psi}$ | 81.0 (3.8) | <0.6$^{\psi}$ | **2.3 (0.3)** | 2.3 (0.9) | 4.3 (1.5) | 13.3 (5.4) |
| L&P | 43.3 (17.6) | <10.0$^{\psi}$ | 81.7 (3.7) | <0.6$^{\psi}$ | **2.0 (0.0)** | 1.0 (0.0) | 4.7 (0.7) | 18.3 (4.3) |
| P | **20.0 (10)** | <10.0$^{\psi}$ | 83.7 (3.2) | <0.6$^{\psi}$ | **2.3 (0.3)** | 2.0 (0.0) | 7.3 (1.8) | 14.7 (1.2) |

| | **Hg (μg $L^{-1}$)** | **Mg (μg $L^{-1}$)*** | **Mn (μg $L^{-1}$)** | **Ni (μg $L^{-1}$)** | **Pb (μg $L^{-1}$)** | **Se (μg $L^{-1}$)** | **Zn (μg $L^{-1}$)** |
|---|---|---|---|---|---|---|---|
| Guideline value | 0.6 | 300$^{\psi}$ | 1700 | 108** | 103** | 11 | 78.4** |
| Lake Kepwari | <0.1$^{\psi}$ | - | 265 | 60 | 6.2 | <5.0 | **450** |
| C | <0.1$^{\psi}$ | 71.7 (0.9) | 132.7 (30.1) | 23.7(2.9) | <10.0$^{\psi}$ | **<20.0$^{\psi}$** | **256.7 (47)** |
| L | <0.1$^{\psi}$ | 71.0 (1.0) | 1.9 (1.2) | 4.0 (0.0) | <10.0$^{\psi}$ | **<20.0$^{\psi}$** | **81.0 (28.3)** |
| L&P | <0.1$^{\psi}$ | 71.7 (1.9) | 1.6 (0.5) | 4.3(0.3) | <10.0$^{\psi}$ | **<20.0$^{\psi}$** | **100.0 (40.0)** |
| P | <0.1$^{\psi}$ | 72.3 (1.8) | 6.0 (1.5) | 26.7(8.7) | <10.0$^{\psi}$ | **<20.0$^{\psi}$** | **226.7 (23.3)** |

* ANZECC/ARMCANZ (2000) Al guideline pH <6.5 = 0.8 μg $L^{-1}$, pH >6.5 = 55 μg $L^{-1}$.

** This figure has been adjusted to a water hardness of 440 mg $L^{-1}$ as $CaCO_3$.

$^{\psi}$ This figure applies to a Mg:Ca ratio of <10:1 after McCullough (2007).

^ There are currently insufficient data to derive a reliable trigger value for Fe. The current Canadian guideline level is 300 μg $L^{-1}$ (CCREM, 1987), which is used as an interim indicative working level.

## Liming and nutrient enrichment mesocosm experiment - Discussion

Isolating Lake Kepwari from surface and groundwater inputs resulted in a sustained and significant improvement in pH and reduced metal concentrations (except B). Although concentrations of Al, Co, Zn and possibly Se remain above ANZECC/ARMCANZ Water Quality Guidelines for the Protection of Aquatic Ecosystems (95% of species) by Day 191. This clearly indicates that the source of acidity into Lake Kepwari needs to be clearly identified and if a substantial quantity is entering through surface runoff, then strategies can be put in place to control/treat these inflows. Groundwater inflows will be more difficult to control, especially if they are deep, although the technologies used to recharge aquifers potentially could be used to inject neutralising compounds/carbon sources directly into the problem aquifer.

If acidity generation is too difficult or expensive to control, then dilution of Lake Kepwari water using further river inflows might offer some benefits, however as the Lake is now full there is little opportunity for substantial further inputs without allowing Lake water to overflow back into the Collie River. Releasing low pH water with metals at toxic environmental levels is unlikely to be permissible, without careful use of dilution by river water or treatment of the discharge water.

Low sulphate levels in Collie pit lakes mean that relying on sulphate reduction by bacteria will not achieve desired pH (Lund et al., 2006). This project examined liming and P additions alone or in combination as remediation strategies for Lake Kepwari water. Liming Lake Kepwari water successfully increased pH and substantially reduced most metal concentrations to below ANZECC/ARMCANZ Water Quality Guidelines for the Protection of Aquatic Ecosystems (95% of species) by Day 191, with the exception of Zn (still substantially above), Co and possibly Se. Consequently, limestone neutralisation of lake water alone will remediate most metals to environmental guidelines. Liming P amendment of Lake Kepwari, equivalent to that necessary to raise mesocosm water from mean pH 4.6 to circum-neutral, would require 800 tonnes of limestone (Limestone chip of *ca*. 80% $CaCO_3$, CSBP Fertilizers Limited, unpublished data). Successful application of this quantity of limestone might be a logistical and practical challenge but is possible. Furthermore there are other (potentially more expensive) neutralising compounds around that might be more practical to use.

P additions alone resulted in slight increases in pH, probably through assimilation and dissimilation of NOx into organic matter generating alkalinity. Although these improvements are minor, they were accompanied by substantial decreases in Mn and Co to levels close to that of liming. Furthermore only a small change in Lake Kepwari pH is required to keep the pH at a level suitable for human recreation. P in combination with limestone appeared to offer little additional benefit than either use alone. P amendment of Lake Kepwari equivalent to the mesocosms would require only around 640 kg of P, or 6.4 t superphosphate per dose (CSBP Fertilizers Limited, unpublished data), with a total annual dosing equivalent to the mesocosm experiment for around 10 doses of only around 64 t. We believe that large doses might be more effective than a series of small doses, as a large dose is more likely to induce an algal bloom, which will generate further alkalinity and provide a valuable source of carbon for other biota. In our opinion there is little risk in P additions to the Lake resulting in eutrophication due to the high quantities of Fe and Al in the water and sediment that can bind the P. Algae are photosynthetic and do not need organic carbon, but can become a source of organic carbon and may become the base of a trophic system (Bocioaga & Mitman, 2002). As a result, stimulation of primary production can also significantly improve environmental values of the pit lake through provision of a carbon sources for herbivores and increasingly complex food webs (Kalin et al., 2001). Presently aquatic community colonization in the aluminium-buffered lake is complex and mostly believed to be controlled by the sensitivity of the organisms towards both protons and also to inorganic reactive aluminium species (Nixdorf, 2003).

Phosphorus may also be released from sediments to again contribute to primary production when sediments are sufficiently reducing (Gonsiorczyk et al., 1997; Murphy et al., 2001; Aldridge & Ganf, 2003). Consequently, assimilative alkalinity-generating processes are generally more important in the early stages of nutrient amendments, when sediment redox conditions are oxidising, with dissimilative processes more important in the later stages of nutrient amendment, or under an organic dosing regime, when sediment redox is reducing.

Although not part of this study, the induction of permanent stratification into Lake Kepwari by additions of saline waters should be considered as this would substantially reduce the volume of water requiring bioremediation.

In conclusion, with Lake Kepwari pH likely to continue dropping as further exposed reactive geologies leach acid, aluminium and heavy metal concentrations will also increase. The increased acidity will require more limestone chip to neutralise, and concentrations of these toxicants will make it more difficult to implement successful bioremediation strategies. This study has demonstrated that bioremediation of Lake Kepwari water is possible and there are several promising lines of enquiry that could be pursued to test these approaches at a more realistic scale.

## Environmental limitations to a viable marron fishery in Collie mining pit lakes - Introduction

Marron are a freshwater crayfish native to permanent waterbodies in the forested, high-rainfall areas of the south-west of Western Australia. Marron is one of the larger freshwater crayfish in the world (their weight can be up to 2 kg). Consequently, an important industry has grown up around marron aquaculture. In 2002, it was realised that there were actually two species of marron, the hairy (*Cherax tenuimanus;*the scientific names are in review) and the smooth (now known as the smooth Marron, *Cherax cainii*). The newly-named hairy marron is endemic to the Margaret River in southwest Western Australia (Department of the Environment and Heritage May 2005). This study will focus on the more common smooth marron, *Cherax cainii*, hereafter referred to as marron (Figure 7.1).

**Figure 7.1.** Marron (Cherax cainii) taken from a Collie pit lake.

Marron are found in most Collie pit lakes, most probably from deliberate introductions. Marron do not burrow to escape drought like other freshwater crustaceans and are comfortable on land for short periods. They are omnivorous, feeding on detritus and other small organisms found on the detritus (Arkive 2005). It is not known whether marron health is affected by the specific environmental variables (high dissolved heavy metal levels/ high acidity) in former open-cut pit lakes. There have recently been a number of studies in the region that have examined possible end-uses for the lakes. A few possible uses are aquaculture and recreational purposes. The problem is that there has been very little research on marron health in the acid lakes of Collie. It is unknown how marron respond to the chemistry of the water, especially the low pH and the high levels of heavy metals. It is also unknown whether there is enough food present in the lakes, to support a viable marron population. These questions need to be answered before a viable marron fishery can be established in the many acidic Collie pit lakes.

The main objective of this research project was to examine what environmental variables best explained marron health and limitations on their populations in the pit lakes of Collie.

## Environmental limitations to a viable marron fishery in Collie mining pit lakes - Methods

### *Study area*

Five pit lakes (Blue Waters, Ewington, Stockton, Black Diamond and Centaur) were examined in Collie.

Ewington and Blue Waters pit lakes (Figure 7.2) are located on a property being managed as a cattle farm. Blue Waters is the most acidic of the historic lakes being studied (mean pH 4.0 at the top of the lake) and the only mine lake to receive any substantial surface run-off from the overburden dumps left on the sides of the pit from 40 years ago.

**Figure 7.2** Left: Ewington Lake, right: Blue Waters

Stockton Lake (Figure 7.3) is another historic pit lake in the area which is a popular water skiing area. Stockton is managed by the Department of Environment and Conservation (DEC) who have rehabilitated some of the lake surrounds. Stockton experiences considerable pH change from the top of the lake (mean pH of 5.5) to the bottom (mean pH 4.8). In the drier summer months of 1994/95, Stockton's pH dropped below 4.5 and it was closed to the public for a short period of time.


**Figure 7.3.** Stockton Lake

Immediate treatments with lime and sodium hydroxide to increase the pH were unsuccessful and it wasn't until the winter of 1995, when Griffin Coal Ltd directed water to Stockton from dewatering activities at a developing mine area, that the pH increased.

Black Diamond (Figure 7.4) was one of the earliest open cut mines in the region and is one of the mine lakes in the Collie Coal Basin resulting from mines abandoned in the late 1950s to early 1960s with no rehabilitation. Black Diamond has a steady pH of around 5.4 and is actively used for public recreation.

**Figure 7.4.** Black Diamond

Centaur Lake (Figure 7.5) is a dark coloured pit lake, water from Chicken Creek flows though the lake. Samples were collected from near the entrance of the Creek.

**Figure 7.5.** Centaur

### *Sampling Program*

Each pit lake was sampled over several days in September 2005. This involved setting three sets of traps and artificial habitats in each lake as shown in Figure 7.6. Marron traps were baited prior to setting and were emptied after 24 h, while artificial habitats were emptied 3 weeks later. Artificial habitats consisted of bundles of PVC pipes of varying diameter (approx. 0.4m long), that were attached together. A system of flaps was developed that could remotely seal the tubes on retrieval. All marron or other crustacea caught in the traps or artificial, were bagged and then placed on ice.

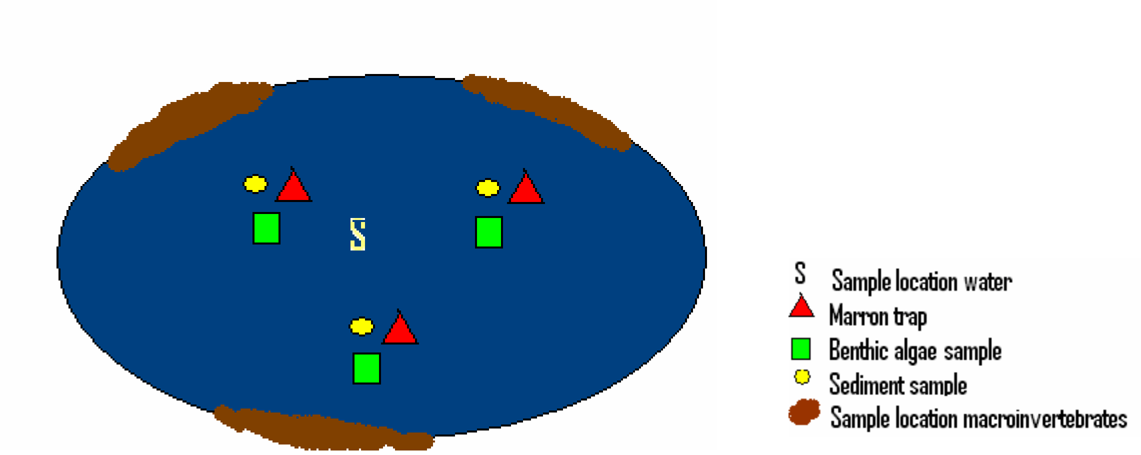



**Figure 7.6.** A diagrammatic representation of the arrangement of the sampling locations in each pit lake

At each location in each lake, a sediment sample was collected by SCUBA using a plastic corer (0.10 m diameter) that was pushed into the sediment to a depth of ~0.3m, before sealing with rubber bungs. Three smaller sediment samples (10 mm depth) were also collected using cut off 25 mL plastic syringes for later determination of chlorophyll *a*. This involved transfer of the material to large centrifuge tubes and the addition of 40 ml of di-methylformamide (DMF) followed by analysis at least 24 h later as per APHA (1998) using the formulae from Speziale et al. (1984). At a central location a 2L surface water sample was also collected. At this site, chlorophyll a, pH, temperature, conductivity, turbidity and redox were measured with the Hydrolab Datasonde (multi-parameter probe). At the same site, light attenuation was estimated from light readings taken over depth adjusted for surface lighting, using a coupled PAR (Photosynthetically Available Light) meter (Li-Cor) with 4 pi (spherical) sensors.

The water sample was split into four aliquots. One aliquot was used to measure acidity in the field, as per APHA (1998). Another aliquot was frozen for later determination of total P and total N (APHA, 1998). The third and fourth aliquots were filtered through 0.5 µm GF filter paper (Pall Metrigard). One filter paper was frozen for later determination of chlorophyll *a* (to validate the Hydrolab measurements). Filtered water was frozen for later determination of metals (sample acidified with $HNO_3$) and NOx, $NH_3$ and FRP.

At three random sites around each lake, littoral macroinvertebrates were sampled using a 500 µm mesh dip net. To standardise the samples, they were all collected from a 1 $m^2$ area over a 20 s period. Collected macroinvertebrates were preserved in 70% ethanol. In the laboratory all macroinvertebrates were removed from the littoral and core sediment and then dried to obtain a dry weight per $m^2$. The remaining core sediment (sans macroinvertebrates) was then sieved through a 1 mm and then a 250 µm sieve in order to separate the fine from the coarse fraction. These fractions were dried at 105°C to constant weight and then ashed at 500°C for 24 h. The ash-free weight was taken as fine particulate organic matter (FPOM) and coarse particulate organic matter (CPOM) respectively.

The number of shell lesions, temnocephalids and other commensals were counted for each marron. The carapace length was measured and they were sexed and weighed. Moulting stage was determined by studying a tail clipping under the microscope. The gills, hepatopancreas, tail muscle and female reproductive organs were removed. A wet mount sample of the gill and the parasites found, was examined using a light microscope for deformations. The dry weight of the hepatopancreas was determined following drying at 80°C. The following indices were then calculated:

$$\text{Wet hepatopancreatic index (Hiwet\%)} = \frac{\text{Wet Wt Hepatopancreas (g)}}{\text{Total Body Wt (g)}} \times 100\%$$

$$\text{Dry hepatopancreatic index (Hidry\%)} = \frac{\text{Dry Wt Hepatopancreas (g)}}{\text{Total Body Wt (g)}} \times 100\%$$

$$\text{Hepatopancreas moisture (HM\%)} = \frac{\text{Organ Wet Wt (g) - Organ Dry Wt (g)}}{\text{Organ Wet Wt (g)}} \times 100\%$$

A tail muscle sample (approximately 5 g) was removed and the dry weight determined at 80°C. The following index was then calculated:

$$\text{Tail Muscle moisture (MM\%)} = \frac{\text{Wet Wt sample (g) - Dry Wt sample (g)}}{\text{Wet Wt sample (g)}} \times 100\%$$

The reproductive organs were checked for eggs (female individuals) and deformations. All individual organs were put back with the marron they came from and each complete marron tissue sample was then homogenised. The metal concentrations of the body was analysed by ICP-AES following a HCl and perchloric acid digestion

### *Data analysis*

Statistical analyses of the lake water chemistry, primary productivity, heavy metal body burdens and marron health indices was undertaken with SPSS and SigmaPlot to examine correlations between marron health and environmental factors. In the graphs showing iron body burdens, one point has been taken out because it was an outlier (sample Blue Waters 1:1 037 mg Fe/kg body weight). The remaining 7 individuals were considered representative.

Principal Components Analysis (PCA) ordinations were made of lake water chemistry, primary productivity, heavy metal body burdens and marron health indices with PRIMER software (version 6; Primer-E) to produce ordinations of environmental data. Prior to analysis, data were $\log_{10}$ transformed to enhance a linear relationship between variables and finally normalised to account for different variable scales (Clarke and Warwick 2001).

Habitat availability data for multivariate analyses was coded for by considering each artificial habitat tube occupied, as a habitat unavailable in the natural environment. Consequently, the habitat availability value consisted of the negative value of the mean number of crayfish found in the artificial habitat enclosures.

## Environmental limitations to a viable marron fishery in Collie mining pit lakes - Results and Discussion

Marron health indices showed that the Marron in Centaur Lake were the healthiest in comparison to the marron caught in the other lakes. Low dry hepatopancreatic indices are typically seen in marron with inadequate nutrient intake and high dry hepatopancreatic indices can be indicative of a high lipid intake in the diet regardless of feed intake. However, it is possible that a high dry hepatopancreatic index may also be seen in marron with adequate dietary intake of lipid but low moult frequency (Evans et al. 2000). It is likely that a low wet hepatopancreatic index indicates poor marron health. Marron caught in Ewington and Stockton Lake (Table 7.1) had the lowest dry hepatopancreatic indices and were therefore the least healthy in the studied lakes. The tail clippings showed that all the marron examined were in pre-moult.

**Table 7.1.** Marron health indices per sampled lake, mean ± standard error

| Lake | Hepatopancreas Moisture (%) | Hepatopancreatic Index wet (% body weight) | Hepatopancreatic Index dry (% body weight) | Tail muscle moisture (%) |
|---|---|---|---|---|
| Ewington | 77.42 ± 2.77 | 4.55 ± 0.92 | 1.01 ± 0.08 | 81.40 ± 1.10 |
| Blue Waters | 75.74 ± 7.65 | 4.42 ± 1.43 | 1.06 ± 0.37 | 79.81 ± 3.31 |
| Centaur | 73.47 ± 10.18 | 6.22 ± 0.97 | 1.71 ± 0.87 | 80.09 ± 1.39 |
| Stockton | 82.3 ± 8.02 | 5.71 ± 0.77 | 1.01 ± 0.30 | 81.94 ± 1.56 |
| Black Diamond | 78.03 ± 3.32 | 5.19 ± 0.48 | 1.13 ± 0.13 | 80.46 ± 1.53 |

The wet hepatopancreatic index from Centaur Lake was significantly different from the wet hepatopancreatic index from Blue Waters (P= 0.026). No other significant differences (P>0.05) between the lakes were found.

In general the data showed no correlation between levels of heavy metals in the water and marron health, but did show a weak negative correlation between acidity of the water and the wet hepatopancreatic index (Figure 7.6). This means that when acidity increased, marron health decreased, probably due to increased uptake and accumulation of lead (Figure 10).

A negative correlation is shown between the oxygen level (mg/L) and the wet hepatopancreatic index. When oxygen levels increased, marron health decreased (Figure 9).

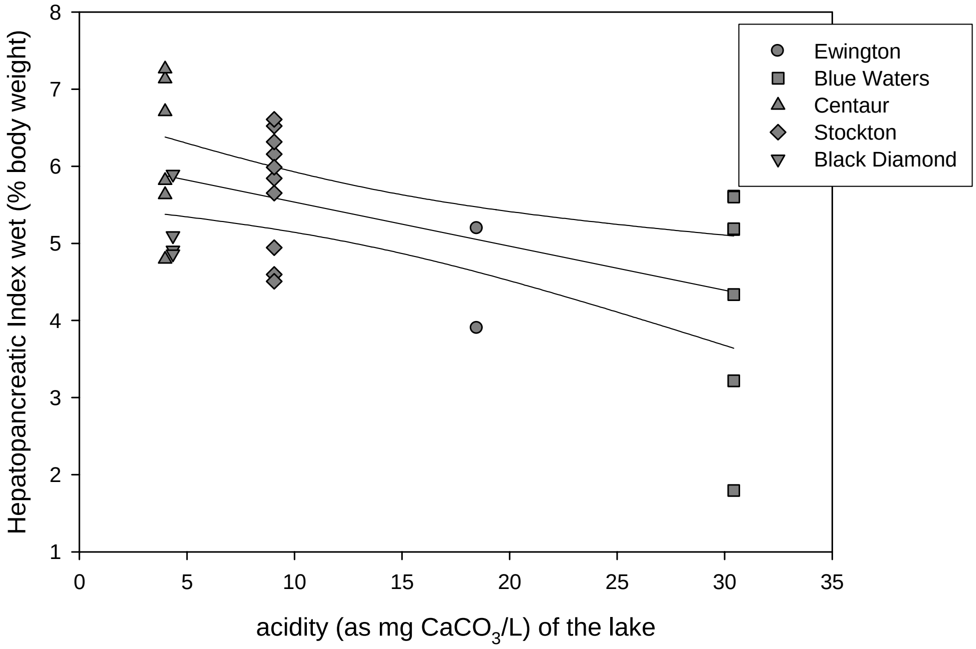



**Figure 7.6.** Hepatopancreatic Index wet (% body weight) vs. the acidity (mg $CaCO_3$) of the lake (linear regression, 95 % confidence interval, $r^2 = 0.24$ (n=29; P>0.05)

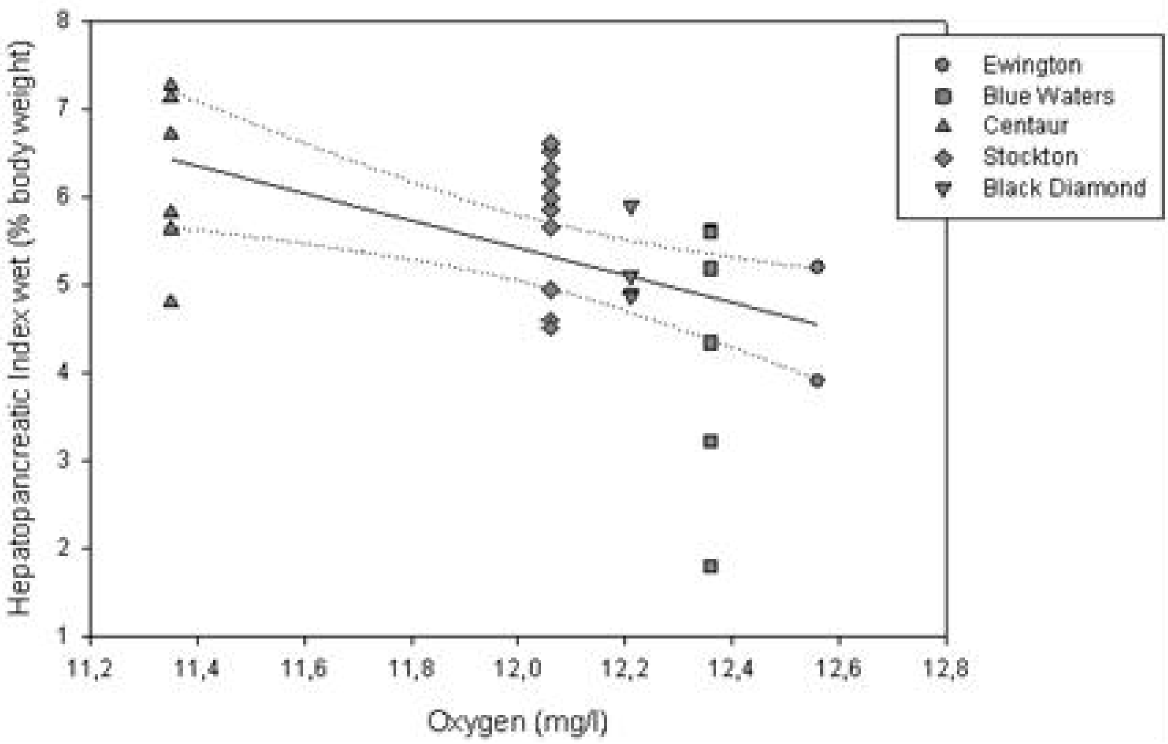



**Figure 7.7.** Hepatopancreatic Index wet (% body weight) vs. oxygen levels (mg/L) (linear regression, 95 % confidence interval, $r^2 = 0.35$ (n=29; P>0.05).

Table 7.2 shows that none of the lakes exceeded the trigger values for pH shown in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality for protection of 95% of the aquatic ecosystem. None of the lakes meet the standard for aluminium, copper and zinc, and also in some cases trigger values for chromium, iron, lead and nickel are exceeded. Marron caught in these lakes appear remarkably resilient, and relatively insusceptible for the high heavy metal levels and low pH in the lakes.

**Table 7.2.** Metal levels and pH compared to freshwater trigger values (95 %) (ANZECC/ARMCANZ 2000)

| | freshwater trigger value (µg/L) 95% | Blue Waters (µg/L) | Black Diamond (µg/L) | Ewington (µg/L) | Stockton (µg/L) | Centaur (µg/L) |
|---|---|---|---|---|---|---|
| Aluminium | 0,8 | 2800 | 110 | 1400 | 490 | 90 |
| Arsenic (III) | 24 | <100 | <100 | <100 | <100 | <100 |
| Arsenic (V) | 13 | | | | | |
| Cadmium | 0,2 | <0,6 | <0,6 | <0,6 | <0,6 | <0,6 |
| Chromium (III) | 3,3 | 1 | <1 | 7 | 1 | <1 |
| Chromium (V) | 1,0 | 1 | <1 | 7 | 1 | <1 |
| Copper | 1,4 | 2 | 2 | 4 | 3 | 3 |
| Iron* | 300 | 380 | 32 | 260 | 150 | 280 |
| Lead | 3,4 | <10 | <10 | 30 | <10 | <10 |
| Manganese | 1700 | 81 | 130 | 23 | 87 | 11 |
| Mercury** | 0,6 | <20 | <20 | <20 | <20 | <20 |
| Nickel | 11 | 39 | <4 | 5 | 20 | <4 |
| Selenium | 11 | <20 | <20 | <20 | <20 | <20 |
| Tin** | 3 | <20 | <20 | <20 | <20 | <20 |
| Zinc | 8 | 150 | 15 | 37 | 120 | 15 |
| | | | | | | |
| pH*** | 7,5 – 8,5 | 3,53 | 4,71 | 3,74 | 4,07 | 6,32 |

| | |
|---|---|
| * | Canadian guideline level (further data are required to establish a figure appropriate to Australian and New Zealand waters) |
| ** | Inorganic |
| *** | Value for wetlands (ANZECC/ARMCANZ 2000) |
| (shaded) | Value exceeds trigger value |

A correlation (r=0.78; P<0.05) was found between the acidity of the lake and the amount of lead accumulated in the entire body of the marron (Figure 7.8).

The marron from the examined lakes appeared to be healthy and, although they contained high levels of heavy metals, this did not appear to impact upon their health.

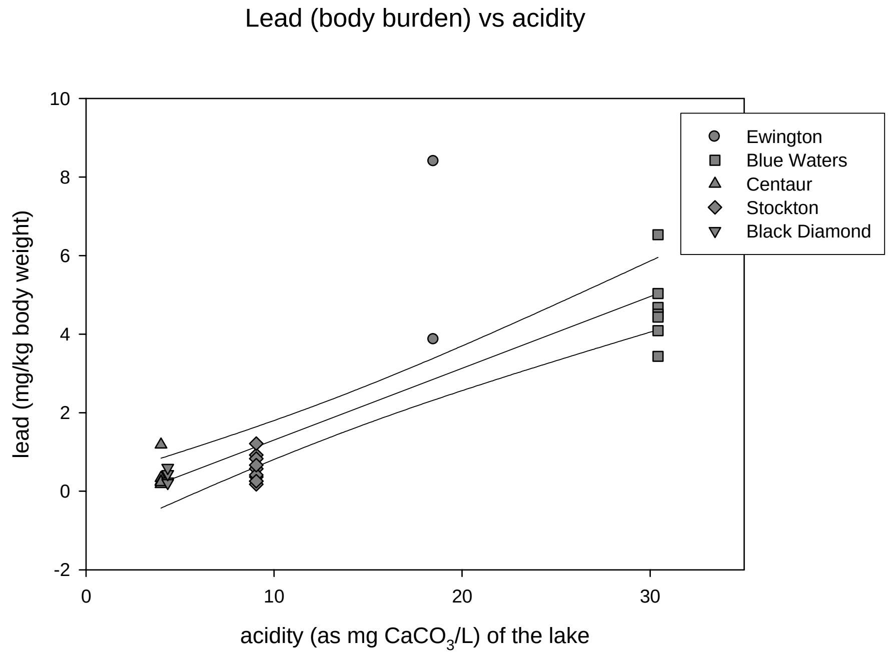



**Figure 7.8.** Lead (body burden) vs acidity (as mg $CaCO_3$/L) of the lake (linear regression, 95 % confidence interval, $r^2 = 0.69$; $P<0.05$, n=29).

Iron, aluminium and lead in the body of marron showed a negative correlation (r=-0.52; P<0.01) with the wet hepatopancreatic index (see Figure 7.9, 7.10 and 7.11 respectively), indicating a decline of marron health at high concentrations of these metals.

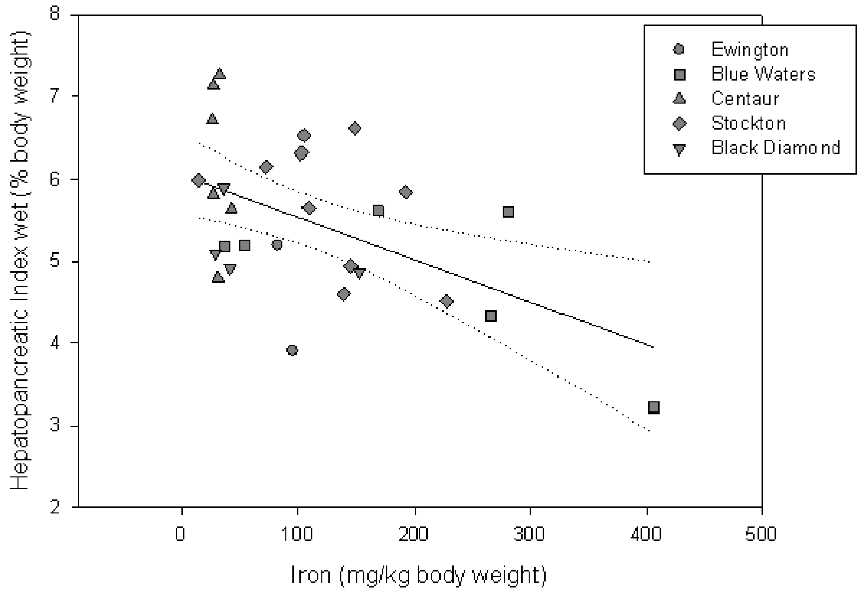



**Figure 7.9**: Wet hepatopancreatic index vs iron (body burden) (linear regression, 95 % confidence interval, $r^2 = 0.25$; $P<0.01$; n=29).

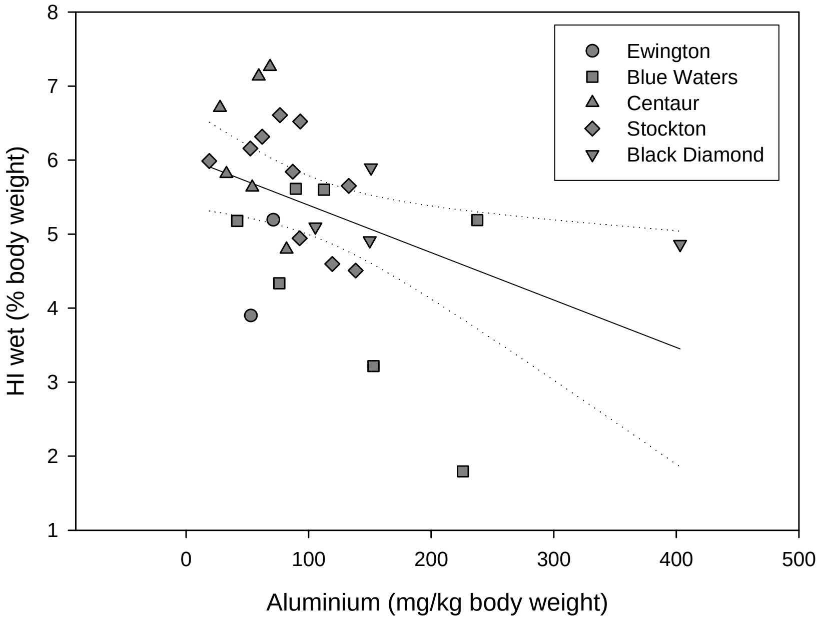



**Figure 7.10.** Wet hepatopancreatic index vs aluminium (body burden) (linear regression, 95 % confidence interval, $r^2 = 0.16$; n=29; P<0.01).

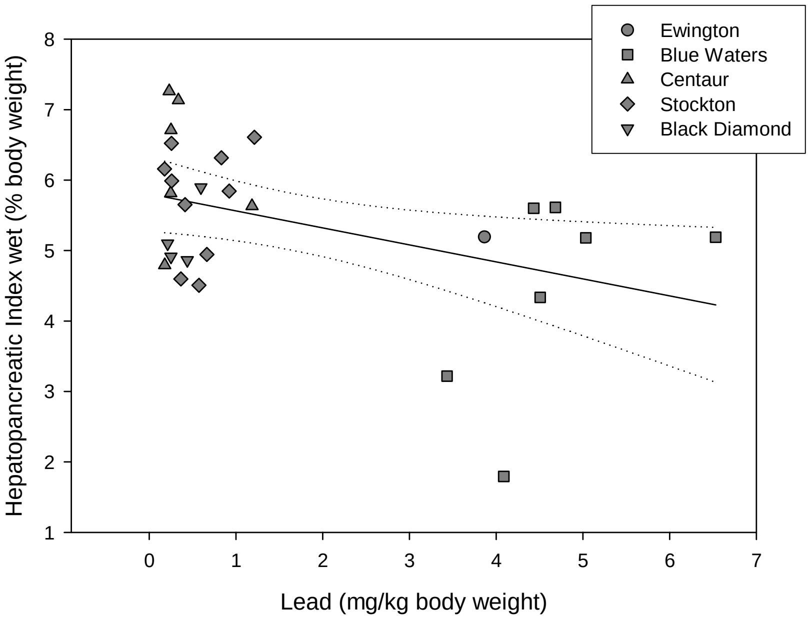


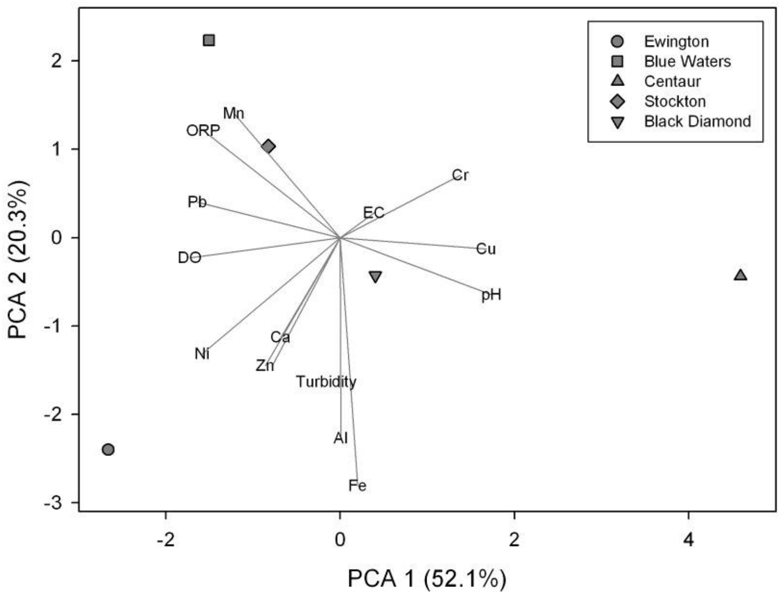

**Figure 7.11.** Wet hepatopancreatic index vs lead (body burden) (linear regression, 95 % confidence interval, $r^2 = 0.19$; n=29; P<0.01).

Centaur Lake had the highest EC and pH, and copper and chromium concentrations, but the lowest dissolved oxygen, ORP, and concentrations of other heavy metals compared to the other lakes surveyed. Blue Waters and Stockton had higher manganese and lead concentrations, and lower copper, aluminium and iron concentrations and pH than other lakes. Ewington Lake had greater nickel, zinc, aluminium, iron and calcium concentrations than other lakes, but lower dissolved chromium and EC (Figure 7.12a).

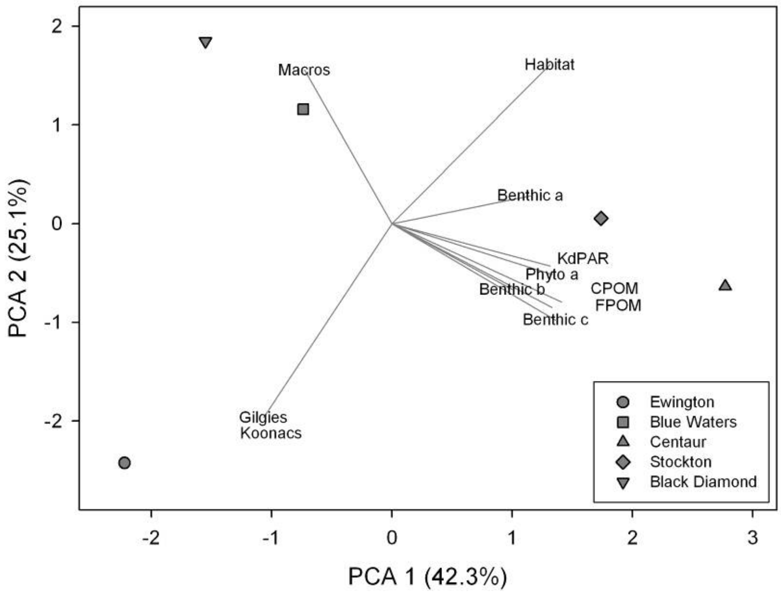
Centaur Lake and Stockton showed high levels of primary production but low levels of secondary production, while Blue Waters and Black Diamond showed high levels of secondary production but low levels of primary production (Figure 7.12b). Ewington Lake showed very little of both. Ewington Lake appeared to have less habitat available for marron than the other lakes, because there was competition for habitat between marron and other species of freshwater crayfish (gilgies and koonacs).

Compared to marron in the other lakes, marron in Centaur Lake showed low heavy metal body burden levels. Marron from Stockton showed relatively high body burden levels of arsenic, nickel, chromium, aluminium, copper, zinc and lead. Marron from Black Diamond showed relatively high body burden levels of calcium, tin, mercury, selenium and manganese. Marron from Blue Waters showed a large variety of heavy metal levels, but predominantly higher cadmium, iron, manganese, selenium and mercury levels. Marron from Ewington Lake showed low heavy metal body burdens. This in contrast with the gilgies caught in this lake. Relative to marron and the single koonac sampled, gilgies had higher body burden concentrations of all metals except for iron and manganese (Figure 7.12c).

a)




b)



c)

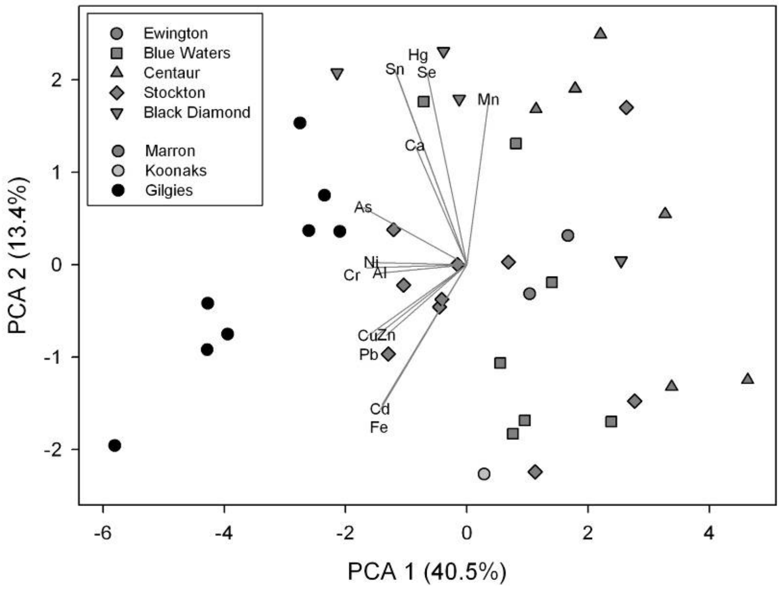



**Figure 7.12.** PCA ordinations of a). pit lake water chemistry, b). primary production and habitat, and c). Marron, gilgie and koonac metal and metalloid body burdens.

**Table 7.3**. Tolerable daily intake and mean metal content of marron tails from Ewington Lake (Evans et al. 2000) and of entire Marron from this study, (mean ± standard error, – = no data. Value in parentheses indicates sample number).

| Metal | Tolerable limit* (mg/day) | Evans *et al.* (3) | Ewington (2) | Blue Waters (7) | Centaur (6) | Stockton (10) | Black Diamond (4) |
|---|---|---|---|---|---|---|---|
| Aluminium | 0.03 | – | 6.4±9.2 | 13.9±23.4 | 5.6±8.5 | 9.1±11.7 | 21.0±67.8 |
| Arsenic | 0.225 | 0.05 | 0.02±0.01 | 0.02±0.01 | 0.02±0.02 | 0.02±0.01 | 0.02±0.03 |
| Cadmium | 0.075 | <0.01 | 0.01±0.01 | 0.01±0.01 | 0.01±0.01 | 0.02±0.02 | 0.00±0.01 |
| Copper | 15 | 2.2 | 1.3±5.1 | 0.96±0.95 | 0.96±3.1 | 2.5±2.8 | 2.1±3.7 |
| Lead | 0.27 | 0.18 | 0.64±2.27 | 0.48±0.36 | 0.04±0.16 | 0.06±0.11 | 0.04±0.09 |
| Mercury | 0.053 | 0.10 | 0.04±0.01 | 0.04±0.02 | 0.04±0.03 | 0.05±0.02 | 0.05±0.03 |
| Selenium | 0.938 | 0.19 | 0.09±0.02 | 0.09±0.11 | 0.09±0.10 | 0.08±0.07 | 0.08±0.06 |
| Tin | 150 | – | 0 | 0 | 0 | 0 | 0 |
| Zinc | 75 | 11.0 | 1.8±2.1 | 2.0±1.3 | 2.0±1.0 | 2.39±1.9 | 2.8±4.1 |

*(Food Standards Australia New Zealand 2003).

Table 7.3 shows that marron from Ewington and Blue Waters contain a level of lead that exceeds the tolerable daily intake. It also shows that aluminium levels in the marron from all of the examined lakes exceed the tolerable daily intake by up to a factor of 200 times. The levels of arsenic, copper, mercury, selenium and lead found by Evans *et al.* in marron in Ewington are higher than the levels found here. Because Evans *et al.* only examined the metal levels in the tail muscle and this study examined the metal levels in the entire marron, it is possible that arsenic, copper, mercury, selenium and lead are stored in the tail muscle.

It has to be taken into account that the lakes which were studied are not natural lakes. They are mine voids, so one could not expect these lakes to meet the freshwater trigger values set by ANZECC (Table 7.2), due to the waste products of mining activities.

In general, humans only eat the tail muscle of a crayfish. It may be possible that certain metals are stored not in the tail muscle of the marron, but in another part of the animal.

Table 7.3 shows metal levels in the entire body of the marron. Therefore it may be possible that the metal levels in the tail muscle do not exceed the tolerable daily intake. Because some of the results are heavily influenced by one or two individuals, the results might have been more reliable when the number of individuals tested (n) had been larger.

This section was adapted from a report by Joseph Steenbergen and Carlieke te Beest (exchange students from Hogeschool Zeeland, The Netherlands).

## Stirling City Acid Sulfate Soil Wetland

The City of Stirling has a number of localised problems associated with acid sulphate soils (ASS). Urban development is generally responsible for oxidation of the primarily arseno-pyrites in peat deposits. Low levels of acidity result (pH<3), and contamination with Fe, Al and As. The contamination generally occurs in the groundwater and becomes obvious either through use of groundwater for domestic irrigation or when it is expressed in wetlands. The Spoonbill lakes in Stirling have low pH ~2 waters derived from ASS contaminated groundwater. These lakes are a focal point of an urban recreational area. The City of Stirling was keen to find treatments solutions for this problem. Using technologies developed to treat AMD in mine sites we proposed a treatment system to be trialled at the site.

The treatment system was designed and established on the northern side of the southern lake's island over the winter of 2006 (Figure 8.1, Figure 8.2). It draws water from the northern lake, neutralises acidity with a computer-controlled dosing of sodium hydroxide solution and then settles and removes the resulting flocculent (predominantly iron ochre) in a settling tank. This neutralised water with low iron concentrations is then passed into the first bioreactor, consisting of 10 t of decomposing potatoes and 18 $m^3$ of hardwood mulch. Mediated by naturally-occurring bacteria, sulfate reduction occurs in this vessel. Further sulfate reduction also then occurs in the next vessel of 27 $m^3$ hardwood mulch. Sulfate reduction is intended to remove excess sulfate in the water which binds arsenic and heavy metals, and also produces further decreases in acidity. Sulfate reduction is essentially a reversal of the arseno-pyrite oxidation that caused the ASS problem following initial wetland disturbance. The treated water is then passed through a final 'polishing' stage in an aerobic wetland constructed in the north of the south lake.

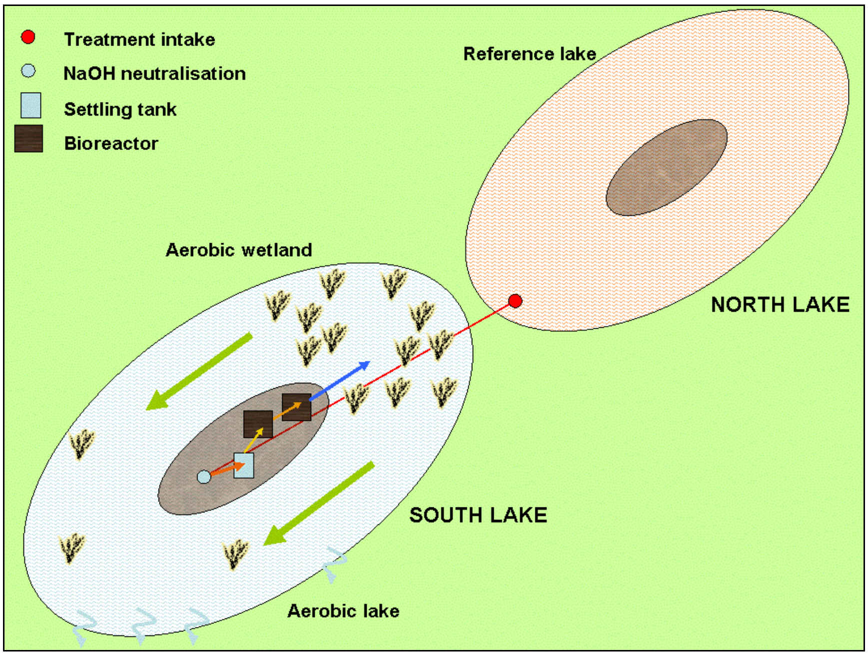



**Figure 8.1.** Schematic of the ECU ASS treatment system. Arrows indicate direction of treated water, arrow colour indicates degree of treatment.

**Figure 8.2.** Construction of the treatment system.

Shake-down testing of the system was completed over the following months, and continuous running of the system treating 10 L minute$^{-1}$ began in November 2006. A Curtin University of Technology PhD student, co-supervised with Associate Professor Ron Watkins, was appointed during this time and is studying the performance of the system with a view to the requirements for further such ASS remediation applications.

Recent monitoring data has shown that the system successfully treats water from an intake water acidity of pH 3 to an exit pH of 7.9. pH being a logarithmic scale, this is a 100 thousand-fold decrease in acidity from original contaminated lake water.

Initial sulfate concentrations of 440 mg $L^{-1}$ are reduced to 33% in the first bioreactor and then to only 10% following treatment by the second bioreactor. Nitrate concentrations are incidentally removed 27% from 300 $\mu L^{-1}$.

At a request from ECU, the City mulched around the northern margin of the southern lake (Figure 8.3). The City also purchased a further 2 000 wetlands plants (*Baumea articulata* and *Schoenoplectus validus*) in addition to the initial 500 planted by ECU for establishing the aerobic wetland. ECU planted these out for the City in early March (Figure .4).

**Figure 8.3.** Mulching of southern lake's north margin, with (right to left) settling tank and bioreactors of treatment system in background.

**Figure 8.4.** ECU students planting out rushes to further establish the aerobic treatment wetland.

## Collinsville Coal Project - Introduction

An ACARP grant (C14052) was received for a project based around remediation of a pit lake at Collinsville Coal Mine (CCP). The aim of this grant was to determine the efficacy of addition of organic matter in the form of primary-treated municipal biosolids and green waste as electron donors for sulfate reduction mediated acidity amelioration in an acid coal min pit lake. This project began in April 2005 and will continue until December 2007.

## Collinsville Coal Project - Methods

This project involves the transfer of knowledge and approach developed for passive biological remediation of acidic coal mine lakes, from the unusual conditions of Collie (south-west Western Australia), to the more typical mine lakes of Collinsville (North Queensland). Biological remediation will be achieved through splitting a large mine pit lake (Garrick East) at the Collinsville Coal Project into a treatment (~50 ML) and control section (~450 ML). Two other pit lakes are used as controls. The treatment will use locally available primary treated sewage sludge and liquid (3913 t) and all council greenwaste (~1032 t) able to be supplied over 6 months. The aim of the treatment is to improve water quality in the void from around pH 2.4 (with associated high concentrations of metals), to water suitable for a range of end uses. The initial end use focus will be for providing water of sufficient quality for dust suppression of mining haul roads to relieve pressure on the Bowen River and groundwater resources.

Monthly monitoring of a number of mine lakes on the mine lease (including Garrick East) has been undertaken over the last year to provide data on baseline conditions. These studies have shown that superficially the mine lakes appear very similar. However, closer analysis suggests that there are features of each that would enhance or reduce the efficiency of the proposed treatment approach. Therefore our recommendation is that at least one year's baseline data is collected prior to any similar treatment.

Garrick East pit lake has now been split (see Figure 9.1) and treatment with both sludge and greenwaste commenced in late June 2006 and concluded in January 2007. All local and state regulatory and mine approvals have been obtained for the treatment. There have been a number of operational issues involved in the smooth delivery of greenwaste and sewage into the treatment lake. However these are now largely resolved and it now appears that both greenwaste and sewage can be evenly distributed across the treatment area. A vertical pipe is being installed to permit the collecting of bottom water samples without risk of meters snagging on submerged greenwaste. The size of the treatment area of Garrick East has been determined from the available organic material and the results of the two core experiments conducted in Perth and Collinsville.

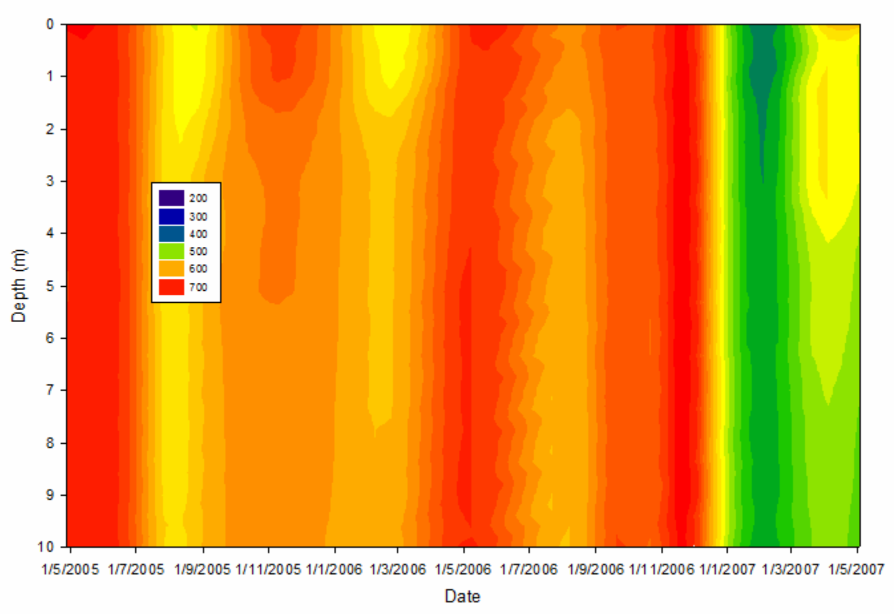
**Figure 9.1**: Photograph of the Garrick East pit lake showing the splitting of the lake into a control (left) and treatment (right)

Monitoring of the effectiveness of the treatment has been made since treatment additions began. No substantial problems have been encountered with the use of sewage. As the pit lake is starting to become stratified it appears that the sewage is beginning to increase pH. Although improvements are initially small they are growing.

## Collinsville Coal Project - Results and Discussion

Preliminary results show that ORP (Redox Potential) has dropped dramatically in the treated side of the lake from >500 mV to 200 mV. This is a very first and important first stage of the process, because ORP has to be substantially reduced (-100mV) before sulphate reduction will occur. We believe that the aside from bringing the ORP down that the sewage and greenwaste are also providing pockets of low ORP water and lake sediments (microenvironments) that sulphate reducing bacteria can utilise.

a) Control




b) Treatment

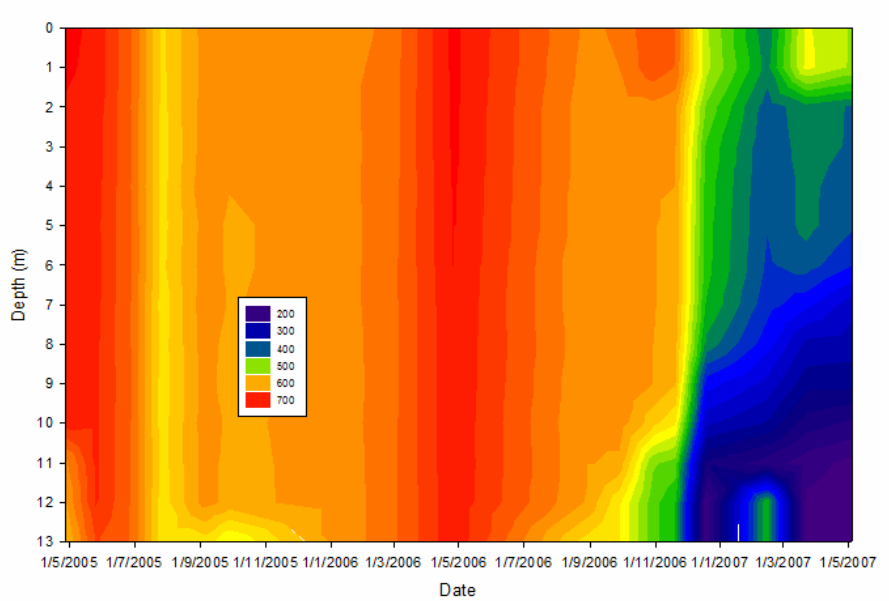
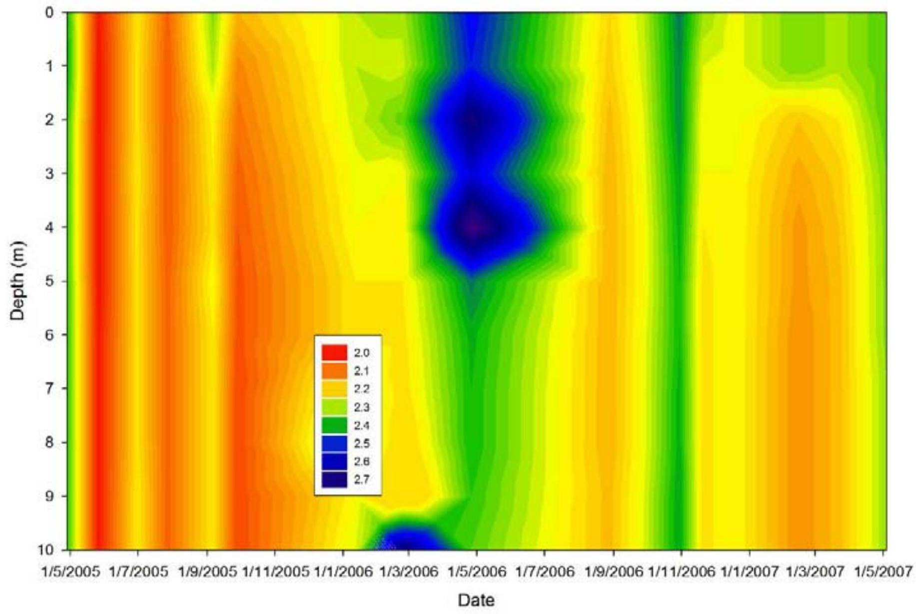



**Figure 9.2:** ORP changes with depth and time in the Garrick East pit lake a) Control and b) Treatment, both prior and after the addition of material to the treatment.

The pH in the control lake (Figure 9.3a) has not significantly changed in the last two years. Moreover, control lake pH has never risen above 2.7. In contrast the pH in the treated lake (Figure 9.3b) has risen at the bottom from ~2 to 3.6 at the time of April sampling.

a) Control




b) Treatment

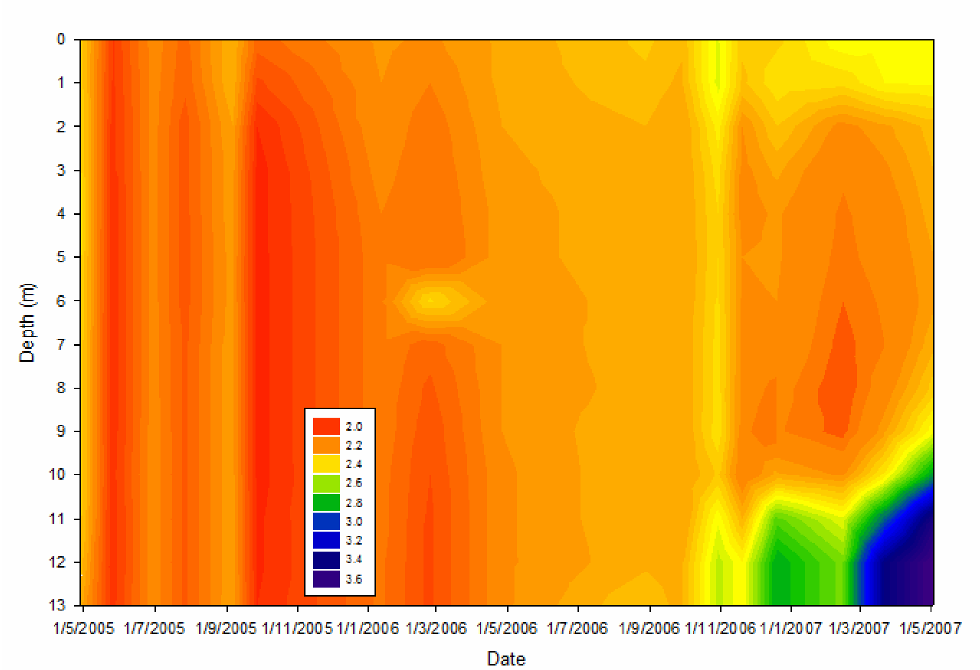



**Figure 9.3:** pH changes with depth and time in the Garrick East pit lake a) Control and b) Treatment, both prior and after the addition of material to the treatment.

The improvements in pH seen in the treated lake are very encouraging and we expect that the alkalinity-generating process will continue to gain momentum, aided by the large quantity of organic matter now added and the high temperatures of the region.

The size of the treatment area of Garrick East has been determined from the available organic material and the results of the two core experiments conducted in Perth and Collinsville. These experiments use acrylic tubes (95 mm diameter and 600 mm long) with 10–15 cm lake sediment topped with mine water (see photographs below). Combinations of greenwaste and sludge were added to these tubes. The water quality of the tubes was then regularly sampled.

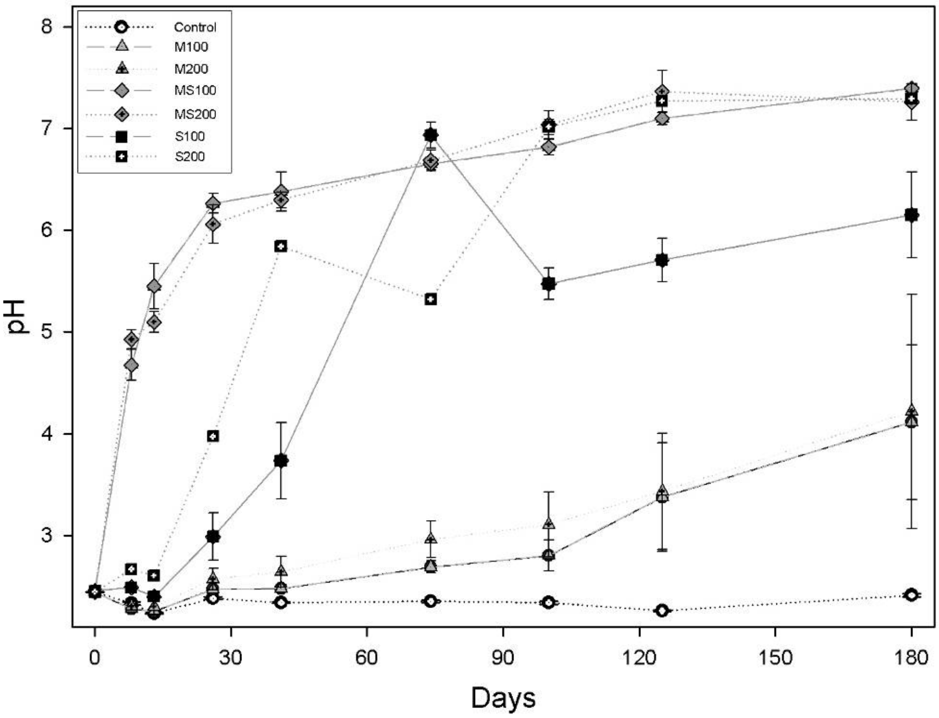
The Perth experiment was set up as shown in Table 9.1.

**Table 9.1:** Experimental design showing the materials added to each treatment

| Treatment level | Individual organic mass (g) | AMD water:greenwaste:sewage ratio | Number of replicates |
|---|---|---|---|
| Control | 0 | 1:0:0 | 6 |
| Limed control | 0 | 1:0:0 | 3 |
| Green waste | 100 | 32:1:0 | 3 |
| Green waste | 200 | 16:1:0 | 3 |
| Limed green waste | 200 | 16:1:0 | 3 |
| Green waste and sewage | 100 | 32:1:1 | 3 |
| Green waste and sewage | 200 | 16:1:1 | 3 |
| Limed green waste and sewage | 200 | 16:1:1 | 3 |
| Sewage | 100 | 32:0:1 | 3 |
| Sewage | 200 | 16:0:1 | 3 |
| Limed sewage | 200 | 16:0:1 | 3 |

Over 180 days, pH in cores with 200 g of sewage alone or with greenwaste and sewage increased to over 7. Although the pH increase was not as great for greenwaste (pH 4 for unlimed and pH 6 for limed greenwaste, Figure 9.4) electrical conductivity dropped 14% in all greenwaste only treatments from 9.7 mS $cm^{-1}$ to around 8.5 mS $cm^{-1}$ (Figure 9.5). There was no difference in the final pH achieved in all treatments regardless of the quantity of material used, which suggests these materials may still have been added in excess of the quantities required to bring about change.

a) Unlimed




b) Limed

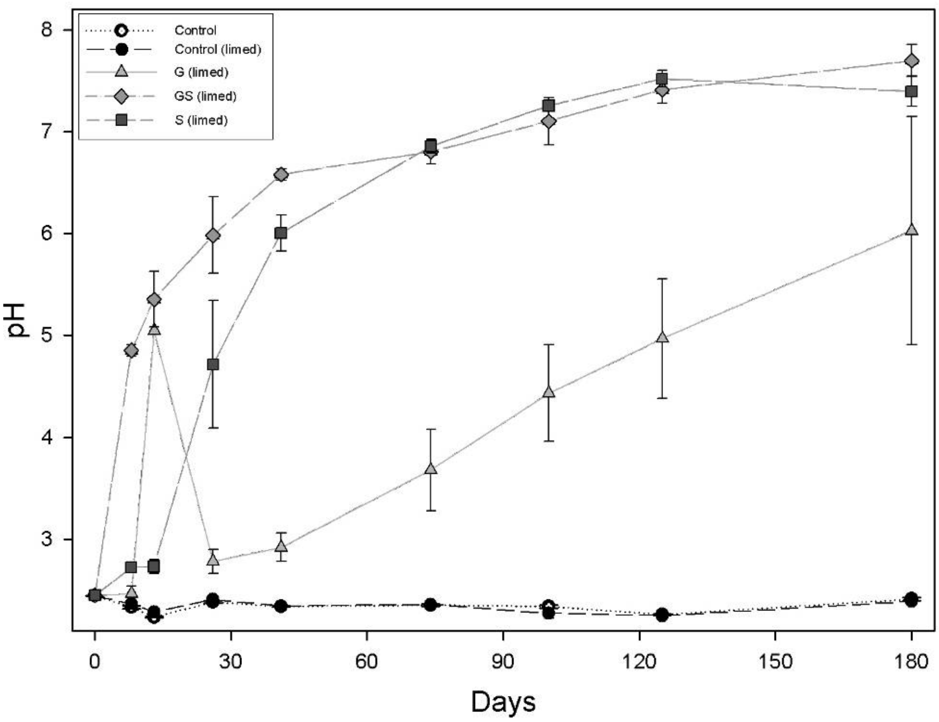
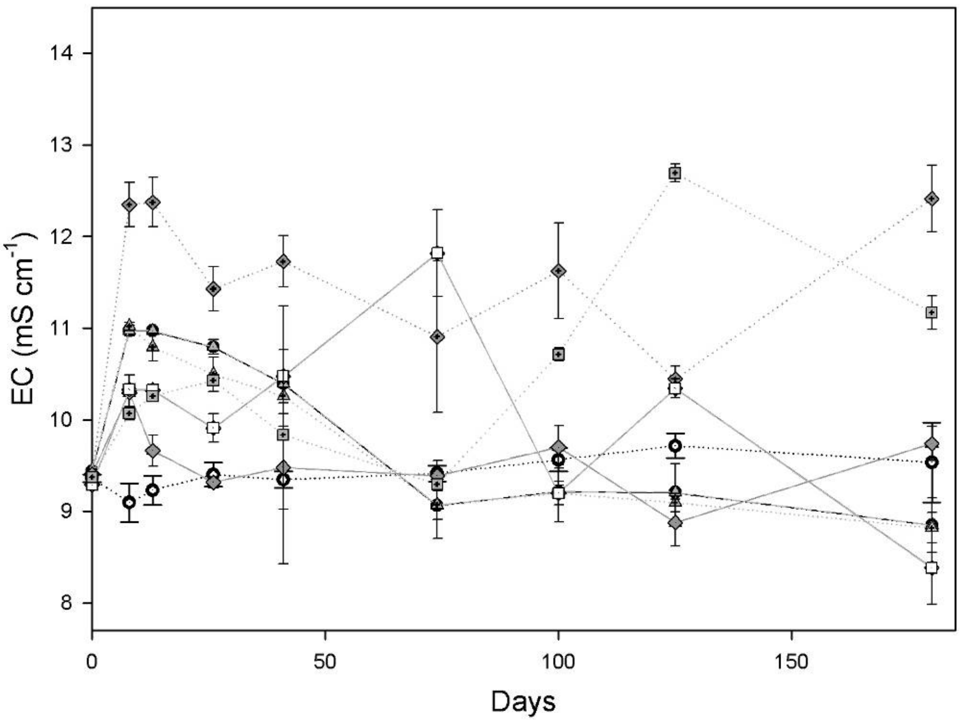



**Figure 9.4:** Mean pH (±se) over the 180 days of the microcosm experiment in a) unlimed and limed treatments (M = greenwaste alone, MS = greenwaste and sewage, S = sewage alone)

a) Unlimed




b) Limed

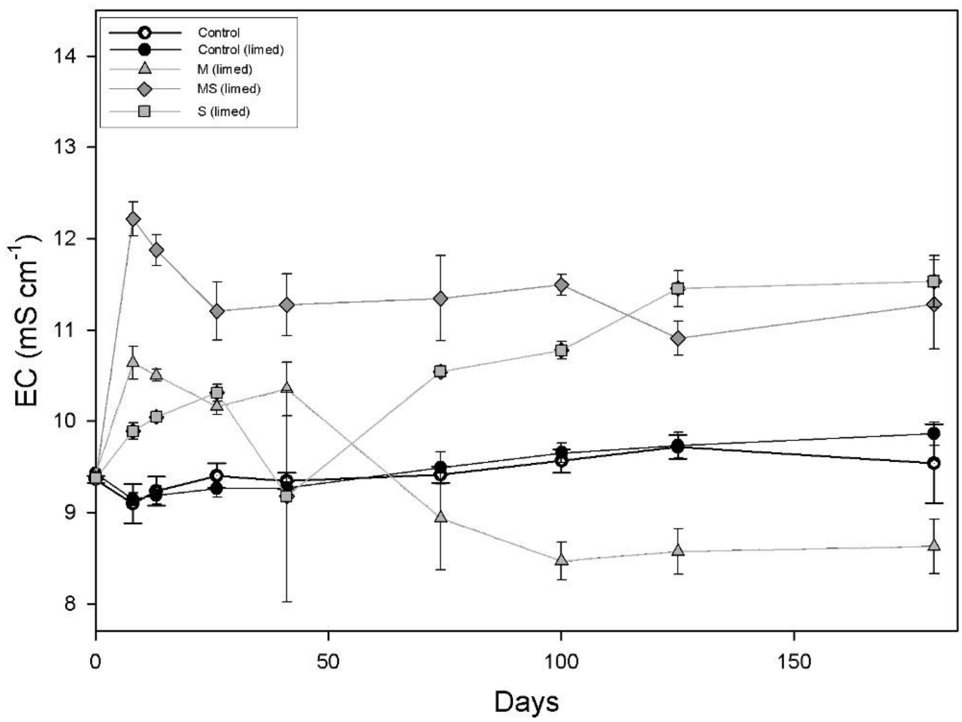



**Figure 9.5:** Mean EC (± standard error) over the 180 days of the microcosm experiment in a) unlimed and limed treatments (M = greenwaste alone, MS = greenwaste and sewage, S = sewage alone)

Treatments displaying a high pH increase tended to turn black with a very fine (<0.45µm) pyrite precipitate. As indicated by a black layer forming in the uppermost sediment layers, sulfate reduction reactions also appeared to take place in these sediment layers in all dosed treatments (Figure 9.6, indicated by arrow). Liming appeared to reduce the time it took for sulfate reduction to begin in the dosed treatments. Only in the greenwaste treatment did adding lime lead to a higher pH at the end of the experiment.

**Figure 9.6:** A representative microcosm of each unlimed treatment (control, mulch (100, 200), mulch and sewage (100, 200) and sewage (100, 200) from left to right) after 60 days

However, sulfate reduction appeared to take place in different parts of the core depending upon the organic medium used. Whilst sulfate reduction in the greenwaste treatment appeared to take place evenly throughout the core, sulfate reduction was predominant in the bottom of the sewage alone treatment and in the top of the greenwaste and sewage treatment. Even with sewage near the top of the greenwaste and sewage core, bottom redox may not have been low enough for sulfate reduction to occur.

Both experiments highlight the importance of greenwaste in the remediation, however sewage appears to have performed better in the recent Perth experiments than it did in the Collinsville experiments. This may be due to the Perth experiments using a mixture of less treated Bowen with the more treated Collinsville sewage sludges (1:3 ratios). The relatively high tropical temperatures compared to similar studies in the Northern Hemisphere also appear to positively influence the rate at which remediation occurs.

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# PROJECT 2.2: MINE LAKE WATER QUALITY ASSESSMENT USING BIOASSAYS AND CHEMICAL ANALYSIS


- Tsvetnenko Y., Evans L., Neil L.
- Centre for Sustainable Mine Lakes
- Curtin University of Technology


## Final Year Annual Research Report

The CSML project *Mine lake water quality assessment using bioassays and chemical analysis* was completed by December 2005 and final year annual reporting information provided in the 1st April 2005 to 31st March 2006 annual report to the State Government.

Acute and chronic bioassays have been developed using the freshwater microalga *Chlorella protothecoides*, the rotifer *Brachionus calyciflorus* and the water flea *Daphnia magna* and used in a range of applications including the assessment of water quality conditions of mine lakes and a wetland treatment system, the efficacy of treatment methods for remediating acidity and metal contamination in mine lake water, and an analysis of the major causes of adverse water quality in Collie mine lakes.

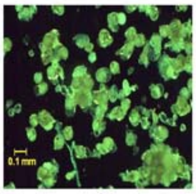
While the project has completed, main findings and outcomes have continued to contribute to the understanding of mine lake water behaviour.

In 2006, the project 2.2 team participated in the South West Development Commission funded *Review of CSML research of Lake Kepwari and recommendations for water quality management*.

Project findings led to the project 2.2 team presenting twp papers at the Interact 2006 Air, Water & Earth conference held in Perth, WA, on the T*oxicity assessment of limed and phosphorus amended mine pit lake water* and *Mine lake water quality assessment using bioassays and chemical analyses*.

Methods developed and employed during project 2.2 were instrumental in the CSML ecotoxicology team being contracted by Devereaux Holdings Pty Ltd on behalf of Griffin Coal to prepare a review that considered options for the discharge of waste water resulting from different ongoing and planned projects. The review determined the favoured option and proposed scheme of disposal of saline water from new industrial developments in Collie, through the existing saline waste water discharge pipeline, should be reconsidered.

Studying the response of freshwater rotifer bioassays against mine lake water featuring varying levels of acidity and contamination.




Transferring rotifers from a hatching trough into test wells.

Algal density determination using spectrophotometer.

## Executive Summary

Water quality in abandoned mine voids may be improved by different types of treatment so that water can be utilised for aquaculture production or potable water supply. Bioassays in addition to chemical analyses can provide a comprehensive characteristic of water quality. By using a suite of bioassays, the aggregate toxicity of all constituents in water can be estimated for a wide spectrum of aquatic organisms. Toxicity caused by compounds commonly not analysed for in chemical assays is detected. In bioassays the bio-availability of the toxic constituents is assessed, and effects of interactions of constituents are measured. This project evaluated the application of bioassays in the assessment of mine lake water quality.

Acidic water samples from 11 mine lakes and wetland sites in Collie, Western Australia with pH in the range of 3 to 5 and concentrations of dissolved metals exceeding Australian water quality guidelines were tested for acute and chronic toxicity to the freshwater microalga *Chlorella protothecoides*, the rotifer *Brachionus calyciflorus* and the water flea *Daphnia magna* using different bioassay protocols.

All water samples caused significant inhibition of algal growth, complete immobilisation of daphnia and mortality of rotifers. Quantitative indices of acute toxicity were generated in the daphnia and rotifer bioassays using a serial dilution approach.

Analyses of 16 chemical descriptors and three toxicity indices for all water samples by a multivariate partial least square method identified concentrations of Al, Ni and Co as the most dominant chemical predictors for the short-term toxicity to *D. magna* and *B. calyciflorus*.

Toxicity of hydrogen acidity was determined for *C. protothecoides* and *D. magna.* These data suggested that toxicity of diluted mine waters could be caused by hydrogen activity which still remained high. PHREEQC titration simulations demonstrated that this activity was maintained due to high buffering capacity of dissolved aluminium.

Neutralisation of acidity by addition of sodium hydroxide caused most aluminium and iron to precipitate and resulted in complete elimination of the short-term toxicity to the alga and daphnia in all samples. The same results were obtained in all bioassays when water samples had been treated by agitating with limestone powder. However, limestone neutralised water exhibited 21-d chronic toxicity displaying significant decreases of daphnia body length, fecundity and intrinsic rate of natural population growth. Chemical analysis indicated that Zn, Ni and Co were not completely removed by limestone treatment. After the addition of a metal chelating agent, EDTA, the chronic toxicity was not observed. The results suggest that the major cause of chronic toxicity is residual metals in limestone treated waters.

## Introduction

Water quality in abandoned mine voids may be improved by different types of treatment so that water can be utilised for aquaculture production or potable water supply. Bioassays in addition to chemical analyses can provide a comprehensive characteristic of water quality. By using a suite of bioassays, the aggregate toxicity of all constituents in water can be estimated for a wide spectrum of aquatic organisms. Toxicity caused by compounds commonly not analysed for in chemical assays is detected. In bioassays the bio-availability of the toxic constituents is assessed, and effects of interactions of constituents are measured. This project evaluated the application of bioassays in the assessment of mine lake water quality. The project was conducted by Dr Yuri Tsvetnenko, Professor Louis Evans and Luke Neil, Curtin University of Technology.

## Methodology

Water samples from Collie mine lakes including Lake Kepwari and from a constructed wet land adjacent to Chicken Creek mine void were assessed for chemicals by quantitative analysis and toxicity by bioassays. The results of bioassays were analysed to determine sensitivity of test organisms to water samples with different levels of acidity and toxic metal contents. To investigate residual toxicity, acidic water samples were neutralised with alkaline compounds or natural limestone and tested in the bioassays.

Microalga bioassay. A standard 72-h bioassay using unicellular alga Chlorella protothecoides was employed for water toxicity testing following the standard protocol (Stauber et al. 1994).

Invertebrate bioassays. Bioassays with the water flea Daphnia magna and the freshwater rotifer Brachionus calyciflorus were conducted in accordance with standard protocols for 48-h and 24-h exposure testing, respectively (Microbiotests Inc.). Stocks of daphnia dormant eggs (ephippia) and rotifer dry cysts were obtained from the overseas supplier, Microbiotests Inc., Belgium. Bioassays using animals originated from dormant eggs/cysts eliminate culturing and maintenance of live stocks which is considered as a major advantage over many aquatic tests.

Chemical analyses. Water samples were analysed for common ions and dissolved metals in MAFR Laboratory at Murdoch University.

Water sampling & handling. Water samples were collected at various sites around Collie, Western Australia comprising four abandoned mine lakes (Bluewaters, Stockton, Ewington, Black Diamond), four sites in Griffin Coal Chicken Creek constructed wetland, the Chicken Creek mine void at Griffin Coal and the WOH5 mine void and Lake Kepwari on the Wesfarmers Premier Coal mine site. Water samples were also collected on three occasions from Collie River in the river reach within Collie townsite. Details of sampling, physical and chemical parameters of water samples are given in Table 1. All water samples were taken 0.2 m below the water surface, delivered to the laboratory and kept in the fridge until testing.

**Table 1.** Physico-chemical characteristics of lake and wetland water samples.

| Sample Code | Date of Collection | Collection Point | Collect. Temp.°C | Salinity ‰ | Conduct. mS/cm | Alkalinity mg/L CaCO3 | Hardness mg/L CaCO3 | pH |
|---|---|---|---|---|---|---|---|---|
| K | 16/03/04<br>11/05/05<br>9/06/05 | Lake Kepwari | 25.0<br>20.6<br>20.5 | ND | 2.62<br>2.42<br>2.46 | <10 | 440<br>412<br>448 | 4.79<br>4.58<br>4.40 |
| BW | 14/03/04<br>9/06/05 | Blue Waters Lake | 25.0<br>20.7 | ND | 1.84<br>1.80 | <10 | 220<br>233 | 4.06<br>3.83 |
| S | 13/03/04<br>9/06/05 | Stockton Lake | 25.0<br>20.7 | ND | 0.52<br>0.49 | <10 | 60<br>72 | 4.30<br>4.05 |
| E | 9/06/05 | Ewington Lake | 20.7 | ND | 1.24 | <10 | 107 | 3.95 |
| BD | 9/06/05 | Black Diamond Lake | 20.4 | ND | 0.51 | <10 | 107 | 5.04 |
| A | 9/06/05 | Wesfarmer Premier Coal's WO5H mine lake | 20.4 | ND | 1.17 | <10 | 200 | 3.18 |
| CC | 8/03/04 | Chicken Creek Lake | 25.0 | 1.5 | 2.55 | <10 | 400 | 3.00 |
| L1 | 8/03/04 | Chicken Creek Limestone treatment 1 | 25.0 | 1.5 | 2.40 | <10 | 460 | 3.49 |
| L2 | 8/03/04 | Chicken Creek Limestone treatment 2 | 25.0 | 1.5 | 2.35 | <10 | 480 | 4.15 |
| W1 | 8/03/04 | Chicken Creek Wetland inflow | 25.0 | 1.5 | 2.38 | <10 | 480 | 4.23 |
| W2 | 8/03/04 | Chicken Creek Wetland outflow | 25.0 | 1.5 | 2.80 | <10 | 600 | 4.02 |
| Collie River | 5/03/05<br>10/03/05<br>18/03/05 | Collie Town | 23.7 | ND | 1.78 | 40 | 280 | 7.12 |

## Results and Discussion

### *Chemical assessment of water samples*

Collected water samples were acidic (pH between 3 and 5) with low salinity (Table 1). Aqueous concentrations of some metals exceeded current national water quality guidelines (Table 2) and warranted further biological toxicity evaluations

**Table 2.** Chemical aqueous concentrations (mg/L) in mine water samples.

| Analyte | Water sample | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **BD** | **S** | **K** | **E** | **BW** | **W1** | **L1** | **W2** | **L2** | **CC** | **A** |
| **Al** | **0.04** | **0.38** | **1.5** | **1.4** | **4.5** | **14** | **15** | **14** | **14** | **18** | **18** |
| **Ca** | 7.3 | 3.2 | 36 | 3.9 | 18 | 45 | 33 | 57 | 43 | 18 | 21 |
| **Cd** | <0.001 | **<0.001** | <0.001 | 0.0007 | <0.001 | 0.0017 | 0.0016 | 0.0019 | 0.0015 | 0.0016 | **0.0011** |
| **Co** | **<0.002** | **0.018** | **0.065** | **0.005** | **0.057** | **0.16** | **0.16** | **0.2** | **0.16** | **0.17** | **0.19** |
| **Cr** | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | **0.003** | **0.003** | **0.003** | **0.002** | **0.004** | **0.007** |
| **Cu** | <0.001 | <0.001 | 0.003 | **0.004** | 0.005 | **0.019** | **0.019** | **0.016** | **0.017** | **0.019** | **0.013** |
| **Fe** | 0.004 | 0.015 | 0.022 | 0.053 | 0.032 | 0.13 | **1.6** | 0.23 | 0.093 | **11** | **0.78** |
| **K** | 3.1 | 3.5 | 6 | 4.4 | 5.3 | 8 | 8.1 | 10 | 8 | 8.3 | 6.4 |
| **Mg** | 16 | 8.4 | 95 | 22 | 59 | 63 | 61 | 75 | 62 | 63 | 32 |
| **Mn** | 0.16 | 0.082 | 0.28 | 0.027 | 0.13 | 0.69 | 0.67 | 0.83 | 0.68 | 0.77 | 1.5 |
| **Na** | 63 | 61 | 390 | 190 | 350 | 256 | 260 | 320 | 256 | 266 | 92 |
| **Ni** | <0.004 | **0.018** | 0.065 | 0.006 | 0.062 | **0.19** | **0.18** | **0.22** | **0.18** | **0.2** | **0.24** |
| **Pb** | <0.01 | **<0.01** | <0.01 | **<0.01** | <0.01 | 0.02 | 0.03 | 0.02 | 0.02 | 0.03 | 0.02 |
| **Zn** | 0.008 | **0.089** | **0.51** | **0.042** | 0.023 | **0.97** | **0.96** | **1.1** | **0.91** | **0.99** | **1.2** |

Values in bold exceed ANZECC/ARMCANZ (2000) water quality guidelines for the protection of 95% species of freshwater ecosystems. The guideline trigger values for Cd, Cu, Ni, Pb and Zn were adjusted to water sample hardness.

### *Toxicity evaluations by standard short-term bioassays*

Toxicity of collected water samples was tested in the bioassays using the alga, rotifer and daphnia. All water samples caused significant inhibition of algal growth, complete immobilisation of daphnia and complete mortality of rotifers (Table 3).

The same bioassays were used to test toxicity after water neutralising with sodium hydroxide and separating from precipitates by filtration. Neutralisation of acidity caused most aluminium and iron to precipitate and resulted in complete toxicity elimination in CC, L1, L2, W1 and W2 water samples (Table 3). The same results were obtained when water samples had been treated by agitating with limestone powder.

Neutralisation of water from other Collie lakes with sodium hydroxide eliminated short-term toxicity for the alga and daphnia but significant residual toxicity for the rotifers was observed in neutralised BW and S water samples (Table 3).

**Table 3.** Toxicity characteristics of intact and neutralised mine water samples.

| Sample | Bioassay Type/Toxicity Response | | | | | |
|---|---|---|---|---|---|---|
| | 72-h Algal Bioassay Growth Inhibition*, % | | 48-h Daphnia Bioassay Immobilisation, % | | 24-h Rotifer Bioassay Mortality, % | |
| | Intact Sample | Neutralised Sample | Intact Sample | Neutralised Sample | Intact Sample | Neutralised Sample |
| BD | **22** ± 1.4 a | 9 ± 3.3 ef | **85** | 0 | **100** | 0 |
| S | **158** ± 2.2 e | -39 ± 7.5 ab | **100** | 0 | **100** | **100** |
| K | **143** ± 6.6 d | -39 ± 7.3 a | **100** | 0 | **100** | 10 |
| E | **147** ± 25.4 cde | 16 ± 2.3 f | **100** | 0 | **100** | 0 |
| BW | **200** ± 40.0 de | -40 ± 7.9 a | **100** | 0 | **100** | **60** |
| W1 | **109** ± 9.9 bc | -1 ± 0.2 d | **100** | 0 | **100** | 0 |
| L1 | **78** ± 2.6 b | **-23** ± 0.8 b | **100** | 0 | **100** | 0 |
| W2 | **99** ± 5.2 c | -1 ± 0.7 d | **100** | 0 | **100** | 0 |
| L2 | **97** ± 6.7 bc | -5 ± 1.0 c | **100** | 0 | **100** | 0 |
| CC | **85** ± 1.8 b | **-12** ± 5.5 cd | **100** | 0 | **100** | 0 |
| A | **231** ± 42.1 de | 1 ± 3.7 cde | **100** | 0 | **100** | 0 |

* Growth inhibition in comparison with the control; negative values of growth inhibition mean growth stimulation; values are mean ± SD; values of the same column with different letters are significantly different according to confidence intervals for medians. Values in Bold are given for those samples where a response was significantly different from that in the control.

The median effective and lethal concentrations, EC50 and LC50, were obtained in bioassays with daphnia and rotifers, respectively, by testing toxicity of water samples at various levels of dilution (Table 4). EC50 and LC50 results indicate the concentration at which 50% of the organisms exhibit the biological response – an increase in this parameter is indicative of a reduction in toxicity. The concentration in both parameters was expressed as a percentage of mine water in a dilution preparation.

**Table 4.** Cumulative toxicity of mine water samples to *D. magna* and *B. calyciflorus*. Values are given as percentages of mine waters in dilution preparations.

| **Sample** | **24-h Daphnia Bioassay** | | **48-h Daphnia Bioassay** | | **24-h Rotifer Bioassay** | |
|---|---|---|---|---|---|---|
| | **LC50** | **95% CI** | **LC50** | **95% CI** | **LC50** | **95% CI** |
| BD | >100 | NC | 85.5 a | 77.0 - 95.0 | >100 | NC |
| S | 90.7 a | 86.5 - 95.1 | 75.1 ab | 69.2 - 81.5 | 84.3 ab | 71.0 - 100. |
| K | 84.8 a | 80.0 - 89.9 | 80.4 a | 76.4 - 84.7 | 85.4 a | 81.0 - 90.0 |
| E | 81.4 a | 75.8 - 87.5 | 70.6 b | 66.7 - 74.7 | 71.2 b | 66.8 - 76.0 |
| BW | 67.5 b | 64.3 - 70.8 | 65.8 b | 60.2 - 71.8 | 65.1 b | 53.0 - 80.0 |
| W1 | 35.4 c | 33.5 - 37.3 | 34.7 c | 33.4 - 36.0 | 35.4 c | 25.0 - 50.0 |
| L1 | 35.0 c | 34.2 - 35.9 | 34.5 c | 33.1 - 36.1 | 35.4 c | 25.0 - 50.0 |
| W2 | 34.7 c | 33.4 - 36.0 | 34.0 c | 32.1 - 36.0 | 35.4 c | 25.0 - 50.0 |
| L2 | 34.0 c | 32.1 - 36.0 | 32.8 c | 27.9 - 38.6 | 35.4 c | 25.0 - 50.0 |
| CC | 27.7 d | 23.9 - 32.2 | 17.1 d | 14.7 - 19.8 | 17.6 d | 17.3 - 17.9 |
| A | 20.2 e | 18.0 - 22.7 | 19.1 d | 16.9 - 21.6 | 24.2d d | 23.3 - 25.2 |

NC = not calculable; values in the same column and with the same letters are not significantly different ($p > 0.05$) according to the exact LC50-ratio test (Greenberg et al. 1992).

The dilutions resulted in a gradual increase of pH and decrease of metal concentrations. The significant increase of EC50 and LC50 values for L1 water with pH 3.5 reflected almost double decrease in toxicity when compared to that of CC water with pH 3.0. Although pH changed to 4.0-4.2 after water passed the additional limestone treatment (sample L2) and the wetland (samples W1 and W2), no further decrease in toxicity was observed. The obtained data indicate that serial dilution testing has higher ability to discriminate different levels of toxicity than single sample testing and that EC50/LC50 values are preferable toxicity indices when small changes in toxicity need to be demonstrated. The conducted bioassays indicated that water of Chicken Creek Lake after limestone treatment in two stations and passing through the constructed wetland was still highly toxic.

Of the seven lakes tested, Lake Kepwari had the least toxicity following dilution compared to the other lakes with one exception, Stockton Lake for the 24-h EC50 result. Laboratory experiments with water acidity neutralisation demonstrated that elevation of pH did not always eliminate toxicity, at least for rotifers.

As the four sets of toxicity data for algal, daphnia and rotifer bioassays were shown to have a normal distribution (Shapiro-Wilks test), they were analysed by the method of principal components (PCA) to ascertain sample grouping by their toxic responses in separate algal and invertebrate bioassays and in all bioassays in their battery. Four groups of samples were distinguished by PCA considering LC50 values for either of the two invertebrate species and the percentage of algal growth inhibition (Table 5). A range of toxicity for each species was divided into four grades with increasing from low to mild, then to moderate and finally to high grade. Group I including the only BD sample has low toxicity to the both alga and invertebrates. Group II combines five samples (L1, CC, L2, W2 and W1) with mostly mild toxicity to the alga and moderate toxicity to the invertebrates. Group III consists of four samples (K, E, S and BW) with the opposite toxicity to the alga and invertebrates. Group IV has one sample A with high toxicity to the both alga and invertebrates.

**Table 5.** Groups of water samples associated by results of bioassays

| Sample | Battery Group of Toxicity | Toxicity Grade | |
|---|---|---|---|
| | | Alga Bioassay | Invertebrate Bioassay |
| BD | I | low | low |
| L1 | II | mild | moderate |
| CC | II | mild | high |
| L2 | II | mild | moderate |
| W2 | II | mild | moderate |
| W1 | II | moderate | moderate |
| K | III | moderate | mild |
| E | III | moderate | mild |
| S | III | moderate | mild |
| BW | III | high | mild |
| A | IV | high | high |

### *Toxicity assessments of hydrogen acidity*

The toxicity of protonic acidity was evaluated for the alga and *D. magna* in bioassays with culture media buffered in the pH range of 3 to 8.

An algaecidal effect for *C. protothecoides* was observed at pH levels below 4.2. At the pH levels between 4.2 and 6 algal growth was inhibited in both soft (50 mg/L $CaCO_3$) and hard (340 mg/L $CaCO_3$) waters. The optimal growth was observed at pH 6.0-6.2 in soft water and at pH 6.8-7.2 in hard water. In hard water preparations the level of bicarbonate was much higher than in soft water preparations. Accordingly, the concentration of carbon dioxide was much greater in hard water than in soft water due to the shift in equilibrium of the reaction of carbon dioxide with water. Therefore, at circumneutral pH the algal growth is driven by the availability of carbon dioxide as the major algal nutrient.

In experiments with *D. magna*, it was demonstrated that animals became immobilised at pH below 5.7 after 24 hours in both soft (70 mg/L $CaCO_3$) and hard (320 mg/L $CaCO_3$) waters and at pH below 5.8 in soft water and at pH below 6.2 in hard water after 48 hours of exposure. Data on *D. magna* immobilisation at various pH were used to calculate $EpH50_c$ or pH of test solution causing 50% immobilisation due to toxic effects of hydrogen ions in clean water.

Data on *D. magna* immobilisation at various dilution levels of mine water were used to calculate $EpH50_m$ or pH of test solution causing 50% immobilisation due to toxic effects of hydrogen and metal ions in mine water samples. Comparisons of 95% confidence intervals for $EpH50_c$ and $EpH50_m$ values for clean and mine waters demonstrated their overlapping for all mine water samples except for BD sample. These data indicate that observed toxicity of most mine water samples could be attributed mainly to hydrogen acidity.

### *Toxicity evaluations by survival time*

In an attempt to investigate whether protonic acidity was a dominant factor in toxicity of mine lake waters, survival time of *D. magna* was measured as a biological end-point. A strong relationship between the pH and survival time for *D. magna* neonates was demonstrated in the pH range from 2 to 4 (Survival time (in seconds) = $0.3496e^{2.533pH}$, $R^2$ = 1). To test the hypothesis that protonic acidity and high concentrations of dissolved metals have additive toxic effects, experiments with water pH adjustments were conducted. According to that hypothesis, survival time in acidic water samples contaminated with metals should be significantly less than in a non-contaminated acidic control providing pH in all samples is adjusted to a certain value, which does not cause significant precipitation. However, two series of experiments with the mine water samples adjusted to pH 3.00 or 4.00 did not support this hypothesis.

### *Toxicity evaluations by chronic bioassays*

To evaluate residual toxicity of neutralised mine lake waters, chronic toxicity bioassays were employed. Mine water samples were treated with limestone powder at a rate of 1.0-1.4 g/L by agitating for 24 h, then separated from precipitate by filtering. Chronic toxicity of neutralised CC and K waters to *D. magna* was evaluated in comparison with natural Collie River water as the control (Tables 6 and 7). The 5-day and 21-day renewal bioassays were conducted with regular animal feeding. At the end of the exposure, animal survival and body length were registered and measured in the 5-d bioassay and fecundity and an intrinsic rate of natural population increase (IRNI) were calculated in the 21-d bioassay as additional parameters.

**Table 6.** Results of chronic tests of Collie River intact water and Chicken Creek Lake water treated with limestone.

| Bioassay Parameter | Control Collie River water | | Chicken Creek Lake limestone-treated water | |
|---|---|---|---|---|
| | M±SE | N | M±SE | N |
| 5-d Mortality, % | $9^a$ | 45 | $13^a$ | 45 |
| 5-d Body Length, mm | $1.54±0.04^a$ | 41 | $1.32±0.04^b$ | 39 |
| Day of First Offspring Release | $9.8±0.36^a$ | 8 | $10.7±0.50^a$ | 9 |
| 21-d Female Body Length, mm | $3.64±0.116^a$ | 8 | $3.19±0.065^b$ | 9 |
| 21-d Fecundity, live offspring number/female | $75.1±9.68^a$ | 8 | $39.6±3.7^b$ | 9 |
| 21-d Mortality, % | $20^a$ | 10 | $10^a$ | 10 |
| 21-d Intrinsic rate of natural increase | $0.307±0.016^a$ | 10 | $0.258±0.015^b$ | 10 |

Figures in the same row with different superscripts are significantly different (p<0.05)

**Table 7.** Results of chronic test of Collie River intact water and Kepwari Lake water treated with limestone.

| Bioassay Parameter | Control Collie River water | | Kepwari Lake limestone-treated water | |
|---|---|---|---|---|
| | M±SE | N | M±SE | N |
| 5-d Mortality, % | 3 [a] | 30 | 0 [a] | 30 |
| 5-d Body Length, mm | 1.35±0.05 [a] | 29 | 1.20±0.02 [b] | 30 |
| Day of First Offspring Release | 10.8±0.28 [a] | 9 | 14.5±0.22 [b] | 6 |
| 21-d Female Body Length, mm | 3.41±0.101 [a] | 8 | 2.80±0.060 [b] | 8 |
| 21-d Fecundity, live offspring number/female | 54.9±8.59 [a] | 8 | 9.2±2.80 [b] | 8 |
| 21-d Mortality, % | 20 [a] | 10 | 20 [a] | 10 |
| 21-d Intrinsic rate of natural increase | 0.266±0.015 [a] | 10 | 0.113±0.022 [b] | 10 |

Figures in the same row with different superscripts are significantly different ($p<0.05$)

In both neutralised water samples survival was close to that in the control. However, by the 21st day of exposure, the body length, fecundity and IRNI were significantly lower in the treated mine lake waters than in the control. The 5-day chronic test was sufficiently sensitive to detect significantly slower growth in the treated waters. Chemical analysis (not shown) of the water samples indicated that such residual chronic toxicity could be caused by zinc, nickel and cobalt, which were not completely precipitated by acidity neutralisation with the limestone.

### *Toxicity identification evaluations*

To ascertain causative relationship between chronic toxicity and metal concentrations, the mine waters treated with limestone were tested for chronic toxicity after further treatments with chelating agents, ethylendiaminetetraacetic acid (EDTA) and thiosulfate prescribed for the toxicity identification evaluation (TIE) procedures (Norberg-King et al. 1992, Durhan et al. 1993, Mount and Norberg-King 1993). Additionally water samples were also tested for toxicity after treatments with another metal binding agent, humic acid (HA). The control treatments in these testings included reconstituted hard freshwater with the same amounts of EDTA, or thiosulfate, or HA used for mine waters. Interactions of these compounds with metalliferous waters can make them less toxic or non-toxic due to formations of non-toxic complexes between cationic metals and EDTA, thiosulfate and HA anions or deactivations of oxidative ions (e.g. $Mn^{2+}$) by thiosulfate. Loss of toxicity with EDTA or thiosulfate additions suggests cationic metals or oxidative ions, respectively, are causing toxicity. Loss of toxicity with HA additions provides subsidiary evidence that toxicity is caused by cationic metals and can be reduced by organic matter.

The 5-d chronic toxicity tests with *D. magna* neonates were used in the present study as shorter versions of chronic tests had been recommended for TIE testing procedures (Norberg-King et al. 1992). The 5-d chronic tests with a body length as a biological end-point were demonstrated to have sufficiently high sensitivity similar to that of the 21-d chronic tests with the body length, fecundity and population growth as end-points.

In the control treatments none of the compounds caused significant changes in animal survival or growth indicating that their concentrations were harmless. Thiosulfate did not improve animal survival or growth in CC limestone-treated water and caused complete immobilisation in K limestone-treated water. The reasons of that extreme response are yet to be investigated. EDTA recovered animal survival and growth in both samples to the control levels.

The addition of HA resulted in the same improvements only in K limestone-treated water. Observations of test solutions with added HA showed that this compound gradually flocculated and settled to the bottom of test wells during the course of the test. However, in CC water this process was considerably quicker than in others. Different stability of HA in the test solutions was verified in a separate 48-h experiment conducted at the same test conditions but without animals. The dissolved HA measurements indicated that flocculation occurred mostly within the first 24 h and significantly reduced thereafter. The addition of algal suspension used in the toxicity tests for daphnia feeding had no significant effects on the flocculation rate of HA. The least flocculation was observed in distilled water almost with no solutes. Apparently, the flocculation of HA in the control synthetic hard water and mine waters was induced and affected by solution solutes. Therefore, the lack of ameliorating effect of HA in CC water could be explained by lower active concentration of this compound due to its more rapid precipitation caused by a specific ionic composition of this water.

The use of metal binding compounds in TIE procedures confirmed the chronic toxicity of heavy metals in limestone-treated mine waters. EDTA with universal metal chelating properties made cobalt, nickel and zinc biologically unavailable for the test organisms, therefore, improved their performance and deleted chronic toxicity. Failure to achieve the same results with thiosulfate also confirms that elevated manganese concentrations in treated mine waters cannot cause toxicity, which is consistent with the low sensitivity of *D. magna* to that metal. The successful removal of chronic toxicity by HA in K water suggests that the quality of that water after limestone treatment may be significantly improved by bioremediation methods promoting the accumulation of organic matter as a major source of HA.

### *Chemistry-toxicity relationship analysis*

A distribution-free method of partial least squares projection to latent structures (PLS) was used to analyse relationships between chemical and toxicity parameters of mine water samples. Sixteen chemical descriptors and four toxicity indices were analysed by PLS to find out their relationships in a dataset of 11 mine water samples. Computations were performed using a statistical package SIMCA-P+, Version 11.0 (Umetrics 2005).

The influence of chemical descriptors on toxicity responses in the model was determined by PLS regression coefficients. The pH, iron and potassium concentrations were the most dominant descriptors for the algal toxicity indices. However, the invertebrate toxicity indices were mostly associated with copper and aluminium concentrations indicating their high contributions in a contrast to other descriptors with lower regression coefficients. The information on PLS weights and regression coefficients over all toxicity responses and PLS components was integrated in the variable influence for the projection (VIP) parameter. In this model pH, Pb, Cu, Al, Cd, Ni, Cr, Fe, Mn and Co were significant explanatory variables as their VIP values were greater than 1.

The initial PLS model was simplified by deleting insignificant descriptors with VIP values less than 1. The resulted model M11x3y4' had two PLS components. The explained variance, goodness of fit and prediction and the validity of these two-component models remained similar to those in the original model. The comparison of chemical parameters with VIP>1 indicates that the both models consider Al and Cu as descriptors of high importance. The other chemical parameters of high importance comprise Cd, Pb and pH in the model including the algal response and Co, Ni and Zn in the model without the algal response. The most important chemical factor was pH in the PLS model including the alga response and Al in the model without the alga response.

PHREEQC computer modelling demonstrated that aluminium was the major buffer component preventing from a gradual pH increase which would occur in acidic water without aluminium in the pH range of 4-5 when diluted with neutral carbonate-buffered water.

Using PHREEQC model, the activity of hydrogen ion and metal concentrations were calculated for the mine water samples diluted with the synthetic freshwater to the point where daphnia 50% immobilisation was determined. Assuming additive toxic effects of hydrogen and different metal ions, a relative contribution of each kind of toxic agents to daphnia mortality was estimated by toxic units.

At the dilution of LC50, the hydrogen ion, accounted for up to 70% of toxicity in studied mine waters. The hydrogen prevailing contribution to toxicity and hydrogen ion activity buffering by aluminium in most samples provide an insight into the dominant role of aluminium in acute toxicity of mine waters suggested by PLS analysis of the relationships between chemical and toxicity factors. This role is fulfilled not through aluminium toxicity but through its pH buffering which keeps high concentration of toxic hydrogen ion in spite of diluting.

## Conclusions

The project:

- demonstrated bioassays ability to determine relative toxicity of mine lake waters differing in levels of acidity and metal contamination
- provided direct evidence of residual chronic toxicity in Chicken Creek Lake and Kepwari Lake waters neutralised by limestone treatment
- indicated that additional water treatment should follow the limestone treatment to make mine lake waters suitable for aquaculture uses

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# Project 2.3: Construction and evaluation of a Fluidised Limestone Reactor (FLR) treatment system


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## Final Year Annual Research Report

The CSML project *Construction and evaluation of a Fluidised Limestone Reactor (FLR) treatment system* was completed by December 2005 and final year annual reporting information provided in the 1st April 2005 to 31st March 2006 annual report to the State Government.

Further investigations to assess alterations in fluidisation dynamics that occur with scaling-up the present design were required to inform the commercial potential of the FLR treatment system – the final stage necessary to develop a commercial sized FLR.

The potential benefit of design refinement for optimum performance of the conical Fluidised Limestone Reactor (FLR), developed and trialled through CSML research undertaken between 2002 and 2005, led to CSML researchers being awarded an ACARP grant in 2006 of $121,430 for a 14-month project titled 'Fluidised Limestone Reactors for the Remediation of Acidic Drainage Waters'. Residual funds in the CSML FLR water treatments equipment budget enabled CSML to contribute to this new ACARP project (C15041).

Results of this ACARP project led to a request for CSML to develop a proposal for the construction of a large FLR for processing 20L/sec of mine lake water at Lake Kepwari in Collie. Curtin University is now in negotiations with the company that produced the design quotation with the view to marketing the technology to mining companies and other clients.

Discussions are also now underway between Curtin University and the mineral processing technology company on joint venturing the commercialisation of the FLR. The company is interested in entering into a commercial arrangement to conduct a market survey to assess the market potential of the technology and, if this proves to be favourable, a further arrangement to manufacture and market the FLR treatment system.

An enquiry for the installation of a small scale FLR at a mine site in Queensland for use in the treatment of low volume acidic leachates was recently received and is expected to lead to the application of the technology at the mine site.

Acidic water from Wesfarmers' WO5H mine lake is passed through the conical FLR in place at the Collie Aquafarm to increase the pH of water ultimately fed into the aquaculture ponds at the Aquafarm.

A cylindrical FLR trialled at Griffin Coal in the early stages of the project.

The mobile FLR was designed to be transported to various AMD and ASS affected sites.

## Executive Summary

A research project was conducted over a four year period that resulted in the development of an innovative technology for remediating acidic and metal contaminated mine lake water. The technology, called a fluidised limestone reactor (FLR), was trialled in the laboratory and at two different mine lakes. Investigations were conducted on reactor design, fluidisation dynamics, upscaling and operating costs. The technology is presently being commercialised through the licensing of the intellectual property from the host university, Curtin University with likely markets including mining companies affected by acid mine drainage and farmers and others affected by acid sulphate soils.

## Introduction

Acid mine drainage (AMD) is a significant problem in many mining areas across Australia and around the world. Acid mine drainage occurs when pyrites and other sulphide minerals are exposed to water and oxygen in the presence of oxidising bacteria. The pyrites and sulphide minerals are oxidised, generating acidity, which lowers the pH of the water. The low pH facilitates dissolution of minerals to give much higher solution metal concentrations than occurs at neutral pH. Both the dissolved metals and acidity impact severely on the ability of the water to sustain aquatic life. Regulations limiting the pH and dissolved metal concentrations in water coming from active mines have been imposed in many locations, and hence the need for the development of efficient methods of treating AMD. Similarly, treatment methods are also needed to remediate the water in acidified mine lakes formed when mining ceases.

Abandoned mine voids at a number of sites in Collie have filled with acid water. A cost effective method of remediation is necessary to develop beneficial mine void end uses. In an attempt to develop an effective approach to remediating acidic mine lake water an anoxic limestone bed was developed and trialled in an ACARP project conducted at Collie from 1996 – 1999. The results of this trial were promising and an upscaled version of this technology was installed at the Collie Aquafarm as part of a second ACARP funded project in 2000. In this installation the limestone was placed above the ground and was exposed to the air. The installation was unsuccessful, compaction and channelling causing the water to flow through preferential flow paths resulting in poor acidity remediation. It was decided to trial an alternative approach, in which the water was passed up through the limestone at sufficient pressure to fluidise the particles thereby avoiding compaction and channelling problems.

Preliminary trials were conducted using a small tubular shaped container in which water was passed up through the limestone aggregate through an opening at the base of the vessel. In the final design a pipe was installed within a cylindrical shaped container so that the water flowed down under pressure to the base of the container and then out through an outflow pipe at the top. At low flow rates the limestone remained stationary and water travelled upwards through the pore spaces without moving the limestone. However at higher flow rates, when the particle and water force suspending the particle was equivalent to the settling rate of the particle, the limestone within the container became suspended. Tests were conducted for extended periods and no compaction or channelling was observed. Following these observations it was decided to conduct a research project aimed at optimising the design of the container so as to maximise the efficiency of limestone dissolution and pH remediation. The treatment system was described as a fluidised limestone reactor (FLR).

The FLR is superior to many other treatment systems due to the simple design and therefore low capital costs. Water is mixed through the turbulent flow of water up the cone and therefore there are no mechanical parts. Limestone is a common and safe to handle neutralisation material that is inexpensive compared to other reagents. A small amount of land area is required and the system can be integrated with other passive treatment systems for compete metal and trace metal removal.

FLR technology is an adaptation from diversion wells developed in Scandinavia and West Virginia (Arnold, 1991; Fraser *et al.*, 1985). In diversion well systems the natural hydraulic gradient of the land is utilised to produce sufficient flow within the well to agitate and suspend the limestone. The advantage of these systems is that wet slurry applications of limestone are applied to the water and this has been shown to be 50% more effective than dry application of limestone to a water body (Warfvinge *et al.*, 1984). Diversion wells typically use ungraded, crushed limestone with a wide range of particle sizes. The turbulent water flow causes to particles to pound against one another, producing abrasion and reducing the accumulation of metal oxyhydroxides on the limestone surface (amourisation).

A literature search conducted at the commencement of the project revealed two research groups working on fluidised limestone reactors. Re-circulating fluidised limestone reactors were reported from South Africa (Maree *et al.*, 2004; Maree *et al.*, 1996a; Maree *et al.*, 1996b) and a $CO_2$ pulsed operated fluidised reactor had been developed in the USA (Sibrell *et al.*, 2003; Watten *et al.*, 2004). These systems use cylindrical containers and differ in their flow dynamics, the South African systems using re-circulating flows and the $CO_2$ pulsed operated fluidised reactor using a sequence of alternating pulsing to treat acidic drainage with limestone and carbon dioxide.

Describing and predicting the physical behaviour of a homogenously fluidised bed such as the FLR requires determination of the increase in volume of the bed (bed expansion) when water is passed upwards though the bed at a known velocity (fluid velocity, ‘U’). The fluid velocity is the upward fluid velocity if there were no aggregate present. This definition is equivalent to the Volumetric Flux (volume flow through a unit area), and is not to be confused with the actual water velocity in the bed, which takes into account the fact that solid particles take up space and the water must flow around them. This problem has been the subject of previous empirical and computational studies, and an equation called the Richardson-Zaki equation has been proposed and widely verified for determining the bed expansion from the fluid velocity (Richardson and Zaki, 1954) under these conditions.

The Richardson-Zaki equation predicts the expansion a fluidised bed based purely on the physical properties of the aggregate and the fluid (in this case water), and the fluid velocity (or equivalently, the volumetric flux).

While determining the physical behaviour of the FLR is best achieved using an experimental, scale-model approach, four important principles that can be concluded from the Richardson-Zaki equation still apply. Firstly, there will be a fluid velocity (called the minimum fluidisation velocity), below which the bed will not fluidise, and will remain static. Secondly, at fluid velocities larger than the minimum fluidisation velocity, the bed will expand with an increase in fluid velocity. Thirdly, larger particles will have a higher minimum fluidisation velocity than smaller particles. Finally, a bed of smaller particles will expand more than a bed of larger particles at the same fluid velocity. These principles formed the basis of the trials aimed at optimising the container design. Initial trials were conducted using cylindrical shaped containers. Later trials concentrated on conical shaped vessels.

## Methodology

### *Aims and objectives*

The objective of this project was to develop a cost effective treatment for acidic drainage waters using fluidised limestone reactors. The fluidised reactor design was to be evaluated with several small scale and medium scale installations and results compared to those obtained using a diversion well system. Both the fluidisation dynamics and chemistry within these systems were to be investigated. A cost analysis on the selected design was to be performed. Commercial scale installations were to be carried out following the research with small scale and medium scale FLRs if a manufacturer and clients could be identified.

### *Operational plan*

The project was conducted in three phases. The first phase involved research into the factors influencing the behaviour and performance of tubular and cylindrical shaped fluidised bed reactors. This research was conducted at Eaglerise Holdings and at Wesfarmers Premier Coal. A diversion well system was also installed at the Griffin Mining Company's Chicken Creek mine and evaluated. Laboratory scale experiments were conducted to develop an understanding of how fluid velocity, aggregate size, static height of the bed and tank dimensions affect the physical behaviour of a fluidised bed using locally available limestone aggregates and lime sand. Other factors that may influence the pH amelioration capacity such as water temperature, the concentration of dissolved salts in the influent and limestone quality, were not investigated and were assumed to not influence the outcome of experimental manipulations.

In the second phase of the project conical shaped containers were used and research was aimed at optimising the design of the cone so as to maximise efficiency of the neutralisation process. In the final phase FLR treatment systems were installed at two mine sites in Collie and their performance was evaluated.

## Griffin Coal diversion well trials - Results and Discussion

Two limestone treatment systems were installed to elevate the pH of water from the Chicken Creek mine void from pH 3 to pH 5.5 at a flow rate of 19L/s. Water was pumped from the mine void and into the first treatment system (Limestone Treatment System 1). After passage through this treatment system, it was pumped to a storage pond (Storage Pond 1), followed by passage through a second limestone treatment system (Limestone Treatment System 2). From the second treatment system, the water was pumped to a second storage pond (Storage Pond 2) and ultimately into a constructed wetland.

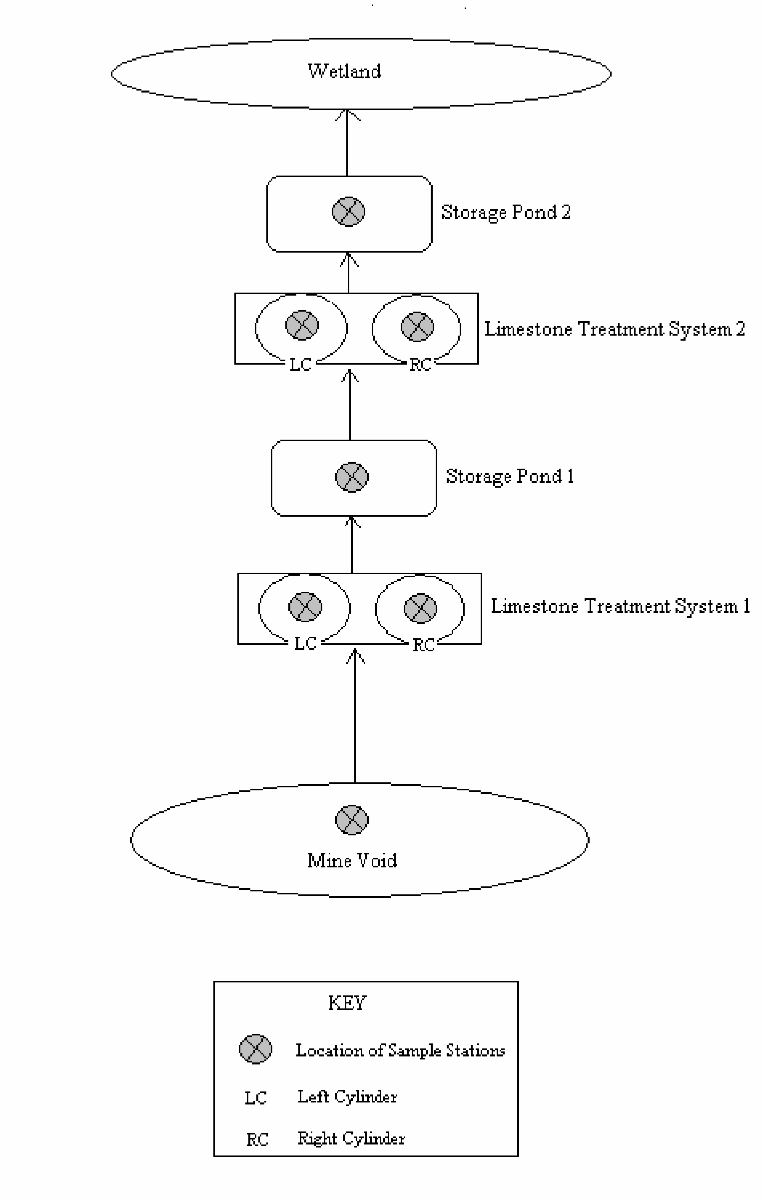


**Figure 1.** Griffin Coal diversion well treatment system

During the operation of this system water from Storage Pond 1 was often recirculated through Limestone Treatment System 1 until pH levels reached approximately 5.5. Considerable problems were encountered in achieving a consistent elevation of pH. An evaluation was conducted after the system had been operating for approximately 9 months at which time the pH elevation was minimal.

**Figure 2.** Chicken Creek diversion well treatment system

In situ water quality parameters, pH, salinity, conductivity and temperature, were measured twice daily (morning and afternoon) using a TPS model Aqua-CP Conductivity-TDS-pH-Temp meter. Measurements were made in the mine void, the two storage ponds and in the outflow stream of each cylinder of both Limestone Treatment Systems. Observations were also performed on the appearance of the fluidised limestone within each of the systems.

In both cylinders in Treatment System 1, fluidisation and finer grade limestone was observed in the surface of the bed closest to the outlet (Figure 3). Within the area containing the finer grade limestone, fluidisation was observed predominantly in patches within a radius of 10cm from the inlet pipes (spears) and along the walls of the container. In the area furthest from the outlet, limestone appeared coarser and no fluidisation was evident. The section of the bed containing the coarser grade limestone covered an area of approximately 40%.

Stationary limestone, preferential flow paths and channelling were also evident in the Treatment System 2 cylinders with water being observed to move around the stationary clumps of limestone.

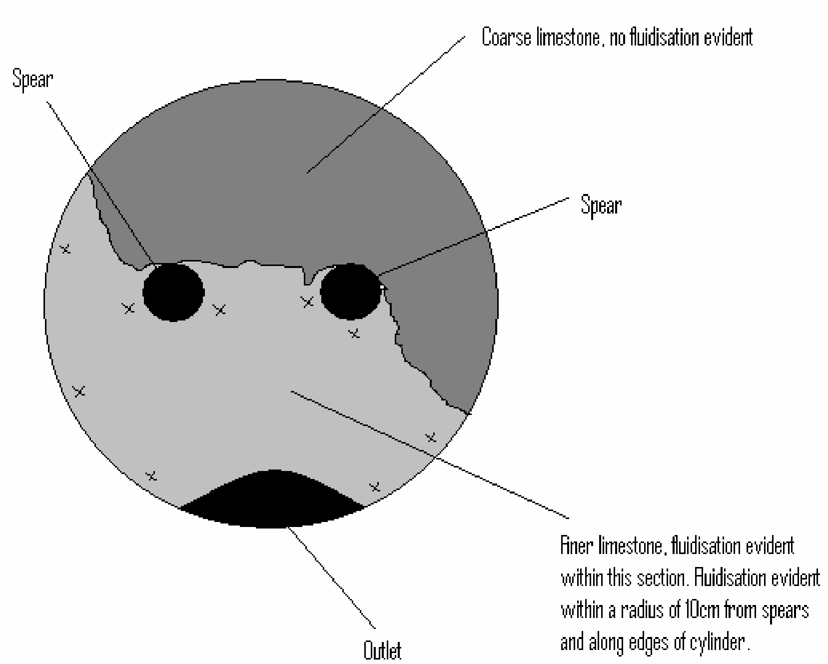


**Figure 3.** Top view of the cylinder, Limestone Treatment System 1. The schematic depicts both the left and right cylinder. The crosses are representative of the areas of fluidisation.

When the flow rate through the cylinders was increased, iron was flushed out of the system, evidenced by the orange colour of the effluent. Significant losses of limestone have been observed when the flow rate was increased.

During the sampling period, pH in the outflow of the left and right cylinders of both Limestone Treatment Station 1 and Limestone Treatment Station 2 exceeded that of the Chicken Creek mine void at all times (Figure 4). pH in the void remained relatively constant, ranging between approximately pH 2.53 and 3.05. pH measurements recorded in Limestone Treatment Station 1, ranged between 3.17 and 3.62 in the right cylinder and 2.99 and 3.68 in the left cylinder. In Storage Pond 1, pH ranged between 3.25 and 3.55. pH measurements recorded in Limestone Treatment Station 2, ranged between 3.28 and 3.81 in the right cylinder and 3.85 and 4.19 in the left cylinder.

Salinity in the void ranged from 1.36ppt and 1.59ppt and conductivity from 2.1mS and 2.6mS. Passage through the treatment system had no effect on either salinity or conductivity.

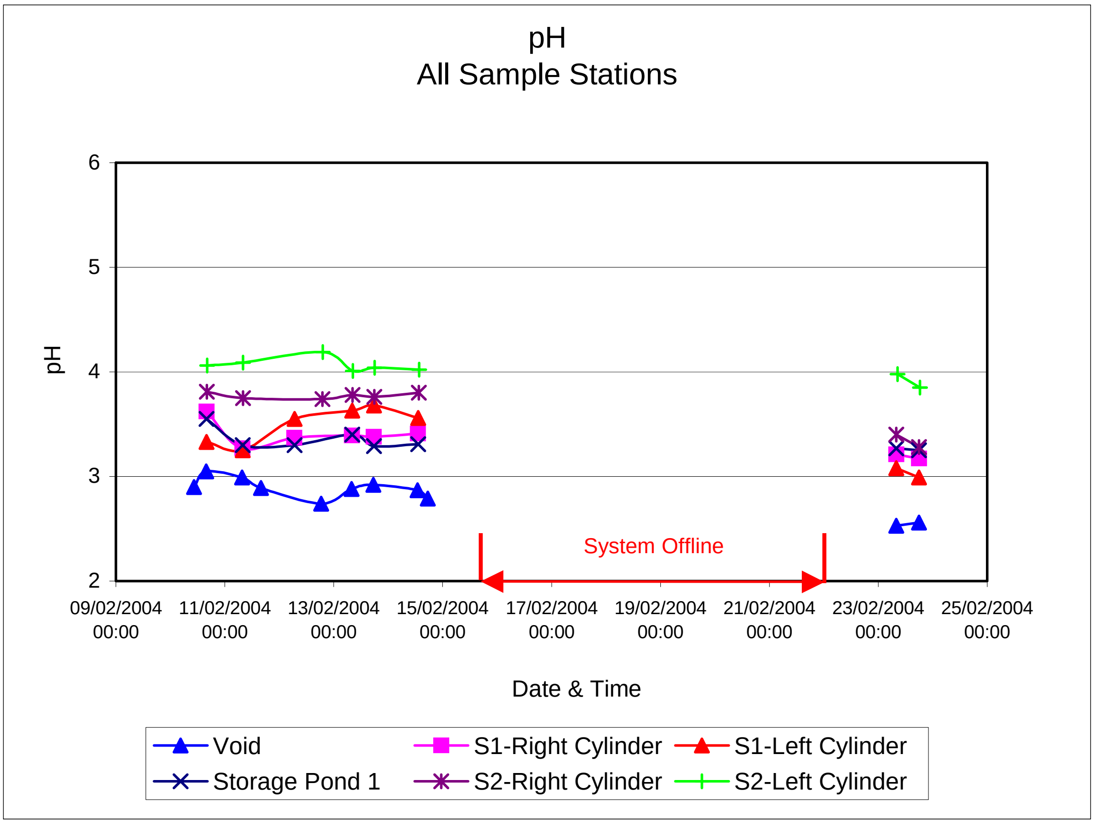


**Figure 4.** pH recorded at all sample stations for the period 11 February 2004 - 23 February 2004. The system was off-line for maintenance of corrosion leaks during the period 14 February 2004 – 22 February 2004. S1=Limestone Treatment Station 1; S2=Limestone Treatment Station 2.

Based on the field data presented in this study, it was concluded that the overall capacity of the diversion well system present at Chicken Creek was low. At the time of measurements, despite water being passed through two Limestone Treatment Stations at a flow rate of 19L/s, the greatest difference recorded in pH between the mine void (pH=2.53) and the outflow from Limestone Treatment Station 2 (pH=4.19) was of the order of 1.66. The reduced capacity of the treatment systems may be associated with the extent of dead zones and channelling within the aggregate bed, which would ultimately have resulted in reduced contact between the influent and the limestone.

Furthermore, results showed that the cylinders at each treatment station functioned independently of each other. A consistent difference in the effluent pH was observed between cylinders for each Limestone Treatment System, despite influent of common pH entering each cylinder. This may have been due to variation in the amount of limestone present in each cylinder or it may have been associated with the extent of channelling prevalent in each cylinder at any point in time.

Corrosion of inlet pipes and cylinders was also a problem. It was decided not to proceed with further development of the diversion well technology.

## Trials with tubular and cylindrical shaped containers - Results and Discussion

The initial trials at Eaglerise Holdings and the Collie Aquafarm were conducted with tubular and cylindrical shaped containers. The aim of the trials were to gain an understanding of how fluidisation of the limestone aggregate is affected by fluid velocity, aggregate size, the height of the aggregate bed under conditions of no flow(static height) and tank dimensions, with particular emphasis on the base area. The objective was to determine the combination of fluidisation velocity and aggregate size to provide an effluent pH above 6.5, the target effluent pH required in the field trials at the Collie Aquafarm. The results obtained in the laboratory trials were to be used as the basis for the design specifications of the cylindrical fluidised limestone reactor proposed for future use in the aquaculture trials at the Collie Aquafarm.

The extent of fluidisation within the filter bed was measured by the fluidised height, relative to the static height of the aggregate bed. Fluidised height is defined as the height of the aggregate bed when water is being passed through the system, whereas static height is defined as the height of the aggregate bed under conditions of no flow. For the purpose of the experiment, fluidisation was measured as the percentage change in the static volume of the bed, relative to the fluidised volume, and termed the percentage fluidisation or bed expansion. Bed expansion is given by the following:

$$B = \frac{V_{fl} - V_s}{V_s} \qquad \textbf{(1)}$$

Where;

$V_{fl} = \pi r^2 (F.H)$ =Fluidised Volume (m$^3$)

$V_s = \pi r^2 (S.H)$ = Static Volume (m$^3$)

$r$ = Radius of Cylinder (m)

$B$ = Bed Expansion (m)

The bed expansion at which all particles in the system were fluidised was termed Minimum Bed Expansion, $B_{min}$.

For a particular static height, flow rates through various tanks were altered and the fluidised height recorded. Experiments were conducted in a hexagonal shaped, medium sized Perspex tank (Medium Perspex Tank) and in a Perspex tube. Quartz sand and 500micron lime sand were used as aggregates in the Medium Perspex Tank and oversize lime sand was used as the aggregate in the Perspex Tube.

In order to investigate the effect of aggregate size on fluidisation, the fluid velocities required to achieve 50% fluidisation for a given static height were determined for the four different aggregates - 500micron lime sand, O/S lime sand, 2-4mm gravel; and 8-10mm gravel.

The static heights in all experiments were kept constant (i.e. 500mm). All experiments were performed using the Medium Perspex Tank.

Results obtained are shown in Figure 5.

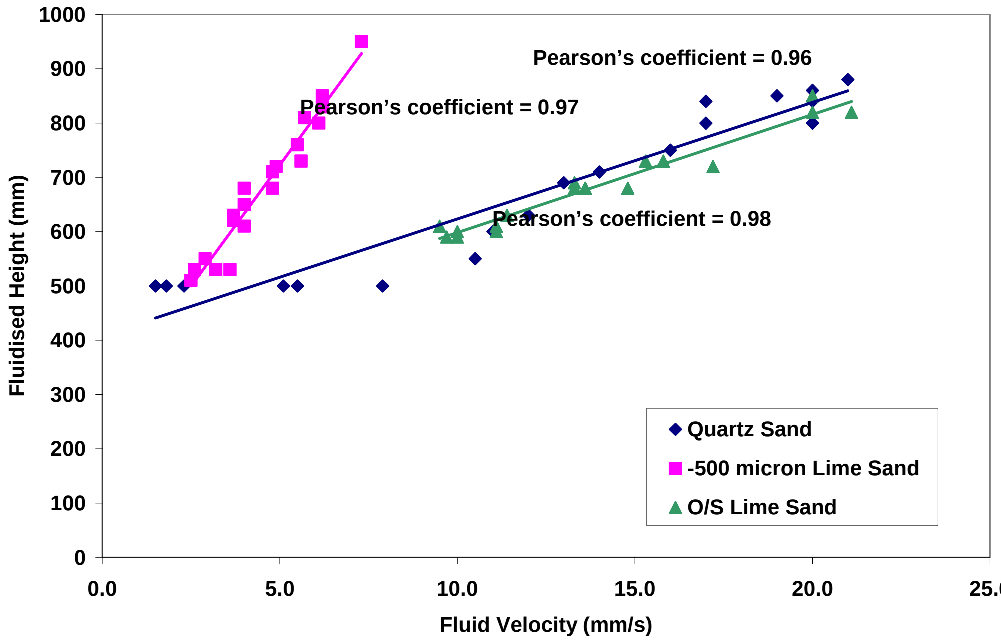


**Figure 5.** Change in fluidised height with an increase in fluid velocity for all aggregates tested.

Once fluidisation occurred in each experimental trial, the increase in fluidised height was proportional to the increase in fluid velocity, until approximately 200% fluidisation. Beyond this point, the boundary between the fluidised aggregate and clear effluent water became diffuse and difficult to distinguish. Under these conditions the fluid velocity approaches terminal velocity (i.e. drag force upwards on a particle due to water flow is equivalent to the downward force due to gravity) for the smaller particles in the aggregate, which continued to rise and were ultimately flushed out of the system.

Ten repetitive measurements of terminal velocities for the various sized aggregates were measured. The results are given in Table 1. Terminal velocity increased with an increase in aggregate size. Maximum terminal velocities of the various aggregates ranged between 70 and 397mm/s and minimum terminal velocities ranged between 12 and 190mm/s.

**Table 4** Terminal velocity measurements recorded for various aggregates.

| Aggregate Type | Maximum Terminal Velocity (mm/s) | Average Terminal Velocity (mm/s) | Minimum Terminal Velocity (mm/s) |
|---|---|---|---|
| 500 micron sand | 70 | 21 | 12 |
| O/S sand | 143 | 60 | 31 |
| 2-4 mm gravel | 228 | 141 | 101 |
| 8-10mm gravel | 397 | 286 | 190 |

In the case of the 500micron sand, the smaller particles (i.e. those with the lowest terminal velocity) were washed out at about 200% fluidisation, achieved at a fluid velocity of approximately 10mm/s.

As the aggregate size increased, a corresponding increase in the fluid velocity was required to achieve 50% fluidisation (Figure 6). Between all aggregates tested, the fluid velocity required to achieve 50% fluidisation ranged between approximately 9 to 140mm/s. The largest grade aggregate (8-10mm gravel) required the greatest fluid velocity for fluidisation to occur (139mm/s).

In the Medium Perspex Tank, a fluid velocity of approximately 19mm/s, was sufficient to fluidise 1-2mm of quartz sand to a fluidised height of 850mm. No fluidisation was observed in the Medium Perspex Tank using 8-10mm limestone gravel operating at a fluid velocity of 19mm/s.

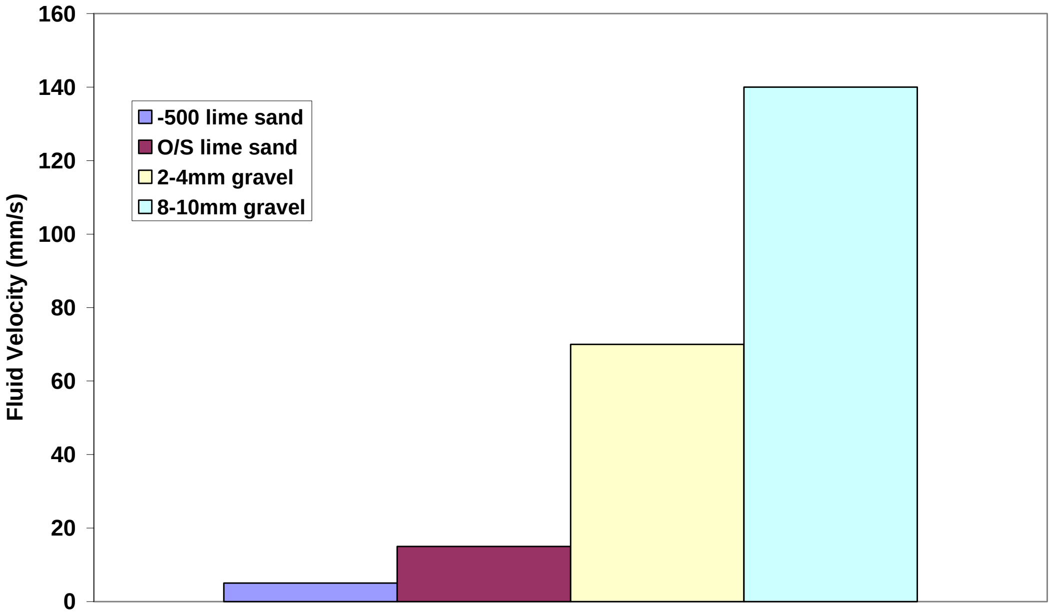


**Figure 6.** Effect of aggregate size on fluid velocity required to achieve 50% fluidisation.

When water flow into the system stopped and the column ceased fluidising, the larger aggregate particles were observed to settle to the bottom of the tank, whilst the smallest particles collected at the top of the bed.

A two stage treatment system was constructed and installed at the Collie Aquafarm. The first stage consisted of a 2m long cylindrical column constructed of PVC piping with an internal diameter of 150mm. The inlet was positioned at the base of the pipe and the outlet positioned at the top of the pipe. The system was designed to operate at a flow rate of 100L/min, resulting in a fluid velocity of approximately 90mm/s. The column was filled with 8-10mm limestone aggregate to a depth of 1000mm.

The second stage of the prototype consisted of an octagonal tank made from 10mm thick Perspex. The tank was 1200mm high, with a face-to-face internal diameter of 600mm, cross-sectional area of $0.28m^2$ and a volume of $0.34m^3$. The system was designed to operate at a flow rate of 100L/min, resulting in a fluid velocity of approximately 5mm/s. The column was filled with 500micron lime sand.

Water was conveyed from the outlet of the first stage to the inlet of the second stage via a poly pipe with an internal diameter of 50mm (Figure 7).

**Figure 7.** Two stage limestone treatment system installed at Collie Aquafarm

The inlet of stage 2 was initially installed with a nozzle structure containing four small pipes arranged at right angles to one another. This design was later altered to a single inlet pipe, due to the occurrence of frequent blockages of one or more of the original four inlets.

During the monitoring period March 2002-October 2002, influent pH ranged between 2.98 and 4.07 and effluent pH ranged between 4.16 and 7.48 (Figure 8). The decrease in effluent pH in mid-May, followed by the increase in effluent pH in early June, were due to trialling of different limestone sands. At all times during the monitoring period, the outlet pH exceeded that recorded at the inlet.

The system was found to operate effectively, producing effluent water at a pH of 6.5 or higher at a flow rate of 90 L/min (Figure 9). However, it required significant maintenance. The octagonal tank required daily stirring and the addition of 30L of aggregate. In addition to this, the lime sand in the octagonal tank was observed to form large clumps, impermeable to water and in an attempt to rectify the problem, the entire limestone bed required fortnightly replacement.

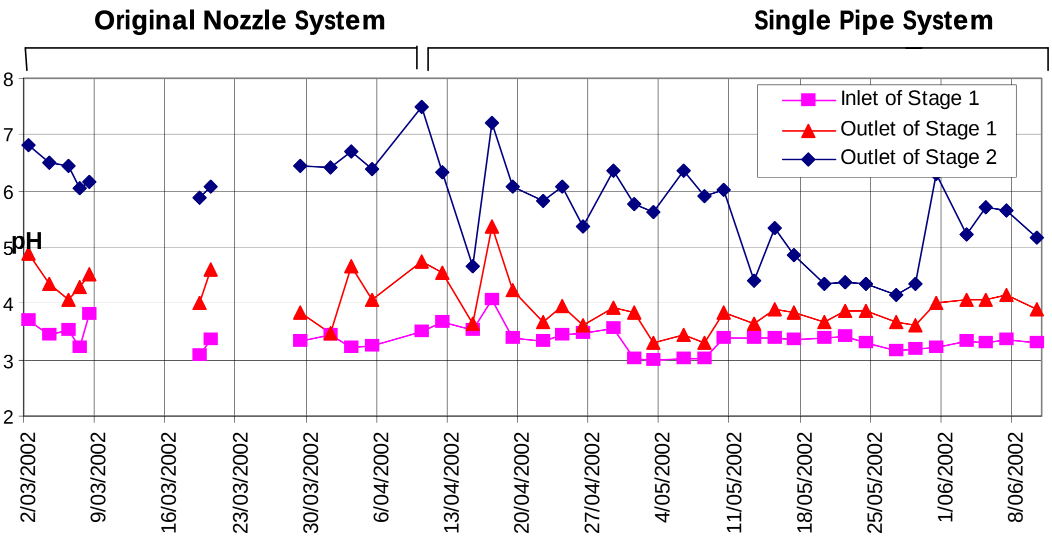


**Figure 8.** pH levels recorded at the inlet of Stage 1, outlet of Stage 1 and the outlet of Stage 2 of the cylindrical prototype Fluidised Limestone Reactor at the Collie Aquafarm.

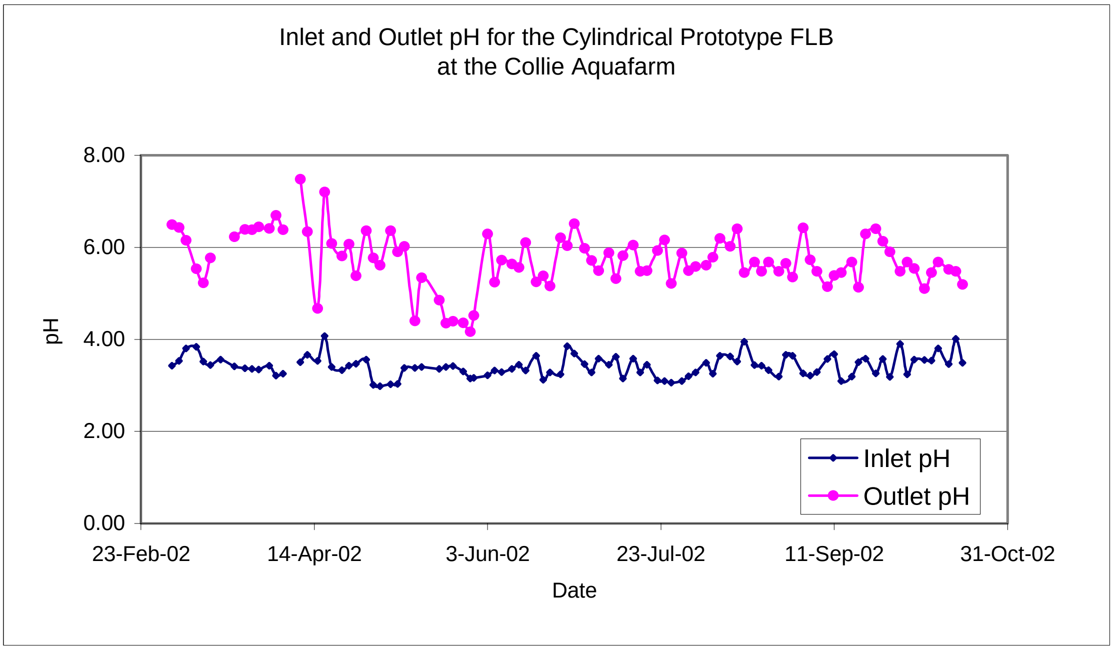


**Figure 9.** pH monitoring results for the inlet of stage 1 and the outlet of stage 2 for the cylindrical Fluidised Limestone Reactor prototype for Stage two, located at the Collie Aquafarm.

At low fluid velocities, fluidisation was observed to only occur within a certain radius around the inlet pipe. For all experiments, non-fluidised aggregate was observed in the bottom area of the tanks (Figures 10 & 11). When the static height was increased, the area of non-fluidised aggregate remained constant. Since the internal dimensions of the fluidised component were conical in shape it was decided to construct and test a conical shaped container.

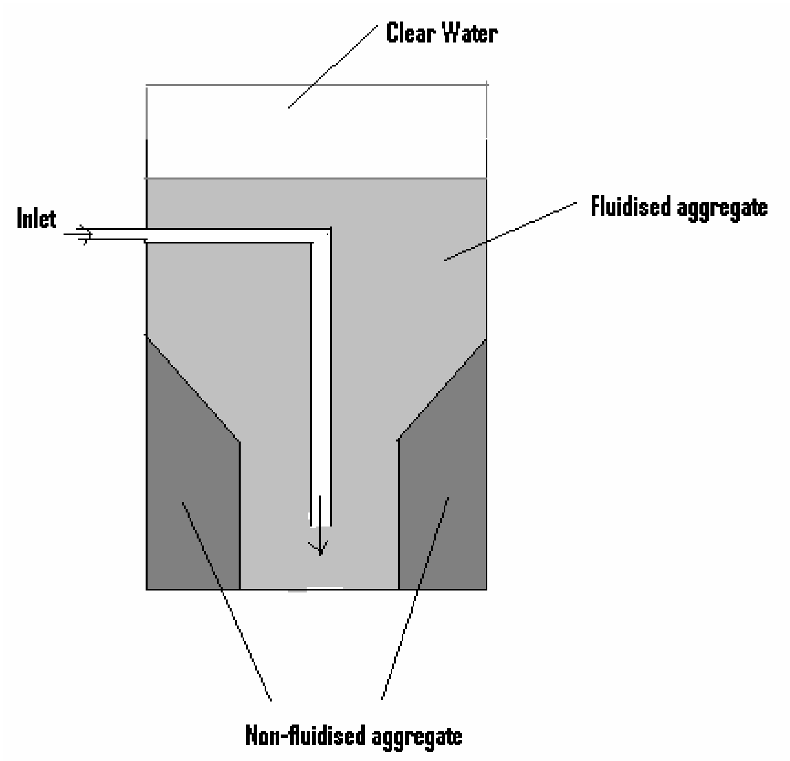


**Figure 10.** Schematic of the Perspex Tube, side view, showing the areas of fluidisation and non-fluidisation. Dark grey depicts areas of non-fluidised aggregate (i.e. areas of solidification) and the light grey depicts areas of fluidised aggregate.

**Figure 11**. Stage two, cylindrical Fluidised Limestone Reactor prototype, Collie Aquafarm. The presence of dead-zones is evident by the white areas along the bottom of the tank.

## Early trials with conical shaped containers - Results and Discussion

### *Advantages of conical reactor shape*

Conical FLRs have both chemical and physical advantages over cylindrical FLRs. Cylindrical FLRs provide a constant upward fluid velocity throughout the column, leading to a small range of "ideal" particle sizes that can be effectively fluidised. Conical FLRs, on the other hand, have an increasing cross-sectional area rising up the column. This gives a fluid velocity profile that is greater in magnitude at the bottom of the cone and smaller in magnitude at the top, enabling conical FLRs to fluidise a wider range of particle sizes. Large aggregates fluidise low in the cone in the fast-moving water, and fine particles fluidise in the slow-moving top section of the cone. The high flow rate at the base of the cone also minimises the likelihood of solids build-up and dead zones in the vicinity of the water inlet.

The aggregate segregation that occurs in a conical-shaped FLR also provides chemical advantages. When limestone is exposed to high levels of iron in oxygenated water, a coating of iron oxide forms on the surface of the limestone. This effect is known as armouring and occurs in waters of pH 6 or greater (Walzlaf et al. 2000). Limestone dissolution has shown to decrease significantly, due to the presence of the iron oxide layer (www.wvu.edu/~agexten/landrec/passtrt/passtrt.htm). Therefore, when limestone particles become amourised, their tendency to dissolve lessens and remediation efficiency is consequently reduced.

### *Aim*

The aim of this series of trials was to design, construct, install and evaluate a conical shaped prototype FLR and, based on the results of these trials, to install an FLR at the Collie Aquafarm to treat water for use in rearing marron and silver perch in the farm ponds. The specific objectives were to:

7. Gain an understanding of how fluidisation of the limestone aggregate is affected by flow rate and fluid velocity in conical-shaped FLRs.
8. Evaluate the pH amelioration capacity of conical-shaped FLRs.
9. Develop a model enabling the prediction of the effluent pH achievable for given conditions of influent pH, flow rate, aggregate type and aggregate volume.
10. Use the results obtained and models developed from the laboratory trials as the basis for the design specifications of the conical FLR for use in aquaculture trials at the Collie Aquafarm.

### *Physical behaviour trials*

Physical behaviour trials were carried out in three different fabricated cones to investigate the effect of flow rate on fluidisation within the bed through the measurement of fluidised height under a range of flow rates. Bed expansion in the conical shaped containers is given by the following:

$$B = \frac{V_{fl} - V_s}{V_s} \qquad \textbf{(2)}$$

Where;

$B$ = Bed Expansion

$$V_{fl} = \frac{\pi h_{fl}\left[\left(\frac{d_{fl}}{2}\right)^2 + \left(\frac{d_{fl}}{2}\right)\left(\frac{d_b}{2}\right) + \left(\frac{d_b}{2}\right)^2\right]}{3} \text{=Fluidised Volume (m}^3\text{)} \quad \textbf{(3)}$$

$$V_{st} = \frac{\pi h_{st}\left[\left(\frac{d_{st}}{2}\right)^2 + \left(\frac{d_{st}}{2}\right)\left(\frac{d_b}{2}\right) + \left(\frac{d_b}{2}\right)^2\right]}{3} \text{ = Static Volume (m}^3\text{)} \quad \textbf{(4)}$$

$d_{fl}$ = Fluidised Diameter, diameter measured at the top of the fluidised aggregate bed (m)

$d_{st}$ = Static Diameter, diameter measured at the top of the static aggregate bed, under conditions of no water flow (m)

$d_b$ = Base Diameter, diameter measured at the base of the truncated cone (m)

$h_{fl}$ = Fluidised Height, height measured from the top of the fluidised aggregate bed to the base of the truncated cone.

$h_{st}$ = Static Height, height measured from the top of the aggregate bed, to the base of the truncated cone, under conditions of no water flow (m).

The measurement of the fluidised height and the flow rate in a container of known dimensions with a known static volume can be used to determine the upward velocity of the water, the fluidised volume and the bed expansion. These are all necessary parameters for fluidised bed design.

Fluidised height was measured for various flow rates in each of the three different conical shaped containers: 1) Small Cone (later changed to Cone 1) - fabricated from polyvinyl chloride (PVC) sheeting, bent into a conical shape; 800 mm high; top diameter of 300 mm; base diameter of 50 mm; 2) Medium Cone - fabricated from a series of four clear plastic buckets of increasing size, chosen so that when the buckets were stacked vertically with the smallest at the bottom, they formed a cone; 800 mm high; top diameter of 270 mm; base diameter of 100 mm; and 3) Large Cone - The large cone was fabricated from a 'Green Cone™', inverted, with the base blocked off to become watertight; 600 mm high; top diameter of 540 mm; base diameter of 300 mm. 500micron limesand was used as the aggregate in all experiments. For the Small Cone, experiments were conducted for static heights of 247mm, 410mm, 485mm and 550mm. In the Medium Cone, experiments were conducted for static heights of 430mm and 480mm and in the Large Cone experiments were conducted at a static height of 250mm.

Flow rates were converted to fluid velocity at the top of the fluidised aggregate bed. A scattergram of flow velocity and bed expansion was constructed and a correlation analysis performed in Excel (Figures 12 & 13).

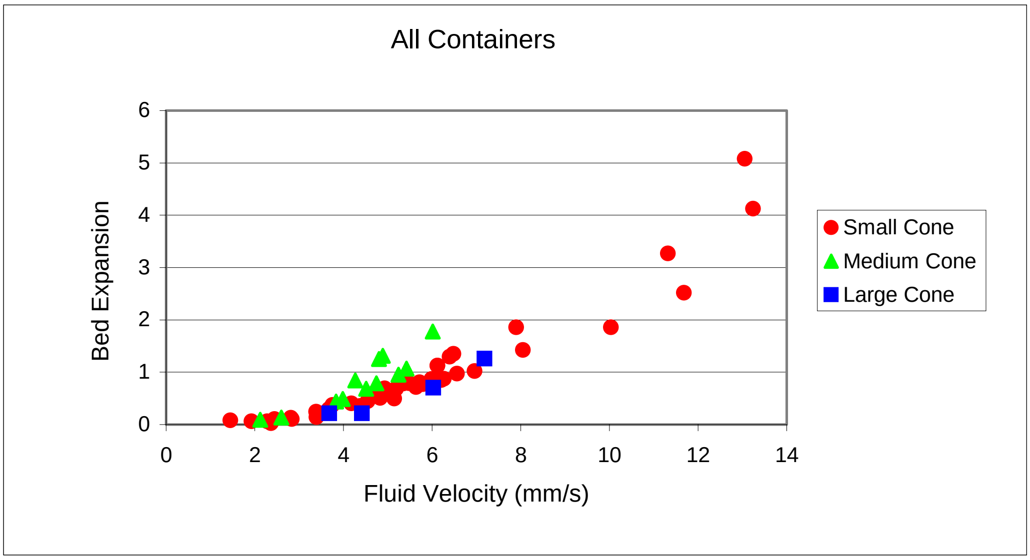


**Figure 12.** Bed Expansion vs. Fluid Velocity for a range of static heights in the Small Cone, Medium Cone and Large Cone, all using 500micron limesand as the aggregate

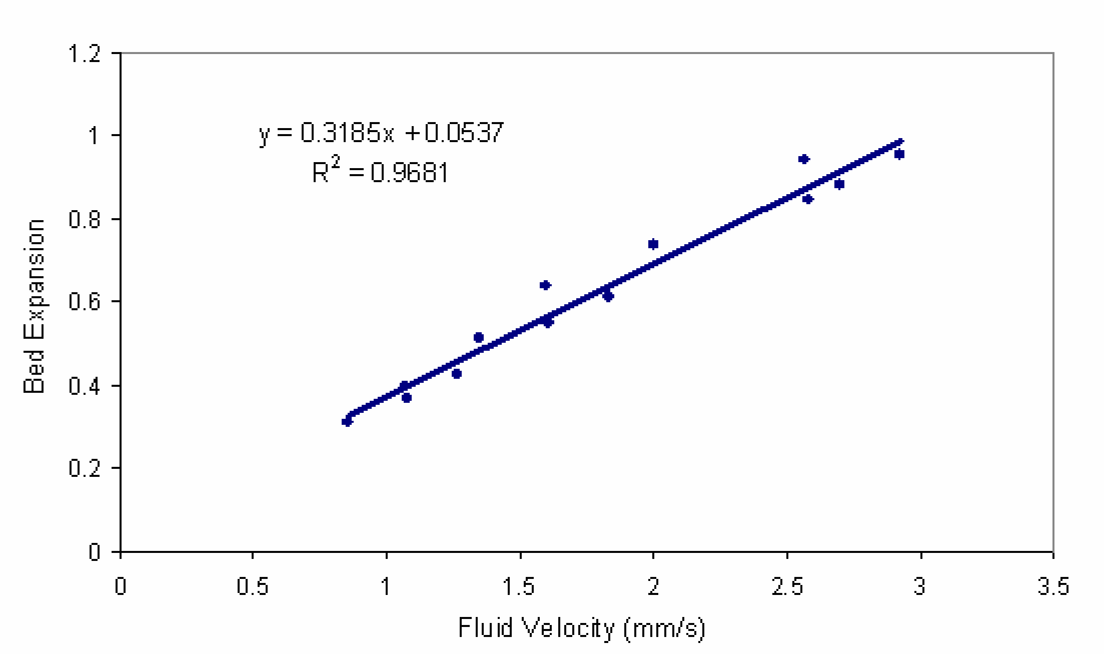


**Figure 13.** Bed Expansion vs Fluid Velocity for 500micron lime sand, tested in the Small Cone. $R^2$ value of 0.97 represents a strong linear relationship between bed expansion and fluid velocity measured at a particular static height.

The correlation analysis performed on all trials conducted in the Small Cone showed a strong linear relationship between bed expansion ($B$ <2) and fluid velocity, regardless of the static height at which the trials were conducted. A linear line of best fit yielded the following:

$$B = 0.3U + 0.05 \quad \textbf{(5)}$$

Where $U$ = Fluid Velocity measured at the top of the fluidised aggregate bed (mm/s)

This linear model was used as the basis of design equations for the design of the prototype Conical FLR at the Collie Aquafarm.

It should be noted that this model is aggregate specific and therefore only applicable to the 500micron limesand.

### *pH remediation trials*

The pH modification achievable in conical-shaped FLRs was determined by measuring the effluent pH for various static volumes of aggregate under varying flow regimes and influent pH. Fluidised height and the diameters at the top of the fluidised aggregate bed were also measured in these experiments. The trials were performed with Cone 1 and 500micron limesand. The influent water used was sourced from the mine void at the Collie Aquafarm. Influent and effluent pH was recorded for fluid velocities ranging between 1.5L/min and 10L/min for various static volumes.

The effluent pH exceeded that of the influent pH for all flow regimes (Figure 14). For flow rates ranging between 1.7L/min and 10L/min and influent pH of approximately 3.5, effluent pH ranged between 6 and 5.

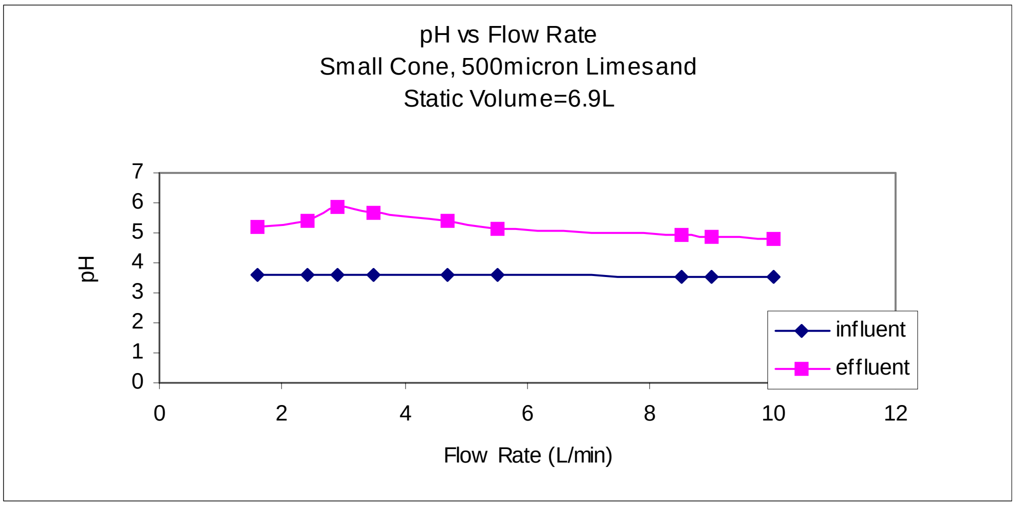


**Figure 14.** pH vs. Flow Rate for the influent and effluent, tested in the Small Cone, using 500micron limesand as the aggregate.

### *Development of a model for predicting effluent pH: derivation of the fluidisation limestone reactor index*

In previous field trials at the Collie Aquafarm using a cylindrical-shaped FLR, it was observed that the effluent pH remained unchanged when both the flow rate and the volume of aggregate in the system was increased (in the same proportion). When the flow rate was kept constant and the amount of aggregate doubled, the effluent pH was observed to increase. Conversely, when the amount of aggregate was kept constant and the flow rate increased, the effluent pH was observed to decrease. These observations were generalised by attributing an 'index' to a system of fixed aggregate type and fixed influent pH. This index was used to design a new FLR that was subsequently installed at the Collie Aquafarm. The design approach used was as follows:

The first step was to determine the design specifications which include the desired outcome of the design and the conditions under which the FLR will be operating. These specifications include the following:

- Minimum influent pH;
- Minimum effluent pH;
- Type of aggregate;
- Minimum Flow Rate ($m^3/s$);
- Maximum Flow Rate ($m^3/s$);

- Minimum Time between the addition of fresh aggregate (d); and
- Limestone usage per day, given the influent pH ($m^3/d$).

In order for the FLR to operate according to design specifications, there are a number of parameters, which need to be determined. The parameter are shown in Figure 15 and described in Table 2. Figure 16 outlines the process involved in determining the design parameters for a particular system and the connection between the various parameters.

**Table 2.** Description of design parameters required for FLR to operate according to design specifications.

| Design Parameter | Symbol |
|---|---|
| Minimum Bed Expansion | $B$ |
| Fluid Velocity required to achieve Minimum Bed Expansion | $U$ |
| FLR Index | $index$ |
| Minimum volume of aggregate required in the FLR at all times | $V_{a(\min)}$ |
| Total volume of aggregate required upon initial installation of the FLR | $V_{TOTAL}$ |
| Fluidised Volume | $V_{fl}$ |
| Base Diameter | $d_b$ |
| Fluidised Diameter (Minimum Flow Rate) | $d_{fl_{(\min)}}$ |
| Fluidised Height (Minimum Flow Rate) | $h_{fl_{(\min)}}$ |
| Fluidised Diameter (Maximum Flow Rate) | $d_{fl_{(\max)}}$ |
| Fluidised Height (Maximum Flow Rate) | $h_{fl_{(\max)}}$ |
| Clearance between the outlet structure and the fluidised height of the aggregate bed under conditions of maximum flow | $h_o$ |
| Clearance between the outlet structure and the top of the reactor | $h_{ot}$ |
| Total Height | $h_t$ |
| Top Diameter | $d_t$ |

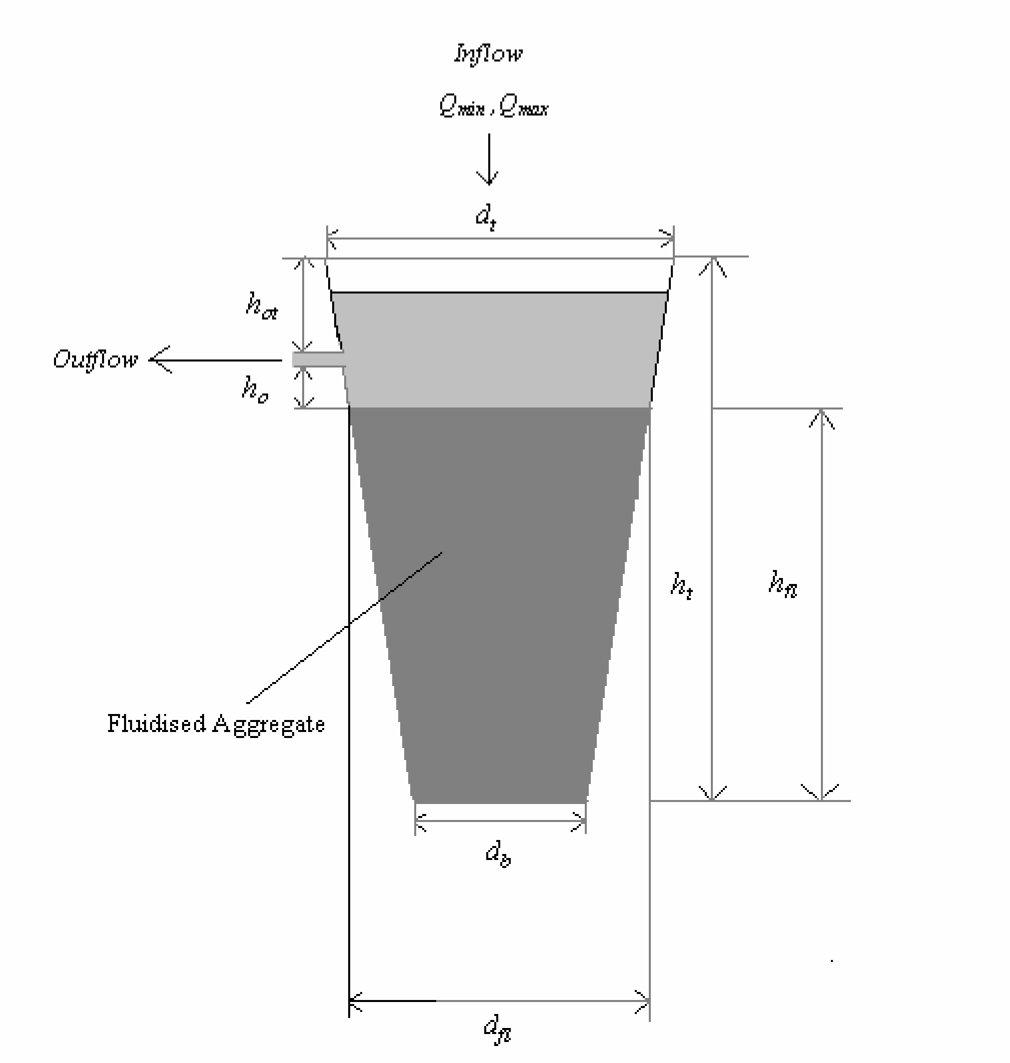


**Figure 15.** Schematic of the cross-section of a truncated cone, showing the design parameters required for the FLR to operate according to design specifications.

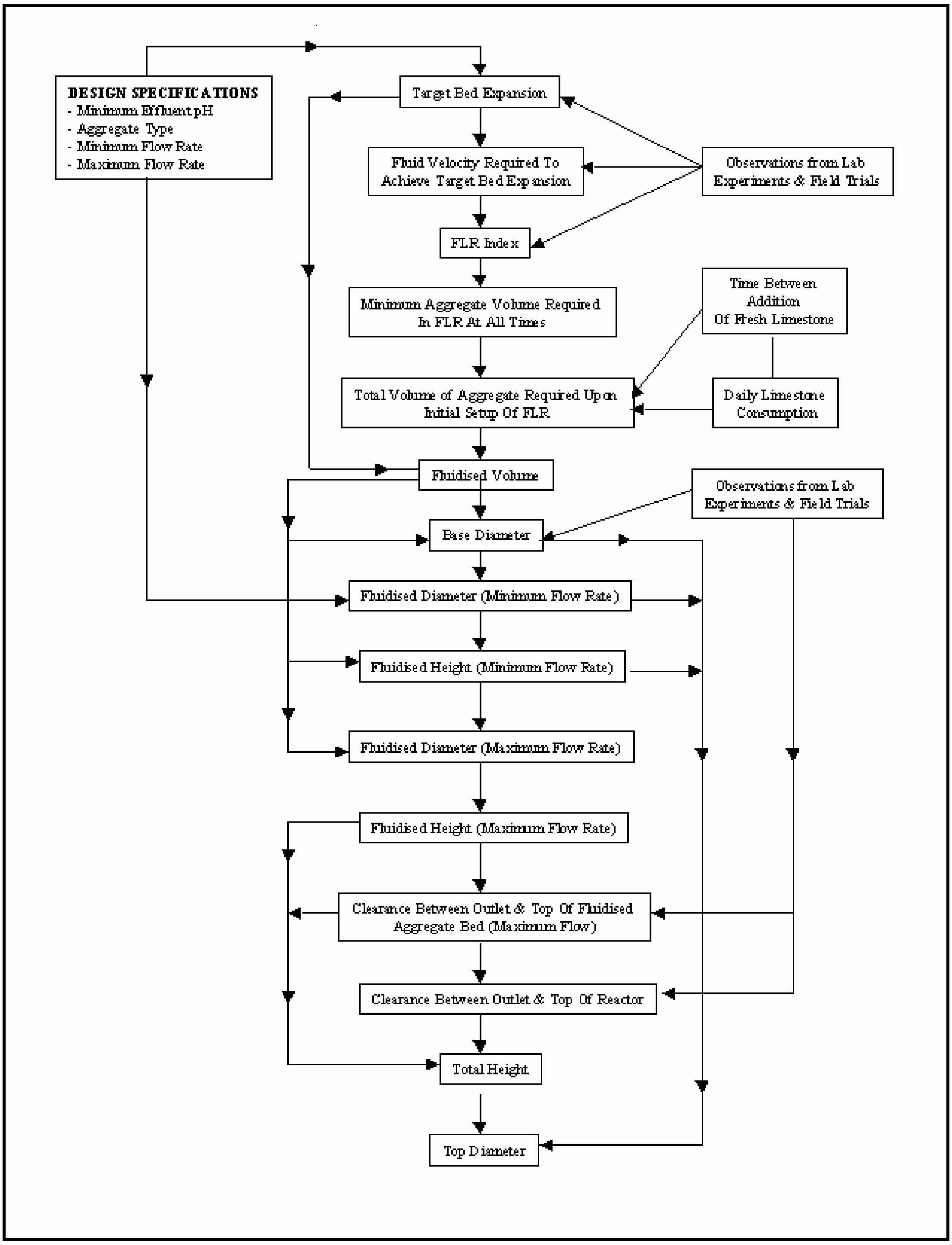


**Figure 16.** Flow chart illustrating the connection between design parameters and design specifications.

Following these design specifications a new FLR was constructed from fibreglass and installed at the Collie Aquafarm (Figure 17).

**Figure 17.** FLR system installed at Collie Aquafarm

During the first 16 weeks of operation, for influent pH ranging between 2.75 and 3.98, the prototype was successful at raising pH levels to between 5.11 and 7.32 (Figure 18).

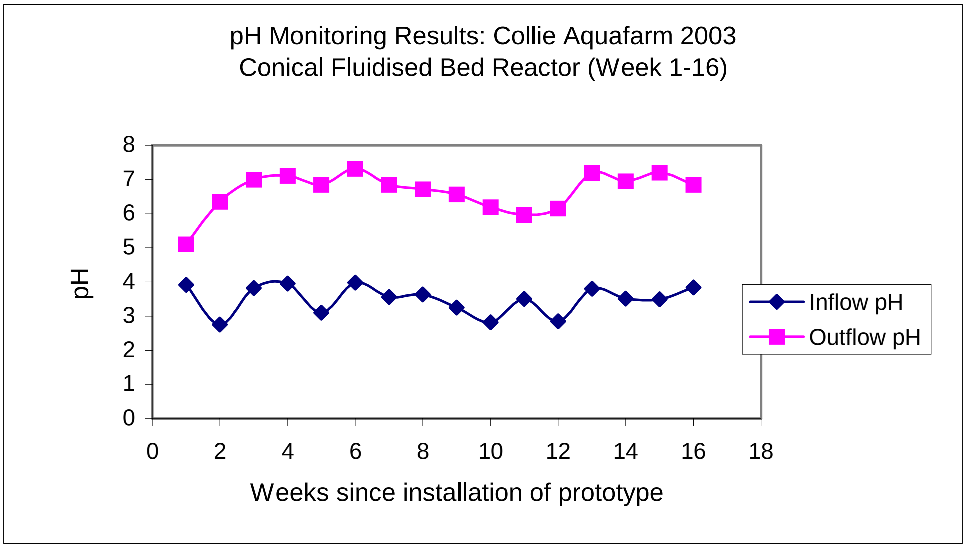


**Figure 18.** pH monitoring results for the first 16 weeks of operation of the conical prototype FLR at the Collie Aquafarm (2003).

Since the installation of the FLR at the Collie Aquafarm in January 2003, the FLR has proven to be reliable at elevating effluent pH levels. For influent pH ranging between 2.75 and 3.98, effluent pH ranged between 5.11 and 7.32. Inadequate pH remediation has occasionally occurred, largely as a result of insufficient limesand being placed in the reactor. Under standard operating conditions the contents of the reactor have to be emptied out approximately once a month.

## Investigations on cone design

Following the upscaling of the original Cone 1 to the Aquafarm Cone a series of studies were conducted aimed at evaluating the effect on fluidisation dynamics and treatment efficiency of alteration of the dimensions of the cone, in particular the angle of the cone wall to the perpendicular. These investigations resulted in the development of an acidic water treatment system, a fluidised limestone reactor (FLR) that was subsequently upscaled and a commercial sized system was designed and installed at the Griffin Coal mine site.

The approach used in these investigations and the results obtained are subject to confidentiality agreements and cannot be included in the final report. Similarly, a major study was performed on the cost efficiency of the FLR the report on which is subject to a confidentiality agreement.

The following four reports were produced from these trials:

11. Fluidised Limestone Reactors (FLR) Investigation into the Fluidisation Dynamics, October 2004 to June 2005 (CSML FLR Report No. 4) (31pp)
12. Evaluation of the Treatment System at the Collie Aquafarm (CSML FLR Report No. 5) (37pp)
13. Cost Analysis of the Fluidised Limestone Reactor (CSML FLR Report No. 6) (23pp)
14. Chicken Creek, Collie. Proposal for a Conical Fluidised Limestone Reactor (CSML FLR Report No. 7) (19pp)

These reports will be made available upon request subject to the signing of a confidentiality agreement. Enquires should be made to Professor Louis Evans, Executive Director, Centre for Sustainable Mine Lakes.

## Conclusions

This project has resulted in the development of innovative technology for treating acidic mine lake water using a cost effective treatment material – crushed limestone aggregate or lime sand. The technology raises the pH of acidic water from approximately 3 to 6 at a cost of $33/ML for water of approximately 136 mg/L $CaCO_3$ acidity. A mobile test system was developed and trialled at a mine site and a commercial size treatment system was installed at a sponsors mine site and used to document the operational procedures and commercial costs of the treatment system operating at 5L/sec.

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# PROJECT 3.1: POLYCULTURE AS A BENEFICIAL END-USE FOR MINE LAKES


- Whisson G., Storer T.
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## Final Year Annual Research Report

A major development within Project 3.1 during the 1st April 2006 to 31st March 2007 reporting period was the construction of an on-site aquaculture hatchery that would have the capability to produce fish and crayfish for stocking ponds and holding harvested stock prior to sale. The original vision was for the Collie Aquafarm to be a demonstration site for commercial operations using remediated mine lake water - the addition of the shed was imperative for the site to be sustainable. Site selection and plans were completed in 2005. Shed construction and set-up was originally costed within the CSML budget at $150,000. However, delays in funding lead to long delays during a construction boom resulting in significant increases in steel prices and general construction costs. To keep the project within budget the size of the hatchery was reduced and cost saving design changes implemented (e.g. area of concrete floor was reduced).

The Hatchery was completed in July 2007, and in summer 2007 the Collie Aquafarm hatchery was used to produce silver perch fry, effectively closing the life cycle of silver perch in acid-remediated mine lake water for the first time. To develop a viable mine lake aquaculture enterprise using treated mine lake water, on site production of fry would be highly desirable and cost-effective, as remediation systems end up flowing through culture ponds once they are full. The production of fry cannot be understated - breeding fish in tanks using artificial hypophysation techniques, collecting and hatching eggs, developing appropriate live feed cultures, and rearing larvae to fry is perhaps the most difficult and risky task carried out in aquaculture. Successfully producing seed stock using treated water confirms the capability of the treatment system to ameliorate acid water to supply water quality adequate for all stages of aquaculture production, demonstrating that mine lake aquaculture has high technical potential.

While on-site experiments were statistically valid, the low replication of treatments due to the low number of ponds (i.e. six) was a limiting factor. Recent applications to ARC and FRDC included proposals to construct a further six ponds that would have facilitated on-going research with higher certainty. A major focus of these funding applications was to take the knowledge generated within CSML, and a decade of polyculture research, and build a production model for aquaculture using mine lake water. Following this, a bioeconomic model was planned to take into account the full costs of labour and remediation. This would have been a desirable end product, encouraging commercial uptake of the aquaculture as a beneficial end use.

Integrated aquaculture candidates Silver Perch and Marron cultivated at the Collie Aquafarm using remediated mine lake water.

The Collie Aquafarm, shown in the foreground, is adjacent to Wesfarmers Premier Coal's WO5H mine lake where integrated aquaculture research on marron and silver perch is taking place.

## Executive Summary

Prior to the formation of the Centre for Sustainable Mine Lakes (CSML), research conducted in ameliorated mine lake water at the Collie Aquafarm demonstrated successful polyculture of marron (*Cherax tenuimanus*) and caged silver perch (*Bidyanus bidyanus*) (2000 – 2003). No growth-density effects were apparent and some mortality in marron was attributed to bird predation. Recommendations arising from this research included the need to further define growth-density relationships for marron-silver perch polyculture in ameliorated mine lake water; examine the influence of habitat complexity on production of perch and marron in polyculture; and extend investigations into interspecific interaction and predator avoidance strategies for species with potential for mine lake aquaculture.

These recommendations formed the basis for the Project 3.1 research program within the CSML. Several laboratory and field-based trials were conducted between 2003 and 2007 with the aim of:

- further defining growth-density relationships for marron-silver perch polyculture in ameliorated mine lake water;
- investigating the role of turbidity in crayfish polyculture by examining predator avoidance strategies and visual isolation;
- examining the influence of habitat complexity on production of perch and marron in polyculture; and
- assessing the impact of grading strategies on marketable yield of perch in cages.

The research plan for Project 3.1 included desktop studies of mine void aquaculture; investigations into stocking densities of crayfish and finfish in polyculture; the use of floating cages to minimise negative interactions between fish and crayfish reared together; trials addressing the issue of habitat complexity; a series of laboratory trials examining fish and crayfish behaviour in mine lake water; studies on habitat abundance and complexity within polyculture ponds; the construction of a multi-functional aquaculture hatchery on the Collie Aquafarm site; and structured efforts to close the life cycle of silver perch in remediated mine lake water.

Results from CSML Project 3.1 were extremely encouraging for the prospect of conducting commercial-scale aquaculture in remediated mine lake water. Most importantly, all participating species survived in aquaculture ponds that were supplied with mine lake water. Further, marron reproduced in all ponds at some point during the project, an indication that conditions were near optimum. Silver perch were also spawned during the project, presenting an attractive proposition to proponents of a commercial operation. At one point the remediation system suffered from “armouring” that resulted in a sudden pH drop, which ultimately killed all fish in one pond. This “fish kill” turned out to be a critical learning experience for the project staff who investigated the causes and symptoms of the event and implemented measures to detect and avoid the situation in the future. Fish and crayfish grew at near commercial rates in all production experiments and survival levels were equal to or higher than industry practice.

Polyculture production demonstrated greater increases in biomass than monoculture ponds in all production trails. This supports previous research into aquatic polyculture and the factors governing production in multi-species environments. From an ecological viewpoint, the faster growth rate shown by marron reared in polyculture compared to monoculture demonstrated a synergistic benefit that is perhaps the greatest attraction for crayfish monoculturists considering polyculture. Explanations for this ~20% higher crayfish growth when stocked in ponds with fish in floating cages include nutritional aspects (e.g. fish producing a faecal pellet that is nutritionally more appropriate for crayfish) and physical aspects (e.g. water quality may be higher when fish are maintained near the surface or conditions under the cages may provide a more conducive environment for crayfish growth). However, in polyculture total biomass is higher, habitat requirements change, density issues are critical, and intra-specific and interspecific interactions heightened.

Unfortunately, three applications for competitive national funding were unsuccessful. The result was that substantial industry support funds (South West Development Commission, Wesfarmers Premier Coal, Collie Shire, Coal Miners Welfare Board) were not consolidated into a future CSML project utilising infrastructure at the Collie Aquafarm.

## Introduction

Relinquishment of final mining voids is a significant issue for coal mining companies. The cost of rehabilitating mine voids and re-establishing pre-existing terrestrial habitats is often prohibitive and not considered to be a viable option by most coal mining companies. Following closure, mine voids gradually fill through seepage from ground water sources and surface runoff to create mine lakes. Mine lakes represent a potential water resource for a range of community and commercial activities. The Collie Aquafarm was an initiative designed to evaluate aquaculture using treated mine lake water as a beneficial end use for final mining voids.

Project 3.1 is the third major research study involving aquaculture in mine lakes. The first study, ACARP Project #C6005: Final Void Water Quality Enhancement was a three-year investigation into the enhancement of water quality in coal mining lakes, which included investigations into the acid tolerance of aquatic species that could be used for mine lake aquaculture. Results from this preliminary study identified marron (Cherax tenuimanus) and silver perch (Bidyanus bidyanus) as having the greatest potential for aquaculture in or around mine lakes existing in the Collie Basin.

The second study, ACARP Project #C9027 incorporated the development of the Collie Aquafarm, a purpose-built field research facility constructed adjacent to the Western Open-Cut 5h mine lake, WO5h (Plate 1). The Collie Aquafarm comprises six aquaculture ponds, a water remediation system (settling pond, macrophyte pond, and compost pond) and an integrated limestone water treatment system. Each aquaculture pond has an outlet that delivers discharge water back into the void, completing the water treatment cycle.

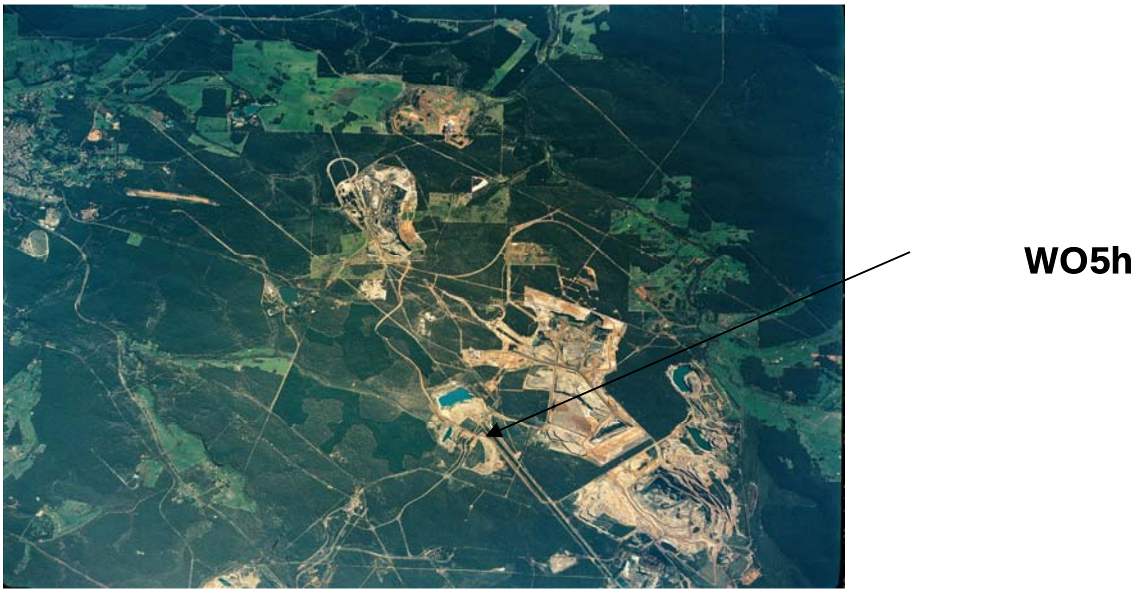



**Plate 1:** Collie Aquafarm, a purpose-built field research facility constructed adjacent to the Western Open-Cut 5h mine lake, WO5h

The rationale behind construction of the Collie Aquafarm was that aquaculture ventures using ameliorated off-take water are a logical starting point for developments of beneficial end use programmes. *In-situ* aquaculture could then be researched over an extended period, as this type of use would require extensive research and development. Under the chosen approach, capital costs are limited to excavation of aquaculture ponds and associated infrastructure (e.g. large sheds feed storage, hatchery production, etc; security; pond netting; aerators; piping, etc).

In Project #C9027, a polyculture system was researched using marron and silver perch. Previous studies by the project team have shown that the financial returns from polyculture of these two species are greater than those obtained through a monoculture approach (Whisson 2000). Outcomes from Project #C9027 indicated that aquaculture had high potential using treated water from mine lakes, with results showing high survival and growth of aquaculture stock. Analysis of polyculture production also indicated synergistic benefits from combining the two species in the same system, compared to monoculture production. These results lead to the inclusion of mine lake aquaculture within the Centre for Sustainable Mine Lakes program (Project 3.1).

### *Background*

Aquaculture in mining voids has been practised for many years at various locations throughout Asia, Europe and America. Most of these developments have occurred in mining voids with water quality conditions conducive to successful fish farming. Low acidity in Collie mining voids limits their use in such ventures unless the pH can be returned to neutral or unless acid tolerant species are used. ACARP Project #C9027 addressed utilisation of final mining voids for production of farmed fish through aquaculture, centring on the development and assessment of exterior ponds utilising remediated water from the voids (Whisson & Evans 1993).

### *Project aims and objectives*

The underlying driver for this research was to offer the coal industry a proactive and cost-effective approach to the relinquishment of final mining voids by collecting preliminary data demonstrating aquaculture as a beneficial end-use option worthy of further investigation.

Recommendations arising from previous ACARP projects included:

1. further investigation into density effects for both marron and caged perch;
2. clarification of the role of turbidity in regulating interspecific interactions;
3. examining the influence of complex habitat on production of perch and marron; and
4. assessing the impact of grading on marketable yield of perch in cages.

Further, aquaculture within mining lakes would complement purpose-built aquafarms by providing access to large areas of water, increasing production efficiencies and also providing recreation options for local communities. However, aquaculture within large waterbodies has the inherent problem of how to harvest free-range crops. Cage culture alleviates this problem and allows greater management of captive stock (grading, feeding, observation, etc). In addition, waterbodies that develop in final mining voids usually display sub-optimal water quality conditions for aquaculture (pH, salinity, etc). Acclimation procedures that allow the gradual transfer of stock into sub-optimal conditions have been developed for other aquaculture applications, and combined with suitable targeting and selection of tolerant strains, could facilitate aquaculture within mining lakes. Developing cage culture techniques will assist with polyculture production strategies in purpose-built ponds as well as helping in-situ initiatives.

The overall aim of project 3.1 was to:

> *Evaluate the role of density, turbidity and habitat complexity in the production of silver perch (Bidyanus bidyanus) and marron (Cherax tenuimanus) in polyculture systems receiving treated mine lake water.*

## Methodology

### *Collie Aquafarm*

Construction of the Collie Aquafarm facility adjacent to the WO5h mine lake (Plate 1) was initiated in 2000. Rehabilitated land surrounding the northeast side of the void was cleared following favorable analysis of soil for clay content. Initial site development included the construction of six aquaculture ponds ($600m^2$ each) and a remediation system comprising a settling pond ($800m^2$), a macrophyte pond (10 x 4 x 0.5m), a compost pond (6 x 3 x 0.5m), an anoxic limestone drain and an algal tank. The remediation components described were based on the previous small-scale demonstration facility at Ewington No 2 mine void.

The official opening of the Aquafarm was 24 October 2000 and was attended by community members, project participants and sponsors and representatives from the Collie Shire and the South West Development Authority. The Industry Monitor, Ian Pigott, represented ARC. Research activities conducted during the following year focused on further construction and modifications of the water remediation components to enable optimal operation of the aquaculture system. The final treatment system incorporated a fluidised limestone bed reactor - replacing the previous algae and ALD systems.

### *Experimental approach*

#### Experimental animals

Marron were chosen as the primary species for polyculture trials as existing infrastructure within the established marron industry would mean that large capital outlays would not be required to extend the results to aquaculture end-users. In addition, marron farming is generally a single crop industry, which is at economic risk from fluctuating market prices - the addition of a second species to current monoculture practices would help diversify risk. Preliminary polyculture data with silver perch has shown a synergistic advantage to marron, with growth rates increasing between 7 and 50% (Whisson 2000). Silver perch were selected for polyculture with marron due to existing translocation policy allowing their import into certain areas in Western Australia. More importantly, silver perch possess a number of characteristics conducive to successful culture with marron. These include schooling behaviour (amenable to high densities), accepting a wide range of water quality conditions, and a generally favorable feeding biology. Although predation of marron by silver perch has been recorded, management strategies targeting turbidity, habitat complexity and utilising cage culture have shown encouraging results.

#### Crayfish polyculture

The technology for culturing silver perch and freshwater crayfish in monoculture is well developed and is currently being practiced throughout Australia (Morrissy et al. 1990; Rowland 1994; O'Sullivan 1995; Morrissy et al 1995a, 1995b). Both these species are farmed in earthen ponds in which natural foods are generated through fertilisation and additional nutrition provided by supplementary feeding with artificial feeds. Polyculture systems are less common than monoculture within Australia but are well accepted overseas and are recognised as efficient farming systems with increased yields compared to single culture operations (Rouse et al. 1987; Scott et al. 1988; Brummett and Alon 1994). Recent research has shown polyculture of marron and silver perch in Western Australia can improve yields over monoculture of these species (Whisson 2006).

### *Research design*

#### Preliminary marron behaviour study (laboratory trial)

This was the first trial in a series of laboratory experiments aimed at understanding how fish and crustaceans communicate. These experiments were designed with the ultimate objective of designing improved polyculture stocking strategies, taking into account behavioural responses of component species to varying forms of interaction cues (chemical, visual, tactile). These experiments examined a number of critical variables, including relative size and sex of component species, variations in abiotic environment (light intensity, shelter) and species composition.

The first trial (conducted at SWAEC, Plate 2) examined the response of small, medium and large marron (Plate 2) to chemical cues from both food and from silver perch. The aim of this, and subsequent trials, was to determine what information from silver perch (i.e. visual or chemical cues), if any, will illicit stress responses in marron. Any stress experienced by an organism will often have a negative impact on growth, either through use of stored resources to fight stress (otherwise used in growth) or through reduced capacity to forage. If the causes of interaction stress can be identified, they may be able to be controlled, therefore increasing growth in aquacultured species.

small (4-8g) medium (70-90g) large (220-240g)

**Plate 2:** Experimental system used in marron behaviour trial and marron size classes (small, medium and large) used

The response of marron to the different odours (food and silver perch) was tested through observation of marron behaviour following injection of cues into the culture tank. Food odours were prepared by mixing marron pellets with water and filtering (process detailed in Storer 2005). Silver perch odours were prepared by sampling water from a tank adjacent to experimental systems containing silver perch at high densities. Silver perch culture water was then combined with food odours to quantify the net responses.

### Marron response to visual fish cues

Understanding the triggers for predator avoidance in marron has implications for management strategies in polyculture. In the previous trial, marron demonstrated responses to chemical cues in food; however, results did not confirm detection of cues in fish conditioned water, with no significant predatory avoidance strategies observed. The lack of apparent predator recognition could be attributed to an evolution devoid of natural predators (Allen et al 2002, Morrissy 1997), where cues were not perceived as threatening. In this trial, the role of visual predatory stimuli was examined, both alone and in combination with chemical cues.

The use of visual signals has previously been demonstrated in decapod crustaceans (e.g. Godin 1997, Hazlett 1999) and in clear-water systems visual signals are most often the main method of communication, providing early accurate information (Bouwma and Hazlett 2001). As marron have evolved in clear-water rivers and streams, visual predator detection is likely to be the major sensory device, and could explain the lack of responses in the first trial. In this trial, small marron were selected. As the previous trial showed no indication of size variation in behavioural responses to solutions, it was determined that this size of marron was simplest to experiment with, while also being the size most prone to predation, therefore requiring the most pronounced avoidance tactics.

Experimental conditions (experimental systems, test solutions and behavioural analysis) were replication from the previous trial. However, in this investigation marron were also exposed to visual cues from silver perch held in bags within the test aquaria (Plate 3). Behavioural responses were compared between marron in systems containing a bagged fish, an empty bag or no bag.

**Plate 3:** Experimental glass aquaria (54L, filled to 25L), showing fish bags.

## Marron response to visual/chemical fish cues

Previous trials have shown a lack of avoidance by marron in response to chemical and visual cues from a potential predator. One explanation for these results is that marron increase alert status in response to a potential threat, maintaining feeding and responding only when attack is imminent. One factor that may trigger avoidance responses in marron is competition, in that individuals competing for resources such as shelter may force conspecifics to respond to a potential threat more immediately. Competitive interactions and habitat use in aquatic systems are largely a function of predation risk. The addition of a sympatric crayfish that is known to respond to exteroceptive cues from potential predators, such as the yabby (Gherardi et al. 2002), may also produce alarm responses detected by marron. Alarm cues have been shown to produce responses in normally non-reactive animals. In a previous study, comparing responses of marron and yabbies, it was shown that both species will react to odour from each other (Gherardi et al. 2002). This may be due to co-inhabiting systems for the past 70 years, phylogenetic inertia (Hazlett 1990), or related to similar methods of chemical detection.

In this trial, one marron and one yabby were held together in a 250L aquarium, with silver perch held in the same system and separated by partitions allowing or preventing the transfer of visual and or chemical cues from fish. Large experimental systems were used in this trial, following suggestions that behaviour of fish and crayfish may have been limited by the size of aquaria used in previous studies. This trial aimed to determine if behavioural responses of marron to silver perch cues were influenced by competitive interaction, or alarm responses, of yabbies in response to cues from silver perch. Flow between compartments containing crayfish and those containing silver perch was constant, therefore any allelochemicals released by silver perch would be present for the duration of analysis, where as in previous trials solutions were introduced once at the beginning of each observation period. Chemical signals in aquatic environments have been shown to quickly decay (Lass 2001), which may have affected responses in previous trials. The variables tested in this trial are outlined in Table 1. Behavioural observations included observation of night-time behaviour (Plate 4), which is of particular importance as marron are primarily nocturnal (Morrissy and Caputi 1981).

**Table 1:** Experimental design showing treatment allocation of cues from silver perch

| Treatment | Partition design | Water flow | Perch | Stimuli tested |
|---|---|---|---|---|
| **1. Control** | Plastic mesh (10mm) | Yes | No | Crayfish only |
| **2. Visual** | Plastic mesh/clear glass | No | Yes | Visual cues |
| **3. Chemical** | Plastic mesh/opaque glass | Yes | Yes | Chemical cues |
| **4.Vis/Chem** | Plastic mesh | Yes | Yes | Vis/chem. Cues |
| **5.Single sex** | Plastic mesh | Yes | Yes | Vis/chem. Single sex |

### *Trials to determine capacity of treated water to support stock*

Several trials were carried out to determine the ability of fish and crustacean species to survive and grow in ameliorated mine lake water from the Aquafarm. These trials were low-density, designed as preliminary investigations to confirm adequacy of water quality without risking high numbers of stock. A summary of trials conducted and outcomes follows.

#### Silver perch quarantine and acclimatisation trial

Silver perch (650 @ 200g ± 0.6) were obtained from a local aquaculture farm. To prevent introduction of disease and parasites, and to optimise conditioning prior to stocking at the farm, all fish were transported to the quarantine facilities at the South West Aquaculture and Environment Centre (SWAEC) and held at densities of approximately 10kg/m$^3$ in 4500L tanks for an acclimatisation period of 14 days. Perch were not fed during this period. Zero perch mortalities occurred during the 14-day quarantine period. Firstly, five perch (200g ± 0.6g) were stocked into six cages in six ponds at the Aquafarm, and behaviour and condition recorded over 14 days. Fish were fed at less than 5% bw/wk on 'Silver Perch Pellets' (Glenforrest Stockfeeders - 4mm grow-out). Zero mortality was recorded in all ponds.

**Plate 4:** (left) Crayfish held with fish, with barrier between compartments manipulated to allow visual cues, chemical cues or both. (right) Crayfish viewed through night-vision goggles to examine nocturnal behaviour

### Marron quarantine and acclimatisation trial

Marron (470 @ ~75g) were obtained from a marron farm in Gidgegannup. To optimise condition and prevent introduction of disease and parasites all stock was held in the six 4500L tanks at SWAEC for a period of 14 days. Marron were not fed during this period. Initial analysis of stock indicated the presence of Epistylis (ectocommensal protozoan parasite). Although not a significant health threat, this parasite is highly transferable between pond systems and extremely difficult to remove once established. To address this all marron were treated at 10ppt marine salt for 2 minutes, and no indication of further infection was observed.

A sample of marron was then introduced into each of the six ponds. Five individuals were placed in two 'opera house' style submersible cages (three marron/cage) and left in the pond for a two-week period to observe survival and general health. Following the 14-day trial period four deaths were recorded, however due to the apparently healthy condition of remaining marron it was thought that the mortalities were due other reasons than pond health. To verify this, a further trial was conducted. Six marron (3 males, 3 females) were held in each of six glass aquariums (300L) at the SWAEC facility over a 14-day trial period. Two aquariums were filled with water from Aquafarm ponds, two were half filled with water from the ponds and with water from the Collie River, and two filled only with water from the Collie River. Results showed 100% survival in all treatments.

### *Polyculture field trial - preliminary assessment*

In March 2002 the first demonstration trial was initiated where silver perch and marron were stocked at low densities in an effort to investigate the potential of the system to sustain a commercial scale trial. Marron were stocked free-range into all ponds at 50 individuals/pond, and three densities of silver perch were stocked into the floating cages (0 fish, 100 fish and 200 fish) – with each density replicated in two ponds. Shelter was provided for marron to reduce competition between conspecifics. Both perch and marron were fed silver perch and marron pellets respectively, three times per week at 5% bw/wk. Growth and survival was monitored over a three-month period.

### *High density polyculture trial (field based)*

In 2004, research at the Aquafarm continued the investigation into optimal stocking densities of caged silver perch and free-range marron, held in polyculture. Marron stocking density was increased from 50/pond in 2002-2003 to 600/pond (1 per $m^2$) in 2004. The number of floating fish cages/pond was increased from 1 to 2 with the same densities of silver perch from the previous year in each cage, effectively doubling the density of fish/pond. This allowed direct comparison of growth-density relationships between data from 2002 and 2004, focusing on pond carrying capacity rather than cage density.

Shelter complexity was also increased with pond shelter density at 1.2 shelters per m$^2$ and 30 shelters introduced into each fish cage. Pond shelters were introduced in setlines, which could be removed from the edge to allow easier sample harvesting and removal for draining. Treatment allocation is depicted in Fig. 1.

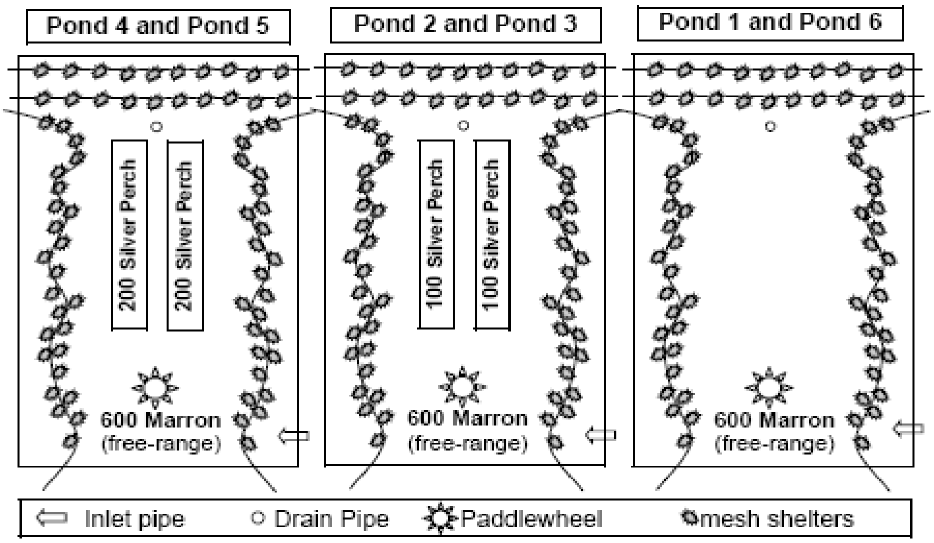



**Figure 1.** Treatment groups for the second polyculture trial at the Collie Aquafarm

### *Polyculture shelter trial (field based)*

To take advantage of the high number of berried female marron recorded in the final sample point, a second trial was designed to examine the predation pressure from silver perch on juvenile marron. In November 2004, 100 berried marron and 150 silver perch were released free-range into all ponds. Three ponds were provided with high levels of shelter (2.4 per m$^2$) and the remaining three ponds with no shelter. The growth and survival of juvenile marron was recorded in late March, as juvenile marron were released from tails of marron between December and January.

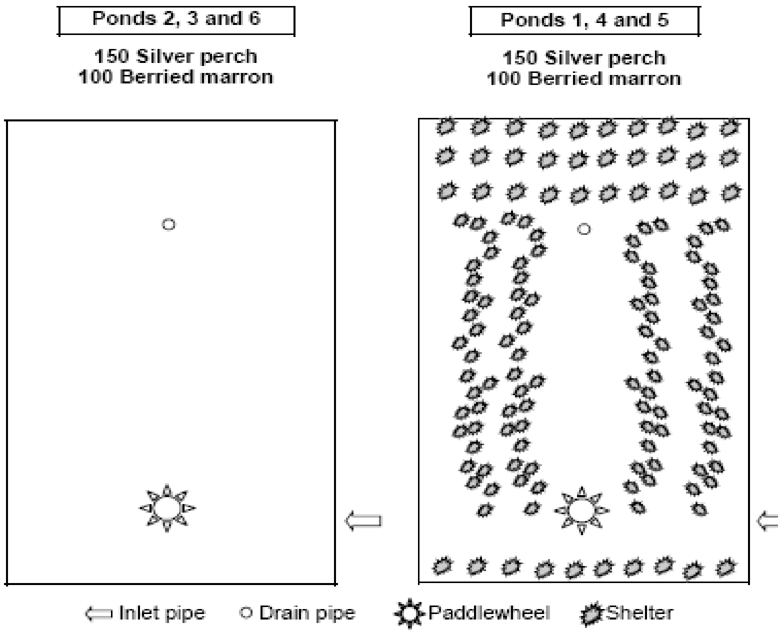



**Figure 2.** Treatment design, replicated in three ponds

## *Marron response to predatory fish cues (laboratory based)*

Previous investigations examining interaction between marron and silver perch failed to demonstrate effective avoidance responses by marron. As silver perch are omnivorous, becoming increasingly herbivorous with age, it was hypothesized that their behaviour might not considered threatening by marron. To test this theory, it was decided to examine marron avoidance behaviour in the presence of a carnivorous species, Murray cod (*Maccullochella peeli*). Murray cod, native to the Murray-Darling (Eastern States), is an ambush predator known to consume freshwater crayfish. It was theorized that Murray cod would place strong predatory pressure on marron and that marron would have few avoidance tactics due to their evolution in absence of aggressive finfish predators. Twenty marron (2.5g each) and one Murray cod (0.75-1.4kg) were placed into single aquaria (250L). A control (no fish) and three treatments were tested: shelter, no shelter and shelter in 0% light intensity. Each group was represented in four replicate tanks (16 total). Survival, shelter use and general behaviour were recorded twice daily (0900h and 1700h) for 14 days. No animals were fed for three days prior and throughout the trial duration. Systems were maintained with two external biological filters and two air-stones for each aquaria.

## *Materials*

### Fish cages

Following preliminary investigations carried out by the research team prior to construction of the Collie Aquafarm, polyculture experiments included the culture of silver perch in floating cages. Cages were floating polypropylene fish cages (15m x 1.5m x 0.75m) covered with bird netting (Plate 5). The use of cages to culture silver perch was chosen for a number of reasons, including fast and efficient grading and harvesting with minimal impact to fish, easy feeding and stock assessment. Cages also prevented predation from birds, and negative physical interaction between fish and crayfish.

**Plate 5.** Floating cages used to culture silver perch in the crayfish polyculture system

### Marron hides

Commercial loose-mesh marron shelters were used in all ponds. Students from Curtin University, South West Regional College of TAFE, and Collie Senior High School were essential in construction of over 600 crayfish shelters and six fish cages.

### Security system

The security system for the Collie Aquafarm was completed in February 2002, following a tender process in 2001. Security measures included a 7-foot high alarmed, electrified perimeter fence, with an additional 30cm of barbed wire, a security access panel and camera system (Plate 6).

**Plate 6:** Security system at the Collie Aquafarm

## Results and Discussion

### *Low density polyculture trial (field based)*

Significant increases were observed in marron and silver perch weight over the trial period, with both growth and survival data comparable to industry monoculture levels. Polyculture production was significantly higher than monoculture (Fig. 3), and marron larger when grown with silver perch ($P<0.1$). While the need for research into higher, commercial densities is evident, the trial successfully demonstrated the potential of crayfish polyculture as a beneficial end use for coal mining lakes in southern Western Australia.

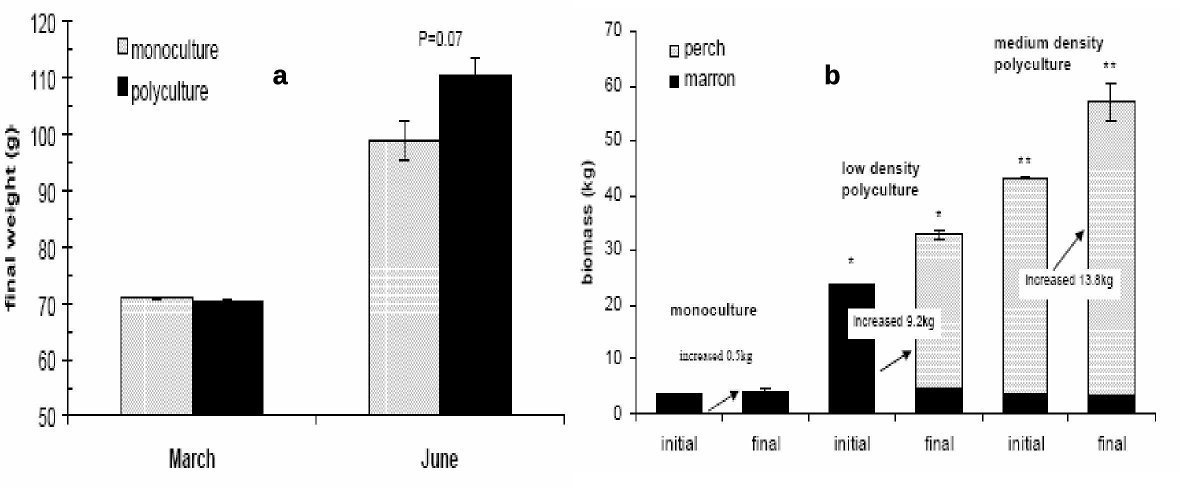



**Figure 3:** [a] average marron weight at start and completion of trial, [b] pond yields: marron monoculture versus marron-perch polyculture.

## Bio-economic model

A bio-economic model was developed, based on results from the first polyculture investigation, containing three major components - the biological factors, technical components and economic factors (Whisson & Evans 2003). The base model showed that for the biological indices used in the polyculture trial, gross margin for a typical year in a 20 year period is negative (-$71,784). However, the second model constructed using commercial stocking rates gave negative gross margins for years 1 and 2 and a positive gross margin of $98,275 in year 3. A cash flow analysis conducted over a 20-year period at a discount rate of 7% showed an internal rate of return of 16.9% and a benefit cost ratio of 1.27. All these financial indices indicated a favourable outcome. However, further studies were required to validate these findings with full remediation costs included.

### *Preliminary marron behaviour study (laboratory trial)*

In order to optimise polyculture management strategies, the factors that influence the occurrence of predation events and predation stress within a specific multi-species system require elucidation. With respect to the polyculture of marron and silver perch, where perch can be held within cages - preventing physical interaction - the most important questions relate to stress associated with perception of risk. That is, whether marron production can be affected by cues from perch held in cages.

The first significant outcome of this trial was confirmation of chemosensory perception in marron. Fig. 4 displays the reaction times of crayfish following injection of distilled water (control), food cues or odour from silver perch combined with food cues. A behavioural change is apparent when comparing reactions of marron under each treatment. This is not surprising, as decapod crustaceans, such as lobsters, crayfish and crabs rely heavily on their sense of olfaction for locating food, shelter, conspecifics and heterospecifics. Fig. 4 also shows little variation in the responses of small, medium and large marron. Lack of variation in the response of marron to food cues versus food cues combined with silver perch odour was also observed. This suggests that marron may not perceive silver perch odour as threatening, otherwise reduced foraging would be expected. Behavioural changes to both test solutions were related to a feeding response, with increases in locomotion and feeding when test solutions were introduced, compared to control.

## Discussion

The use of chemosensory perception by marron was demonstrated through responses to food odour, although it is unclear whether marron detected cues from silver perch and were only detecting the food cues within the silver perch test solution. If marron do not detect fish odour, or more importantly, do not perceive fish odour as indication of a potential risk, then this is encouraging for polyculture of marron and caged silver perch – as marron should not reduce foraging. Size and sex of marron appeared to have little bearing on behaviour of marron in response to either food or food combined with silver perch odour. Further research is required in order to confirm findings and extend understanding to other information cues (i.e. visual).

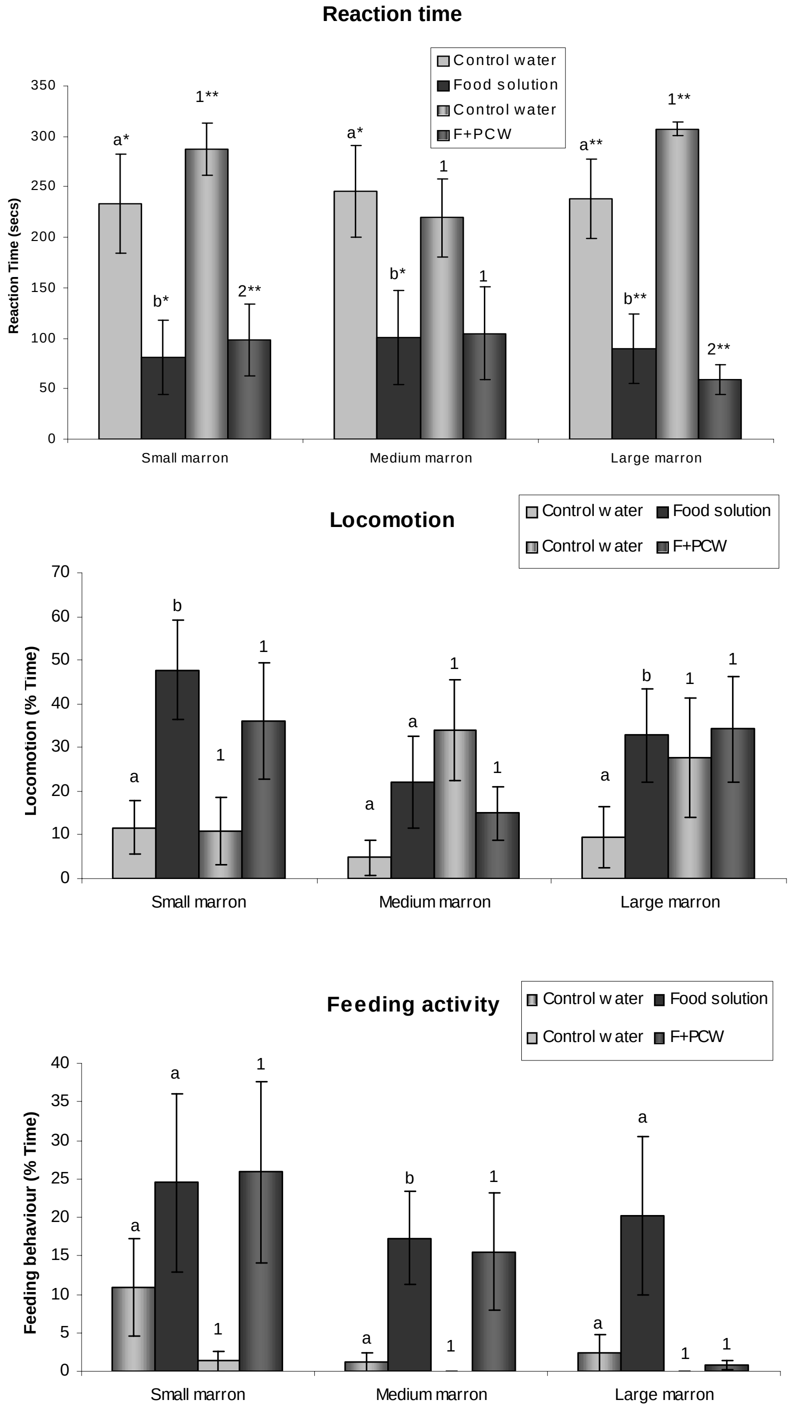



**Figure 4:** Reaction times, locomotion and feeding activity of marron (small, medium and large) to control and test solutions.

### *Marron response to visual fish cues (laboratory trial)*

Detection of silver perch visual cues by marron was supported by results in this trial. Marron in aquariums containing silver perch displayed increased antennule flicking compared to the monoculture treatment ($P<0.01$) and increased antennae movement compared to the empty bag treatment ($P<0.05$) (Fig. 5). Marron with fish chose lower posture significantly more than other groups ($P<0.05$), and climbed more ($P<0.05$) than marron with only an empty bag in the aquarium.

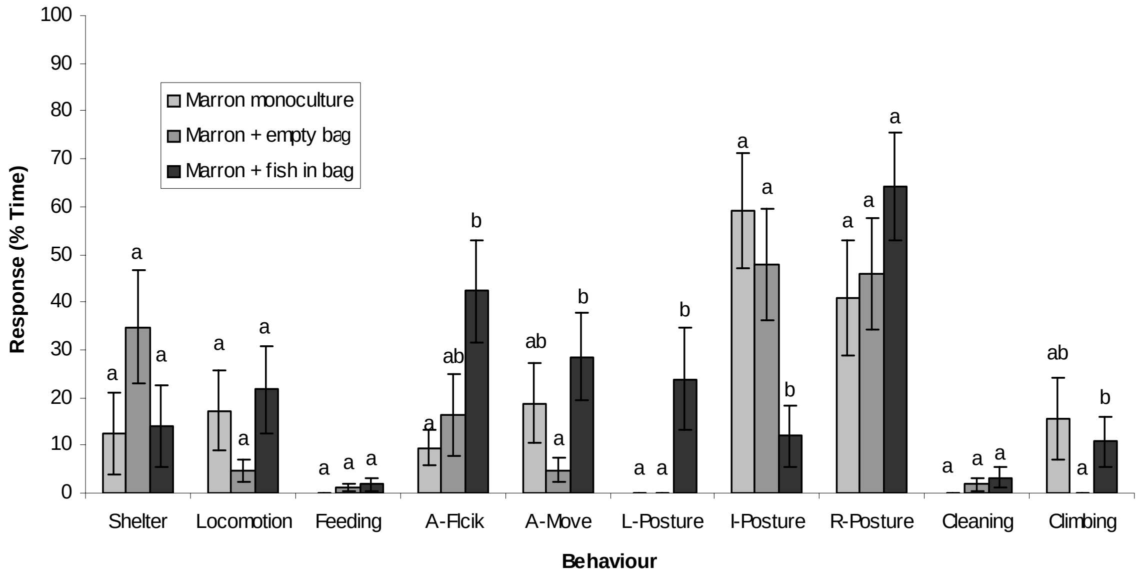



**Figure 5:** Behaviours displayed by marron in each treatment block, recorded following addition of control water. Significant variations between treatments within each behaviour are identified by different letters ($P<0.05$).

As was seen in the previous trial, marron responded to both food cues and food cues combined with silver perch odour with an increased reaction time, locomotion and feeding (Fig. 6). Increases in antennule and antennae movements were also seen in response to both solutions (Fig. 7). These responses were all indicative of typical feeding responses in marron, and showed little discernable variation whether visual cues from silver perch or the empty bag were present, in comparison to the control. Although marron did show variations in behaviour to visual cues from perch under control solutions, once food cues were added these variations were not apparent, suggesting that feeding outweighed the response to visual stimuli from silver perch.

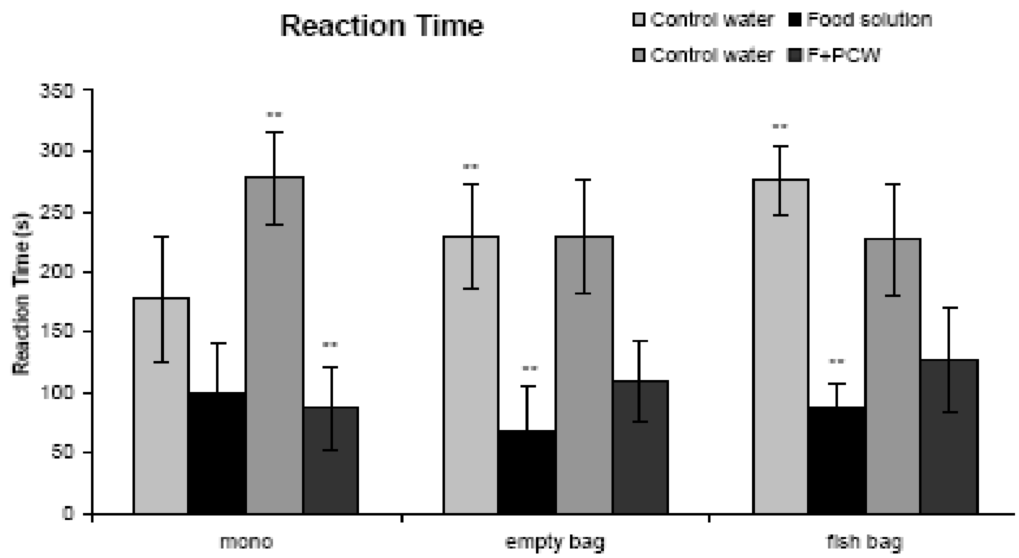



**Figure 6:** Reaction times of marron held in monoculture (mono), with an empty bag, and with bagged fish, in response to control and test solutions (F+PCW = food +perch culture water).

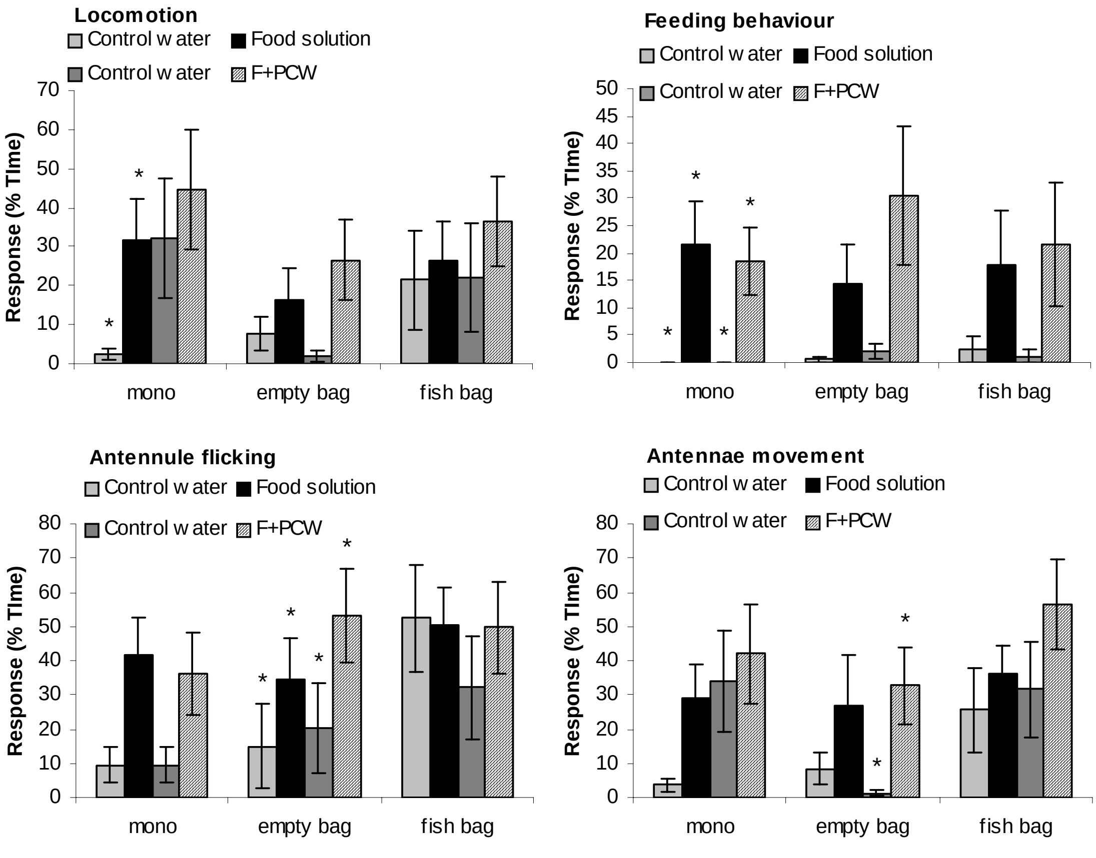



**Figure 7:** Behavioural responses of marron held in monoculture (mono), with an empty bag, and with bagged fish, in response to control and test solutions (food, and F+PCW) for locomotion, feeding behaviour, antennule flicking and antennae movements.

### Visual cues

The behaviour of marron when exposed to visual cues from silver perch seen in this trial is consistent with anti-predator responses. Hazlett (1990) and Gherardi et al. (2002) showed that in freshwater crayfish, increased use of antennules is seen with detection of environmental signals pertaining to threat. Lowered posture has previously been correlated to responses to predatory cues in the crayfish Orconectes virilis (Hazlett and Schoolmaster 1998) or avoidance of high-risk areas (Brown et al. 1995), such as climbing, is a documented predator avoidance strategy.

### Chemical cues

The ability of marron to detect and recognise cues relating to food was apparent in findings in this study, supporting observations made in the previous trial. Marron in all treatment groups responded positively to cues in both test solutions examined, with significantly faster reaction times and significant increases in feeding activity, locomotion, antennule flicking and antennae movement, compared to control solutions. Antennules and antennae are the primary device used by freshwater crayfish in detecting chemical cues (Hazlett 1971, Hazlett et al. 2002).

The lack of variation between the behaviour of marron responding to food solution and responses to F+PCW solution, suggests that marron do not detect fish cues in silver perch culture water. Another explanation is that marron detect chemical cues from silver perch, but do not associate them with potential risk, or that risk level was not high enough to warrant behavioural change. In many species, recognition of threat from novel predators requires association of predatory cues with known risk cues, such as alarm odours, and in some cases avoidance behaviour is only triggered following physical interaction with a predator (Chivers and Smith 1995).

### Discussion

Results from this study support findings in the previous trial which demonstrate the ability of marron to detect and respond to cues in the test solutions provided, however as no significant differences were found between test solutions, it is unknown whether detection of silver perch chemical cues by marron occurred.

Perhaps, the most important finding of this trial was the apparent avoidance responses displayed by marron when exposed to visual cues from silver perch held in bags. As visual cues from silver perch in cages would be present in the polyculture regime being trialed at the Collie Aquafarm, this could have negative effects on production as avoidance responses in marron could affect their growth and condition. More work is required to determine what effects avoidance could have on production, and whether detection of perch visual cues by marron can be controlled by management techniques such as manipulating turbidity.

### *Marron response to visual/chemical fish cues (laboratory trial)*

Studies reported here, and also by Gherardi et al. (2002) and Height and Whisson (2006), have examined the baseline behaviour of both marron and yabbies when held alone in aquariums.

### Crayfish interaction behaviour (no fish cues)

Following establishment of dominance hierarchies, results showed that marron were the victor in almost all aggressive encounters, monopolised shelter and screens, and shelter competitions always resulted in the exclusion of yabbies. Based on these results it could be concluded that cohabitation of the two species would result in marron out-competing yabbies. Introduction of the invasive yabbies usually resulted in displacement of marron, where marron are adversely affected by the highly competitive yabbies (Morrissy 1983, Lynas 2002) that display high behavioural plasticity (Gherardi et al. 2002, Height and Whisson 2006). The observed physical dominance of marron over yabbies in this trial does not contradict previous findings, as it should be noted that direct interaction between competing crayfish species constitutes only part of the displacement scenario. For example, yabbies are favoured as an invader owing to a higher breeding frequency and burrowing capability (Lawrence and Jones 2002). Behaviours of both crayfish species examined at night time showed no significant differences when compared with previous periods, however the number of aggressive conflicts increased and the use of shelter and climbing reduced. These observations are consistent with increased activity displayed by crayfish in this time period, being predominantly nocturnal or crepuscular (Morrissy and Caputi 1981).

### Detection of fish cues

Both crayfish species were clearly able to detect cues presented from silver perch (visual, chemical, visual/chemical combination), with significant increases in reaction time, antennule flicking and antennule movement across all treatments compared with control.

### Chemical cues

Although eliciting significant behavioural responses in both species, chemical cues presented in this trial did not produce feeding activity in either species. In previous trials, where food and fish cue combinations were used (Gherardi et al. 2002, Height and Whisson 2006) feeding was significantly increased. Even if the dominance relationship between marron and yabbies prevented feeding in yabbies, it is still likely that foraging responses would be seen in marron if they perceived fish as food. Hazlett (1999) reported that in other species of freshwater crayfish when faced with imminent predatory risk, behaviour is commonly inhibited, but rarely prevented. These findings provide evidence of the ability of marron and yabbies for chemo-differentiation of signals pertaining to food, and those pertaining to silver perch. The ability of freshwater crayfish to detect odours associated with potential predatory species has been shown in previous studies (Hazlett 1999, Hazlett and Schoolmaster 1998).

### Visual cues

Behavioural responses to visual cues (presented alone) were apparent in this investigation, with significantly increased reaction times in both species. Although no significant differences were seen in other behaviours compared to control, antennule and antennae movement were increased for both species. This supports findings from the previous trial, where significant increases in antennule flicking, low posture and climbing were also found in response to visual cues from silver perch. The use of visual cues as the primary information source, especially in clear-water conditions indicative of the natural rivers systems in south-west Western Australia has previously been demonstrated (Culp et al. 1991, Murray and Jenkins 1999, Bouwma and Hazlett 2001).

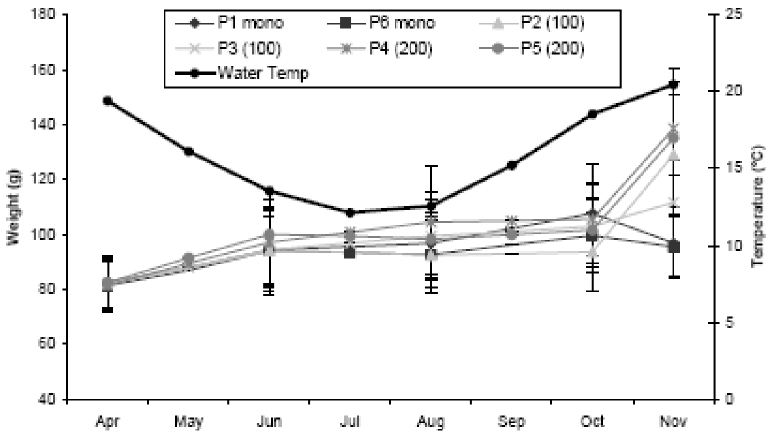
### Conclusion

This trial confirmed the chemo- and photo-sensory ability of both crayfish species, and their capacity to differentiate and respond to environmental information based on the nature of stimulus (food versus fish cues). However, results showed an absence of significant avoidance behaviour in marron. These findings may be a function of the natural selection of marron species in fishless regions where it is the largest, dominant invertebrate; or they may reflect an alternate predator response mechanism such as tail-flipping, which would be consistent with increased alert status but lack of behavioural change to perceived threat.

An understanding of the ecological roles of aquatic species also has direct application in developing management tools that may be employed in marron polyculture systems to mediate negative interactions between cohabitants exhibiting overlapping feeding regimes. The most encouraging finding from all previous laboratory studies described in this report for polyculture of these species is that even though marron detect fish cues, behavioural responses were not evident. Therefore, if cages were employed in polyculture with a predatory species, or system variables altered to reduce effectiveness of predatory strategies, marron would be likely to maintain growth, as they would not be directing energy to avoidance.

### *High density polyculture trial (field based)*

Following introduction of stock in Feb-March, growth of marron and silver perch was measured bimonthly, and survival recorded at final harvest in November. Although the trial was conducted outside of the optimal growing season (i.e. October-April) the growth rates were equal to or above industry standards for both marron and silver perch (Fig. 8). There was also a synergistic advantage apparent to marron held in polyculture with silver perch, which was especially evident as growth rates increased later in the trial. The difference between the monoculture and polyculture marron after 7 months is shown in Fig. 8. Growth of stock plateaued between June and August, coinciding with reduced feeding activity during winter months.



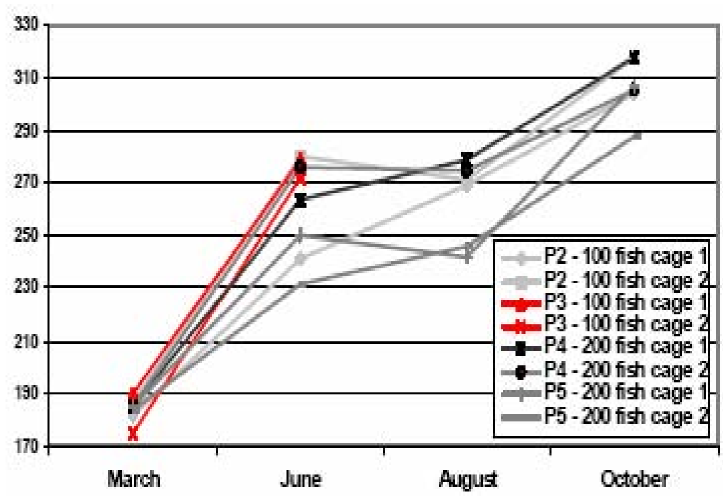




**Figure 8:** Growth of marron (top) and silver perch (bottom) reared in polyculture with silver perch

### Fish kill

The data for medium density polyculture in August and October was only calculated from Pond 2, as a fish kill occurred in Pond 3 in June. Fish health and water analysis revealed that the sudden death of all fish in this pond was attributed to a combination of low pH and high aluminium levels. Follow-up work revealed that armoring in the fluidised limestone bed reactor led to a rapid drop in pH in all ponds from approximately 7.5 to just above 6.0. This level of pH is well within tolerance limits of stock - determined in initial ACARP research (Evans et al. 2000). The fact that fish were only affected in Pond 3, and to some extent in

Pond 2, was due to further reduction in pH (to around pH 5.6) in these ponds via run-off from the adjacent settlement-pond banks (Fig. 9), with the fish kill recorded immediately following a high amount of rainfall. Even at pH 5.6, both marron and silver perch should be able to tolerate conditions.

The direct cause of the fish kill was believed to be aluminium precipitation on the gills of fish, starving them of oxygen. Water quality and sediment analysis showed that low levels of aluminium were passing through the remediation systems and accumulating in the ponds, although when pH is within normal ranges (above pH 6.0) the aluminium is not ordinarily in a form that can be taken up by stock. At pH levels below 6.0 aluminium becomes increasingly mobile, and it is believed that once pH levels fell below 6.0 in Pond 3 the large levels of aluminium trapped in sediment and solution were oxidized on the gills of fish, leading to suffocation and rapid death. Now that minimum pH levels have been identified for marron and silver perch, this problem can be avoided and periodic testing for aluminium accumulation included in routine analysis. Methods for extraction of existing metals and removal prior to entry to aquaculture systems requires further investigation.

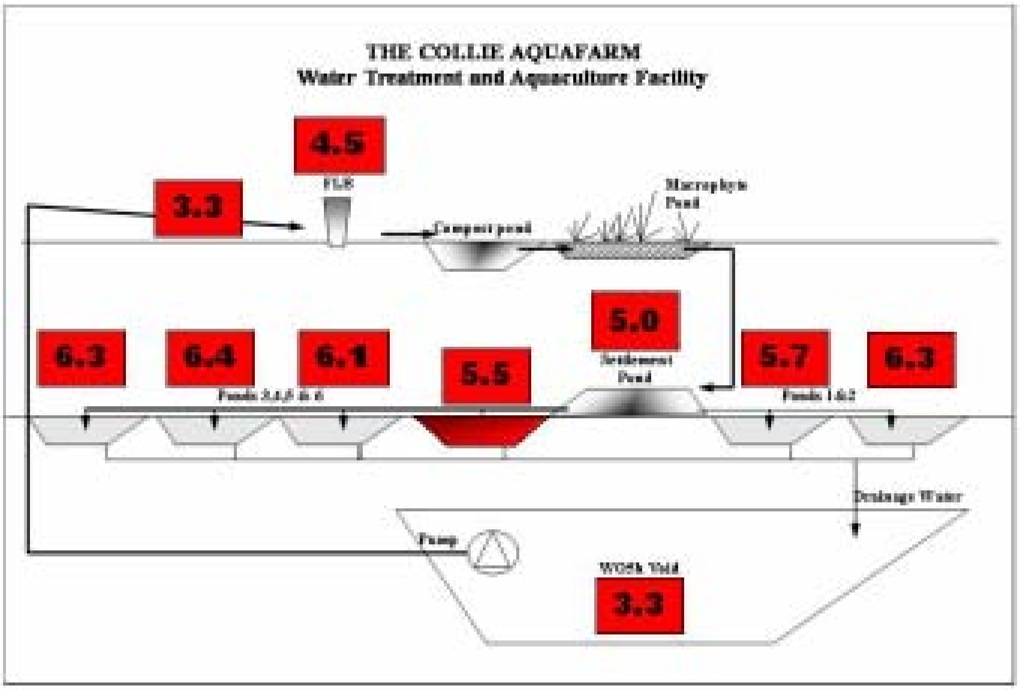



**Figure 9:** Farm layout in relation to pH levels at time of fish kill

## Marron and perch survival

In the remaining aquaculture ponds, survival of silver perch was excellent, however marron mortality was relatively high. The reduced survival of marron in all ponds was likely related to the high levels of aluminium recorded in water, sediment and accumulated in stock. As it is unlikely that predators would target all ponds equally. Survival was higher in the polyculture ponds, compared to monoculture. Increased shelter from the fish cages reduced bird predation, which was observed for the first time at the Aquafarm, with a cormorant observed frequently at the site, and a number of ducks found trapped in bird netting. Approximately 80% of all female marron were berried, which indicated successful remediation, producing suitable conditions for spawning (Plate 7).

**Plate 7:** Berried marron collected from Aquafarm ponds

## Discussion

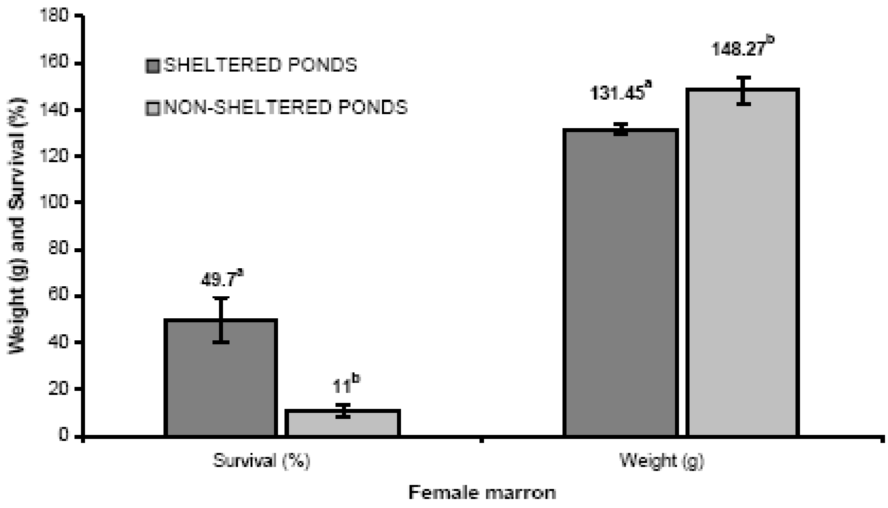
Regardless of problems with water treatment, the data from the aquaculture ponds has not shown any growth density restrictions. Further increasing densities of both component species is recommended. The examination of shelter harvesting using shelter-lines as a management tool for marron culture, and as a less-intrusive sampling method for research trials was successful. Marron were quickly removed for the 30% samples with low stress to stock and low disturbance to ponds.

Future strategies for controlling bird predation should be considered and could include the increased provision of shelters in close proximity to shoreline to protect molting marron, as non-diving bird predators such as crows can access stock at this time. Complete coverage of the ponds with bird netting should also be considered.

Finally, levels of aluminium in water, sediment and in marron were higher than normal and are a definite concern for future work and eventual commercialisation of activities. Although consumers would need to ingest almost one kilogram of tail flesh per day to exceed average intake for humans (5-7 mg/day) (NHMRC 1996) the effects of aluminium on humans and cultured animals is poorly understood. It would not be recommended that farm stock are sold for consumption until the problem is investigated for both perch and marron. A complete analysis and discussion of aluminium levels is provided within Michelle Ingram's thesis, working with Project 3.3, and is reviewed in the annual report for that project. Efforts are being made within Project 2.3 to rectify this problem.

### *Polyculture shelter trial (field based)*

High predation by silver perch recorded for marron all ponds, however results showed higher survival for juvenile and adult female marron when shelter was provided (Fig. 7).



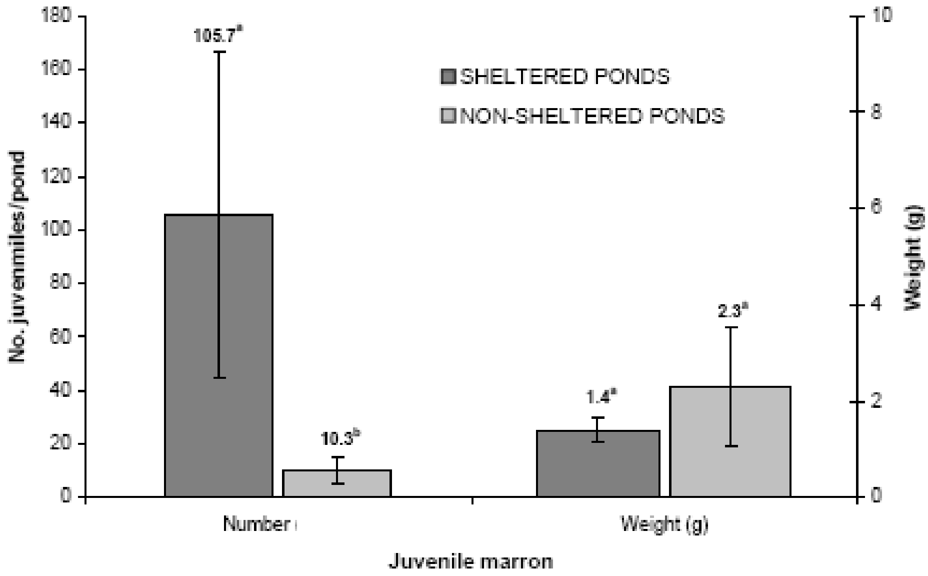




**Figure 10:** final weight of adult female marron (top) and juvenile marron (bottom) in sheltered and non-sheltered treatments.

### *Laboratory trial - marron response to predatory fish cues*

Strong predation on marron was observed in all treatments (Fig. 11). Highest mortality was observed when shelter was not provided, with no individuals remaining after 12 days. Mortality when shelter was provided in 0% light intensity was also high, 85% after 12 days, followed by shelter, which had 25-45% mortalities in three aquaria and 80% in one (explaining high standard errors). Molting indirectly accounted for 2-3 mortalities/aquaria, as demonstrated in the control. Predation was observed after 1-2 days in all treatments, although mortality rate increased strongly after 4-5 days in T2 (no shelter). Shelter occupation (Fig. 12) in the control group was approximately 80% over the first 8 days, and gradually declined there after (approximately 40% at day 14). Shelter was not utilised until after the first predation events were recorded in each treatment. There was almost 100% shelter use after 2-3 days in 0% light intensity (T4), and the same response after 8 days in shelter (T3). Although no shelter was provided marron displayed avoidance behaviour in T2, Plate 8 shows the 3 marron remaining in one aquarium.

Murray cod were shown to be effective predators of marron. Extrapolation of results suggested that given time all marron would be consumed, especially when the need for foraging was critical. The drop in mortality rate in the last days of the trial in most aquaria, coupled with lack of avoidance in the first days of this trial, may reflect learning by marron, apparent in Plate 8. This requires further investigation (i.e. learning).

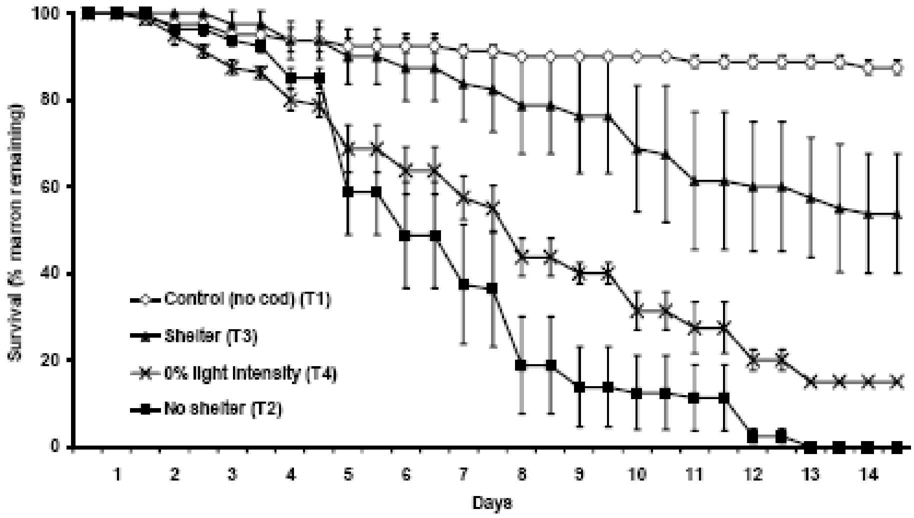



**Figure 11:** survival of marron (%) in each treatment group

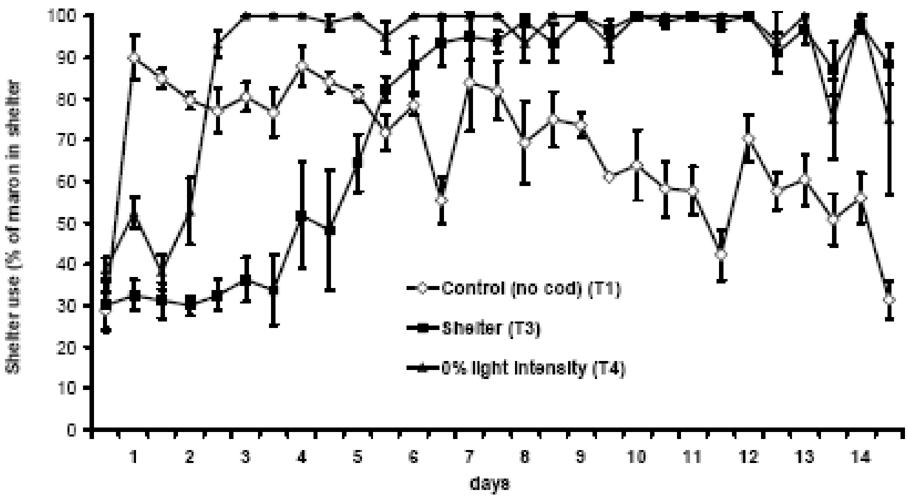



**Figure 12:** shelter occupation (%) of marron in each treatment group

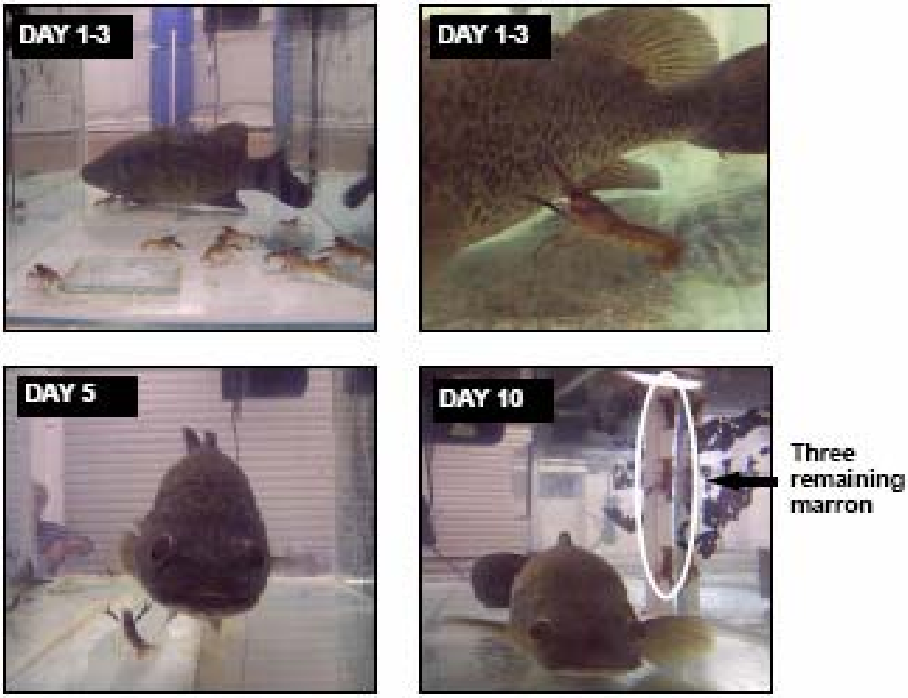



**Plate 8:** Interaction between Murray cod and juvenile marron

Variations in survival between treatments map directly with predation pressure from cod, reflecting possible associative learning. Reduced shelter use towards the end of the trial in all treatments may reflect the increased need for food. In pond polysystems, cage culture may be necessary. Aside from high mortality - growth rates would be affected through reduced foraging.

### *Hatchery construction at the Collie Aquafarm*

A major development within Project 3.1 was the construction of an on-site aquaculture hatchery that would have the capability to produce fish and crayfish for stocking ponds and holding harvested stock prior to sale. The original vision was for the Collie Aquafarm to be a demonstration site for commercial operations using remediated mine lake water - the addition of the shed was imperative for the site to be sustainable. Site selection and plans were completed in 2005 (Fig. 13). Shed construction and set-up was originally costed within the CSML budget at $150,000. However, delays in funding lead to long delays during a construction boom resulting in significant increases in steel prices and general construction costs. To keep the project within budget the size of the hatchery was reduced and cost saving design changes implemented (e.g. area of concrete floor was reduced). The finished hatchery (Plate 9) was used to complete a spawning of silver perch fingerlings in 2007.

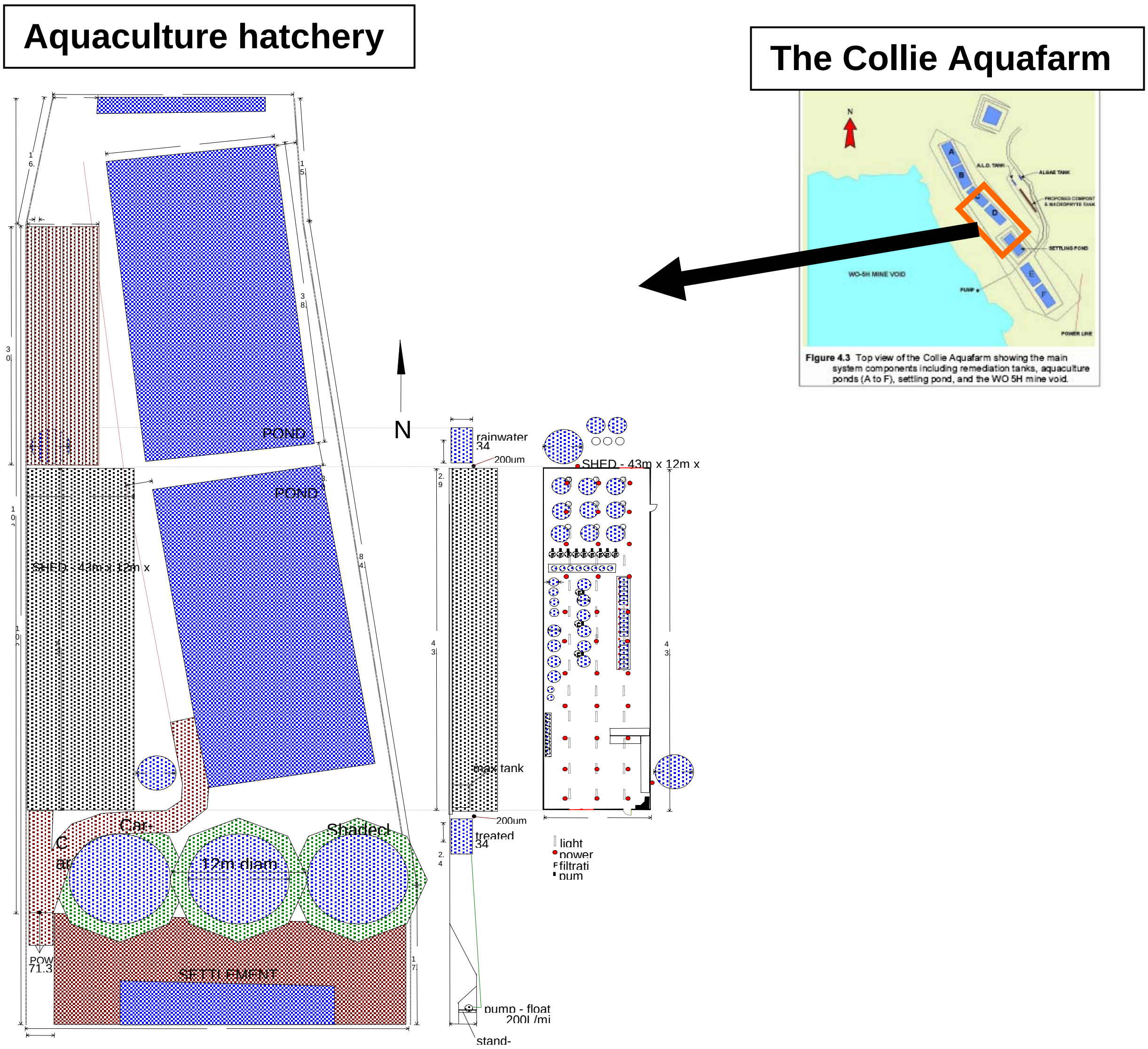



**Figure 13:** Aquaculture hatchery schematic diagram

**Plate 9:** Development of the aquaculture tank facility at the Collie Aquafarm

### *Hatchery production*

In summer 2007, the Collie Aquafarm hatchery was used to produce silver perch fry (Plate 10), effectively closing the life cycle of silver perch in acid-remediated mine lake water for the first time. To develop a viable mine lake aquaculture enterprise using treated mine lake water, on site production of fry would be highly desirable and cost-effective, as remediation systems end up flowing through culture ponds once they are full. The production of fry cannot be understated - breeding fish in tanks using artificial hypophysation techniques, collecting and hatching eggs, developing appropriate live feed cultures, and rearing larvae to fry is perhaps the most difficult and risky task carried out in aquaculture. Being able to successfully produce seed stock using treated water confirms the capability of the treatment system to ameliorate acid water to supply water quality adequate for all stages of aquaculture production, demonstrating that mine lake aquaculture has high technical potential.

**Plate 10:** Silver perch fingerlings produced in mine lake water at the Collie Aquafarm.

## Limitations of the research

The initial goals and objectives for CSML Project 3.1 were based on the provision of a post-doctoral research fellow. This was a significant element of the research plan, as it was anticipated that such a researcher would have evolved the research programme to a point that would have remained sustainable following cessation of CSML. Unfortunately, this position was removed from Project 3.1 by the CSML Executive, against the wishes of the project leader. This placed pressure on the research objectives, which had to be refined. Applications for ARC and FRDC funding to continue the development of a production model were submitted in 2005, 2006 and 2007, however they were not successful.

A number of modifications and maintenance requirements regarding the treatment system components slowed results, for example: fish in one pond were killed due to heavy metals leaching through the treatment system and a drop in pH in ponds due to armouring in the FLB. Also, trial start times were delayed while new components of the treatment system were made, bought or modified – which reduced trial duration through optimal growth conditions. However, these delays were all centred on dealing with problems that have now been permanently rectified; therefore future trials can now operate free of these uncertainties.

While on-site experiments were statistically valid, the low replication of treatments due to the low number of ponds (i.e. six) was a limiting factor. Applications to ARC and FRDC included proposals to construct a further six ponds that would have facilitated on-going research with higher certainty. A major focus of the recent funding applications was to take the knowledge generated within CSML and a decade of polyculture research and build a production model for aquaculture using mine lake water. Following this, a bioeconomic model was planned to take into account the full costs of labour and remediation. This would have been a desirable product, encouraging commercial uptake of the aquaculture as a beneficial end use.

## Recommendations for further research

CSML Project 3.1 continued the pioneering development of aquaculture in remediated mine lake water. It also continued a decade of research into the polyculture of marron and silver perch, further elucidating the factors that govern production in multi-species systems. The research, however, stopped short of producing a bio-economic model that incorporated the full costs of remediation for application by the wider mining community. The aquaculture industry also requires such a model, which would be built on a robust production model that incorporated initial stock size, relative densities, habitat complexity and abundance, and turbidity. It is recommended that efforts continue to meet these goals with funding applications stressing the importance to regional development in places like Collie.

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# PROJECT 3.2: INLAND SALINE AQUACULTURE


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## Final Year Annual Research Report

The CSML project *Inland Saline Aquaculture* was completed by December 2006 and final year annual reporting information provided in the 1st April 2005 to 31st March 2006 annual report to the State Government.

While the project has been completed, main findings and outcomes have continued to contribute to the progressing understanding of mine lake water beneficial end uses.

During the last reporting period the CSML project 3.2 team initiated a three-year PhD research project, with industry support from BHP Billiton, on the Cultivation of seaweed in inland saline water.

This project builds on research results from the inland saline aquaculture research and will include a series of seven trials, with information gained from each trial used in the subsequent trial. The initial trials will investigate the optimum culturing technique (vegetative propagation or sporulation) for growing *Gracilaria cliftonii Withell*, Millar, & Kraft, 1994 in inland saline water and potassium fortified inland saline water. The next trial will include the effects of different N-P-K ratios on the productivity of *G. cliftonii* in laboratory conditions. Further trials will compare the productivity of *Gracilaria* farming by using three different cultivation techniques (line farming, raft farming and bottom planting) in inland saline water. Other trials will investigate the production parameters of *G. cliftonii* in earthen ponds with appropriate culturing method and N-P-K ratio in inland saline water. The extraction process of agar from *G. cliftonii* will be modified to suit farming conditions and nutrient composition of the product. Physical and chemical properties of extracted agar and the effect of the nutrient profile of inland saline water on quality will be determined. Finally an economic model will be developed for the commercialization of *Gracilaria sp.* The results of laboratory trials will be further validated and modified, if necessary.

The research will help in understanding the life cycle of locally available seaweed species when grown in inland saline water and provide information that can be used to determine the suitability of inland saline water in Western Australia for commercial seaweed culture.

Short- and long-term physiological responses to selected species exposed to inland saline water was examined in Wannamal and Goomalling, WA.

## Executive Summary

The main aim of the project 3.2 was narrowed down to investigate the physiological responses of the selected aquatic species to the inland saline water (ISW) in order to evaluate its suitability for aquaculture. The financial support provided by the CSML was mainly used to fund a portion of the operational costs of the research conducted by the post-graduate students under the supervision of Dr Fotedar.

The main species selected were western king prawns (*Penaeus latisulcatus*) and black tiger prawns (*Penaeus monodon*) though some preliminary research was conducted in greenlip abalone (*Haliotis laeviagata*), western rock lobsters (*Panulirus cygnus*), giant freshwater prawns (*Macrobrachium rosenbergii*), barramundi (*Lates calcarifer*) and red macrophyte (*Gracilaria sp.*). The general research methodology involved transporting the ISW from Wannamal (31º 15"S, 116º 05"E), 100 km northeast of Perth and testing its suitability under laboratory conditions. The physiological responses were investigated when these species were exposed and then cultured in varying salinity levels and ionic profiles of ISW. The short-term responses (survival, changes in osmoregulatory and ion-regulatory capacities and hepatosomatic index) and long-term responses (growth, moult-frequencies, survival and organosomatic indices) were measured after the selected species were exposed to different water types for different time periods. The ionic profile of inland saline water was altered by three ways: by mixing different proportions of ocean water (OW) with inland saline water; by adding various quantities of KCl salt to ISW; and by diluting the ISW with freshwater. After analysing the responses shown by these species and understanding the underlying factors behind these responses, it was quite evident that there is a necessity to manipulate the ionic profiles of potassium-deficient ISW to provide ideal conditions for these selected species to exhibit commercially acceptable survive and grow rates. However, the requirement for potassium is species specific and dependent on the concentration of other ions present in ISW.

## Introduction

In order to investigate the aquaculture viability of the selected high-value aquatic species, it is imperative to have a sound understanding of their physiological response(s) when they are exposed to inland saline water (ISW) sourced from the mining sites. The ISW sourced form mining voids has a distinct ionic profile and water quality parameters than ocean water (OW).

The research conducted at Aquatic Sciences, Curtin University has shown potential for inland saline water aquaculture. The species such as, black tiger prawns (*Penaeus monodon*), western king prawns (*P. latisulcatus*), Western rock lobsters (*Panulirus cygnus*), greenlip abalone (*Haliotis laeviagata*), giant freshwater prawn (*Macrobrachium rosenbergii*), barramundi (*Lates calcarifer*) and red seaweed (*Gracilaria sp.*) have shown mixed outcomes in terms of their survival and growth when cultured in ISW. Using SWOT analysis, the species were short listed and used as candidate species for further study. These short-listed species were western king prawns (*Penaeus latisulcatus*) representing stenohaline crustaceans and black tiger prawns (*Penaeus monodon*) representing euryhaline crustaceans.

Inland saline water (ISW) is in abundance in Australia as a result of anthropogenic activities, which in turn has led to environmental, social and economical problems. Remedial measures could include the use of ISW for culturing both stenohaline and euryhaline marine prawn species. The abundant supply of saline water from mining lakes offers an opportunity to investigate whether this environment can support aquaculture of marine species in a sustainable way. However, as ISW has a different ionic profile than ocean water (OW), it is imperative to understand the physiological responses of marine prawns when they are exposed and then cultured in ISW in order to evaluate their culture suitability.

This study focused on investigating the effects of K+ deficiency of ISW on the survival, growth, osmoregulatory capacities, regulatory mechanisms of Na+, K+, Ca2+ and Mg2+

concentration and the ratio of Na+ and K+ in *P. monodon* and *P. latisulcatus haemolymph.*

## Methodology

The main aim of the proposed research was to investigate the technical feasibility of rearing selected aquatic species using inland saline water.

This aim was achieved by fulfilling the following objectives:

- By identifying the source(s) of inland saline water and record the water quality data during the entire term of the project.
- By conducting acclimation, growth and stress trials on target species under controlled conditions using water from inland saline water bodies.
- By investigating the short-term and long-term physiological responses of the target species when cultured in inland saline water.

Saline water from Lake Wannamal (31° 15''S, 116 ° 05''E), 110 km northeast of Perth, was brought to the Curtin Aquatic Research Laboratory (CARL). Based on the water chemistry and its ionic dynamics over a period of time, the water was assumed to be a typical representative of the saline water from mining lakes. The inland saline water was aged and its ions manipulated by mixing different proportions of ocean water (OW) with inland saline water, by adding various quantities of KCl salt to ISW; and by diluting the ISW with freshwater or de-ionised water (tested only for euryhaline species). In all these trials raw OW and ISW were used as two extreme controls.

A series of laboratory trials were conducted on western king prawns and black tiger prawns to determine the effect of acclimation to potassium-deficient inland saline water (ISW), the minimum and optimum potassium concentrations requirements for the culture (with larvae, post-larvae and juveniles), the effect of sudden changes in salinity and potassium concentration in ISW on prawns, and the viability of prawn grow-out in potassium-fortified ISW. Prawn survival, growth, ingestion rate, moulting, osmoregulation, ionic-regulation, organosomatic indices and moisture content were monitored, analysed and correlated with the survival and growth of the prawns. The effect of various ionic conditions of ISW and K+ fortified ISW, which included different salinities, Na+/K+ ratios and level of K+ fortification were tested on prawn survival, growth, osmo- and iono-regulation and organosomatic indices. Various proportions of inland saline water and ocean water at various salinities were mixed to achieve different concentrations of K+ and other ionic profiles. KCl was also added to raw ISW in order to increase the K+ concentration of ISW without altering the other ionic profile.

## Results and Discussion

The research demonstrated that when western king prawns are cultured in ISW with different potassium concentrations, they show varied physiological responses. The performance of these prawns improved when reared in ISW with increased potassium concentration as compared to raw ISW. The research has also demonstrated that potassium fortification of ISW to at least 80% of the marine water concentration is required for sufficient post-larval and juvenile western king prawn growth and survival. Length of acclimation to ISW between 1 and 6 h has no impact on prawn survival, ingestion rate or osmoregulatory capacity (OC). PL and juvenile western king prawn survival has a positive linear relationship with potassium concentration in ISW. The direct transfer of prawns to ISW from OW results in a rapid decrease in serum potassium concentration. This changed serum ionic ratios and disrupted cellular ionic gradients and perhaps intracellular acid-base balance.

Western king prawns can tolerate sudden decrease in salinity (32 to 25 ppt) and change in ionic proportions in potassium-fortified ISW. Transfer of prawns to ISW results in significant reduction in serum potassium concentration and increase in Na+/K+ ratio. Western king prawns are stronger regulators of divalent ($Ca^{2+}$, $Mg^{2+}$) than monovalent ($K^+$, $Na^+$) cations in their haemolymph. The potassium deficiency in ISW reduces the ingestion rate (appetite), OC and ionic-regulatory ability of prawns. Western king prawn condition improves with increasing potassium concentration in ISW and is higher in OW than ISW. These results demonstrate the importance of fortifying ISW with potassium for the culture of western king prawns. However the lower growth rates and condition factors of prawns reared in potassium-fortified ISW than those reared in OW suggests the presence of other limiting factors in ISW. The relationship between medium osmolality (mOsm/kg) and salinity (ppt) was determined by the following equation:

$$y = 26.474x + 47.907 \quad (r^2 = 0.9948;\ n = 26)$$

where, y is medium osmolality (mOsm/kg) and x is medium salinity (ppt).

A significant ($P < 0.05$) positive linear relationship exists between western king prawn serum osmolality and medium osmolality. The difference in slope between the osmoregulation line and the isosmotic line (slope = 1) indicates the degree of osmoregulation by prawns. The slope of the osmoregulation line for western king prawns in the present research is 0.327, which fits into the range previously reported for this species: 0.267-0.372 for prawns 2.95 to 5.79 g in weight.

OC had a significant ($P < 0.05$) negative correlation with external osmolality and serum osmolality. Western king prawns were not maintaining a constant serum osmolality as salinity changed but were regulating to a certain extent and the degree of regulation increased as salinity decreased. OC was negatively correlated with osmolality and ion concentrations because all trials were conducted at or below the isosmotic point for western king prawns.

The present research has demonstrated a positive correlation between potassium concentration in ISW and prawn survival and a negative correlation between $Na^+/K^+$ ratio in ISW and prawn survival at different life stages. This is summarised in Table 1.

There were strong positive correlations between external osmolality and serum sodium and between serum osmolality / OC and serum sodium, external sodium and chloride. This demonstrates the important role sodium and chloride play in osmoregulation. Sodium and chloride are the major ions in prawn haemolymph, accounting for between 75 and 94% of haemolymph osmolality in several penaeids. Sodium appears to be the least regulated of the major cations in prawn haemolymph, as shown by its strong correlation with external osmolality and sodium. Chloride has a similar regulation pattern to sodium in prawn haemolymph.

**Table 1:** Correlation between prawn survival and potassium concentration in inland saline water.

| | Survival | |
|---|---|---|
| | Pearson's | N |
| $K^+$ Concentration | 0.814 | 12 |
| % of OW $K^+$ | 0.849 | 12 |
| $Na^+/K^+$ Ratio | -0.881 | 12 |

Magnesium and sulphur were the ions in western king prawn serum with the weakest correlations with external and serum osmolality. This demonstrates that these two ions are the least affected by changes in external osmolality and are the most strongly regulated over the range tested. These two ions are both regulated in crustaceans by the antennal gland. Above 30ppt the haemolymph sulphate concentration increases linearly with the medium sulphate concentration.

The degree to which western king prawns regulated each individual ion in their serum was also reflected in the correlation between serum and external ionic concentrations. Sodium, being the least regulated ion (measured in the present research) in western king prawn serum had the highest correlation with its external concentration (0.765), followed by potassium (0.748), calcium (0.640), sulphur (0.405) and magnesium (0.203). Thus divalent cations were more strongly regulated than monovalent cations. These correlations also follow the degree to which ion is regulated by the antennal gland. Sulphur and magnesium are the most regulated by this organ, followed by calcium, potassium and sodium, with the latter two ions only regulated by the antennal gland following sudden salinity change. Serum potassium concentration appeared to be much more affected by its concentration in the external medium (0.748) than by overall osmolality (0.466). This was also slightly observed for calcium (0.640 / 0.564) but not sodium (0.765 / 0.756). This reflects the close correlation between sodium concentration and osmolality.

Excluding calcium, there appeared to be an inverse relationship between the number and strength of correlations of a serum ion with external ions and how strongly each ion was regulated. There may also be some inter-ion species relationships represented in the correlations. Excluding serum sodium and external chloride, calcium was the only ion that had the highest serum-external ionic correlation with a different external ion, magnesium. Thus the external magnesium concentration may have a role in haemolymph calcium regulation. Calcium and magnesium, both divalent cations, may share a common carrier and prawns need to strongly hypo-regulate haemolymph magnesium. Therefore an increase in external magnesium concentration may result in prawns needing to increase internal calcium concentration in order to reduce the influx of magnesium and decrease the work load of the antennal gland. However this correlation did not exist in western king prawns in OW due to a more constant external magnesium concentration. Several correlations existed between western king prawn condition indices and osmolality / ionic concentrations. The western king prawn hepatopancreas energy reserves increased and tail muscle energy reserves decreased slightly as salinity increased (decreasing OC) in the range 20 - 33.5 ppt.

The present study has demonstrated that K+ deficient ISW has a negative effect on the survival, organosomatic indices and ability of Penaeus monodon to osmo- and iono-regulate in their haemolymph. The negative effects were greater at higher salinities than at lower salinities. As P. monodon are a strong osmo- and iono-regulators at low salinity, prawns exposed to and cultured in low salinity (5 ppt) ISW without K+ fortification had improved survival and osmo- and iono-regulation compared to those at high salinity. This study highlighted the underlying physiological reasons for the low survival of P. monodon when cultured in ISW having low K+ concentration. These reasons are mainly based on the osmoregulatory capacity (OC), ionic regulation, organosomatic indices and growth responses of P. monodon. The growth of PL and juveniles in low salinity ISW was comparable to those reared in OW.

Both PL and juveniles of tiger prawns reared in ISW displayed a similar survival pattern with increase in salinity (hence increase in the K+ concentration) decreased their survival rate. This indicates that increasing the K+ concentration alone (by increasing salinity) without changing its ratio with Na+ has not altered the detrimental impact of K+ deficient ISW on PL and juvenile survival. The synopsis of survival and specific growth rate (SGR) results is provided in Table 2a and b.

**Table 2a:** Synopsis of survival when five species were exposed to two water types

| **Species** | **Mean survival days in raw ISW** | **Mean survival in fortified ISW** | **Remarks** |
|---|---|---|---|
| *P.monodon (pl)* | 4 days | 80% (14 days) | Probit of mortality (96 hours) = 0.54x[ISW]-2.8; R2 = 0.81; PL showed lower (SGR) when reared in >ISW50 |
| *P. monodon* | 10 days | 57% (56 days) | >50% of fortification of K+ is required in raw inland saline water to make it suitable for rearing P. monodon juveniles; ISW70 resulted in higher OC than ISW50 (-49.3±2.7 and -60.3±2.8 respectively) |
| *P. latisulcatus* | 12 days | 100% (20 days) | survival% = -0.20 x [K+] + 0.96; R2 = 0.99; SGR, moult increment and feed ingestion rate were higher when reared in OW than in other water types |
| *Panulirus. Cygnus* | - | - | Iso-osmotic point in ISW was 35 ppt |
| *Haliotis Laeviagata* | 4 days | 20% (21 days) | The acute LC50 value for inland saline water was between ISW75 and ISW100 |

**Table 2b:** Survival (mean ± S.E (%)) and SGR (mean ± S.E. (%g/day)) and osmoregulatory capacity (mean ± S.E (mOsm/kg)of P. monodon juveniles over 56 day of trial.

| Day | ISW | OW | ISW fortified with 70% conc. of OW | ISW fortified with 50% conc. of OW |
|---|---|---|---|---|
| Survival | 0 | 271.4± 5.8a | 257.1 ± 8.3a,b | 246.7 ± 10.2b |
| SGR | n.a | 20.8 ± 0.1a | 20.8 ± 0.1a | 1,2,40.5 ± 0.1b |
| OC | n.a | -42.2 ± 5.9a | -49.3 ± 3.1a | -60.3 ± 3.3b |

*Data in the same column within the same parameter (Weight, SGR and FCR) having different subscript letters (1, 2, 3, 4) are significantly different at level of 0.05. Data in the same row having different superscript (a, b) are significantly different at level of 0.05.*

On the other hand, fortifying K+ in ISW to various proportions of the K+ concentration in OW at wide salinity range (5 to 45 ppt) could eliminate the detrimental effect of K+ deficient ISW on the physiological mechanisms of this prawn species. Fortifying K+ in ISW to 50 to 70% of the K+ concentration in OW by adding KCl improved the survival, growth and OC of prawns (Chapter six). Further, increasing the K+ concentration of ISW to 100% of the OW K+ concentration improved the survival, growth, osmo- and iono-regulatory ability and organosomatic indices of prawns to a level comparable to those reared in OW.

This research on other decapods including black tiger prawns revealed that the K+ deficiency of ISW has a lethal effect on prawns, which was increased following an increase in exposure time and salinity. However, at 5 ppt ISW, prawns could survive and demonstrated comparable growth to those reared in OW. The reason for prawn survival and growth in ISW at 5 ppt was their strong ability to iono-regulate their serum K+ concentration similar to those in OW. This allowed the establishment of normal intercellular Na+/K+ ratios which plays an important role in the activation of Na+/K+ ATPase. Furthermore, the strong ability of PL tiger prawn and juveniles to osmo- and iono-regulate was related to the prawns being euryhaline. Comparisons made with other euryhaline (Macrobrachium rosenbergii de Man) and stenohaline (Panulirus cygnus) crustacean species demonstrated that at a low salinity of ISW, tiger prawns had a similar ability to osmo- and iono-regulate their haemolymph as M. rosenbergii. In contrast, P. cygnus had a poor ability to osmo- and iono-regulate as compared to both the euryhaline species (Table 3).

Following the K+ fortification of ISW to a concentration ranging from 50 to 100% of the K+ concentration in OW, all the negative effects of K+ deficient ISW were eliminated within the salinity range of 5 to 45 ppt. The prawn survival, growth, osmo- and iono-regulation and organosomatic indices demonstrated comparable responses as those exposed to and reared in OW.

**Table 3:** Serum osmolality and osmoregulatory capacities (OC) of P. monodon and P. cygnus exposed to ISW at different salinities.

| Species | Salinity (ppt) | Serum osmolality (mOsm/kg) | OC (mOsm/kg) |
|---|---|---|---|
| *P. monodon* | 5 | 547.0 – 581.8 | 397.7 – 445.2 |
| | 15 | 584.4 – 648.7 | 159.7 – 224.0 |
| | 25 | 639.7 – 671.6 | -33.3 – (-61.4) |
| | 35 | 746.0 – 888.0 | -64.1 – (-206.1) |
| *P. cygnus* | 16 | 650.9 – 822.6 | 170.7 – 342.3 |
| | 22 | 746.2 – 854.4 | 100.2 – 208.4 |
| | 28 | 843.7 – 922.8 | 35.1 – 114.2 |
| | 34 | 962.6 – 979.4 | 12.9 – 20.6 |

This study demonstrated that K+ deficient ISW could be used to culture tiger prawns only if the salinity is lowered to 5 ppt. On the other hand, ISW at salinity higher than 5 ppt is only suitable for tiger prawns culture if ISW is fortified with K+ to 50 to 100 % of the OW K+ concentration.

## Conclusions

Some important outcomes of the research are:

1. $K^+$ deficient ISW has a lethal effect on PL and juveniles of western king prawns and black tiger prawns. The $K^+$ concentration in ISW should be fortified to between 50 and 100% of the $K^+$ concentration of OW to allow the normal physiological mechanisms of western king prawns to function. A potassium concentration greater than 76% of that in OW and a $Na^+/K^+$ ratio of less than 39 are necessary to maintain a comparable level of juvenile of western king prawn survival, as in OW. Potassium concentration plays an important role in efficient osmo -and iono-regulatory functioning in western king prawns with potassium fortification of ISW allowing prawns to maintain a higher OC and stronger ionic regulation than those reared in non-fortified ISW.
2. However, increasing $K^+$ concentration in ISW by increasing salinity has no positive effect on the survival of tiger prawns.
3. ISW at 5 ppt may be used to culture tiger prawns. However, PL of tiger prawns show high mortalities in 5 ppt due to higher cannibalism, juveniles of tiger prawns are more suitable to culture in this water type.
4. The ability of tiger prawns to survive and grow in ISW at 5 ppt is supported by their strong ability to osmo- and iono-regulate their haemolymph. This strong ability has enabled prawns to maintain strong serum $K^+$ regulation and establish the serum $Na^+/K^+$ ratio within a range allowing proper physiological functioning to continue.
5. The length of acclimation to ISW has no significant impact on the survival and osmolality of western king prawns.
6. Exposing tiger prawns juveniles to ISW at a salinity range of 5 to 35 ppt reduced their serum $K^+$ concentration and diminished the ability of prawns to regulate other ions including $Na^+$, $Ca^{2+}$ and $Mg^{2+}$.

7. $K^+$ deficient ISW negatively affects the physiological mechanisms of tiger prawns by disrupting the $Na^+/K^+$ ATPase mechanism. Fortification of $K^+$ in ISW by either adding KCl or mixing ISW with OW corrected the $Na^+$ and $K^+$ balance and brought the medium $Na^+/K^+$ ratio closer the $Na^+/K^+$ ratio of OW.

8. Euryhaline crustaceans such as P. monodon and M. rosenbergii have more flexibility to adapt to culture in ISW than stenohaline crustaceans such as P. cygnus.

9. Western king prawn juveniles can tolerate sudden salinity decrease, from 32 to 25ppt and 27 to 20ppt in ISW and 80-100% potassium-fortified ISW. P. latisulcatus juveniles can tolerate a sudden increase in medium potassium concentration, from 78 to 284 mg/L and 78 to 365 mg/L in ISW. P. latisulcatus juveniles have the ability to recover from three-day exposure to ISW when the potassium concentration is increased.

10. Western king prawn tolerance of ISW improves as prawns grow from PL to juvenile stage and this is related to changing osmo-and iono-regulatory capability with life stage.

11. Transfer of western king prawns to ISW results in significant reduction in serum potassium concentration and increase in $Na^+/K^+$ ratio. Western king prawns condition improves with increasing potassium concentration in ISW and is higher in OW than ISW. Hepatopancreas and tail muscle moisture contents and indices are suitable indicators of prawn condition, particularly for exposure periods greater than 48 h. A linear relationship exists between serum and medium osmolality in western king prawns.

12. There are factors other than potassium concentration in ISW than can affect performance of both stenohaline and euryhaline prawns. These are likely to be different proportions and ratios of other ions, such as calcium and magnesium, in ISW.

13. Western king prawns temporarily stop osmoregulating soon after ecdysis, with serum becoming isotonic to the medium.

14. Western king prawns are stronger regulators of divalent ($Ca^{2+}$, $Mg^{2+}$) than monovalent ($K^+$, $Na^+$) cations in their serum.

15. As with other penaeids, western king prawns strongly hypo-regulate serum magnesium and strongly hyper-regulate serum calcium in the salinity range 20 - 33.5 ppt. Serum calcium concentration appears to be regulated towards a constant proportion of the external medium over the osmolality range of 772 – 946 mOsm/kg. If the calcium concentration in the external medium increases prawns will increase their serum calcium concentration to take advantage of increased calcium availability.

16. The most common cation in western king prawns serum and the least regulated major cation is sodium. Its serum concentration is closely correlated with osmolality.

## Project 3.3: Environmental management system for mine lake aquaculture


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### Final Year Annual Research Report

In the period 1st April 2006 to 31st March 2007, the focus of the CSML project *Environmental management system for mine lake aquaculture* was on determining the potential of constructed wetlands to filter nutrients from aquaculture waste.

The project found zeolite, a naturally occurring aluminosilicate mineral found in volcanic sedimentary rocks, was effective in removing total ammonia nitrogen and aluminium from pond water. Subsurface flow wetlands, incorporating the estuarine sedge *Juncus kraussii* removed up to 69% of the total nitrogen load and 88.5% of the total phosphorous load from aquaculture effluent.

This project has provided, for the first time, a comprehensive summary of beneficial end uses of mine lakes and mine lake water from throughout the world. It has also identified the general environmental impacts associated with these different end uses and developed a detailed assessment of the potential environmental impacts from different aquaculture production systems using mine lakes and mine lake water. Nutrient and heavy metal contamination has been monitored at the Collie Aquafarm and mitigation procedures for these impacts have been tested.

Results of this CSML project led to a successful application to the Rural Industries Research and Development Corporation in 2006, to further investigate the potential for utilising crop and forage plants to filter aquaculture effluent in an agricultural setting. This research has the potential to provide a basis for integrated agri-aquaculture systems in rural areas of Australia.

The major new area of research which has arisen as a result of the project is the investigation of measures of ecosystem function, such as productivity, species diversity and system resilience, with a view to establishing monitoring protocols for the impact of mine lake aquaculture upon the surrounding environment. This is now being pursued as a PhD project.

Small scale Sub Surface Flow system established at Murdoch University's Fish Health Unit for experimental testing on nutrients and other pollutants removed by soil/plant ecosystem.

## Executive Summary

There are a range of potentially beneficial end uses of mine lakes and of extracted mine lake water. The major research emphasis of CSML has been on aquaculture and horticulture using extracted and treated water, but the lakes themselves may at some point provide facilities for recreation, eco-tourism and nature conservation. While the identification of economically viable end uses is an essential part of any strategy to develop sustainable mine lakes, these end uses may have their own environmental impacts. It is important that potential impacts be identified, the risks of each impact assessed and a strategy for managing the risks developed.

In this project, we reviewed the national and international literature and conducted focus group interviews to identify potential end uses for mine lake water and the environmental risks associated with such end uses. Nine principal end uses were found: recreation and tourism; wildlife conservation; aquaculture; irrigation of crops or pasture; horticulture or floriculture; livestock water source; potable water source; industrial water source; and chemical extraction. All of these end uses have environmental impacts associated with them, which must be balanced against their economic or social benefits.

Three different types of production systems have been used for mine lake aquaculture in Australia and overseas: net pen culture within the mine lake; pond culture (free or in net pens) using water extracted from the mine lake; and recirculating tank culture using water extracted from the mine lake. We used surveys, interviews and site visits to identify potential environmental impacts associated with these production systems. These potential impacts may be classified into those that occur through the consumption of resources, such as land, water, seedstock and feed, and those that occur through the production of wastes, such as uneaten and excreted nutrients, chemicals, pathogens and feral fish. Many of these impacts can occur both within the production system (on-site) and external to the production system (off-site).

The Collie Aquafarm, an existing aquaculture facility in Collie, uses treated mine lake water from the Premier Coal W05H void to produce silver perch and marron in ponds. We identified two major issues that may have detrimental effects both on-site and off-site at the Collie Aquafarm: nutrients (principally nitrogen and phosphorous) derived from uneaten feed and excretion products of fish; and heavy metals, particularly aluminium, which are present in extracted mine lake water. A range of nutrient and heavy metal parameters were therefore monitored at the Aquafarm. The only water quality parameters to consistently exceed ANZECC environmental trigger values were ammonium, nitrite/nitrate and aluminium. Aluminium levels were also high in the pond sediments, and likely to have been responsible for a major fish kill in one of the ponds.

Zeolite, a naturally occurring aluminosilicate mineral found in volcanic sedimentary rocks, was effective in removing total ammonia nitrogen and aluminium from pond water. Subsurface flow wetlands, incorporating the estuarine sedge *Juncus kraussii* removed up to 69% of the total nitrogen load and 88.5% of the total phosphorous load from aquaculture effluent.

## Introduction

Final mine voids are the pits that remain when open cut mines have ceased operation. Many open cut mines extend below the watertable, and require substantial groundwater abstraction during mining operations. When dewatering ceases, abandoned mine voids usually fill with a combination of groundwater, surface runoff and sometimes diversion from other water sources. Mining approval processes have typically paid little attention to the environmental problems associated with final mine voids or lakes. In recent years, however, increasingly stringent reclamation rules and regulations have meant there is a need on behalf of mining companies for more judicious operational planning and more thorough restoration techniques for mine voids (Norton 1992; Axler *et al.* 1996; Cloke *et al*. 1996; Johnson and Wright 2003). The preferred restoration method for final mine voids is often backfilling and rehabilitation to pre-mining or adjacent 'reference' ecosystems (Schuman *et al*. 1990; Cloke *et al.* 1996; Bell 2001; Ludwig *et al.* 2003). With very large voids, however, backfilling is not an economically viable strategy, and both mining companies and land management agencies have recently focused on beneficial end uses for mine lakes (Axler *et al.* 1996; Johnson and Wright 2003).

Beneficial end uses can be defined as goods or services provided by the mine lake, or any element or segment of the mine lake, which provide economic, health, welfare, safety, or aesthetic benefits to the community. While the identification of economically viable end uses is an essential part of any strategy to develop sustainable mine lakes, these end uses may have their own environmental impacts. Environmental impacts are here defined broadly to include any adverse effects upon people, natural biota or natural resources. It is important that potential impacts be identified, the risks of each impact assessed and a strategy for managing the risks developed.

## Methodology

There were three broad aims to this project:

1. Identify potential end uses for mine lakes and extracted water in the Collie region, and the major environmental impacts associated with these end uses.
2. For one particular end use, aquaculture, assess and monitor potential environmental impacts.
3. Investigate mitigation procedures for environmental impacts identified as significant from (2).

### *Identify potential end uses and environmental impacts*

We conducted a literature survey and a focus group interview with resource managers for two sources of information. The first was to compile a list of end uses that we determined to have most practical relevance to treated acid mine lakes. The second was to understand how any given end use could create further environmental impacts and to rank them accordingly. To minimise subjectivity in our ranking procedure, we used the risk management guidelines of the Standards Association of Australia (Anon 1999) to develop a semi-quantitative assessment of the likelihood of occurrence and the consequences of environmental impacts for each potential end use. Risk scores were calculated for each potential use in each of seven environmental risk categories: public health and safety; visual pollution; landscape alteration; adverse changes to water quality; heavy metal deposition; wind and water erosion; and atmospheric pollution. Three assumptions were made for this analysis:

1. Closure criteria for mine voids will require engineering works and site rehabilitation to a standard which minimises public safety issues and visual pollution associated with the void itself. The environmental impacts we consider, therefore, are due only to the beneficial end use, not to the void from which water may be derived.
2. The mine void water has been treated in some way to reduce acidity to a level appropriate for the end uses.
3. Each end use is considered separately. In practice, many potential end uses may not be mutually exclusive and this may produce new combinations of environmental impacts.

### *Assess and monitor environmental impacts from mine lake aquaculture*

Aquaculture production systems utilizing mine lake water, and potential environmental impacts from such systems were identified in three ways. 1) A search of the published literature on mine lake aquaculture. 2) Focus group interviews with representatives from resource management agencies in Western Australia. 3) Site visits to the Collie Aquafarm, an existing aquaculture facility which uses treated mine lake water from the Premier Coal W05H void to produce silver perch and marron.

In our site visits to the Aquafarm, we identified two major issues that may have detrimental effects on productivity within aquaculture ponds: nutrients (principally nitrogen and phosphorous) derived from uneaten feed and excretion products of fish; and heavy metals, particularly aluminium, which are present in extracted mine lake water. We therefore monitored the levels of nitrogen, phosphorous and aluminium in ponds at the Collie Aquafarm. In 2004, two ponds at the Collie Aquafarm were stocked with 600 marron, two ponds with 600 marron and 200 caged silver perch, and two ponds with 600 marron and 400 caged silver perch. Total nitrogen, ammonia, ammonium, nitrite, nitrate, total phosphorous, aluminium and a range of other water quality parameters (dissolved oxygen, pH, alkalinity, conductivity, temperature, turbidity, total dissolved solids, chlorophyll A, cadmium, iron, magnesium, manganese, lead) were monitored monthly in these ponds between February and September, 2004.

### *Investigate mitigation procedures*

Monitoring studies suggested that water parameters most likely to effect polyculture productivity at the Collie Aquafarm were ammonia (which exists in equilibrium with ammonium in solution) and aluminium. We tested the efficacy of zeolite, a naturally occurring aluminosilicate mineral found in volcanic sedimentary rocks, in removing total ammonia nitrogen (TAN, the sum of ammonia and ammonium) and aluminium from pond water. Experiments were conducted at the CSML aquarium facilities in Collie. Essentially, water of different TAN or aluminium concentrations (spanning the ranges found in pond water) was made up in aerated tubs and randomly assigned to different combinations of zeolite type (rock or powder) or dosage level (10 g/L and 30 g/L), with four replicates per treatment combination. TAN or aluminium concentrations and other water quality parameters (temperature, pH, conductivity, turbidity) were then measured regularly over a 24 hour period. Differences in TAN and aluminium concentrations were compared over treatments and time of measurement using repeated measures analysis of variance.

The water parameters most likely to have off-site effects if aquaculture effluent is released from the Aquafarm and not captured by the mine lake are total nitrogen (TN) and total phosphorous (TP). We tested the efficacy of subsurface flow constructed wetlands in removing these nutrients from aquaculture effluent. We constructed 16 wetland cells, planted with the estuarine sedge *Juncus kraussi*, and allocated them randomly to high (5 mg/L TN, 1 mg/L TP) and low (0.5 mg/L TN, 0.1 mg/L TP) nutrient treatments, derived from aquaculture waste. Samples of inflow and outflow water were taken regularly over a 38 day test period and analysed for TN and TP concentrations. Concentrations were converted to loads and amount removed expressed as a percentage of input load. Percentage removal data were normalized and compared over nutrient treatments and time by repeated measured analysis of variance.

## Results and Discussion

### *Identify potential end uses and environmental impacts*

From the literature, we identified nine end uses, which have either been proposed or implemented in mine voids around the world (Table 1). Of these end-uses, only recreation and tourism, and possibly aquaculture, use the mine void directly; all the other end-uses rely on the void as water storage, with the water being extracted for use away from the void.

These end uses all have their impacts, albeit to varying degrees (Table 1). Recreation and tourism is often promoted as a potential end use for mine lakes (Edwards *et al.* 1996; Pretes 2002) and especially for water sports using powerboats, however this invariably generates noise (atmospheric) pollution and can cause water erosion, lead and oil deposition, and can endanger other users of the water body. Horticulture and floriculture can affect biodiversity through pesticide and herbicide usage, and irrigation with mine void water can result in heavy metal and nutrient deposition on the land (Anderson 1996; Cloke *et al.* 1996; Al-Jamal *et al.* 2002; Ramirez and Rogers 2002). Broadacre crop irrigation is likely to produce similar impacts to horticulture and floriculture, such as changes to water quality and the effect of water usage on landscape erosion and pollution (Ericsson and Hallmans

1994; Tchobanoglous and Angelakis 1996; Annandale *et al.* 2001). The overwhelming impact of aquaculture is the generation of nutrient-enriched wastewaters that in turn require treatment (see Axler *et al.* 1996; Viadero and Tierney 2003). The obvious impact associated with potable re-use concerns issues of public health (Geldreich 1996; Tchobanoglous and Angelakis 1996). The use of mine waters for livestock watering can impact on biodiversity, while industrial re-use of water could result in heavy metal deposition (Anderson 1996). Both could cause human health concerns depending on the nature of the industry (e.g. Harper *et al.* 1997). Chemical extraction and wildlife conservation were the two potentially beneficial end-uses generating the lowest risk of adverse environmental impacts from our analysis, although neither were risk free. The extraction of chemicals from mine waters might generate health concerns (Ericsson and Hallmans 1994). The establishment of a conservation area such as a wetland (e.g. Tyrrell *et al.* 1997) may impact on biodiversity through a change in landscape pattern, and may also lead to health issues associated with vector-borne diseases (see Russell *et al.* 1997).

Current proposals for beneficial end uses of mine voids in Collie have focused on recreation and tourism, aquaculture and horticulture for particular voids. While some of these proposals are being developed through extensive planning and consultation, they are essentially piecemeal, in that they do not consider a strategic approach to the wider issue of sustainable mine closure in the whole Collie region.

**Table 1.** Potential end uses for mine void water, and risk assessment of environmental impacts in different categories. The potential end uses are ranked from greatest to least environmental impact, using a qualitative risk assessment approach.

| End use | Description | Potential environmental risks | | | | | |
|---|---|---|---|---|---|---|---|
| | | Public health/ safety | Bio-diversity | Water pollution | Land pollution | Erosion | Atmos-pheric pollution |
| Recreation and tourism | Active and passive recreation within the mine lake, especially water sports | High | Low | Med | Low | Med | Med |
| Crop or pasture irrigation | Extraction of mine void water to irrigate broad acre agricultural crops or pastures | Low | Med | Med | Med | Med | Low |
| Horticulture and floriculture irrigation | Extraction of mine void water to irrigate horticultural crops or flowers | Med | Low | Med | Med | Low | Low |
| Aquaculture | Farming of fish or crustacean species, either in cages within the mine lake or using extracted water | Low | Med | High | Low | Low | Low |
| Potable water source | Use of treated mine void water to supplement drinking water supplies | High | Low | Low | Low | Low | Low |
| Livestock water source | Extraction of mine void water for livestock | Med | Med | Low | Low | Low | Low |
| Industrial water source | Use of mine void water in industrial processes, e.g. cooling, wash down, road making, fire fighting | Low | Low | Low | Med | Low | Low |
| Chemical extraction | Extraction of chemicals, such as sodium chloride, magnesium oxide, iodine | Low | Low | Low | Med | Low | Low |
| Wildlife conservation | Use of mine void water to create wetland habitat for native plants and animals | Med | Low | Low | Low | Low | Low |

### *Assess and monitor environmental impacts from mine lake aquaculture*

#### General assessment of impacts

Three different types of production systems have been used for mine lake aquaculture in Australia and overseas: net pen culture within the mine lake (Axler *et al.* 1996a); pond culture (free or in net pens) using water extracted from the mine lake (Viadero and Tierney 2003; Whisson and Evans 2003); recirculating tank culture using water extracted from the mine lake (Viadero and Tierney 2003). Rearing within the mine lake itself generally precludes water treatment, but the use of offtake water in either ponds or recirculating systems allows water treatment prior to aquaculture. All three production systems may vary in biomass density, feeding practices (feed type, feeding frequency) and water flow characteristics (closed, static or flow through).

Table 2 represents our classification of the potential impacts from mine lake aquaculture, identified from literature reviews, interviews with resource managers and site visits to the Collie Aquafarm. This classification divides potential environmental impacts of aquaculture production systems into those that occur through the consumption of resources, such as land, water, seedstock and feed, and those that occur through the production of wastes, such as uneaten and excreted nutrients, chemicals, pathogens and feral fish. Many of these impacts can occur both within the production system (on-site) and external to the production system (off-site).

Environmental impacts occurring within an aquaculture facility, if they affect stock survival or growth, have obvious effects on productivity and profitability. In addition, there are two ways in which on-site effects can be considered to also adversely impact upon the external environment. First, adverse impacts may occur when aquaculture occurs within the mine lake itself, and the lake also has other end-uses. For example, mine pit lakes were used for intensive net pen aquaculture in Minnesota, USA between 1988 and 1995, but was discontinued because of deteriorating water quality in the vicinity of the net pens (Axler *et al.* 1996, 1998). Second, when extracted mine lake water is used in pond or recirculating tank systems, any water quality changes within the system will affect the quality of discharge water unless treatment processes are put in place.

Potential off-site environmental impacts from aquaculture include displacement of vegetation, alteration of hydrological regimes, increased demand for fishmeal, introduction of exotic species and pollution of natural waterways. Wastes expelled into waterways may include particulate solids, dissolved nutrients, chemotherapeutics, heavy metals, salinity and acidity. The impact of water discharged from aquaculture production systems into receiving water bodies depends on discharge rates and differences in quality between discharge and receiving water.

**Table 2:** Potential environmental impacts from mine lake aquaculture, as identified by site visits, a literature review and interviews with representatives of resource management agencies in Western Australia.

| Environmental impact | Description of impact |
|---|---|
| **Resource Consumption** | |
| Clearing of vegetation | The construction of ponds or other systems for using water extracted from mine lakes may require the clearing of natural vegetation and associated terrestrial communities. |
| Use of water | The use of mine lake water for aquaculture, either within the lake or in offtake systems, may impact adversely on other beneficial end uses. |
| Consumption of natural feed | Mine lakes may contain native flora and fauna, and where culture occurs within the lake, cultured fish may have ecological effects upon existing aquatic communities through predation, competition and habitat disruption. |
| Consumption of artificial feed | Many commercial fish diets are based on up to 50% fishmeal, and it is estimated that 5 t of fish are required per 1t of fishmeal. Any contribution to the global demand for fishmeal contributes to the global decline in ocean fisheries, the source of fishmeal. |
| **Waste Production** | |
| Nutrient wastes | Nutrients are principally nitrogen and phosphorous derived from uneaten feed, undigested solids and excretion[4], which remain in the culture system in dissolved form, as unsettled, particulate solids or in the sediment. This may lead to eutrophication, with harmful effects on cultured fish or other organisms in the system. Soluble or particulate nutrients may also be discharged as effluent from the culture system to natural waterways, with harmful effects on aquatic communities. |
| Chemical wastes | Chemicals used in fish culture, such as chemotherapeutics, disinfectants or anaesthetics, may enter the culture system and have harmful effects on cultured fish or other organisms in the system. Chemicals that are discharged as effluent from the culture system to natural waterways may have harmful effects on aquatic communities. |
| Escaped fish | Fish that escape from pens or ponds into the mine lake or into natural waterways may have ecological effects upon existing aquatic communities through predation, competition, habitat disruption and as vectors for parasites or disease. |
| Water discharge | Mine lake water, even after treatment for aquaculture production, may contain contaminants such as heavy metals, acidity or salinity which will have detrimental effects on some aquatic or riparian communities. Discharge from aquaculture facilities may increase the chances of contaminated mine lake water entering natural waterways. |

### Monitoring at the Collie Aquafarm

There were no significant differences among ponds in total nitrogen, ammonia, ammonium, nitrite, nitrate, total phosphorous, or aluminium concentrations. There were, however, significant differences among sampling dates for all parameters, with nutrient levels in particular greater in the first four months of sampling (when higher water temperatures meant that fish growth rates were greater).

The only water quality parameters to consistently exceed ANZECC environmental trigger values were ammonium (mean concentration over all ponds and sampling times 0.20 ± 0.10 mg/L; range 0.003-0.76 mg/L), nitrite/nitrate (mean concentration over all ponds and sampling times 0.18 ± 0.09 mg/L; range 0.002-0.30 mg/L) and aluminium (mean concentration over all ponds and sampling times 1.34 ± 0.15 mg/L; range 0.13-0.76 mg/L). Aluminium levels were also high in the pond sediments, averaging 30,000 (± 5,000) mg/kg over the monitoring period. Aluminium also accumulated in the benthic dwelling marron: mean aluminium concentration in the tail muscle of 54 marron sampled from all ponds was 8.6 (± 2.4) mg/kg, more than double the concentration found in marron before they entered the ponds.

On 2 June 2004, there was a fish kill in one of the ponds, with almost all 200 fish dying in a few days. There appear to have been a number of contributing causes, but pathology investigations suggested that the most likely scenario was that a drop in pH in the pond, caused by reduced efficiency of the fluoridised limestone bed, caused an increase in aluminium in solution, which bound to the fish gills, causing suffocation. Aluminium is most toxic in the pH range 5-5.5, because of the release of aluminium hydroxides into the water.

### *Investigate mitigation procedures*

Zeolite rock and zeolite powder at both dosage rates were effective in removing TAN from pond water in the experimental systems. Figure 1 shows the reduction in TAN from an initial concentration of 8 mg/L in treatments using two different forms of zeolite (rock and powder) at a dosage rate of 500 g (corresponding to 30 g/L), compared to a control treatment of no zeolite. There was a steady decline in TAN concentration, with removal of approximately 70% of TAN over the 24 hour period. A similar trend was seen at a dosage rate of 10 g/L. At both dosage rates, decline in TAN concentration was significantly greater with zeolite powder than zeolite rock for the first 2 hours, but not significantly different thereafter. Zeolite powder, but not zeolite rock treatments led to an increase in water turbidity and pH from 7.4 to 8.4 in the first 2 hours. No other changes in water quality parameters occurred in any of the treatments. The increase in pH was due to a rapid uptake of $H^+$ ions from ammonium, and a concomitant increase in free ammonia concentration; this may have harmful effects on aquaculture stock if zeolite powder is used as an in-pond aquaculture treatment.

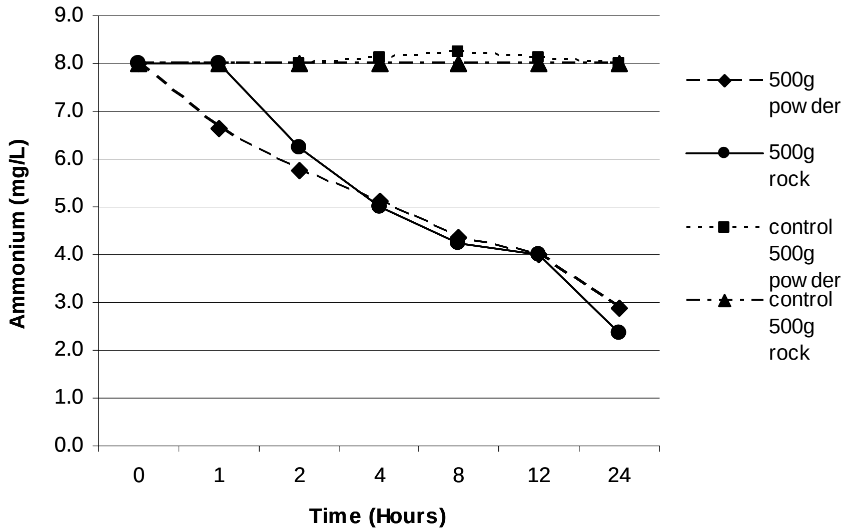


**Figure 1**. TAN concentration over a 24 hour period in treatments of 500 g of zeolite rock and 500 g of zeolite powder, applied to an initial TAN concentration of 8 mg/L.

Zeolite rock, but not zeolite powder, at both dosage rates was effective in removing aluminium from pond water in the experimental systems. Figure 2 shows the decrease in aluminium from an initial concentration of 14 mg/L, using zeolite rock at a dosage rate of 500 g (corresponding to 30 g/L), compared to a control treatment of no zeolite. There was a steady decline in aluminium concentration, with removal of 72% of aluminium over the 24 hour period.  A similar trend was seen at both dosage rates and there were no significant changes in other water quality parameters in any zeolite rock treatment.

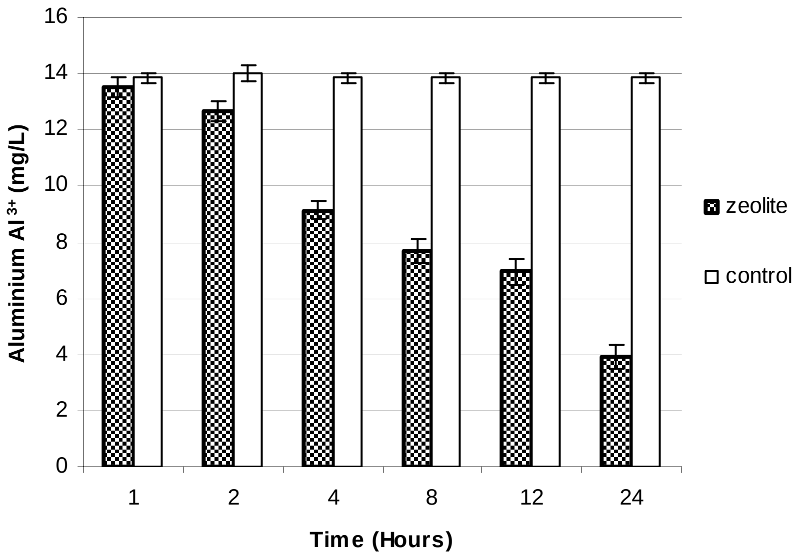


**Figure 2.** Dissolved aluminium concentration over a 24 hour period in mine void water treated with 500 g of zeolite rock, compared to water without zeolite treatment.  (Error bars denote standard error of mean).

After 38 days, constructed wetland plots removed up to 69% of the TN load and 88.5% of the TP load. TN removal increased markedly over time whereas TP removal remained relatively constant (Figure 3). The percentage removal of both TN and TP were significantly greater at high nutrient loads than at low nutrient loads.

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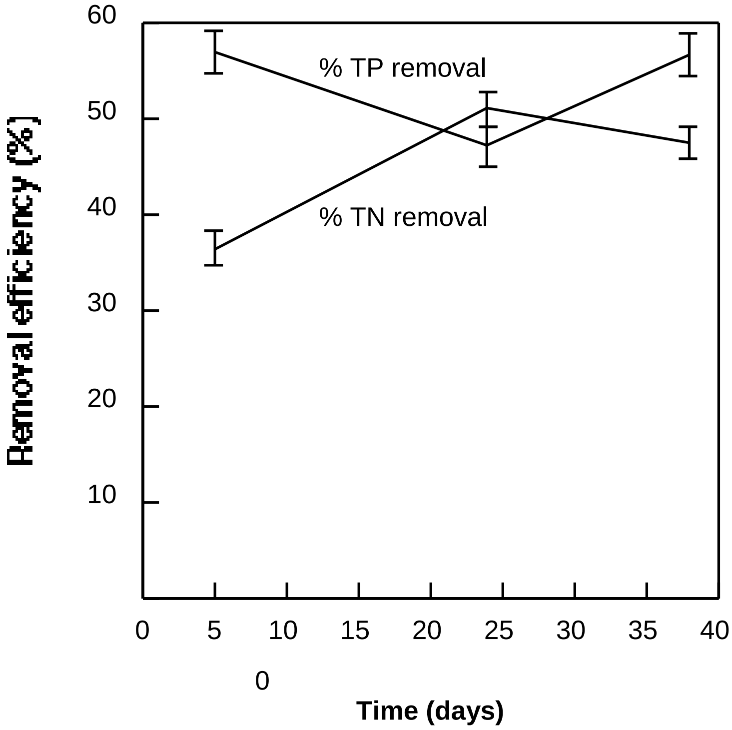


**Figure 3.** Percentage removal of total nitrogen (TN) and total phosphorous (TP) from aquaculture effluent by constructed wetlands at three measurement times. Values are least square means (with standard error bars), averaged over nutrient treatments.

## Conclusions

This project has provided, for the first time, a comprehensive summary of beneficial end uses of mine lakes and mine lake water from throughout the world. It has also identified the general environmental impacts associated with these different end uses and developed a detailed assessment of the potential environmental impacts from different aquaculture production systems using mine lakes and mine lake water. Nutrient and heavy metal contamination has been monitored at the Collie Aquafarm and mitigation procedures for these impacts have been tested.

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# PROJECT 3.4: AQUACULTURE HEALTH MANAGEMENT

**Final Year Annual Research Report**

The CSML project *Aquaculture Health Management* was completed in 2003 as a core component of an Honours project titled: Acute handling stressor affecting immunity in the freshwater crayfish, *Cherax tenuimanus.*

The results of this study were presented at several industry meetings and workshops and have contributed to an improved understanding on the part of marron farmers of the approaches that should be taken to avoid tail blister formation in harvested stock.

The results were particularly relevant to CSML project 3.1 *Polyculture as a beneficial end-use for mine lakes* with respect to the rearing and harvesting practises engaged in the project.

## Executive Summary

An industry survey and two preliminary laboratory trials were conducted to provide insight into factors that contribute to the occurrence of tail blisters in harvested marron. Processors often reject farmed marron that have unsightly lesions in their tail fan and the condition could lead to significant financial losses in the WA crayfish industry. The industry survey showed that the lesions were mostly evident in marron that had been harvested, purged and stored in processing tanks. While there were some anecdotal reports of the disease being occasionally observed in marron present in farm ponds no animals harvested from the farm ponds in this study exhibited tail blisters. Two laboratory trials were conducted to determine whether tail blisters could be induced *in vitro* by applying a handling stressor to marron held in aquarium. Two groups of marron were tested, one sourced from a farm with a history of tail blisters and the other from a farm whose stock did not exhibit this condition. In the first trial a handling stressor was applied every three days over a 21 day period and in the second trial the handling stressor was applied on a daily basis over 10 days. The trials demonstrated that tail blisters could be induced in the laboratory and that there was a tendency for the marron from the farm that did not report tail blisters to develop less blisters that those from the farm which reported regular occurrences of the condition. The increase in the level of stress induced in the second trial through a daily application of the stressor resulted in a higher incidence of tail blisters in both groups compared to the control and also some mortalities in the test animals. Further studies are recommended to evaluate the optimum stressor application for induction of tail blisters without attendant mortality. The results of the research were communicated to the marron industry through presentations at meetings and seminars.

## Background

Polyculture of marron and silver perch is being evaluated as a beneficial end use for mine lakes in the Collie region. A health management problem that has emerged in marron aquaculture is the occurrence of unsightly tail lesions in postharvest stock. Processors often reject crayfish with tail lesions and this has lead to significant financial losses in the WA crayfish aquaculture industries. In a recent survey of marron farmers this loss was estimated at approximately 5-10% of harvested stock (Storer, pers.comm.).

The tail lesions commonly appear along the margins and ventral surfaces of the tail fan appendages that are in regular contact with the ground. The cuticle in the vicinity of the tail fan is often split or perforated. Tail lesions appear as either swollen, fluid filled blisters or as black, swollen and eroded areas in the exoskeleton that can extend through the epi-cuticle, exo-cuticle and the calcified endo-cuticle and, in extreme cases, penetrate the non-calcified endo-cuticle to the internal tissues. The advanced lesions contain fibrous scar tissue and are often infected with a variety of opportunistic bacteria (Herbert, 1987). The etiology of the necrotic lesions in the tails of the *Cherax* species is unclear, but exoskeleton infections in other crayfish species are known to result from injury to the exoskeleton due to abrasive damage (Vogan et al. 1999), fighting injuries (Dyrynda, 1998), chemical attack (Schlotfeldt, 1972) or bacterial degradation (Cipriani et al. 1980). There are undoubtedly many factors, both internal and external, that may influence the prevalence and severity of the lesions.

From studies conducted by the Aquatic Science Research Unit, Curtin University, over the past two years it is apparent that some farms consistently observe tail lesions in their harvested stock and that the syndrome is stress related and exacerbated by poor postharvest handling practices. Stock from well managed farm ponds with an abundance of live feeds in the water column appear to have less tail lesions following harvest and storage that animals from ponds with low levels of natural productivity. This study was aimed at describing the underlying patho-physiological processes that lead to tail lesions in marron and at identifying animal husbandry and postharvest handling methods that reduce the incidence of tail lesions in harvested stock.

## Aims and Objectives

The aim of this research was to:

reduce the incidence and prevalence of tail lesions in cultured marron through development of improved rearing, harvesting and purging practises.

The specific objectives of the project were to:

- Define the syndrome and document lesion occurrence according to the size classes, sex, season, harvesting methods and procedures of post harvest handling.
- Investigate the patho-physiological processes that lead to tail blisters and advanced tail lesions under laboratory conditions.
- Evaluate the effect of pond productivity on lesion occurrence in harvested stock.
- Develop a set of recommendations for pond rearing and post harvest handling practises that reduce the occurrence of tail lesions in harvested stock.

## Results and Discussion

### *Industry survey*

To investigate the industry significance and likely causes of tail blisters in marron, a preliminary survey of marron growers in the southwest of Western Australia was conducted with the view of attempting to correlate farm site characteristics to tail blister occurrence and development. Data analysis of the preliminary survey suggested variations in the prevalence and conditions contributing to tail blister syndrome (TBS) over different farms. Two observations were consistently reported – the relative absence of tail blisters in marron freshly harvested from the farm pond and the increasing prevalence of tail blisters with increasing time after harvesting. TBS predominantly appears in the processing stages, in which handling of marron is inevitable. A handling stressor may be implicated in TBS inducement during processing.  A third observation was that some farms had stock that consistently developed TBS while the stock from others were consistently free of the condition.

The preliminary survey of 17 marron farms was used to document a comprehensive list of site characteristics for each farm. Some site characteristics included management, production, design, topography and incidences of where and when tail blisters occurred. Although all the information provided by marron growers on TBS incidence was anecdotal, trends were observed in the survey data. Growers expressed growing concern and felt TBS possibly threatened the future expansion of marron aquaculture in Western Australia. Every grower surveyed had experience with blistered marron, some with incidence rates of 100% per harvest.

The survey revealed two forms of tail blisters. The first form is a translucent fluid filled sac that can be moved under pressure (plate 1).

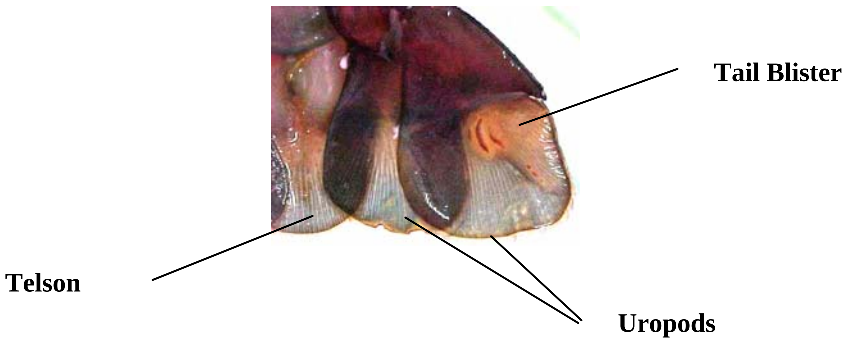


**Plate 1:** Tail blister on marron uropod (ventral view)

Small examples of the first form blisters are only evident on the ventral side of the tail. Further enlargement of these blisters forces fluid to encroach on the dorsal side (plate 2).

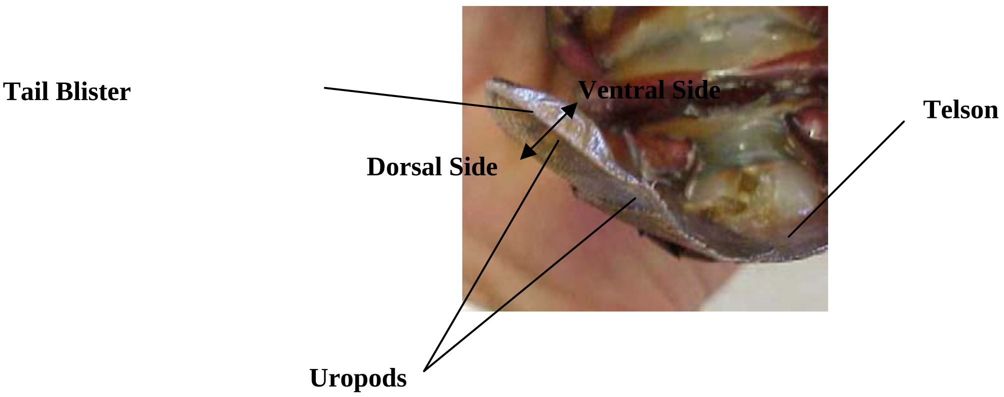


**Plate 2:** Profile of tail blister, highlighting pressure build up

The second form of blisters, the necrotic blisters (plate 3), are characterised by a dense mass of white tissue. Orange to brown discolouration may occur on both forms of blisters as a result of melanisation. At present the only known method of removing TBS is allowing the marron to moult.

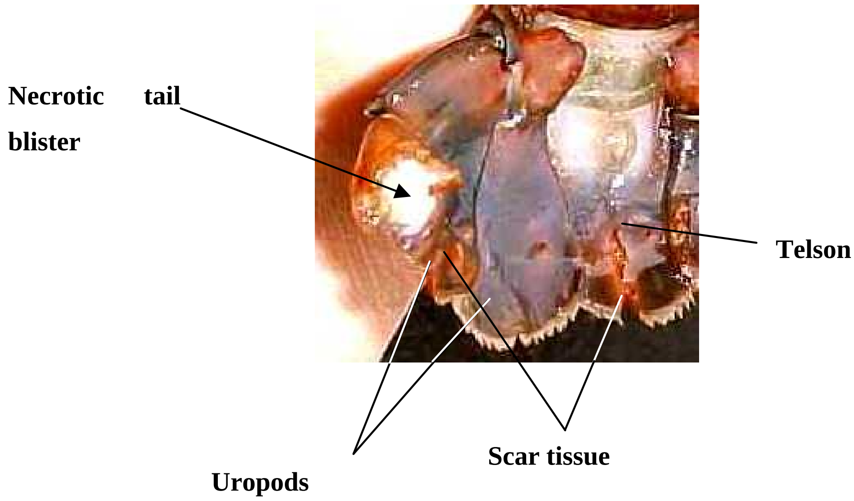


**Plate 3:** Marron tail fan (ventral view) showing necrotic tail blister

Blisters are believed to be discarded with the old exoskeleton, leaving large gaps in the tail fan where the blisters once were (plate 4).

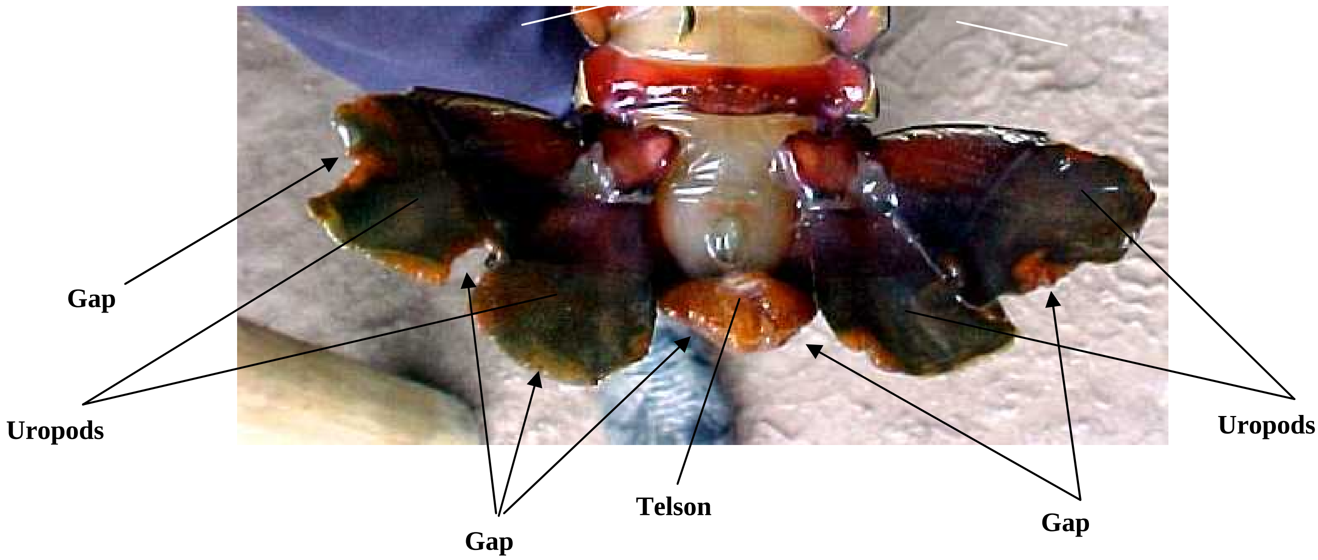


**Plate 4:** Marron tail fan displaying gaps (ventral side).

TBS appeared predominantly during processing. For example, the highest number of farms (55%) consistently experienced TBS following purging. Purging occurs at a relatively short time after harvesting, flushing and grading. In addition, TBS incidence was suggested to increase when purging duration was extended 5-7 times beyond industry recommendation, high densities of marron were purged simultaneously and/or there was poor water quality resulting from purging system deficiencies. TBS incidence decreased following the resolution of these problems. TBS was not observed in any of the animals sampled directly from the ponds in all farms surveyed.

Although tail blistered marron are not often found in the ponds, marron from some ponds were pre-disposed to developing tail blisters during processing. Some characteristics noted of these ponds were a high pH (pH=8.0), high anaerobic soil depth and discoloured water around the pond inflow. Differences in pond characteristics may explain variations of TBS incidence between farms, especially when processing procedures is similar across the whole marron aquaculture industry.

Although the exact prevalence and impact of TBS is still unknown, it is widespread and it is a growing concern amongst industry. TBS appears to be triggered during processing, however pond condition may pre-dispose marron to developing tail blisters, indicating that TBS may be induced when marron are exposed to a variety of stressors.

### *Preliminary laboratory studies on tail blisters in marron*

Two laboratory trials were designed to evaluate the two most important findings of the field survey. The first trial investigated the effects of TBS history and site characteristics on TBS development in response to an intermittent handling stressor (handling every three days over a 21 day period). The second trial examined an acute handling stressor (handling every day for 10 days) on TBS development. Two groups of marron were used in each experiment: TBS susceptible marron – 1) those with a history of TBS with a high proportion of postharvest animals developing tail blisters and; and 2) TBS resistant marron, those less inclined to develop tail blisters.

Blisters were induced with a handling stressor every 3 days over a 21 day period in the first trial. This demonstrated that the TBS onset speed in TBS susceptible marron was significantly faster than in TBS resistant marron. A lower proportion of TBS resistant marron (66.7%) developed tail blisters when compared to the TBS susceptible group (91.7%) however this difference was not significant. Evidence of a pre-emptive blister was found in trial 1. A pre-emptive blister appeared as a light patch (not engorged with fluid) on the tail fan. It was hypothesised that pre-emptive blisters developed into fluid filled tail blisters, however no evidence of this was found in this trial. Several immunological parameters were measured in the two groups of marron. Only hemolymph clotting times of TBS susceptible marron before and after the trial were significantly different.

Tail blisters were induced with a daily handling stressor over a 10 day period in the second laboratory trial. The handling stressor increased the proportion of marron developing tail blisters. In addition, the handling stressor unexpectedly caused mortalities. Mortalities occurred earlier and at a higher rate in the marron group exposed to the handling stressor. The development of tail blisters coincided with the development of the pre-emptive tail blister. The hepatopancreas moisture of TBS resistant marron was significantly lower than TBS susceptible marron, indicating a significant difference in condition between those groups.

In both laboratory trials the handling stressor induced TBS development. Reliably inducing tail blisters can be used as a platform to study the condition.

## Conclusion

It is evident from both the preliminary survey and laboratory trials that improving processing management to decrease stressors may decrease TBS. However, pond condition also appears to play a role in the development of tail blisters during processing. Once factors affecting marron condition in the ponds are identified and removed, TBS incidence should decrease. Further research is required to fully identify the causative agent(s) of this disease condition. Further studies are also recommended to evaluate the optimum stressor application for induction of tail blisters without attendant mortality.

## PROJECT 3.5: MINING FOR COUNTRY


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### Final Year Annual Research Report

In 2006 the Mining for Country project was mainly focussed on enhancing the capacity of members of the Ngalang Boodja community in Collie to obtain employment or develop enterprises and on exploring common features of agreements between mining companies and Aboriginal mining communities. The latter work was conducted by the CSML Research Fellow, Darryl Cronin, partially through a consultancy with the Goldfields Land and Sea Council while the capacity enhancement activities were conducted through education, aquaculture and land care projects for which funding was obtained through the joint collaboration of Mining for Country researchers and the Ngalang Boodja Council.

The capacity enhancement activities comprised mentoring of two Aboriginal community members through the final year of their UniReady business course, assisting one of the students to establish a small land clearing business and enhancing the confidence and capacity of four other community members by employing them as either Teachers Associates or Research Assistants in a DEST funded education project, ASISTM Plants for People Multimedia Pilot Project, an NHT funded conservation and land management project conducted in partnership with the Collie Weed Action Group and a DAFF funded aquaculture project at the Collie Aquafarm. A review of the capacity development strategies conducted over the four year period of the project was also conducted, resulting in the submission of two research papers to research journals and presentations on Mining for Country outcomes at three national conferences.

The Goldfields Land and Sea Council (GLSC), the Native Title Representative Body for the Goldfields region, contracted CSML to analyse and report on the performance of mining and other agreements entered into by the aboriginal peoples of the Goldfields region. The study assessed the mining agreements and their outcomes; analysed issues and trends; examined options to improve monitoring, implementation and compliance of agreements; examined options to maximise the economic development benefits for Goldfields Aboriginal people; and examined and assessed the level and kind of resources required for governance and capacity. Twenty mining industry future act agreements negotiated by native title claimant groups in the Goldfields region of WA with the assistance of the GLSC were examined and their outcomes evaluated.

The study examined the outcomes that arose from the contents or provisions of the agreement on the basis of eight critical components. The eight critical components were: 1) environmental management; 2) cultural heritage protection; 3) rights and interests in land; 4), financial payments; 5), employment and training; 6) business development; 7) indigenous consent and support; and 8) implementation measures.

The Wild Fig or 'ili', whose fruits are eaten fresh or dried and ground into a paste for later use.

The Desert Raisin or 'kampurararpa' is a low shrub whose fruits are eaten fresh or dried.

## Executive Summary

The CSML Mining for Country project was conducted over a four year period in partnership with the Collie Ngalang Boodja Aboriginal community and the Tjupan Ngalia community in Leonora. The project had two core foci: 1) investigations on cultivation of plants of cultural significance, both on minesites and in other locations; and 2) participatory action research on enhancing the capacity of Aboriginal people in Collie to plan and conduct social and business enterprises.

Cultivation studies were conducted on a total of eleven native plant species nearly all of which have reported uses by Aboriginal people as either bush food or bush medicine plants. Major studies were conducted on tuberous plants found in the South West (*Haemodorum spicatum*, blood root), and in the North East Goldfields (*Ipomoea calobra*, a yam species) involving propagation investigations and growth trials under hothouse and field conditions. Both studies demonstrated the horticulture potential of these two native tuberous plants. Growth trials were also conducted on eight different medicinal plant species at Muresk Institute, Northam and at several other sites. The highest growth and survival was observed in *Atriplex nummularia, Dodonea viscosa and Meleleuca pressiana.*

The project achieved significant outcomes in identifying success factors for Aboriginal social and business enterprise development as well as in assisting Collie Ngalang Boodja community to enhance their skills and capacity to conduct such enterprises. Identified success factors were:

- Operation of a project by a cohesive social group;
- Local champions with the passion and ability to lead the project;
- Long lead time to develop community understanding and support for the development project;
- Aboriginal control and commitment in decision making;
- Access to appropriate information;
- Acceptance by decision makers of each other's goals and responsibilities;
- Reward for effort;
- Compilation of management plans with realistic feasibility assessments;
- Access to sufficient resources to carry out the plan;
- Networking with other Aboriginal people with similar enterprise development plans;
- Technical support in financial and corporation management;
- Genuine partnerships between local people and support agencies;
- Underpinning economic development activities with remedial and further education.

The capacity of the local Aboriginal community to conduct social and business enterprises was enhanced in a number of different ways. The governance skills of the NBCAC committee members were improved through the planning and implementation of strategic planning meetings and networking events. Two community members completed a university bridging course and are now pursuing business enterprise development initiatives. Attendance at workshops on integrated aquaculture and soap and body products manufacture, and at networking events, built skills and determination to develop enterprises in these areas. Resources have been sourced to conduct a mine lake aquaculture project and employment in other projects funded through grant applications has commenced. Scholarship support from mining companies for education and training initiatives is being negotiated.

Future goals of the Ngalang Boodja Council are to take over the management of the Ngalang Boodja Nursery and to develop a mine lake aquaculture enterprise at the Premier Coal minesite with funding support from the company and from local and state government agencies.

## Introduction

The CSML Mining for Country project was one of a suite of projects conducted by the Plants for People Program, a research and capacity building program administered by the Centre for Sustainable Mine lakes (CSML). The Plants for People program (P4P) aims to document, evaluate and apply knowledge of Indigenous plants for the benefit of local Indigenous communities and, in association with government and the mining industry, develop Indigenous business enterprise models based on tourism, horticulture or enhanced wild harvest activities involving selected plant species. The program is multifaceted with different projects contributing to the overall aim of preserving traditional knowledge of native plants of medicinal, bush tucker and other cultural value, and applying this knowledge for the benefit of local communities.

The Mining for Country project specifically addressed the cultivation of selected plant species of cultural significance to Aboriginal people in mine site rehabilitation and decommissioning operations and the establishment of Indigenous business enterprises based on the plant species selected for study. A core element of the Indigenous enterprise project was the investigation of suitable strategies for enhancing the capacity of Collie based Indigenous people and organisations to conduct natural resource enterprises. The project was carried out by Professor Louis Evans, Executive Director, CSML; Dr Geoff Woodall, CSML Research Fellow in Minesite Horticulture and Senior Research Associate, UWA Centre for Natural Resource Management; Darryl Cronin, CSML Research Fellow; Wendy Smith, WA Department of Education and Training and David Riha, Project Officer. Kado Muir, a PhD student who is also the CEO of the Leonora based Walkatjurra Cultural Centre, also participating in the project.

## Methodology

## Aims and objectives

The overall aim of the Mining for Country project was to successfully establish trial and demonstration plant cultivation/farm forestry Indigenous enterprise projects at selected mine sites and other locations in Western Australia and to identify successful approaches to enhancing the capacity of local Aboriginal groups to develop and operate these enterprises. The specific objectives of the project were to:

- Contribute to sustainable development within the Australian mining industry by facilitating Indigenous community groups to develop natural resource based social and business enterprises for operation during the life of the mine &/or after mine closure,
- Identify factors that contribute to sustainability of Indigenous social and business natural resource enterprises, and
- Develop effective approaches to building the capacity of Aboriginal people to establish and operate these enterprises.

The project was conducted in two independent but linked groups of activities – investigations on native plant cultivation technology and participatory action research on capacity development for Indigenous social and business enterprises. These two groups of activities are reported separately.

## Operational plan - Native plant cultivation studies

Propagation and cultivation trials were conducted at five different locations – Griffin mine site, Collie; Muresk Institute, Northam, Walkatjurra Cultural Centre, Leonora, UWA Centre for Natural Resource Management nursery, Albany and at Challenger TAFE, Murdoch. Yam seed collections and boronia cutting collections were also carried out at sites near Leonora, NE Goldfields and at Collie respectively.

### *Haemodorum spicatum cultivation studies at Griffin mine site, Collie*

#### Introduction

*Haemodorum* (heem-o-DOR-um) *spicatum* occurs naturally in the Collie region and the fleshy bulb was an important food plant for aboriginal people prior to European colonization. It is a member of the Haemodoraceae, a family more widely known for spectacular flowers (eg Kangaroo Paws and Catspaw) than food plants. It is widely distributed from 100 km south of Geraldton to Albany in the south and east as far as the Esperance region. The black flowers of this perennial herbaceous geophyte (bulb) are produced in October-November on an inflorescence spike up to 1.5 0.3-1m high. m in height. Aboriginal names for this plant vary according to location and include: meen, mardja and bohn.

The red colour (and hot taste) of bulbs is due to the presence of a compound called Haemocorin which is a phenylphenalenone. Phenylphenalenones are a subgroup of diarylheptanoids and one notable example is curcumin, which is the is widely used as a food dye and spice, e.g. in curry (The Max Planck Institute for Chemical Ecology in Germany 28/10/2005). Daw et al. (2001) states that Haemocorin shows promise as a pharmaceutical, having both anti-tumour and microbial properties. The original source of this information appears to be Harborne et al. (1999).

Research conducted by a RIRDC funded project (UWA 86A) has identified this species has having potential as a spice. Local aboriginal people are interested in commercially cultivating this species and one option is for them to cultivate it on mine spoils at Collie. Although native to the area this species has not been included revegetation programs used by either of the two coal mining companies.

**Figure 1.** Haemodorum spicatum (Blood root) bulbs

## Aim of study

This CSML trial aimed to determine whether *Haemodorum spicatum* can be grown in mine spoils and compare sown seed versus seedling planting establishment methods.

## Methods

In June 2005, at four locations, *H. spicatum* seeds were sown or small *H. spicatum* seedlings planted at Griffin Coals (Collie WA) Chicken Creek area adjacent to the secondary treatment pond off Centor Rd (up slope of the treatment pond). This area had been rehabilitated in 2003 and sown with a mix of local native species (excluding *H. spicatum*). The soil consisted of a thin veneer (10-50 mm) of topsoil (stripped from areas prior to mining) over a class 1 interburden. The topsoil was of a sandy loam – loamy sand texture and often mixed with interburden. The average pH (1:5 soil extract, n=3) of soil (from a depth of 0-5cm) where seed/seedlings were sown/planted was 5.54.

At each of the four locations 20 seeds were sown (10 mm below the soil surface) in small trench 0.3m long and 10mm deep made with a ruler. Adjacent to this a line of 20 seedlings was planted, such that the base of the developing bulb was 20mm below the soil surface. Germination of sown seed was assessed in Oct 2005 and survival was assessed when germinants were dormant (January 2006).

The planted seedlings were propagated from the same seed batch (Nindethana seeds Pty Ltd) and were approximately 3 months of age. Germination of sown seeds and survival (after 6 months) of germinants and planted seedlings was monitored.

**Figure 2.** Chicken Creek trial site. Fence droppers denote planting/sowing locations.

## Results and Discussion

23% of sown seed produced an emergent seedling that was still alive in Oct 2005. 66% of emerged seedlings were still alive in January 2006, ie 15% (SE 10.2 n=4) of sown seed produced a small dormant bulb that was alive as of January 2006 (6 months after sowing). A similar establishment result was achieved with seedlings where, 13.8% (SE 3.8 n=4) of planted seedlings were alive (but dormant) 6 months after planting.

The growth of all seedlings was slow and at 6 months of age mean plant dry weight of seedlings produced from sown seed was 24 mg (n=5) and 28 mg for transplanted seedlings (n=5). In comparison the dry mass of mature bulbs is in the order of 5-10 g. Thus it may take many years to produce mature bulbs of this species.

Results suggest that *Haemodorum* could be cultivated on mined lands where a thin veneer of topsoil has been placed over mine spoils. Growth of germinants was slow and it is therefore likely that the production of a marketable product will take several years and it is unknown whether plants will persist for this length of time. If a marketable product were to be produced its composition would need to be investigated to ensure that product cultivated on mine spoils was safe to consume.

### *Northam plant cultivation studies*

## Introduction

The plant cultivation trials conducted at Curtin University's Muresk Campus, Northam were part of a wider project in which students from the Athene College of Herbal Medicine collaborated with a post graduate student from Muresk Institute to conduct planting trials on a suite of native plants chosen for their reported traditional medicinal use by Aboriginal people from Western and Central Australia. The aim, of the project was to determine the growth and survival that could be achieved in the Southern region of WA with a range of plants of medicinal value most of which are endemic to Central Australia. Three identical experiments were established in May – June 2003 at the Muresk Institute, Northam and at private landholdings including sites in Calingiri in the Wheatbelt, and at Helena Valley, Perth.

## Methods

Seedlings from the following plant species were propagated at commercial nurseries and distributed for planting at the three different sites:

- Acacia tetragonophylla
- Acacia victoriae
- Atriplex nummularia
- Cymbopogon ambiguus
- Dodonea viscosa
- Eremophylla glabra
- Eremophylla maculata
- Meleleuca pressiana

Each experiment was arranged in a completely randomized design. A single plant formed an experimental unit. Each experiment had 80 plants. Plants were spaced at 2.5m by 2.5m apart.

The two sites at Helena Valley and Calingiri were planted in the random block design and managed by Athene College of Traditional Medicine students. At four other sites at Mundaring, Bellevue, Helena Valley and Toodyay, managed by Athene College students, sets of 80 plants were also established. These plantings were not arranged in a single block but instead were planted at random in sites selected by the project participant.

Measurements were performed on all plants at the commencement of the trial and had been planned to be similarly performed on all plants at the conclusion. Interim measurements, performed at monthly intervals, were only performed on the three block design sites (Muresk, Calingeri and Helena Vale).

Measurements and observations were made of the following: plant height, number of branches/ tillers, plant vigour and incidence of pests/ diseases.

### Results and discussion

In the block design study sites, species performed best at Muresk followed by Helena Valley and Calingiri.

At Muresk, based on the growth performance, the species were ranked as follows: 1. *Atriplex nummularia, 2. Dodonea viscosa, 3. Meleleuca pressiana, 4. Eremophylla glabra, 5. Acacia tetragonophylla, 6. Acacia victoriae, 7. Eremophylla maculata, and 8. Cymbopogon ambiguus.* Half of the *Cympogon ambiguus* did not survive the winter period.

At the Helena Valley site, the best performing species were *Dodonea viscosa*, *Meleleuca pressiana* and *Atriplex nummularia.* Only 20% of the plants at Calingiri survived up to early November 2003, and therefore no meaningful comments could be made on that experiment.

At least one visit was also conducted to the other four study sites. Growth performance of the species at these sites was similar to that seen in Muresk, although differences in overall performance were noted.

Plants at Muresk were irrigated twice a week via drippers during the summer period and at Helena Valley once a week. Irregular watering was carried out at the other sites.

Unfortunately, the postgraduate student conducting this research project withdrew from his studies in late 2003 and the Athene College of Herbal Medicine ceased operation not long after. Approaches were made to a local Aboriginal group with the aim of continuing the study commenced at Muresk Institute but difficulties were encountered in establishing a natural resource enterprise project involving the Muresk plantings due to native title issues. These difficulties were not resolved and it was agreed that the trial should be terminated. The plants were removed and the land returned to pasture.

## *Leonora plant cultivation studies*

### Introduction

The aim of this study was to assess the potential for a species of yam, *Ipomoea calobra*, found in Central and Southern Western Australia for culturing in a formal market-garden situation as an Aboriginal business enterprise. Several field trips were made to Leonora where the partners in the project, the Walkatjurra Cultural Centre, escorted members of the P4P team to various sites to collect yam seeds which were subsequently taken to Albany for nursery propagation studies.

#### Taxonomy

Plant collections were positively identified as *Ipomoea calobra* (Figure 2). Aboriginal names for this plant species include Wather (Leonora area; Kado Muir, pers. comm..) and Intal (Ashburton area, Bindon 1998).

Family: Convolvulaceae. Members of this family are herbs or shrubs, sometimes parasitic (e.g. *Cuscuta*), usually twining or prostrate. About 55 genera exist, including *Ipomoea*, with approximately 1800 species in tropical, tropical and temperate parts of the world. There are approximately 36 *Ipomoea* species in Australia of predominantly tropical and sub-tropical origin. This group also includes *Ipomoea batatas* (sweet potato), which is an important horticultural crop in many parts of the world and is naturalised in some parts of Australia.

*Ipomoea calobra* is a deciduous perennial climber (Figure 3) and usually climbs up through Mulga (*Acacia aneura*). It occurs in red deep sands along drainage lines.

**Figure 3.** Ipomoea calobra

Distribution

*Ipomoea calobra* is widely distributed within Ashburton, Carnarvon and Austin botanical districts of Western Australia. The collection made at Terracotta, 12.5 km west of Depot Springs is 150 km further south than the known populations shown in Figure 4.

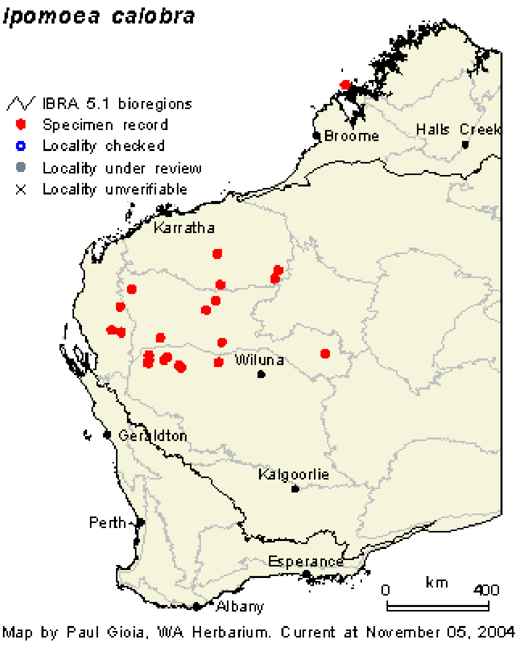


**Figure 4.** Ipomoea calobra distribution (http://florabase.calm.wa.gov.au)

Tuber size, shape and mass

Tubers are of variable shape, size and mass. Individual plants produce numerous tubers, the largest of which may have a fresh weight of >1.5 kg and have dimensions of 15 cm (width) x 30 cm (length) x 6 cm (depth). These observations are somewhat different to those of Pate and Dixon (1982) who described the tubers as only being 2-4 cm wide and 2-25 cm long. The tubers are produced along the main root, confirming the findings of Pate and Dixon, and the tubers form also at intervals along roots other than the main root.

A partial excavation of less than 10 percent of the estimated soil volume occupied by a mature individual yielded five tubers (fresh weight of 50, 320, 620, 640 and 1400g, totalling 3500 g). The excavated vine was assumed to be old and its total tuber mass was estimated at 35 kg (fresh weight). The mean moisture content of the harvested tubers was 88%, significantly higher than the mean obtained for five sweet potato tubers (Ipomoea batatas) 79% (t-test, P<0.01). Some tubers from a single parent plant exhibited browning of the freshly cut tuber while other tubers did not. Browning was localised within and around severed vascular bundles.

Propagation

Propagation from seed and tuber segments was trialled in Albany under hothouse conditions. Propagation from root and tuber segments was unsuccessful, potted segments lasted up to four months before rotting off. Potted tubers produced new roots but no shoot initiation was observed.

Attempts by Aboriginal people to propagate this species from seed collected from Terracotta and sown in Leonora were mostly unsuccessful. Difficulties with germination were also noted in Albany where 24 sown seeds (July 2004) produced only one seedling. The remaining 23 seeds were removed from soil after three months and examined visually. A few seeds had rotted but the remaining 15 seeds did not appear to have deteriorated. A literature search revealed that nicking the seed, treatment with dry heat and soaking the seed in warm water were options to improve the germination of Ipomoea species in general (Ralph 1997).

A plus and minus seed scarification pot trial was established in December 2004 (Figure 4). A small section of the seed coat was removed with coarse sandpaper. Five pots were sown with 10 seeds (5 scarified and 5 intact) and the emergence of seedlings monitored for 42 days. The results clearly show that seeds of *Ipomoea calobra* are of high viability and that scarification lead to rapid germination.

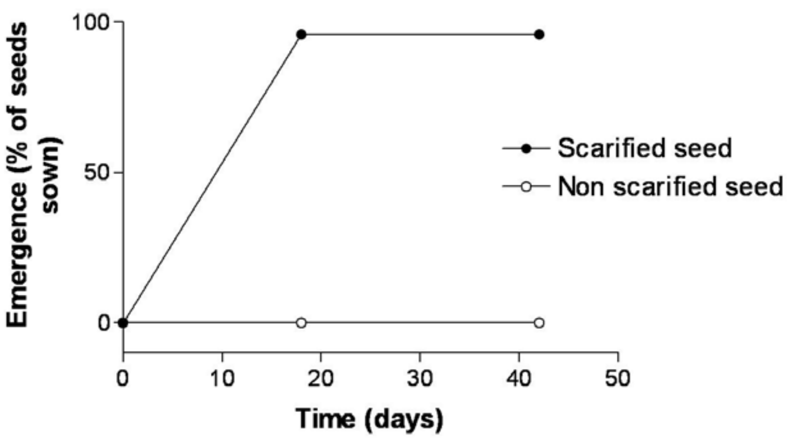


**Figure 5.** Emergence of scarified and non-scarified Ipomoea calobra seed (each point represents the mean n=5).

Tuber Production

Little has been published on tuber production except that tubers are known to be perennial and that resources are added to each year (Pate and Dixon, 1982). Small seedlings can produce a small tuber (see Figure 6) on the main tap-root before the age of eight weeks and may produce a carrot-sized product within six months when cultivated in a hot-house.

**Figure 6.** Cultivated Wather (I. calobra) seedling

*Boronia propagation study*

A proposal to cultivate *Boronia megastigma* (boronia) as an Aboriginal enterprise conducted through the Ngalang Boodja Nursery was explored during the latter part of this project. Members of the Ngalang Boodja Community in Collie collected cuttings from several boronia plants just after spring flowering in October 2006. Cuttings were collected from Boronia Gully and other sites near Collie and delivered to the Ngalang Boodja Nursery which in turn transported the cuttings to Challenger TAFE at Murdoch where they were placed in growth pots and observed for several months. Unfortunately none of the cuttings survived and the horticulture team from Challenger TAFE recommended that new cuttings are collected during the growing period in 2007. This recommendation was given to the Ngalang Boodja Nursery which may continue this work as an independent project.

## Summary and conclusions from native plant cultivation studies

Cultivation studies were conducted on a total of eleven native plant species nearly all of which have reported uses by Aboriginal people as either bush food or bush medicine plants.

The two major studies conducted by Dr Geoff Woodall, UWA Centre for Natural Resource Enterprise, both demonstrated successful propagation and cultivation techniques for native plant species of horticulture potential. Of eight different medicinal plant species trialled at Northam the highest growth and survival was observed in *Atriplex nummularia, Dodonea viscosa and Meleleuca pressiana.*

One of the main species studied, *Haemodorum spicatum*, was cultivated with some success on a minesite rehabilitation site in Collie. The species has not been used in restoration projects at Collie before but its inclusion into restored mined lands may have enterprise and cultural maintenance benefits. Trials conducted at Griffin Coal's Chicken Creek area aimed to determine whether *Haemodorum spicatum* could be grown in mine spoils and to determine the most appropriate establishment method. Results suggest that this species can be cultivated for six months in post mining environments and that spot sowing of seed would be a feasible establishment method. The production of a marketable product is however likely to take several years and it is unknown whether plants will persist for this period of time.

Investigations conducted in the other major plant cultivation study demonstrated the horticulture potential of a local yam species of cultural significance to the Tjupan Ngalia people from Leonora, *Ipomoea calobra*. Propagation trials using root and tuber segments were unsuccessful. However, seeds collected by members of the Tjupan Ngalia community and given to Dr Woodall for propagation trials in Albany were successfully germinated using a scarification technique. Small tubers were produced on the main tap-root before the age of eight weeks and a carrot-sized product within six months when cultivated in a hot-house. Dr Woodall returned all of the propagation material to the Tjupan Ngalia community at the end of the trials and provided them with information on preferred propagation and cultivation techniques.

Further studies on the potential of these five native plant species for cultivation as an Aboriginal business enterprise are recommended.

## Operational Plan - studies on capacity development for Indigenous social and business enterprises

### *Introduction*

The CSML Aboriginal economic development project component was commenced in January 2004. The project was aimed at facilitating the successful development of sustainable Ngalang Boodja owned and operated enterprises through a phased approach based on empowerment and inspiration, sourcing of enterprise resources, strategic planning and governance training and education and skills development.

The project was conducted by a partnership group comprising P4P staff and students and the Ngalang Boodja Council Aboriginal Corporation, (NBCAC), an Aboriginal corporation that represents Noongar people from Collie and whose members are involved during the project period in three successful CDEP projects – the establishment of the first accredited native plant nursery in Australia, the development of fire wood collection enterprise and the establishment of an arts and crafts centre in the NEEDAC building in Collie.

### *Project activities*

Project activities were focussed around five core themes:

1. Strategic planning and governance training
2. Empowerment through community networking
3. Education and training
4. Funding applications for enterprise resources
5. Collaborative research on traditional knowledge about plants and their uses

Activities conducted and outcomes achieved in each of these five different areas are described below.

### *Strategic planning and governance training*

Partnership meetings, Jan 2004 – Dec 2005

The project commenced with a series of meetings between P4P researchers and members of the NBCAC. The then Chairperson of the NBCAC, Joseph Northover, was employed as a CSML Research Officer for a three month period to assist with project planning and the preparation of project grant applications to NHT and the Department of Agriculture, Fisheries and Forestry (DAFF). The NHT application was unsuccessful and the DAFF project, though finally approved for funding, did not commence until late 2006.

CAG planning meetings, Jan 2004 – March 2004

In early 2004 CSML collaborated with the WA Office of Aboriginal Economic Development and the WA Department of Indigenous Affairs in an effort to establish a Collie Action Group (CAG) that would comprise representatives from all Aboriginal family groups in Collie. A series of meetings aimed at coordinating the development of the CAG were conducted by the Department of Indigenous Affairs (DIA), the then Office of Aboriginal Economic Development (OAED), CSML and NBCAC. CSML convened a meeting at the Collie TAFE in March 2005 to discuss the proposal further and commence the process of identifying the main family groups in Collie. The main families in Collie were listed (38 family names) and arranged into five core family groups (Ugle 1, Hayward, Hart, Ugle 2 and Turvey groups).

A detailed family mapping project was subsequent conducted by the OAED that identified 189 different Aboriginal families in Collie, all of whom were assigned into one of the five CAG family groups. Subsequent progress in forming the CAG was slow due to a lack of support from some sections of the Collie Aboriginal community. However, core members of the Hayward, Ugle 1 and Hart family groups have since been very active in representing the Collie Noongars in government meetings, employment initiatives and further CSML project work.

Ngalang Boodja Council Strategic Planning Meetings

Two strategic planning meetings were convened by the NBCAC, one in February, 2006 and the second in January 2007. CSML assisted the NBCAC convene both meetings and prepared a briefing document to explain the purpose and process of strategic planning. The aim of the first meeting was to scope out key development issues for Collie Noongars and to obtain a consensus view on future activities. Seventeen representatives from four of the five family groups attended. Several government agencies showed an interest in participating in the meeting (DIA, OAED and DEWR) and were also invited to attend.

Eight strategic priorities were identified (listed below in priority order):

1. Improving health services to Noongar people in Collie.
2. Creating and establishing employment and enterprise opportunities.
3. Improving educational outcomes by supporting children, and youth and encouraging adults to undertake training or further study.
4. Obtaining ownership of land and seeking control of cultural heritage management.
5. Building the infrastructure and functional capacity of Ngalang Boodja Council.
6. Developing ways to enable Noongar people to own their homes.
7. Addressing important family and cultural issues.

The second strategic planning meeting comprised a bus trip and BBQ during which fifteen members of the Ngalang Boodja Community visited sites at which NBCAC existing funded projects were being conducted and discussed strategic priorities for 2007/2008. A video was made of the planning meeting and this was subsequently used by the NBCAC to inform potential sponsors of their activities and plans.

Both of these meetings provided opportunities for governance training for NBCAC leaders, who developed the agenda, arranged for invitations to be forwarded to nominated representatives of the five main Ngalang Boodja family groups identified in the CAG meeting and chaired the meeting. Empowerment through action and decision making was identified by members of the participatory action research team as one of the successful strategies used for capacity building with the Ngalang Boodja community.

Empowerment through community networking

Plants for People conducted a range of networking events during this project with sponsorship funding from the Indigenous Land Corporation and the DK-CRC as well as CSML. These events facilitate representatives from different Aboriginal communities gathering together for workshops and meetings to discuss common issues and initiatives, plan enterprises or projects, undertake short courses, receive practical hands on training and undertake action research activities.

The workshops:

- Create a vision for Aboriginal people to participate in the mainstream economy;
- Create an awareness of the potential and opportunities available in natural resource enterprises and land management;
- Provide a forum for dialogue where participants can identify business opportunities and undertake preliminary planning for small community enterprises or natural resource management projects;
- Provide a forum where Aboriginal people can network, collectively solve problems, and develop entrepreneurial skills;
- Provide skills training;
- Incorporate Aboriginal knowledge into the planning and learning experience to enable the participants to develop new methods and skills which are in harmony with their cultural practices and social structures;
- Facilitate Aboriginal people conducting and directing participatory action research projects aimed at documenting and applying traditional knowledge about plants and their uses.

Plants for People convened six networking events (visits to different communities, seminars, workshops, P4P Annual Meeting; Table 1) as part of the Mining for Country project and also participated in the convening of a major workshop in Broome on capitalising on Natural Resources and Indigenous Knowledge. Two of the networking workshops were aimed at skills development – the Integrated Aquaculture Workshop convened by P4P in Northampton, November 2005 and the Soaps and Body Products Workshop conduced by First Australians Business at Titjikala in February 2006. Ngalang Boodja project team members have attended all seven events.

The networking component of the project helped to build the confidence and enthusiasm of community members for enterprise development, as evidenced by comments made by workshop attendees (Evans and Cronin, 2006), the ongoing communication between some of the networking groups (Collie and Titjikala – occasional telephone conversations (Kahn, J., pers. comm.)) and the independent decision of the NBCAC to initiate an invitation to First Australians Business to conduct a business management and soaps manufacture workshop at Collie in 2006. The forwarding of the invitation to First Australians Business was arranged through the NBCAC at the instigation of Ngalang Boodja community members, Mareka Hayward and James Kahn, following their attendance at the workshop in Titjikala. Merika Hayward has commenced to develop her own health and beauty products business and Phillip Ugle has set up a machinery hire and land clearing business, Ngalang Moorts Boodja. These outcomes provide evidence of empowerment resulting from participation in networking workshops and other capacity and skills development initiatives conducted through the CSML project.

**Figure 7.** Attendees at P4P aquaculture workshop inspecting a fish pond

**Table 1.** P4P networking events attended by Ngalang Boodja Community members

| Date | Location | Nature of event | Comments |
|---|---|---|---|
| 2nd – 6th Aug, 2004 | Broome, WA | Aboriginal networking workshop: *Capitalising on Natural Resources and Indigenous Knowledge Workshop* | Convened by several agencies including P4P; 60 Aboriginal attendees; presentations and workshop discussions; Proceedings published on espace@Curtin (Battey et al., 2005) |
| 6th – 8th Feb, 2005 | Perth, WA | *Plants for People Annual Meeting* held at Oasis Resort, Swan Valley | 40 attendees; Attended by 15 community members from Collie, Leonora, Titjikala and Perth; presentations and workshop discussions |
| 9th June, 2005 | Collie, WA | *CSML Annual field trip* | A community leader from another community with which P4P is involved (Leonora) visited Collie and had discussions on enterprise development and other issues with NBCAC members. |
| 10 – 13th Oct, 2005 | Titjikala, NT | *Visit to Titjikala by two Ngalang Boodja community members* | Arranged for discussions on collaborative nursery project |
| 16th – 18th Nov, 2005 | Northampton, WA | *Integrated Aquaculture Networking Workshop and Seminar* held at Gregory Springs Farm, Northampton | 38 attendees; attended by 16 community members from Collie, Kalbarri, Northampton and Yalgoo. Training course and seminar on integrated aquaculture; Proceedings published on espace@Curtin (Evans and Cronin, 2006) |
| 7th – 8th Mar, 2006 | Titjikala, NT | *Soap and Body Products Making Workshop* presented by First Australians Business | Attended by Titjikala community members, community members from Collie (2) and Ceduna (1); practical workshop on manufacture of soaps and other both products |
| 21st April, 2006 | Kalgoorlie, WA | *Aboriginal Wild Harvest and Land Management Seminar*, CMAE Seminar Room, Dept of Agriculture, Kalgoorlie | 30 attendees, 15 from Aboriginal community groups from Kalgoorlie, Leonora and Pia Wadjarri community; seminar presentations on medicinal plants, land management and enterprise development |

Empowerment through education and training

*Participation in post secondary education programs*

Soon after the commencement of this project an informal survey was conducted by NBCAC and P4P of the availability and willingness of Collie Aboriginal people to participate in a TAFE Aboriginal Aquaculture Certificate course and a Curtin University Uni-Ready (bridging) Course majoring in natural resource management and enterprise. Twenty three Aboriginal students enrolled in the TAFE certificate course and four people enrolled in the Uni-Ready course, both of which commenced in February 2005. Only one student successfully completed the TAFE course. An investigation was conducted into the reason for the high drop-out rate and it was found that many of the students who enrolled were primarily interested in obtaining Abstudy rather than pursuing a career in aquaculture.

Of the four students from Collie who enrolled in the Foundations Studies course, three successfully completed the first mathematics unit in Semester 1, 2005 with one student achieving a grade of 87%. The assessment used in this unit was the same for all students throughout the state, making this achievement even more commendable. Two Aboriginal students from Leonora also enrolled in this unit but subsequently withdrew. A lack of personal contact with tutors and the lecture based approach to tuition appeared to have been major contributing factors to the decision to withdraw. Two of the Collie students went on to successfully complete the bridging course. This success was in part due to the approach that was taken in tutoring these two students – regular mentoring support through telephone calls and meetings, insistence on compliance with assessment procedures, recognition of need for flexibility in course delivery and a clear commitment to assisting the students to complete the course - as well a strong commitment by the students themselves.

*Delivery of culturally appropriate education and training programs*

The delivery of culturally appropriate education and training programs to Aboriginal people was one of four topics discussed at the workshop on Capitalising on Natural Resources and Indigenous Knowledge held in Broome in August 2004 (Batty et al. 2005). The workshop was attended by 60 people, mostly Aboriginal community members. The workshop proceedings were written by Professor Louis Evans, P4P and Wendy Smith, WA Department of Education and are now published on various websites including espace@Curtin.

The main comments and recommendations from the discussions on culturally appropriate education and training programs were as follows:

- Engage good teachers - some trainers exhibit unacceptable attitudes.
- Engage Aboriginal Elders in training – involve Aboriginal people in the training program.
- Culturally appropriate assessments are required.
- Flexibility in delivery is required - If you are working in Aboriginal education you need to be aware that everything is different for different groups.
- There is a lack of recognition of Aboriginal knowledge and skills eg. Aboriginal health workers.

Culturally appropriate strategies to address these key issues were reported as:

- Hands on training and practical demonstrations are important in course delivery.
- There should be more involvement of community Elders and other community members in curriculum development.
- The community want ownership on who delivers the training – they want to vet the prospective trainers and decide whether they have the communication skills and appropriate attitude to conduct the training program.

P4P has addressed the some of the above listed issues and recommendations in its education programs. Efforts are made to ensure that:

- Lecturing staff have the communication skills and appropriate attitudes to teach Aboriginal people.
- Course delivery is flexible, and teaching schedules are altered to allow for attendance at funerals, involvement in important meetings and for other cultural matters.
- Community leaders and elders participate in curriculum planning discussions.
- Practical demonstrations are incorporated into the teaching program where possible.
- Course participants are encouraged to provide feedback about different lecturers and teaching and learning activities.

<u>Skills training in oral presentations</u>

In addition to mentoring students through a university bridging course program P4P also provided skills training in oral presentations. The CSML Research Fellow, Darryl Cronin, assisted one of the community member, (Merika Hayward, to prepare a powerpoint presentation describing the Soap and Body Products workshop she attended at Titjikala in February 2006. Merika first presented this talk at an NBCAC meeting comprising mostly family members and, as a result of the confidence gained from this experience, made a similar presentation at the P4P Kalgoorlie Seminar. P4P staff have recently worked with Philip Ugle to submit an abstract for an oral presentation at the 2nd Australian Aboriginal Enterprises in Mining and Exploration Conference held in Perth in October 2006.

Funding applications for enterprise resources

Since commencing working together, P4P and the NBCAC have submitted seven funding applications to NHT (2), SW Development Commission (2), ILC (2), DIA (1), DEST (1), Collie Shire (1) and the Australian Government of Agriculture Forestry and Fisheries (DAFF) as follows:

- NHT - River reclamation project (2004 - $48,000; not funded)
- DAFF - Aquaculture infrastructure (2005 - $27,200; funding approved)
- DIA - Heritage project (2005 - $2,500; funding approved)
- DEST - ASISTM school multimedia project (2005 - $84,000; with Leonora and Bunbury schools; funding approved)
- ILC – sponsorship of Integrated Aquaculture Networking Workshop (2005 - $10,000; funding approved)
- Shire of Collie – sponsorship of Integrated Aquaculture Workshop ( 2005 - $2000 – not funded)
- ILC – sponsorship of a 3 year Aboriginal networking project ( 2006 - $240,000; not funded)
- NHT weed control and habitat restoration project (2006 - $40,200 funding approved)

These funding applications have yielded significant funding for resourcing projects involving NBCAC community members, though insufficient to establish an enterprise.

## Collaborative research

The central focus of P4P research program is to work within two knowledge systems – traditional Indigenous knowledge and western science – to record traditional knowledge about plants and their uses, improve livelihoods and develop enterprises. P4P conducts participatory action research in which a desired goal or outcome is scoped and formulated through a series of structured workshops involving researchers and Aboriginal community members. Activities are then conducted in partnership to achieve those goals. This approach is recognized as an effective method of empowering Indigenous people to participate in activities that will improve livelihoods or sustain and manage natural resources. New knowledge is obtained by observation and evaluation of strategies used to attain the stated goal.

Several of the funding applications prepared by P4P and NBCAC had a research focus, in particular the DIA and ASISTM projects. Through these projects a review has been conducted on plants of cultural significance to the Ngalang Boodja people. The review comprised interviews with two senior members of the community, Joeseph Northover and James Khan, and a literature search on SW plants recorded as being of cultural significance to Noongar people. It is planned to publish this review following completion of the ASISTM project.

## Summary and Conclusions

The Mining for Country Project has achieved significant outcomes over the four year project period. The governance skills of the NBCAC committee members have improved as has their self esteem. Strategic planning events have brought a focus to goals that the group want to achieve in the future and a strong commitment to achieving these goals is apparent. Core members of the Ngalang Boodja Council are working closely as a team, a process that was not occurring at the commencement of the project.

Attendance at workshops on integrated aquaculture and soap and body products manufacture, and at networking events, have built skills and determination to develop enterprises in these areas. Resources have been sourced to commence an aquaculture venture and employment in projects funded through grant applications has commenced. Scholarship support from mining companies for education and training initiatives is being negotiated.

A future goal is to take over the NEEDAC managed enterprises in Collie and manage them through the NBCAC.

A significant outcome of this project has been the recognition of a number of success factors for Aboriginal social and business enterprise development projects. These include:

- Operation of a project by a cohesive social group;
- Local champions with the passion and ability to lead the project;
- Long lead time to develop community understanding and support for the development project;
- Aboriginal control and commitment in decision making;
- Access to appropriate information;
- Acceptance by decision makers of each other's goals and responsibilities;
- Reward for effort;
- Compilation of management plans with realistic feasibility assessments;
- Access to sufficient resources to carry out the plan;
- Networking with other Aboriginal people with similar enterprise development plans;
- Technical support in financial and corporation management;
- Genuine partnerships between local people and support agencies

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# Project 3.6: World's best practice closure outcomes


- Hunt D., Murray-Prior R., Rola-Rubzen F., Evans L
- Muresk Institute, Centre for Sustainable Mine Lakes
- Curtin University of Technology


## Final Year Annual Research Report

The completion date for CSML project *World's best practice closure outcomes* was adjusted from December 2006 to February 2007, as detailed in last year's CSML Annual Report to State Government, due to an illness of a family member of the PhD student Douglas Hunt.

Since the project completion date adjustment was reported, the significance of the illness required Mr Hunt to take a leave of absence between April and July 2006 and as a result no research was conducted during this period. This combined with a subsequent move by Mr Hunt and his family back to Victoria and a change of enrolment status with Curtin University of Technology from full-time to part-time resulted in a further delay in project completion.

The project team has conducted a literature review based around the project aims, and completed a detailed case study analysis of good and bad closure practice at various mine sites both in Australia and overseas. With the return to study by Mr Hunt, a benefit-cost analysis of proposed end-use options for the Lake Kepwari mine site in Collie is currently underway, the finish of which will complete project objectives.

Ultimately, the project will establish an analysis of world's best closure practices, with a major focus on Wesfarmers Premier Coal's Lake Kepwari mine rehabilitation development as a case study on best closure practices. The project will provide a checklist of best closure practices and make recommendations on changes to legislative requirements surrounding mine closure towards a greater emphasis on developing a holistic approach to mining, particularly the need to focus on closure at the start of a mining project. It is also envisaged that the use of Lake Kepwari as a major case study will demonstrate the need for increased community participation in the mine closure process.

Project 3.6 was not financially assisted by the State Government funding contribution although support was provided from other sources. The cost-benefit analysis and dissertation is expected to be completed by October/November 2008.

Project outcomes to date enabled the project team to contribute to two chapters in the Society for Mining and Engineering's international workbook on the management of metal mine and metallurgical process drainage, that synthesises current knowledge on mine lakes, intended for use as a worldwide handbook for the mining industry.



Wesfarmers Premier Coal's award winning community development through mine site rehabilitation program includes the Lake Kepwari Project — a mine to recreational lake development of 103 hectares.

## Executive Summary

The project has been designed to determine what constitutes 'world's best practice' closure outcomes for mining voids. The project will provide a background on the different options for mine closure, it will focus on the concepts surrounding sustainable development, it will then focus on the issue of governance and the legislative requirements both in Australia and overseas for mine closure, and determine how to value the different end-use options for mine void closure. The project will provide examples of good and bad closure outcomes from mine sites throughout the world, with a major case study and benefit-cost analysis on the Collie mine closure of Lake Kepwari (formerly known as W5B).

## Introduction

### *Background*

The project has been designed to determine what constitutes 'world's best practice' closure outcomes for mining voids. The project has provided a background on the different options for mine closure, it has also focused on the concepts surrounding sustainable development, on the issue of governance and the legislative requirements both in Australia and overseas for mine closure, and it is currently in the process of analysing how to value the different end-use options for mine void closure. In addition to this, the project has provided examples of good and bad closure outcomes from mine sites throughout the world, with a major case study and benefit-cost analysis on the Collie mine closure of Lake Kepwari (formerly known as W5B).

The rehabilitation of mining voids in Australia is an issue that involves mining companies meeting certain legislative requirements at both State and Federal levels. Whilst there has been some research conducted into these legislative requirements, little research has been conducted into examining mining companies social objectives once mining has ceased. Their social objectives need to consider the best possible end-use from the point of view of all stakeholders in the local community, from shire councils through to local indigenous groups and even the mining companies themselves. This project has essentially been a bio-economic evaluation of the end-use of mine voids. It has firstly examined the regulatory requirements of mine void closures in Australia and compared this process with what occurs overseas in other developed nations. The project has then reviewed mine void closures in both Australia and overseas in order to categorise what end-use options have been achieved in these mine void closures.

One of the other aims of the project has been to value the needs of the community in relation to the closure of these mining voids. This valuation must include both the use and non-use values i.e. what is the best possible end-use for these mining voids and determine whether an economic or aesthetic value can be placed upon their end-use. Economic modelling is currently being conducted on Lake Kepwari mine void site in Collie analysing the benefits and costs of the possible end-uses. The closure process needs to consider the involvement of the community in determining mine void closure objectives. This project has sought to examine the level of participation needed to develop some type of policy process framework regarding community participation in mine void closures.

### *Research Gaps*

The research was aimed at providing a broad approach to the issue of mine closure in Australia examining what exactly constituted world's best practice in mine void closure. The research identified the need to provide a holistic approach to the issue of mine closure, by examining a number of areas that impacted upon the closure of mine voids including options for void closure, regulatory guidelines, the concept of sustainability in the mining industry, and how economic modeling can be used to place a value on mine void end-uses. Such a broad approach to the issue of mine void closure had, until the commencement of this research, not been conducted.

### *Motivation for conducting the project*

The motivation for conducting the project was to determine what constituted 'world's best practice' in mine closure. Lake Kepwari in Collie was chosen as an example of a 'best practice' closure example due to the processes undertaken in the closure of the mine void. The project team also decided to analyse what value (both financial and non-financial) can be placed on end-uses at the site with the intent of demonstrating the value of such an approach for future mine void closures.

## Methodology

### *Aims and Objectives*

To develop and explore a framework for evaluating the end-uses of mine voids.

The other objectives of the research are to:

- Examine the different options for mine void closure.
- Investigate a process that determines what level of stakeholder participation is needed in the closure of mine voids and who are the stakeholders that should participate.
- Illustrate how economic modeling can assist in determining the use/non-use values of these mining voids at closure.
- Determine what is world's best practice for mine void closure.
- Suggest a policy framework for the mine void closure process.

### *Techniques used to achieve these aims and objectives:*

The first phase of the study involved a review of the literature on mine void closures both in Australia and overseas, categorising these closures and examining the types (if any) of remediation strategies undertaken. During this phase the research was also need to examine the mine closure process, determining the pressures exerted on mining companies for a beneficial end-use of these mine voids. It has attempted to determine the optimal closure method for mine voids as required by legislation, examining the literature both in Australia and comparing this with other developed nations where the mining sector is a significant contributor to the economy.

Phase two of the research involved desktop studies and detailed investigation of selected cases in order to evaluate what elements constitute 'world's best' closure practice and what constituted poor closure practice. This process examined a number of areas that impacted on the closure process, some examples included; regulatory guidelines, levels of community engagement in the closure process, support from all levels of government, the role played by the mining industry in the closure process what level of planning is required for successful closure outcomes.

The third phase of the research is currently on going and involves developing and testing economic models that will assist in determining the best possible end-uses for rehabilitated void sites. This end-use modeling examines both use and non-use options for these sites. The economic modelling that will be used in the research will consist of a cost-benefit analysis examining both use and non-use values for Lake Kepwari, the former Wesfarmers Premier Coal Mine Void that is being developed for use as a recreational lake.

The town of Collie in the southwest region of Western Australia will be used as a case study to refine the results of the above research methods. It has a population of approximately 9000 (ABS, 2001), it is the only coal mining region in Western Australia and boasts a number of mining voids that have been rehabilitated, or are in the process of being rehabilitated. At present the Collie shire council and Wesfarmers Premier Coal are in the process of establishing one of the former mine voids (Lake Kepwari) into a recreational, tourism lake. This project forms the basis for the case study.

The case study has used the methodological strategies outlined above and has also incorporated an ethnographical approach to the research framework. This ethnographic approach will use the research phases as outlined above and apply them to the township of Collie. This has included data collection using qualitative and quantitative techniques, attending meetings relating to Western Five, the collection of newspaper and other media articles and discussions with other stakeholders involved in the development of Western Five.

Following on from these research phases and the Collie case study, it is envisaged that the data collected from the project will enable the suggestion of a policy framework for the mine void closure process in the Collie region, with the intention of using this framework to establish a state and national framework. Further, more detailed studies will be required by other researchers in this area, as it is only the aim of this project to establish a broad framework.

## Results and Discussion

### *Key Findings*

The outcomes from the project have been written directly from the research that has been undertaken by the project team with a discussion of the findings and their significance.

#### Strategies for mine closure

The last few years have seen a plethora of documentation in relation to mine void closure. Today both industry and regulators are paying greater attention to the environmental, social and visual impacts surrounding mine voids. The need for an effective management strategy applies not only to mine void closures, but also to those still in operation. There are three basic, but broad mine void closure strategies (Wright 2002: 385):

- Waste Storage
- Water Storage
- Open Void

Waste storage is the back filling of voids with tailings/waste material from a mine site. It is only an option where the volume of ore is relatively small compared to the volume of material extracted and the environmental benefits outweigh the capital costs. This closure process is well suited to the coal and gold sectors and is increasingly being used in the goldfields (Wright 2002). This process is popular due to cost savings in both disposal and rehabilitation.

Water storage is the use of water surface runoff from a mine site into a mine void. The aim of this method is to reduce reliance on groundwater (which can be high in salinity), hence saving costs in pumping and extraction. The main advantage of water storage is that should further mining be considered feasible then the mine needs only to be dewatered.

The use of an open void involves allowing a mine void to fill with water, with the aim of using the void in the future for some form of recreational or commercial use. The major issue regarding this method of closure is the issue of pit wall stability and safety (Kruger et al. 2002). The closure criteria in this option are quite strict if the void is to be used for aquatic purposes, but is less strict if it is to be used for irrigation and livestock.

Wright (2002) believes that in Western Australia the main emphasis on mine void closure should focus around hydrogeological linkages and the potential impact on groundwater, particularly given the finite nature of groundwater supplies in this state. Wright's concern in Western Australia is the potential for mine void lakes to become sources of hypersaline water. Low rainfall and high evaporation in much of the state is the reason many of these water bodies become groundwater sinks. He goes on to say that this is not as large a problem in the southwest of the state, with its higher rainfall, however, acid mine drainage is of major concern in this region, particularly in the Collie coal region.

According to Mallet and Mark (2001), Wright (2001) places too much emphasis on the hydrogeological and groundwater issues concerning mine void closure, as this is just one of the factors that impact upon mine closures. Mallet and Mark in Wright (2001:23) developed a set of decision pathways that can be used to determine the steps and data necessary to choose the most suitable option. This involves three factors:

- Climate
- Site geology
- Social settings

The final decision relating to mine void closures then is arrived at via a cost/benefit analysis and includes engineering costs, liability risks, public image, environmental benefits, economic benefits and regulatory acceptance. This approach adopts a more wide ranging analysis than Wright and is one that will increasingly be required of mining companies when closing a void and determining possible tradeoffs for the post-mining use of that site. It incorporates many of the factors that this project team argues are needed in the mine void closure process.

## Governance

There currently exists no Commonwealth legislative role for mine void closure in Australia. The Commonwealth can become involved in mine void closures, but only when there has been a severe impact on the environment. It does this through the Environmental Protection and Bio-diversity Act 2000. This then leaves the states to implement their own legislation with regards to mine void closures; hence there is a complete lack of uniformity on the issue. In Western Australia there are three acts that control the operation of mine voids (Jackson 1991):

- Mining Act 1978
- Environmental Protection Act 1986
- Rights in Water and Irrigation Act 1914

Jackson (1991), Khanna (1999), Hall (2002), Johnson and Wright (2002) all review or analyse aspects of these acts or similar acts elsewhere in the country. The authors generally all realize shortcomings within the acts. As an example Johnson and Wright (2001:32) have the following to say on the issue of mine void closure and legislation:

> During the mine approval process in the past, little attention has been paid to the issue of mine closure. Closure plans weren't initially integrated into feasibility studies or Run of Mine (ROM) plans and companies paid little attention to closure issues until a few years before mining was to cease.

The authors pay little attention to what needs to be done to alter the situation regarding mine void closure in this country other than broad statements recognising the need for closer working relationships between companies and regulators and the need for greater community engagement. This appears to be similar in rhetoric to what has been discussed in the mining literature over the last 15-20 years. There needs to be greater recognition that the rhetoric of sustainable mine void closure needs to be put into practice. Hall (2002:24) in his article on the Premier Coal mine rehabilitation in Collie recognises this and has been able to find a company that is rehabilitating beyond what is required of it and perhaps establishing a new benchmark for mine void closure:

> With the increased emphasis in society on sustainability, Premier…is determined to leave a positive legacy for the community in the mine closure process, whilst with complying and in some cases exceeding regulatory requirements…

Restoration/rehabilitation requirements have found their way into mining legislation over the last 30 years and community expectations have forced some mining companies to recognise that they have a responsibility to the communities in which they operate, although the legislation, particularly regarding mine void closure, is lacking in detail and not all mining companies feel the weight of community expectations. Biggs (2003) believes that regulators will increasingly need to respond better to the closure issues, making an example of poor performers in the industry and rewarding good performers. Again, although Biggs addresses these issues he does not spell out the specifics, leaving the need for more detailed research to be conducted into the regulatory issues surrounding mine void closure in Australia and comparing this with legislative requirements for mine void closure in other developed nations.

### Sustainability and Stakeholder Engagement

The project team has found that mining companies are being forced to maintain their social licenses to operate, in part by poor regulatory guidelines and past (and present) questionable rehabilitation standards by some in the mining industry,. In other words, they are being forced by community expectations to become more sustainable in their mining practices and this has forced a cultural change within the industry. It has led to various reports being commissioned by the industry on sustainable development in mining and the establishment of stronger links by mining companies and communities.

The project has developed a timeline of the various reports on sustainability commissioned by the industry and the processes that drove this change. The reports start from the Mining Industry Code for Environmental Management that established an environmental code for the mining industry – part of which was to develop guidelines for community involvement in the mining industry. This report attempted to establish more sustainable practices within the industry; however, as a whole it was largely unsuccessful, as primarily the larger mining companies adopted it.

The project team also conducted a critical review of the Mining Minerals and Sustainable Development Report, which is seen as the benchmark for the move towards sustainable development by the industry. It was found that the report was quite critical of past mine closure practices by the industry and regulators. A good guide to the depth of its influence is that it forms the basis for the New South Wales Mining Act, which is seen as the most comprehensive in Australia.

Community consultation is increasingly becoming an accepted and essential feature of the mine void closure process. Pressure to become more open and consultative in the mine void closure process has increasingly been placed upon companies from a variety of sources. Companies are increasingly being required to report and disclose information relating to mining activities in order to help restore faith in the entire mining process. In her article on the issue, Khanna (1999:159) lists this pressure on mining companies as coming from a number of sources:

- Environmental pressure groups, such as Minewatch, Greenpeace, Friends of the Earth, and the Mineral Policy Centre, all of who have a generally negative attitude towards mining.
- Non Government Organisations such as the World Bank, United Nations Environmental Programme, and the International Council on Minerals and the Environment, all of who are providing the industry with guidelines to follow.
- National governments, which are responsible for the establishment of legislation and ensuring compliance (except in the case of Australia, where state governments are responsible).

Mining associations are assisting members to improve environmental, social and economic performance. The implication behind the 'codes of practice' is that corporate peer pressure is enough to encourage members to comply voluntarily. In addition to this, the international media, whose coverage of mining disasters can be intense and bring such news very quickly to the attention of the general public who gain most or all of their knowledge about a company, mine or event by reading newspapers, magazines, journals, watching television or surfing the Internet are placing pressure on mining companies to improve mining practices and in particular the closure outcomes.

It appears from much of the literature surveyed and the case studies, that the most ignored group in the whole mining process has been the local community; this has particularly been the case with regards to void closure. In the past mining companies were only part of the local community during the mining operation phase, but once it came to closure the mining companies would close down and leave the community in which they had been operating in an often-precarious situation socially, economically and environmentally.

Few of the articles or books reviewed paid much attention to the issue of local community engagement in the void closure process with Clifford (1997), Barbier (2003) and Chadwick (1998) placing most of their emphasis on the issue of sustainable development and the need for mining associations such as ANZMEC and MCA to adopt a more pro-active approach to the issue of mine void closure, by adopting industry standards. Community engagement must be part of this process and it has a significant part to play in the issue of sustainable mine void closure. It also needs to be determined what groups from the community should play an active role in the void closure process, articles such as that by Khanna discuss the pressure applied by lobby groups – as discussed above – but do not give any clear guidelines as to how much influence these groups should have on the void closure process.

It will be important for mining companies to ensure that local communities in which they wish to undertake mining are fully informed as to the void closure process from the planning phase of the project. This will ensure that communities feel that they have some input into the outcome of mining operations. This type of two-way dialogue may in fact see communities more open to the idea of mining. According to (Lazzaro and Pooley 2003:1):

> … if miners showed similar ingenuity in community negotiations to that applied in recovering and processing minerals, we may have far more economic, timely closures that see other communities wanting miners to enter their society for a decade or three.

## Valuation of Environmental Resources

There are different and competing uses for environmental resources within society. Environmental resources have value beyond their direct use that may have a monetary or non-monetary value. There are some in society who say that we should act as stewards for the environment and protect it for use by future generations; indeed this is the view that Indigenous landowners take concerning the environment (Barbier 2003:260). In the western world, however, a more complex view is taken over competing environmental uses.

Allen et al. (2001) suggest that a variety of claims are made by people on the environment. Some of these claims may be complimentary (e.g. river management, fishing, swimming, water supply to industry and households may all compliment one another). On the other hand, they go on to argue, in some instances mining, logging or even some tourism activities may not be consistent with the idea of preserving an area as a tourist reserve. Decisions surrounding the environment and its competing uses involve costs and benefits that may see these costs and benefits accruing to more than one person in society.

What is the best way to determine how these costs and benefits are calculated? Braden and Kolstad (1991) believe that the use of contingent valuation is the best way to calculate this cost. This involves people deciding how much they are willing to pay for a particular environment or how much they are willing to accept for a reduction in the quality of their environment. Braden and Kolstad (1991:2) suggest the following questions to be asked when using this technique:

- What are the non-use benefits of an environmental resource?
- Do non-use benefits from one kind of use exceed the use benefits from an alternative kind?
- What is the total benefit (use and non-use) of a given environmental resource?

The problem with answering the questions outlined by Braden and Kolstad is that a monetary value needs to be placed on the use of an environment for recreation, habitat preservation, soil preservation, in other words on their non-use benefits. Further to this is the problem of providing quantifiable data to the questions that are posed. Respondents who answer in their own strategic interests may skew the data.

The Federal Department of Environment (1998:2) discusses another method for determining the value of the environment – the replacement cost technique. This simply 'identifies the expenditure necessary to replace an environmental resource or human made good or asset'. The incurred expenditure provides only a minimum willingness to pay to receive a particular benefit, it is only a minimum, as more money may be spent if it seen as necessary to do so. It is too narrowly focused to use as the only option when determining mine void closures however, as it only places an economic value on the resource at the expense of other options.

A cost-benefit analysis is another option that can be used in determining the best possible end use for a mine void; hence it was this option that was used in the research. A cost-benefit analysis is 'an appraisal of the advantages and disadvantages of closure options, valuing as many of these as possible in monetary and non-monetary terms' (Elliot 2003:8). It is a tool to assist in the making and understanding of decisions. A set of models can then be developed that assess closure options, these models can be (Elliot 2003:8):

- Subjective or objective
- Qualitative or quantitative
- Deterministic or stochastic

An example of a cost/benefit analysis includes a multiple accounts analysis (MAA). MAA works using the following methodology (Mining Magazine 2000: 98):

- Identify the impacts (benefits and costs) to be included in the evaluation
- Quantify the impacts (benefits and costs)
- Assess the combined or accumulated impacts for each alternative and develop a preference list (ranking, scaling, weighting) of the alternatives

Contingency Valuation and the Replacement Cost Technique are too narrow in their focus to be used as the only tools for measuring willingness to pay for environmental resources and will be used in conjunction with a cost-benefit analysis. It has been argued that a cost-benefit analysis (as with all issues surrounding mine void completion) should be conducted during the planning phase of the mine and it should be part of an ongoing closure process. Elliot (2003) and Khanna (1999) recognise this and in fact believe that in order to practice sustainable mining, companies need to provide financially for void completion from the outset (Elliot 2003:11):

> If companies want to achieve sustainability at mine completion, they must provide financially for this, for the same reasons as they provide for mine closure as it is today...

## Case Studies

This section included 12 case studies examining poor mine closure practice and world's best mine closure practice. The case studies also included mine closures where no void was left at the end of closure, as the aim was to examine what is 'best closure' practice, which at times may include backfill of a void. The case studies included the following examples:

Poor Mine Closure Practice:

- Rum Jungle – Northern Territory
- Mount Todd – Northern Territory
- Summitville – USA
- Mount Lyell – Tasmania
- Windimurra Mine- Western Australia

World's Best Mine Closure Practice:

- Flambeau Mine – USA
- Ridgeway Mine –USA
- Elliot Lake – Canada
- Penrith Lakes – NSW
- Golden Cross – New Zealand
- Rother Valley – UK
- Cadia Hill – NSW

The research found that a number of similarities existed in cases of poor practice closure, these included; poor regulatory guidelines, lack of a bond mechanism (this is essential in the case of premature mine closure), lack of community engagement, limited, or no initial closure planning by companies (and local governments) and variable commodity prices.

Successful mine closures similarly exhibited a number of similarities including: strong regulatory guidelines, flexible approach to closure by regulators, early planning for mine closure, progressive rehabilitation (both of these have been found to reduce long-term costs associated with mining projects, community participation (at the very least) actual engagement delivered the best outcomes, redistribution of mining royalties back to local communities for the specific purpose of delivering beneficial mine closure outcomes, regulators and mining companies working together to achieve beneficial outcomes for mine closure.

The review has found that there is no one best strategy for mine closure, hence the requirement for a more flexible approach to closure from regulators. At the same time there exists a need for Australia to adopt a more comprehensive and uniform approach to the legislative requirements of mine void closure, as there currently exists wide variation between the states and territories. This lack of clarity and uniformity makes it difficult for mining companies and communities to plan effectively for mine closure.

## Benefit-Cost Analysis Lake Kepwari

Lake Kepwari has provided a good example of successful mine closure, as it exceeded regulatory guidelines, and engaged with the local community and regulators in determining what are the best outcomes for closure of the void. A benefit-cost analysis is being undertaken to examine potential beneficial end-uses for the site as outlined by the report commissioned for the South West Development Commission that examined end-use options for the site.

In addition to this a survey will be conducted in both the Perth Metropolitan region, as well as the Bunbury-Collie region with the aim of gauging what value (both financial and non-financial) that people would be willing to place on the site. The advantage of this approach is that it will provide a full economic analysis of the site, not just a financial analysis. This is expected to be finalised in the latter half of the year.

### *Recommendations*

The project team believes that once the research is completed there will be some useful applications of the findings. Some of the potential applications for these findings include:

- Illustrating how economic modelling can assist in analysing the use and non-use values of mine voids at closure;
- A set of guidelines outlining what constitutes world's best closure practice; and
- Suggest a policy framework for mine void closure.

## Conclusions

The literature review has provided an overview of the main study areas that this research has undertaken. The review has found that Mallet and Mark (1995) have adopted the most suitable approach to determining the most viable mine void closure options, by undertaking a comprehensive cost/benefit analysis.

Similarly, a review of the legislative requirements for mine void closure in Australia found a lack of uniform legislation across the country, but little research has been conducted into what legislative changes are necessary, and indeed if there is a need for more uniform approach to mine void closure. In deciding on what approach to take, a review of legislation in other developed nations is necessary, in order to assist in developing a framework for Australia.

Thirdly, it was determined that a method needs to be developed regarding the use and non-use values for mine sites that places a value on these sites. A review of the literature found that a cost/benefit analysis was the best method for determining mine closure options in conjunction with contingency valuation and the replacement cost technique and that closure should be an ongoing consideration during the entire mining process.

In addition to this, the research has found that community engagement (as separate from community consultation) and the concerns that the community has with regards to the mining process need to be examined. It was found that this is one of the least researched areas in the literature. Community engagement, as a topic has only been seriously examined during the last 5-10 years and even then has only been given rudimentary research. More thorough guidelines for community engagement are needed, as is greater three-way dialogue needed between mining companies, legislators and local communities. The town of Collie has been used as a case study for this issue, examining 'world's best practice' in mine void closure, due to the current closure process for Premier Coal's Western 5 void that is being undertaken in the town.

The BCA is examining both the economic and social costs involved in the development of Lake Kepwari. The economic costs will conduct a benefit cost analysis of the potential development options for Lake Kepwari. The social BCA will place a value on the non-monetary options for Lake Kepwari, by examining the benefits and costs to the community of the Lake.

This section is currently still in the process of being finalised and it is anticipated that this section of the research will be completed towards the latter half of the year.

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Mallet, L and Mark, S, 1995, in Wright, A, 2001, *"What do we do with those great big holes that are left behind once mining ceases?"* Water and Rivers Commission, Perth.

"Mining and Sustainable Development: the next steps", (Ed.), *Mining Magazine,* Volume 182, Number 2, February 2000, pp 98-99.

Wright, A. (2000). What do we do with those great big holes that are left behind once mining ceases? In: *Minerals Council of Australia 25th Annual Environmental Workshop*, 2000, pp 385–390.

# PUBLICATIONS

In the CSML proposal to the State Government, research publications were considered a necessary and important indicator of scientific and community merit, providing the barometer of CSML's contribution to local business and community development.

Across the funding period, CSML researchers were highly successful in publishing research results, which has led to an enhanced understanding of mine lake management.

A number of publication avenues have been utilised to maximise the outreach of CSML research outcomes:

- Refereed journal papers
- Non-refereed papers
- Book chapters
- Conference papers and industry articles
- Conference posters
- Research grant and consultancy reports to client groups
- Editorialships

When the last submitted and accepted paper is printed, a total of 103 research output materials will have been published by CSML researchers for the benefit of industry and future mine lake research. This total includes 26 refereed journal papers; three book chapters; 35 conference papers and industry articles; 24 research grant and consultancy reports to client groups; and five Editorialships. A further 12 thesis papers have been published by postgraduate students who completed research projects relating to CSML research (see Section 4 Education and Community Service).

Indicative of the high reputation WA researchers have in mine lakes and mine closure, in 2006 CSML researchers across all three research programs were invited to contribute to an international workbook on the management of metal mine and metallurgical process drainage. Three chapters have been accepted for publication that relate to regulatory requirements and planning required to develop successful beneficial end uses, successfully rehabilitated pit lake examples, and mine lake water quality modelling. Research outcomes relating to mine lake research at Wesfarmers Premier Coal features strongly in these chapters. This book is an international effort to synthesise current knowledge on pit (mine) lakes, and is intended for use as a worldwide handbook for the mining industry on pit lakes and the issues surrounding them. The acceptance of CSML researchers' chapters for inclusion in the publication is a strong indication that CSML is leading the way internationally in mine lake research.

As the majority of CSML projects were completed by December 2006, this last funding period in particular has seen significant publishing activity. As shown in the following tables, the majority of CSML researcher refereed journal papers appeared in publications in 2006 and a high number of papers are due to be published later this year or early 2008.

| REFEREED JOURNAL PAPERS | | | |
|---|---|---|---|
| **Year** | **Author(s)** | **Article Title** | **Publication/ Journal Details** |
| 2007 | McCullough C.D. | Approaches to remediation of acid mine drainage water in pit lakes | International Journal of Mining, Reclamation and Environment 3:1-15 |
| 2007 | Tantulo U., Fotedar R. | Osmo and ionic regulation of black tiger prawn (*Penaeus monodon* Fabricius 1798) juveniles exposed to $K^+$ deficient inland saline water at different salinities | Comparative Biochemistry and Physiology 146:208-214 |
| 2006 | Lymbery A.J., Doupé R.G., Bennett T., Starcevich M. R. | Efficacy of a subsurface-flow wetland using the estuarine sedge *Juncus kraussii* to treat effluent from inland saline aquaculture | Aquacultural Engineering 34:1-6 |
| 2006 | Stephens F.J., Ingram M. | Two cases of fish mortality in low pH, aluminium rich water | Journal of Fish Diseases 29:765-770 |
| 2006 | Tantulo U., Fotedar R. | Comparison of growth, osmoregulatory capacity, ionic regulation and organosomatic indices of black tiger prawn (*Penaeus monodon* Fabricius, 1798) juveniles reared in potassium fortified inland saline water and ocean water at different salinities | Aquaculture 258 (1-4): 594-605 |
| 2006 | Prangnell D., Fotedar R. | The growth and survival of western king prawns, *Penaeus latisulcatus* Kishinouye, in potassium-fortified inland saline water | Aquaculture 259: 234-242 |
| 2006 | Prangnell D., Fotedar R. | Effect of sudden salinity change on *Penaeus latisulcatus* Kishinouye osmoregulation, ionoregulation and condition in inland saline water and potassium-fortified inland saline water | Comparative Biochemistry and Physiology 145:449-457 |
| 2006 | Whisson G. | Impact of free-range and caged silver perch on system yields in marron polyculture ponds | Freshwater Crayfish 15:98-109 |
| 2005 | Prangnell D., Fotedar R. | The effect of potassium concentration in inland saline water on the growth and survival of the Western king shrimp, *Penaeus latisulcatus* Kishinouye, 1896 | Journal of Applied Aquaculture 17(2):19-34 |
| 2005 | Doupé R.G., Lymbery A.J. | Environmental risks associated with beneficial end uses of mine lakes in southwestern Australia | Mine Water and the Environment 24: 134-138 |
| 2005 | Lymbery A.J. | Parasites and ecosystem health | International Journal for Parasitology 35:703 |
| 2004 | Storer T., Whisson G., Evans L. | Crayfish polyculture in ameliorated water from acid mine lakes | Freshwater Crayfish 14:116-120 |
| 2004 | Sang M.H., Fotedar R. | Growth, survival, haemolymph osmolality and organosomatic indices of the western king prawn (*Penaeus latisulcatus* Kishinouye, 1886) reared at different salinities | Aquaculture 234 (1-4):601-614 |
| 2002 | Storer T., Whisson G., Evans L. | Seasonal variation in health and condition of marron (*Cherax tenuimanus*) from acidic and non-acidic water bodies in the Collie Basin, Western Australia | Freshwater Crayfish 13:525-538 |
| | | **TOTAL** | 14 |

| REFEREED JOURNAL PAPERS – IN PRESS | | | |
|---|---|---|---|
| **Year** | **Author(s)** | **Article Title** | **Publication/ Journal Details** |
| 2007 | Evans L. | Opportunities, impediments and capacity building for enterprise development by Australian Aboriginal communities | Journal of Aboriginal and Economic Development: Volume 5 |
| 2007 | Huber A., Wake G., Ivey G., Oldham C. | Near surface wind induced mixing in a mine lake | ASCE Journal of Hydraulic Engineering |
| 2007 | Fotedar R., Harries S., Savage S. | Short-term physiological responses of greenlip abalone, *Haliotis laevigata* Donovan 1808, when exposed to different ionic profiles of inland saline water | Aquaculture Research |
| 2005 | Storer T., Jenkinson S., Whisson G. | Behavioural interactions between an invasive and a non-invasive freshwater crayfish under threat from a potential predator in Western Australia | Freshwater Crayfish 15 |
| | | TOTAL | 4 |

| REFEREED JOURNAL PAPERS – SUBMITTED | | | |
|---|---|---|---|
| **Year** | **Author(s)** | **Article Title** | **Publication/ Journal Details** |
| 2007 | Neil L., McCullough C.D., Tsvetnenko Y., Evans L., Lund M.A. | Bioassay toxicity assessment of mining pit lake water remediated with limestone and phosphorus | Ecotoxicology and Environmental Safety |
| 2007 | Evans L. | Opportunities, impediments and capacity building for enterprise development by Australian Aboriginal communities | Journal of Aboriginal Economic Development |
| 2007 | Read D.J., Oldham C., Ivey G. | The addition of dissolved organic carbon to promote aerobic respiration in sediments: estimation of a rate constant | Journal of Environmental Engineering |
| 2007 | McCullough C.D., Lund M.A., May J. | Biological remediation of acidic mine waters using a sewage evaporation pond | Hydrobiologia |
| 2007 | Marti C.L., Oldham C., Imberger J. | Interplay of physical and degradation processes controlling vertical flux of particles in a stratified lake | Water Resources Research |
| 2007 | Salmon U., Oldham C., Ivey G. | Aqueous geochemistry and nutrient dynamics in an acidic pit lake | Water Resources Research |
| 2007 | Oldham C., Salmon U., Hipsey M., Ivey G. | Modelling pit lake water quality: Coulding of lake stratification, dynamics, lake ecology, aqueous geochemistry and sediment diagenesis | Journal for the Society of Mining Engineering |
| 2005 | Tantulo U., Fotedar R. | Survival, growth, osmoregulatory capacity and organosomatic indices of black tiger prawn (*Penaeus monodon* Fabricius, 1798) juveniles reared in inland saline water at different levels of $K^+$ | Aquaculture International |
| | | TOTAL | 8 |

| NON-REFEREED PAPERS | | | |
|---|---|---|---|
| **Year** | **Author(s)** | **Article Title** | **Publication/ Journal Details** |
| 2006 | McCullough C.D., Lund M.A. | Opportunities for sustainable mining pit lakes in Australia | Mine Water and the Environment 25(4):220-226 |
| 2004 | Storer T., Whisson G. | Interaction between Murray cod (*Maccullochella peelii*) and marron (*Cherax tenuimanus*): translocation impacts and polyculture potential in Western Australia | Biothon Event, Department of Environmental Biology Curtin University:27 |
| 2004 | Storer T. | Influence of a potential predatory threat on the interaction behaviour between an indigenous and an invader crayfish species | Biothon Event, Department of Environmental Biology Curtin University:35 |
| 2003 | Whisson G., Storer T. | Investigating aquaculture potential in mine lakes | Marron Growers Bulletin 25(4):6-9 |
| | | **TOTAL** | 4 |

| BOOK CHAPTERS – IN REVIEW | | | | |
|---|---|---|---|---|
| **Year** | **Author(s)** | **Title** | **Chapter Title** | **Publisher** |
| 2007 | McCullough C.D., ECU; Evans L., Hunt D., Curtin | Workbook of Technologies for the Management of Metal Mine and Metallurgical Process Drainage | Social, Economic, and Ecological End Uses – Incentives, regulatory requirements and planning required to develop successful beneficial end uses | Society for Mining Engineering (SME) |
| 2007 | McCullough C.D., ECU; Hunt D., Evans L., Lund M.A., Murray-Prior R., Rola-Rubzen F., Curtin | Workbook of Technologies for the Management of Metal Mine and Metallurgical Process Drainage | Social, Economic, and Ecological End Uses – Beneficial end uses for pit lakes | Society for Mining Engineering (SME) |
| 2007 | Oldham C., Ivey G., UWA | Workbook of Technologies for the Management of Metal Mine and Metallurgical Process Drainage | Mine Lake Water Quality Modelling | Society for Mining Engineering (SME) |
| | | | **TOTAL** | 3 |

| NATIONAL/INTERNATIONAL RESEARCH CONFERENCE PAPERS AND INDUSTRY ARTICLES | | | | | |
|---|---|---|---|---|---|
| **Year** | **Conference Title** | **Location** | **Date** | **Article Title** | **Author(s)** |
| 2007 | Plants for People Aboriginal Wild Harvest and Land Management Seminar (2006) | Kalgoorlie, WA | Apr | Plants for People - A Process for Aboriginal Empowerment and Enterprise (proceedings) | Evans L. |
| 2006 | Water in Mining Conference (2006) | Brisbane, QLD | Nov | Mine water sustainability; what is it, and how do I get it? (proceedings) | McCullough C.D., Lund M.A. |
| 2006 | Desert Knowledge Symposium (2006) | Alice Springs, NT | Nov | Case study on intellectual property protection of traditional knowledge of plants and their uses (abstract) | Evans L., Scott H., Briscoe J. |
| 2006 | Pit Lakes 2004 | Reno, Nevada, USA | Nov | Mine lake environmental and social sustainability research in Western Australia (abstract) | Evans L., Ashton P. |
| 2006 | Engaging Indigenous Communities Conference (2006) | Brisbane, QLD | Oct | The plants for people approach to aboriginal economic development - successes, failures and lessons learnt (abstract) | Evans L. |
| 2006 | Mine Closure 2006 | Perth, WA | Sep | Prediction of long-term water quality in acidic mine lakes (proceedings) | Oldham C., Salmon U., Hipsey M., Wake G. |
| 2006 | Interact 2006 Air, Water & Earth | Perth, WA | Sep | Toxicity assessment of limed and phosphorus amended mine pit lake water (proceedings) | Neil L., McCullough C.D., Tsvetnenko Y., Evans L. |
| 2006 | Interact 2006 Air, Water & Earth | Perth, WA | Sep | Mine lake water quality assessment using bioassays and chemical analyses (proceedings) | Tsvetnenko Y. Neil L., Evans L. |
| 2006 | Interact 2006 Air, Water & Earth | Perth, WA | Sep | The chemical profile of inland saline water and its effect on the aquaculture potential of selected marine species (proceedings) | Fotedar R., Sarathchandra W.D. |
| 2006 | ACMER 5th Australian Workshop on Acid Rock Drainage (2005) | Fremantle, WA | Aug | Closure for beneficial outcomes (proceedings) | Evans L., Hunt D., Ashton P. |
| 2006 | ACMER 5th Australian Workshop on Acid Rock Drainage (2005) | Fremantle, WA | Aug | An overview of limestone treatment systems (proceedings) | Green R., Evans L. |
| 2006 | ACMER 5th Australian Workshop on Acid Drainage (2005) | Fremantle, WA | Aug | Standard protocols for the monitoring of water quality in mine lakes – a proposal (proceedings) | Oldham C., Franzmann P., Douglas G., Eigeland K., Ghadouani A., Ivey G., Salmon U., Reynolds D., Samaraweera |

| NATIONAL/INTERNATIONAL RESEARCH CONFERENCE PAPERS AND INDUSTRY ARTICLES | | | | | |
|---|---|---|---|---|---|
| | | | | | S., Stauber J. |
| 2006 | Sustainability of Indigenous Communities National Conference (2006) | Murdoch, WA | Jul | Sustainability through enterprise and land management (abstract) | Evans L., Cronin D., Riha D., Ugle P. |
| 2006 | Goldfields Environmental Management Group Workshop on Environmental Management (2006) | Kalgoorlie, WA | May | Pit lakes: benefit or bane to companies, communities and the environment? (proceedings) | McCullough, C.D., Lund M.A. |
| 2006 | 7th International Conference on Acid Rock Drainage (ICARD) (2006) | St Louis, USA | Mar | Microcosm testing of municipal sewage and green waste for full-scale remediation of an acid coal pit lake, in semi-arid tropical Australia (proceedings) | McCullough C.D., Lund M.A., May J.M. |
| 2006 | 7th International Conference on Acid Rock Drainage (ICARD) (2006) | St Louis, USA | Mar | In-situ coal pit lake treatment of acidity when sulphate concentrations are low (proceedings) | Lund M.A., McCullough C.D., Yuden |
| 2005 | MCA Sustainable Development Conference (2005) | Alice Springs, NT | Oct | Standard protocols for the monitoring of water quality in mine lakes – a proposal (proceedings) | Oldham C. |
| 2005 | MCA Sustainable Development Conference (2005) | Alice Springs, NT | Oct | Mining for Country – Aboriginal enterprise and capacity building through partnerships between mining companies and Indigenous communities (proceedings) | Muir K., Evans L. |
| 2005 | MCA Sustainable Development Conference (2005) | Alice Springs, NT | Oct | Community development through mine site rehabilitation projects (proceedings) | Ashton P., Evans L. |
| 2004 | Acid Sulfate Soil Workshop: Focus on Aquatic Impact Assessment and Management (2004) | Mandurah, WA | Sep | Metal toxicity in ameliorated mine lake water: case study of a fish kill in Collie (abstract) | Storer T., Ingram M., Evans L., Whisson G. |
| 2004 | Acid Sulfate Soil Workshop: Focus on Aquatic Impact Assessment and Management (2004) | Mandurah, WA | Sep | Fluidised limestone reactor technology in acid sulphate soil remediation (abstract) | Evans L., Scott D., Milne J., Milne S. |
| 2004 | International Conference on Indigenous Knowledge and Bioprospecting (2004) | Sydney, NSW | Apr | Plants for People: A community based approach to recording and protecting Indigenous knowledge about plants (abstract) | Evans L., Muir K., Barr A., Scott H., Briscoe J. |

| NATIONAL/INTERNATIONAL RESEARCH CONFERENCE PAPERS AND INDUSTRY ARTICLES | | | | | |
|---|---|---|---|---|---|
| 2004 | 15th Symposium of the International Association of Astacology (2004) | London, UK | Mar | Impact of crayfish polyculture on pond production and ecology (abstract) | Whisson G. |
| 2004 | 15th Symposium of the International Association of Astacology (2004) | London, UK | Mar | Do visual and chemical predator cues affect competition for shelter between native (Cherax tenuimanus) and invasive (Cherax albidus) crayfish in Western Australia? (abstract) | Storer T., Jenkinson S., Whisson G. |
| 2003 | MCA Sustainable Development Conference (2003) | Brisbane, QLD | Nov | Beneficial end uses for open cut mine sites: planning for optimal outcomes (abstract) | Evans L., Rola-Rubzen F., Ashton P. |
| 2003 | ACMER workshop on water quality issues in final voids and temporary streams (2003) | Brisbane, QLD | Jul | Mine lake research – water quality prediction, amelioration and use with emphasis on aquaculture (abstract) | Fotedar R., Evans L. |
| 2003 | ACMER workshop on water quality issues in final voids, salt lakes and ephemeral streams (2003) | Perth, WA | May | Emerging technologies in modelling void water quality (abstract) | Ivey G. |
| 2003 | ACMER workshop on water quality issues in final voids, salt lakes and ephemeral streams (2003) | Perth, WA | May | International case study (abstract) | Oldham C. |
| 2003 | ACMER workshop on water quality issues in final voids, salt lakes and ephemeral streams (2003) | Perth, WA | May | CSML Research programs and mine lake water treatment systems (abstract) | Evans L., Scott D. |
| 2003 | ACMER workshop on water quality issues in final voids, salt lakes and ephemeral streams (2003) | Perth, WA | May | Data requirements for predicting and monitoring final void water quality (abstract) | Ivey G., Oldham C. |
| 2002 | 14th International Symposium International Association of Astacology (2002) | Queretaro, Mexico | Aug | Utilising ameliorated water from acidified mining lakes for polyculture in Western Australia (abstract) | Storer T., Whisson G., Evans L. |
| | | | | TOTAL | 32 |

| NATIONAL/INTERNATIONAL RESEARCH CONFERENCE PAPERS AND INDUSTRY ARTICLES – IN PRESS | | | | | |
|---|---|---|---|---|---|
| **Year** | **Conference Title** | **Location** | **Date** | **Article Title** | **Author(s)** |
| 2007 | 17th International Biohydrometallurgy Symposium | Frankfurt, Germany | Sep | The diversity of benthic microorganisms in acidic mine lake sediments | Pham H.A., Oldham C., Plumb J.J. |
| 2005 | 9th Conference of the International Society for Salt Lake Research | Perth, WA | Sep | Osmoregulatory mechanism and growth of black tiger prawn (*Penaeus monodon* Fabricius, 1789) juveniles reared in fortified inland saline water | Tantulo U., Fotedar R. |
| 2005 | 9th Conference of the International Society for Salt Lake Research | Perth, WA | Sep | Effect of sudden changes in potassium concentration on *Penaeus latisulcatus* Kishinouye survival, osmolality and condition when reared in inland saline water | Prangnell D., Fotedar R. |
| | | | | **TOTAL** | 3 |

| NATIONAL/INTERNATIONAL RESEARCH CONFERENCE POSTERS | | | | | |
|---|---|---|---|---|---|
| **Year** | **Conference Title** | **Location** | **Date** | **Poster Title** | **Principal Author** |
| 2006 | 7th International Conference on Acid Rock Drainage (ICARD) | St Louis, USA | Apr | In-situ coal pit lake treatment of acidity when sulphate concentrations are low | Lund M.A. |
| 2006 | 7th International Conference on Acid Rock Drainage (ICARD) | St Louis, USA | Apr | Neutralization of acid rock drainage using a fluidized limestone reactor | Evans L. |
| 2004 | 15th Symposium of the International Association of Astacology | London, UK | Mar | Do visual and chemical predator cues affect competition for shelter between native (Cherax tenuimanus) and invasive (Cherax albidus) crayfish in Western Australia? | Storer T. |
| 2004 | 15th Symposium of the International Association of Astacology | London, UK | Mar | Impact of crayfish polyculture on pond production and ecology | Whisson G. |
| 2004 | Second New Crops Conference | Brisbane, QLD | Sep | Value adding to the developing plantation sandalwood industry through new nut products | Woodall G. |
| 2003 | Management & Remediation of Abandoned Mines workshop | Brisbane, QLD | Nov | Quality assessment of water from mine voids | Tsvetnenko Y. |
| | | | | **TOTAL** | 6 |

Research reports generated from grants and contracted research also provided a record and means of transfer of information to key industry stakeholders and the broader community.

| RESEARCH GRANT AND CONSULTANCY REPORTS TO CLIENT GROUPS | | | |
|---|---|---|---|
| **Year** | **Report Title** | **Client** | **Author(s)** |
| 2007 | Regional mining and other Agreements review | Goldfields Land and Sea Council | Cronin D., Evans L. |
| 2007 | Scoping project for Dalwallinu Shire wattle feasibility study, final report | Wheatbelt Development Commission | Evans L., Fairnie H., Turnbull H. |
| 2007 | Review of CSML Research of Lake Kepwari and recommendations for water quality management, final report | South West Development Commission | Evans L., Oldham C., Lund M., Salmon U., Tsvetnenko Y., McCullough C.D., Neil L. |
| 2007 | Plants for People Final Report: Executive Summary | Desert Knowledge – CRC | Evans L., Cheers B., Muir K., Scott H., Briscoe J. |
| 2007 | Intellectual property rights for traditional knowledge about plants, with specific reference to Australian Indigenous peoples and plants. In Evans L., Briscoe J., Muir K., Scott H. (Eds.) Plants for People Final Report: Part B. Background Papers | Desert Knowledge – CRC | Evans L., Muir K. |
| 2007 | Opportunities, impediments and capacity building for enterprise development by Australian Aboriginal communities. Plants for People Final Report: Part B. Background Papers | Desert Knowledge – CRC | Evans L., Scott H., Briscoe J. |
| 2007 | A synopsis of Part A of Desert Knowledge CRC Traditional Knowledge Scoping Project Report, Smallacombe et al., (2006) | Desert Knowledge – CRC | Evans L. |
| 2007 | Plants for People Final Report: Part C. Laboratory Study Report | Desert Knowledge – CRC | Evans L., Briscoe J. Baker E., Barr A., Locher C., Muir K., Savigni D., Semple S., Scott H., Tsvetnenko E., Tsvetnenko Y., Wang S. F. |
| 2007 | Plants for People Final Report: Part D. Intellectual Property Protection Study Report | Desert Knowledge – CRC | Evans L., Scott H., Muir K., Briscoe J |
| 2007 | Plants for People Final Report: Part F. Plants for People Publicity Report | Desert Knowledge – CRC | Evans L., Duncan A. |
| 2006 | Reclamation of Traditional Indigenous Knowledge of the South West Noongar Indigenous Community (Collie, WA) | Department of Indigenous Affairs | Evans L. |
| 2006 | Review of quality limits for Collie industrial saline water discharge into the ocean | Devereax Holdings Pty Ltd | Tsvetnenko Y., Evans L., Oldham C. |

| RESEARCH GRANT AND CONSULTANCY REPORTS TO CLIENT GROUPS | | | |
|---|---|---|---|
| 2006 | Mine lake water quality using bioassays and chemical analysis | Australian Coal Research Ltd | Tsvetnenko Y. |
| 2006 | Bush produce systems project, Leonora Bush Foods project, final report | Desert Knowledge-CRC | Evans L. |
| 2006 | Future mass balance calculations for Chicken Creek mining void | GHD and Department of Water | Salmon S., Oldham C. |
| 2006 | Potential of pit lakes as a positive post-mining option – examples, issues and opportunities | Rio Tinto | Evans L., Cronin D. Doupé R.G., Hunt D., Lymbery A.J., McCullough C. D., Tsvetnenko Y. |
| 2005 | Toxicity of commercial fungicide SWITCH to juvenile marron | Denmoore Charlais | Tsvetnenko Y., Evans L. |
| 2005 | Plants for People progress report – Leonora study site | Desert Knowledge – CRC | Singleton G., Evans L. |
| 2003 | Toxicity assessment of water from Eneabba West mine void | Iluka Resources Ltd | Tsvetnenko Y. |
| 2003 | Aquaculture as a relinquishment option for final mining voids (final report – project C9027) | Australian Coal Research Ltd | Whisson G., Evans L. |
| 2003 | Polyculture of marron and silver perch using ameliorated mine lake water. In: Whisson G. and Evans L. 2003 Aquaculture as a relinquishment option for mining voids. | Australian Coal Research Ltd | Whisson G., Storer T. |
| 2003 | Development of Collie Aquafarm. In: Whisson G. and Evans L. 2003 Aquaculture as a relinquishment option for mining voids. | Australian Coal Research Ltd | Storer T., Evans L. |
| 2002 | Hazard assessment of water from Eneabba West mine void | Iluka Resources Ltd | Tsvetnenko Y. |
| | | TOTAL | 23 |

| RESEARCH GRANT AND CONSULTANCY REPORTS TO CLIENT GROUPS – IN PREPARATION | | | |
|---|---|---|---|
| **Year** | **Report Title** | **Client Name** | **Author(s)** |
| 2007 | CSML Collie Aboriginal integrated aquaculture project | Department of Fisheries, Forestry and Agriculture | Evans L. |
| | | TOTAL | 1 |

| EDITORIALSHIPS | | | | |
|---|---|---|---|---|
| **Year** | **Location** | **Date** | **Conference/Workshop/Seminar Proceedings Title** | **Editor(s)** |
| 2007 | Kalgoorlie, Western Australia | Apr | Plants for People Aboriginal Wild harvest and Land Management Seminar (proceedings: 51pp) | Evans L., Duncan A. |
| 2007 | Alice Springs, Northern Territory | Feb | Recording Indigenous Knowledge on Electronic Data Bases Workshop (proceedings: 24pp) | Evans L. |
| 2006 | Northampton, Western Australia | Nov | Integrated Aquaculture Networking Workshop (proceedings: 26pp) | Evans L., Cronin D. |
| 2005 | Broome, Western Australia | Aug | Capitalising on Natural Resources and Indigenous Knowledge Workshop (proceedings: 26pp) | Batty D., Cornwall T., Edgar K., Evans L., Flugge K., Smith W., Thomas R., Worth K., Zed J. |
| 2004 | Mandurah, Western Australia | Sep | Acid Sulphate Soils Workshop – Focus on Aquatic Impact Assessment and Management (abstract proceedings: 38pp) | Evans L., Duncan A. |
| | | | **TOTAL** | 5 |

# 3. CSML RESEARCH - COMMERCIAL, SCIENTIFIC AND INDUSTRIAL VALUE

In 2000, when discussions with key organisations in the industry and the university sector first began on the urgent need to establish a sustainable mine lakes research centre, mining and petroleum production accounted for around 20% of the Gross State Product and exceeded 75% of state exports. The total value of production was in excess of $25.7 billion (at that time a record figure) and the industry provided more than 40,000 jobs[5]

Fast forward to 2006 and the value of mineral and petroleum resources to the state reached a new record of $48.4 billion, with the resource industry's dominance in the state's economy now accounting for 88% of exports. By 2006 the average number of people employed in the minerals and petroleum industry had risen to almost 62,000[6].

The actual and potential commercial, scientific and industrial value of CSML research outcomes to this major contributor to WA's economy must not be understated – when WA's mining sector is booming and set to continue a sustained growth, where does it leave the environment and what effect does this have on mining communities?

While the state is in the grip of its biggest-ever mining boom, and mining below the water table increases, CSML researchers have been developing the science underpinning mine closure criteria so as to ensure ecologically sustainable closure plans are achievable and realistic, so as to assist mining companies to provide economic, social and environmental benefits on pit closure and relinquishment.

The following provides a description of the commercial, scientific and industrial value of CSML research project outcomes and any actual or intended proposals to exploit this value.

## MINE LAKE PREDICTIVE MODELLING; FREE TO USE TECHNOLOGY

A mine lake water quality prediction model, developed through Project 1, will provide enormous value to the mining industry, regulatory agencies and other stakeholders to predict both short- and long-term water quality in mine lakes. Understanding the behaviour of mine lake water over time has been a significant hurdle in the relinquishment of mine lakes. Up to now there has been no available model that combines geochemical process descriptions with the limnological process descriptions of the classic lake stratification and NPZ models.

The CSML mine lake water quality prediction model will be free for use and after beta-testing will be available from a standard model download site via http://www2.sese.uwa.edu.au/research/minelakes/. This means that any organisation (national and international) will have access to the models for their own uses. While this may remove some short-term commercial benefit to the model developers, experience has shown that ultimately the increased usage of the models ensures rapid technology transfer into the relevant sectors, and this in turn drives increased funding to the researchers. As more sectors use the models, increasingly sophisticated questions are being asked, particularly by regulatory agencies, and interpretation of these questions and the resulting model output, typically requires extensive consultation with the researchers.

Due to the free for use nature of the model no commercialisation possibilities exist.

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[5] Western Australia Mineral and Petroleum Statistics Digest, 2000-01

[6] Western Australia Mineral and Petroleum Statistics Digest, 2006

## DEVELOPMENT OF PASSIVE REMEDIATION TREATMENT SYSTEMS FOR ACIDITY PROBLEMS

As highlighted in last year's annual report, active and passive remediation systems under trial at Spoonbill Lakes in the City of Stirling has the potential to produce a design for a permanent treatment system that can be adapted to other urban contexts where acid sulphate soils (ASS) is a problem.

Research by the CSML ECU team showed that the Chicken Creek wetland at Griffin Coal Mining Company did not provide any significant conditioning for limed acidic mine water, and that an anaerobic wetland cell after the liming stage was required to remove toxic metals from the limed water. Results from this study, along with the examination of water dynamics of five acidic mine lakes, plus a macrocosm experiment that investigated organic matter and phosphorous additions to improve water quality within a mine lake, all contributed to a conceptual model of the ideal passive remediation system currently on trial in the City of Stirling. Results from passive remediation systems under trial at Spoonbill Lakes in the City of Stirling has shown the potential to produce a design for a permanent treatment system that can be adapted to other urban contexts where acid sulphate soils (ASS) is a problem.

Across Australia particularly, such a system will be of significant benefit to urban developers and urban environmental managers as a tool to alleviate the impact of ASS on population health, the green environment and the built environment.

ECU's success in biological remediation led to a further ACARP funded project to clean up toxic and acid mine water at the Collinsville Coal Project (Xstrata Pty Ltd), North Queensland. This project led to Collinsville winning the Ergon Energy Tidy Towns 2006 Award for Environmental Innovation. In collaboration with the Bowen Shire Council, the project is investigating whether municipal sewage and green waste is able to stimulate microbially-mediated sulphate reduction sufficiently to remediate a highly acidic mine lake. While sewage and green waste additions to the mine lake only commenced in July 2006, results to date indicate that bacteria feeding on the organic matter are reversing the process that caused the acidity to develop in the first place. Monitoring is planned until the end of 2007.

While there is potential commercialisation associated with ECU's treatment approach in urban and mine site contexts, the project team is committed to open publication of the results to the benefit of all parties.

## BIOASSAYS AND CHEMICAL ANALYSES IN THE ASSESSMENT OF MINE LAKE WATER QUALITY

An accurate assessment of adverse water quality conditions of mine lake water provides mining companies with vital insight into the main sources of poor water quality for their specific water issues (acidity, elevated metals or a combination of both). This insight is the starting point for targeting water remediation options that will produce the most effective results. Understanding the toxicity potential of mine lake water at different stages of treatment is also an essential component for the development of effective treatment systems.

Through this CSML project a suite of bioassay test protocols and test species have been established that, when used in conjunction with chemical analyses, will provide a comprehensive characterisation of mine lake water quality. By using a suite of bioassays, the aggregate toxicity of all constituents in water can be estimated for a wide spectrum of aquatic organisms. Toxicity caused by compounds commonly not analysed for in chemical assays is detected. In bioassays the bioavailability of the toxic constituents is assessed, and effects of interactions of constituents are measured.

The development of acute and chronic toxicity test protocols for freshwater aquatic organisms and the use of these assays in estimation of toxicity potential are not limited to a mine lake water application. Griffin Coal is considering options for discharge of waste water resulting from different ongoing and planned projects. One option is to use an existing pipeline constructed for ocean disposal of saline waste water of the Collie Power Station for discharge. However advances in technology for power station cooling operations and new projects for water desalinisation and carbonisation may well change the current water composition and increase the volume of waste water discharged into the ocean. In turn this could breach conditions of the current Department of Environment licence limits and national marine water quality guidelines. CSML was contracted by Devereaux Holdings Pty Ltd on behalf of Griffin Coal to prepare a review of the current concentration limits for Collie Power Station saline water discharged in the ocean pipeline; determine water quality parameters of current and prospective effluents; estimate water quality parameters in a composite effluent, and toxicant concentrations in a mixing zone of the ocean outfall, with and without desalinisation; and review available data on environmental impacts of the toxicants to marine organisms. The review determined the proposed scheme of disposal of saline water from new industrial developments in Collie, through the existing saline waste water discharge pipeline, should be reconsidered.

## FLUIDISED LIMESTONE REACTORS FOR THE REMEDIATION OF ACIDIC DRAINAGE WATERS

Acid mine drainage (AMD) is the single biggest environmental threat facing the domestic and international mining industry today. CSML has been studying the application of Fluidised Limestone Reactors (FLR) in the remediation of acidic mine lake water since 2002.

Innovative, low cost cylindrical and conical FLRs were developed, installed and trialed at Wesfarmers Premier Coal and Griffin Coal, Collie. By the end of 2005, results of this research proved the FLR to be a cost effective system to raise mine lake water pH and remove iron and aluminium through conical small-scale treatment systems. However, the research also found that fluidisation properties and neutralising efficiency varied with change in vessel dimensions and limestone aggregate properties. Further investigations to assess alterations in fluidisation dynamics that occur with scaling-up the present design were required to inform the commercial potential of the FLR treatment system – the final stage necessary to develop a commercial sized FLR.

The potential benefit of design refinement for optimum performance of the conical Fluidised Limestone Reactor (FLR), developed and trialled through CSML research undertaken between 2002 and 2005, led to CSML researchers being awarded an ACARP grant in 2006 of $121,430 for a 14-month project titled ‘Fluidised Limestone Reactors for the Remediation of Acidic Drainage Waters’. The Project aimed to design a cost efficient commercial sized conical FLR, and to develop design guidelines for FLRs that efficiently utilise limestone and are capable of raising the pH above 6 in waters rich in iron and aluminium.

Results of this ACARP project, informed by previous CSML research, led to a request for CSML to develop a proposal for the construction of a large FLR for processing 20L/sec of mine lake water at Lake Kepwari in Collie. Curtin University is now in negotiations with the company that produced the design quotation with the view to marketing the technology to mining companies and other clients.

Discussions are also now underway between Curtin University and the mineral processing technology company on joint venturing the commercialisation of the FLR. The company is interested in entering into a commercial arrangement to conduct a market survey to assess the market potential of the technology and, if this proves to be favourable, a further arrangement to manufacture and market the FLR treatment system.

An enquiry for the installation of a small scale FLR at a mine site in Queensland for use in the treatment of low volume acidic leachates was recently received and is expected to lead to the application of the technology at the mine site.

## AQUAFARM 'WORLD FIRST' ECOURAGES COMMERCIAL-SCALE PROSPECTS

CSML Project 3.1 continued the pioneering development of aquaculture in remediated mine lake water. It also continued a decade of research into the polyculture of marron and silver perch, further elucidating the factors that govern production in multi-species systems, and determining polyculture increases profitability of two marginal monoculture candidates which has obvious economic spin-off for marron farmers.

Based on project outcomes, the prospect of conducting commercial-scale aquaculture in remediated mine lake water is extremely encouraging. Most importantly, all participating species survived in aquaculture ponds that were supplied with mine lake water. Further, marron reproduced in all ponds at some point during the project, an indication that conditions were near optimum. Silver perch were also spawned during the project, effectively closing the life cycle of silver perch in acid-remediated mine lake water for the first time, presenting an attractive proposition to proponents of a commercial operation.

Polyculture production demonstrated greater increases in biomass than monoculture ponds in all production trials, which supported previous research into aquatic polyculture and the factors governing production in multi-species environments. The prospect of conducting commercial-scale aquaculture in remediated mine lake water was greatly encouraged as all participating species survived in aquaculture ponds that were supplied with mine lake water. Further, marron reproduced in all ponds at some point during the project, an indication that conditions were near optimum. Silver perch were also spawned during the project, presenting an attractive proposition to proponents of a commercial operation.

Such research has made significant inroads into the role of aquaculture as a beneficial end use of mine lake water.

## ENVIRONMENTAL MANAGEMENT SYSTEM FOR MINE LAKE AQUACULTURE

Environmental impacts can be defined broadly to include any adverse effects upon people, natural biota or natural resources. It is important that potential impacts be identified, the risks of each impact assessed and a strategy for managing the risks developed. An environmental management system (EMS) is a generic term to describe a systematic approach used by an organisation to manage its impacts on the environment. This involves setting environmental objectives and targets, monitoring performance against the targets, and, if necessary, developing treatment systems to comply with the targets.

Reporting on potential environmental impacts from aquaculture, developing indicators of ecosystem health, and reporting on nutrient effluent and aluminium toxicity monitoring and treatment were a key focus of the CSML research project 3.3 – Environmental Management System for mine lake aquaculture.

In the study of environmental impacts from mine lake aquaculture the project team identified two major issues that may have detrimental effects on productivity within aquaculture ponds: nutrients (principally nitrogen and phosphorous) derived from uneaten feed and excretion products of fish; and heavy metals, particularly aluminium, which are present in extracted mine lake water. In this part of the study, the level of nitrogen, phosphorous and aluminium in ponds was monitored at the Collie Aquafarm, and options for within-pond treatment were investigated.

This project has provided, for the first time, a comprehensive summary of beneficial end uses of mine lakes and mine lake water from throughout the world. It has also identified the general environmental impacts associated with these different end uses and developed a detailed assessment of the potential environmental impacts from different aquaculture production systems using mine lakes and mine lake water. Nutrient and heavy metal contamination has been monitored at the Collie Aquafarm and mitigation procedures for these impacts have been tested.

Results from the final-year of this project led directly to a successful application to the Rural Industries Research and Development Corporation (RIRDC) for a three-year project titled

‘Integrating inland saline aquaculture and livestock production’. The RIRDC Environment and Farm Management program grant funding of $93,428 will support the further investigation of the potential for utilising crops and forage plants to filter aquaculture effluent in an agricultural setting.

## BEST PRACTICE STRATEGIES FOR ABORIGINAL ECONOMIC DEVELOPMENT

Participatory action research on enhancing the capacity of Aboriginal people in Collie and Leonora to plan and conduct social and business enterprises, along with on-the-ground studies of cultivation of selected native plant species, has led to the identification of success factors for successful enterprise development. These include:

- Operation of a project by a cohesive social group;
- Local champions with the passion and ability to lead the project;
- Long lead time to develop community understanding and support for the development project;
- Aboriginal control and commitment in decision making;
- Access to appropriate information;
- Acceptance by decision makers of each other’s goals and responsibilities;
- Reward for effort;
- Compilation of management plans with realistic feasibility assessments;
- Access to sufficient resources to carry out the plan;
- Networking with other Aboriginal people with similar enterprise development plans;
- Technical support in financial and corporation management;
- Genuine partnerships between local people and support agencies;
- Underpinning economic development activities with remedial and further education.

These strategies are now being employed in Aboriginal enterprise development projects at Laverton, sponsored by AngloGold Ashanti, and Collie, sponsored by local mining companies and community organisations.

## WORLD’S BEST PRACTICE CLOSURE OUTCOMES

Setting the scene for positive mine closure outcomes through CSML’s research project into world class closure outcomes will allow mining companies to make educated decisions on the future of a mine site that reflect changing public priorities and environmental imperatives.

Ultimately, the project will establish an analysis of world’s best closure practices, with a major focus on Wesfarmers Premier Coal’s Lake Kepwari mine rehabilitation development as a case study on best closure practices. The project will provide a checklist of best closure practices and make recommendations on changes to legislative requirements surrounding mine closure towards a greater emphasis on developing a holistic approach to mining, particularly the need to focus on closure at the start of a mining project. It is also envisaged that the use of Lake Kepwari as a major case study will demonstrate the need for increased community participation in the mine closure process.

Such outcomes will inform regulators and mining companies seeking to develop a policy framework for mine void closure that addresses the current gaps that exist in mine closure legislation in Australia. The economic modelling being performed in this project has the potential to be applied by mining companies considering mine closure outcomes.

The research project's review to date was a significant component of the CSML Consultancy Report to Rio Tinto on the 'Potential of Pit Lakes as a Positive Post-Mining Option'. Project outcomes also led to a major contribution to two chapters in the Society for Mining and Engineering's international workbook on the management of metal mine and metallurgical process drainage, that synthesises current knowledge on mine lakes, intended for use as a worldwide handbook for the mining industry.

These chapters focus on:

- Social, Economic, and Ecological End Uses – Incentives, regulatory requirements and planning required to develop successful beneficial end uses, and
- Social, Economic, and Ecological End Uses – Beneficial end uses for pit lakes

# 4. EDUCATION AND COMMUNITY SERVICE

## HIGHER AND CONTINUING STUDIES IN MINE LAKE MANAGEMENT AND DOWNSTREAM USES

Since CSML was established in 2002, university partners in the Centre have continued to attract and retain high calibre students interested in pursuing PhD, Masters, and undergraduate degrees in the diverse fields that encompass the study and management of mine lakes and downstream uses.

Local graduates from engineering, environment, agriculture and aquatic sciences have chosen to continue their education through undertaking postgraduate studies directly applicable to the mining, water, and fisheries industries. The first student to receive a PhD relating to CSML research into mine lake management issues graduated in 2006, and is now applying his expertise in aquatic ecosystems impacted by acid sulphate soils to the estuarine environment. To date, four students have completed postgraduate degrees relating to CSML research, with a further nine in progression. Nine final-year undergraduate projects (Honours) have also been completed. Research undertaken by these students has contributed to the global understanding of mine lake mechanics and management, particularly in the areas of mine lake environmental fluid dynamics, aquatic ecosystem dynamics, and beneficial end uses.

CSML's multidisciplinary approach to research and education has resulted in a number of higher and continuing studies students being supervised by researchers from more than one CSML partner university. Such collaboration is the cornerstone of CSML's approach to providing value-added solutions for important mine closure questions that confront mining companies throughout Australia and in many countries.

The following table highlights students that have completed postgraduate research projects relating to CSML research.

| POSTGRADUATE RESEARCH PROJECTS – COMPLETED | | | | |
|---|---|---|---|---|
| **Year** | **Student** | **Title** | **Degree** | **University** |
| 2007 | Wangpen P. | The role of shelter in Australian freshwater crayfish (*Cherax* sp.) polysystems | PhD | Curtin |
| 2007 | Huber A. | Role of internal waves in mining lakes | Masters | UWA |
| 2006 | Storer T. | Ethology and production of freshwater crayfish in aquatic polysystems in Western Australia | PhD | Curtin |
| 2003 | Gyem P. | Characterisation of Idronaut sensors against temperature and pressure for long-term deployment in mine lake site WO5B | PGDip | Curtin |

## GRADUATE PROFILE: TIM STORER

In 2006, Curtin student Tim Storer was awarded a PhD in Aquatic Sciences and Resource Management for his thesis titled 'Ethology and production of freshwater crayfish in aquatic polysystems in Western Australia'. Tim was the first student to receive a PhD relating to CSML research, with work focusing on validation of acid mine water treatment technologies through assessment of fish and crayfish cultured in the ameliorated water. Tim's research was also designed to assist the marron industry in Western Australia in implementing appropriate management strategies for diversification. This was achieved through elucidation of the role of system specific variables (density, turbidity, habitat complexity) on ecological function of multi-species aquaculture systems. By focusing his research using off-take mine lake water, Tim in turn was integral to the success of CSML project 3.1, which determined polyculture was a beneficial end use for mine lake water. Whilst studying his PhD, Tim was permanently based at the CSML Collie operations and employed as the CSML Facilities and Projects Manager, and as lecturer for the Bachelor of Science in Natural Resource Management course. Tim's diverse roles within CSML were crucial to the success of the Collie base as a southwest hub for mine lake research and education. Now employed as an Aquatic Ecologist at the WA Department of Water in the Water Sciences portfolio, Tim has the opportunity to apply his experiences and expertise in the aquatic impact of acid mine drainage to the closely-related problem of acid sulphate soils to freshwater and estuarine environments.

Students in the process of completing mine lake related postgraduate research projects are shown below.

**POSTGRADUATE RESEARCH PROJECTS – IN PROGRESS**

| Year | Student | Title | Degree | University |
|---|---|---|---|---|
| 2006 - | Kumar V. | Feasibility of seaweed culture, Gracilaria Species, in inland saline water | PhD | Curtin |
| 2006 - | Das A. | Geochemical assessment of an innovative treatment system to treat urban Acid Sulfate Soil contaminated waters | PhD | Curtin, ECU |
| 2005 - | Sureshan S. | Developing a risk assessment approach to managing end-uses of pit lakes in the Goldfields of WA | PhD | ECU |
| 2005 - | Pham H. | Understanding microbial dynamics in mine lakes | PhD | UWA |
| 2003 - | Read D. | Sediment diagenesis in mine lakes | PhD | UWA |
| 2003 - | Hunt D. | Evaluation of beneficial end uses of mine lakes | PhD | Curtin |
| 2003 - | Gyem P. | Deployment of chemical sensors for long-term monitoring of water quality in mine void lakes in Collie WA | PhD | Curtin |
| 2003 - | Neil L. | The development and application of bioassays for mine lake aquaculture | PhD | Curtin, ECU |
| 2003 - | Yuden Y. | Using the effectiveness of organic matter and phosphorous additions for reducing acidity in abandoned cola mine lakes ion Collie (WA) | MSc | ECU |

| CURRENT STUDENT PROFILE: LUKE NEIL |
|---|
| Luke Neil is currently studying a PhD in Ecotoxicology and Aquaculture at Curtin University of Technology under the co-supervision of CSML researchers at Edith Cowan University. Luke has an interest in utilising fresh water bodies in WA for aquaculture, and is working with CSML using ecotoxicology combined with chemical analysis to provide insight into the suitability of such lakes for aquaculture. During the research for his thesis titled 'The development and application of bioassays for mine lake aquaculture', Luke has participated in numerous consultancy studies on environmental impact assessments of industrial products and effluents. Luke recently made a presentation on Toxicity Assessment of Limed and Phosphorous Amended Mine Pit Lake Water at the INTERACT 2006 Air, Water and Earth Conference, held in Perth, WA. |

The continued success of CSML researchers in attracting grant funding for long-term projects has also contributed to undergraduate students participating in Honours projects in mine lake research studies. Following is a table listing students that have completed Honours research projects at CSML partner universities.

| HONOURS PROJECTS – COMPLETED | | | | |
|---|---|---|---|---|
| **Year** | **Student** | **Title** | **Level** | **University** |
| 2006 | Kay G. | Remediation of inland saline aquaculture waste utilising sub-surface flow wetlands vegetated with NyPa Forage (*Distichlis* sp.) | Honours 1 | Murdoch |
| 2005 | Turnbull A. | Deep chlorophyll maxima in acidic mine lakes | Honours 2A | UWA |
| 2004 | Derham T. | Biological communities and water quality in acidic mine lakes | Honours 1 | UWA |
| 2004 | Ingram M. | Assessment and mitigation of ammonia and aluminium in mine lake aquaculture | Honours 1 | Curtin, Murdoch |
| 2004 | Nguyen T. | Modelling the hydrodynamics of Chicken Creek mining lake | Honours | UWA |
| 2003 | Chapman P. | Long-term stratification dynamics of a mine lake | Honours 2B | UWA |
| 2003 | Craven E. | Acid production in the overburden of Lake WO5B, Collie | Honours 1 | UWA |
| 2003 | Ridley P. | Acute handling stressor affecting immunity in the freshwater crayfish, *Cherax tenuimanus* | Honours | Curtin |
| 2002 | Read D. | Oxygen chemistry and transport in mine lake sediments | Honours 1 | UWA |

## INDIGENOUS EDUCATION PLATFORM

Education and training are well recognised as fundamental building blocks for success in facilitating Aboriginal entrepreneurs or organisations to develop enterprises or assisting community members to obtain employment. Most agencies involved in Aboriginal enterprise and employment projects focus their efforts on training programs that enhance the skills of Aboriginal participants to enter into the workforce or develop their own businesses. While the importance of skills acquisition should not be underestimated, remedial and further education is of equal if not more importance if Aboriginal entrepreneurs and organisations are to succeed in their desire for financial independence from the welfare system. Mentoring is a fundamental strategy in this process.

Mentoring, education and training have been core elements of the participatory action research conducted by the CSML Plants for People Program over the past four years. The program has been conducted in partnership with Aboriginal communities from WA, SA and NT. Members of the WA communities have been enrolled in tertiary education bridging courses and TAFE courses and employed as research assistants or teachers associates in DEST, NHT and DAFF funded research, conservation or community development projects. Community members have also been sponsored to attend workshops, meetings and conferences focussed on Aboriginal employment, education and enterprise. As a result of these activities the following outcomes have been achieved:

## Collie Ngalang Boodja Community

- Two Aboriginal community members from Collie have completed the requirements for the one year UniReady bridging course conducted by the Centre for Regional Education, Curtin University.
- An Aboriginal entrepreneur from Collie has started up a small land clearing business
- Four Aboriginal community members from Collie were employed as teachers associates or research assistants in CSML projects and, as a direct result of the confidence and skills gained in this employment, three of these people have now entered part time or full time employment.
- The other community member, a traditional owner who is actively involved in community activities, has regained his drivers licence and can now fully participate in representing his community on a range of committees, working parties and native title organisations.

## Tjupan Ngalia Aboriginal Community

- One community member successfully completed units mathematics, English communication and introductory business management in the Curtin UniReady bridging course and then went on to manage the CDEP program awarded to the Tjupan Ngalia group in 2005.
- Another community member was sponsored to attend a five day natural resource management course in Darwin after which he and his family were sponsored to attend a two day business development seminar in Perth.
- The knowledge and information gained from education and business planning initiatives conducted by CSML staff have contributed to the successful development of a small business enterprise, the Walkatjura Cultural Centre, which is now contracting its skills to local mining companies and other organisations.

## Laverton Wongatha Wonganara community

Education and training activities at this community have only recently commenced. A Guiding Circles workshop is to be held in the near future and enrolment in distance education courses are being discussed.

Through the various education and training activities conducted over the past four years by the Plants for People Program insight has been gained into successful strategies for conducting education and training programs with Aboriginal people. These strategies include:

- Embed the education and learning experiences in practical, outdoor activities
- Conduct the program in partnership with community members – elders, key decision makers and young people
- Involve the community in the planning of the course, and, where possible, in the course delivery

- Include remedial literacy and numeracy education as core program elements
- Include multimedia as both a course delivery tool and an empowerment strategy
- Provide on-going mentoring to individual participants and, if required, governance support to participating organisations
- Strongly committed lecturers and trainers who have empathy with Aboriginal people and insight into Aboriginal culture will significantly enhance the success of the program
- Flexibility in course delivery is essential – family commitments such as attendance at funerals need to be accommodated in the course delivery approach
- Where possible, the program should be delivered at the community location rather than the students having to travel to the educational institution
- Conduct networking activities in which Aboriginal community members can interact with other like-minded Aboriginal people involved in education and enterprise development programs

## OTHER CSML EDUCATION ACTIVITIES

### Bachelor of Science with a focus on natural resource management and enterprise

In mid 2005 CSML established an arrangement with the Curtin University Centre for Regional Education (CRE) to offer students based in Collie a course of study within the CRE Bachelor of Science focussed on natural resource management and enterprise. At this time, and still today, there are no undergraduate science course offered locally in the South West. Delivery of course was made possible through a local tutor, a part time CSML employee and PhD student, being based at the Collie TAFE. The provision of accommodation free of charge at a house owned by Wesfarmers was another important facilitating factor. Four students enrolled in the bachelor degree course, all of whom successfully completed the first year of the course and commenced their second year studies. Unfortunately, due to the winding down of CSML activities in 2006, the course in Collie was not offered in 2007. Despite the withdrawal of the educational program one of the students has continued his studies through distance education and has now been employed in a local mining company as an environmental officer.

## CONFERENCES, WORKSHOPS AND SEMINARS

In addition to the publication of research results, transfer of CSML research outcomes to the broader community of mine lake management information has been through national and international conferences, workshops and seminar presentations.

Two CSML Scientific Review Seminars and associated research field trips across the State Government funding period to showcase mine lake research were conducted by the Centre. The last CSML Scientific Review Seminar was held in March 2007 at Wesfarmers Premier Coal, Collie WA. The seminar attracted 34 delegates from the mining industry, government, and Indigenous community interested in research outcomes during the past five years. Core CSML Mining industry sponsors from Wesfarmers Premier Coal and Griffin Coal Mining Company answered questions on the value of the research to their companies.

In the last funding period alone, CSML researchers prepared and delivered twenty two presentations to industry and government agencies interested in research results stemming from the Centre. Since the establishment of the Centre, close to one hundred presentations have been delivered.

An indication of the importance and value of CSML research results to the broader community is the high number of presentations by CSML researchers at key national and international conferences and symposiums, including: Water in Mining Conference 2006;

Mine Closure 2006; INTERACT 2006; ICARD conferences; International Association of Astacology symposiums, MCA Sustainable Development conferences; Pit Lakes 2004; and World Aquaculture Society conference 2005. Further to this, the Executive Director of CSML, Professor Louis Evans was invited to join the organising committee for the 10th International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production (SWEMP 2007), Bangkok, Thailand, December 2007.

A full list of national and international research conference, workshop and seminar presentations by CSML researchers across the State Government funding period is presented below.

| NATIONAL/INTERNATIONAL RESEARCH CONFERENCE, WORKSHOP AND SEMINAR PRESENTATIONS | | | | | |
|---|---|---|---|---|---|
| **Year** | **Conference Title** | **Location** | **Date** | **Presentation Title** | **Principal Presenter** |
| 2007 | Indigenous Mining Training and Employment Task Force (IMTEF) meeting | Darwin, NT | Apr | Plants for People update | Evans L. |
| 2007 | CSML Information Seminar | Collie, WA | Mar | Prediction of water quality in mine lakes, with and without remediation | Oldham C. |
| 2007 | CSML Information Seminar | Collie, WA | Mar | Biological remediation treatment systems | Lund M.A. |
| 2007 | CSML Information Seminar | Collie, WA | Mar | Construction and evaluation of a fluidised limestone bed treatment system | Evans L. |
| 2007 | CSML Information Seminar | Collie, WA | Mar | Polyculture as a beneficial end use | Whisson G. |
| 2007 | CSML Information Seminar | Collie, WA | Mar | Environmental management system for mine lakes | Lymbery A. |
| 2007 | CSML Information Seminar | Collie, WA | Mar | Mining for Country | Evans L. |
| 2007 | CSML Information Seminar | Collie, WA | Mar | World's best practice closure outcomes | Murray-Prior R. |
| 2007 | 2007 National Reconciliation Forum | Kalgoorlie, WA | Feb | Science and Technology – Aboriginal and Indigenous Issues | Evans L. |
| 2006 | Water in Mining Conference | Brisbane, QLD | Nov | Mine water sustainability; what is it, and how do I get it? | McCullough C.D. |
| 2006 | Desert Knowledge Symposium | Alice Springs, NT | Nov | Case study on intellectual property protection of traditional knowledge of plants and their uses | Evans L. |
| 2006 | Engaging Indigenous Communities Conference | Brisbane, QLD | Oct | The plants for people approach to aboriginal economic development - successes, failures and lessons learnt | Evans L. |
| 2006 | Mine Closure 2006 | Perth, WA | Sep | Prediction of long-term water quality in acidic mine lakes | Oldham C. |
| 2006 | INTERACT 2006 Air, Water & Earth | Perth, WA | Sep | Toxicity assessment of limed and phosphorus amended mine pit lake water | Neil L. |
| 2006 | INTERACT 2006 Air, Water & Earth | Perth, WA | Sep | Mine lake water quality assessment using bioassays and chemical | Tsvetnenko Y. |

| NATIONAL/INTERNATIONAL RESEARCH CONFERENCE, WORKSHOP AND SEMINAR PRESENTATIONS | | | | | |
|---|---|---|---|---|---|
| | | | | analyses | |
| 2006 | INTERACT 2006 Air, Water & Earth | Perth, WA | Sep | The chemical profile of inland saline water and its effect on the aquaculture potential of selected marine species | Fotedar R. |
| 2006 | Environment Matters – Conservation Council of WA | Perth, WA | Aug | Pit lakes: Liability of Opportunity? | McCullough C.D. |
| 2006 | Centre for Ecosystem Management seminar series | Perth, WA | Aug | Mining Pit Lakes: Liabilities or Opportunities? | McCullough C.D. |
| 2006 | 16th Symposium of the International Association of Astacology | Gold Coast, QLD | Jul-Aug | Comparison of short-term physiological responses of two freshwater crayfish species (*Parastacidae*: Cherax) when exposed to inland saline water | Fotedar R. |
| 2006 | Sustainability of Indigenous Communities | Murdoch, WA | Jul | Sustainability through enterprise and land management | Evans L. |
| 2006 | Goldfields Environmental Management Group Workshop on Environmental Management | Kalgoorlie, WA | May | Pit lakes: benefit or bane to companies, communities and the environment? | McCullough C.D. |
| 2006 | 7th International Conference on Acid Rock Drainage (ICARD) | St Louis, USA | Apr | Microcosm testing of municipal sewage and green waste for full-scale remediation of an acid coal pit lake, in semi-arid tropical Australia | McCullough C.D. |
| 2006 | 7th International Conference on Acid Rock Drainage (ICARD) | St Louis, USA | Apr | In-situ coal pit lake treatment of acidity when sulphate concentrations are low | Lund M.A. |
| 2006 | Desert Knowledge-CRC Annual Conference | Alice Springs, NT | Feb | Plants for People | Evans L. |
| 2006 | NT Indigenous Mining Training and Employment Task Force (IMTEF) meeting | Alice Springs, NT | Feb | Mining for Country | Evans L. |
| 2005 | Australian Society for Limnology 44th Annual Congress | Hobart, TAS | Dec | The addition of green waste and municipal sewage to a tropical acid pit lake, a novel approach to remediation; or, 'Why we filled a pit lake with dead plants and poo' | McCullough C.D. |
| 2005 | Integrated Aquaculture Networking Workshop | Northampton, WA | Nov | Polyculture as a beneficial end use for mine lakes | Storer T. |
| 2005 | Integrated Aquaculture Networking Workshop | Northampton, WA | Nov | Native plant cultivation | Woodall G. |

| NATIONAL/INTERNATIONAL RESEARCH CONFERENCE, WORKSHOP AND SEMINAR PRESENTATIONS | | | | | |
|---|---|---|---|---|---|
| 2005 | MCA Sustainable Development Conference | Alice Springs, NT | Oct | Mining for Country – Aboriginal enterprise and capacity building through partnerships between mining companies and Indigenous communities | Muir K. |
| 2005 | MCA Sustainable Development Conference | Alice Springs, NT | Oct | Community development through mine site rehabilitation projects | Ashton P. |
| 2005 | MCA Sustainable Development Conference | Alice Springs, NT | Oct | Standard protocols for the monitoring of water quality in mine lakes – a proposal | Oldham C. |
| 2005 | Australasian Society for Ecotoxicology 2005 Conference | Melbourne, VIC | Sep | How toxic is MgSO4? Implications for the mining industry | van Dam R. |
| 2005 | International Association for Sediment Water Science | Bled, Slovenia | Sep | Understanding and modeling redox reactions in carbon limited sediments | Read D. |
| 2005 | 9th Conference, International Society for Salt Lake Research | Perth, WA | Sep | The growth and survival of western king prawns *Penaeus latisulcatus* in potassium fortified inland saline water | Prangnell D. |
| 2005 | 9th Conference, International Society for Salt Lake Research | Perth, WA | Sep | Technical feasibility of inland saline water aquaculture – an osmoregulatory approach | Fotedar R. |
| 2005 | 9th Conference, International Society for Salt Lake Research | Perth, WA | Sep | Osmoregulatory mechanisms and growth of black tiger prawn (*Penaeus monodon* Fabricius, 1798) reared in fortified inland saline water | Tantulo U. |
| 2005 | 5th Australian Workshop on Acid Drainage | Fremantle WA | Aug | Closure for beneficial outcomes | Evans L. |
| 2005 | 5th Australian Workshop on Acid Drainage | Fremantle, WA | Aug | Overview of limestone water treatment systems | Green R. |
| 2005 | 5th Australian Workshop on Acid Drainage | Fremantle, WA | Aug | Standard protocols for the monitoring of water quality in mine lakes – a proposal | Oldham C. |
| 2005 | Acid Sulphate Soils Technical Workshop | Perth, WA | Aug | Understanding acidity issues and targeting research gaps | Evans L. |
| 2005 | CSML Scientific Review | Perth, WA | Jun | Mining for Country | Evans L. |
| 2005 | CSML Scientific Review | Perth, WA | Jun | Mine lakes water quality assessment using bioassays and chemical analyses | Tsvetnenko Y. |
| 2005 | CSML Scientific Review | Perth, WA | Jun | Aquatic polyculture – a beneficial end use for mine lakes | Whisson G. |
| 2005 | CSML Scientific Review | Perth, WA | Jun | Prediction of long term water quality in mine lakes | Salmon U. |

| NATIONAL/INTERNATIONAL RESEARCH CONFERENCE, WORKSHOP AND SEMINAR PRESENTATIONS | | | | | |
|---|---|---|---|---|---|
| 2005 | CSML Scientific Review | Perth, WA | Jun | Stratification cycles in Collie mine lakes | Wake G. |
| 2005 | CSML Scientific Review | Perth, WA | Jun | Evaluation of beneficial end uses of mine lakes | Hunt D. |
| 2005 | Muresk Institute PhD conference | Northam, WA | Jun | Evaluation of beneficial end uses of mine lakes (PhD research findings to date) | Hunt D. |
| 2005 | World Aquaculture Society | Bali, Indonesia | May | Inland saline water aquaculture research at Muresk Institute, Curtin University of Technology: an update | Fotedar R. |
| 2005 | World Aquaculture Society | Bali, Indonesia | May | Can greenlip abalone, *Haliotis laevigata* be cultured in inland saline water? | Fotedar R. |
| 2005 | World Aquaculture Society | Bali, Indonesia | May | The effect of sudden decrease in salinity on the survival of Western king prawns, *Penaeus latisulcatus* in inland saline water | Prangnell D. |
| 2005 | World Aquaculture Society | Bali, Indonesia | May | Osmoregulatory mechanism of Western rock lobster, *Panulirus cygnus*, exposed to inland saline water | Tantulo U. |
| 2005 | Centre for Water Research, Environmental Dynamics Seminar | Perth, WA | Apr | Aquatic geochemistry in mine lakes | Salmon U. |
| 2005 | UWA Mine Lake Symposium | Perth, WA | Apr | Aqueous geochemistry of coal mine pit lakes, Collie, Western Australia | Salmon U. |
| 2005 | UWA Mine Lake Symposium | Perth, WA | Apr | Prediction of long term water quality in mine lakes | Salmon U. |
| 2005 | UWA Mine Lake Symposium | Perth, WA | Apr | Stratification cycles in Collie mine lakes | Wake G. |
| 2005 | Ngalang Boodja Council Aboriginal Corporation meeting | Collie, WA | Apr | Proposal for the development of an aboriginal cultural centre at the former coal mining void owned by Premier Coal, now known as Lake Kepwari | Hunt D. |
| 2005 | WA Department of Agriculture Workshop 'Getting the drift' | Perth, WA | Mar | The application and limitations of ecotoxicology and biomarkers in the detection and assessment of spray drift incidents | Tsvetnenko Y. |
| 2005 | Plants for People Annual Review and Planning Workshop | Perth, WA | Feb | Overview of Plants for People program – philosophy, strategies and desired outcomes | Evans L. |
| 2005 | Plants for People Annual Review and Planning Workshop | Perth, WA | Feb | Plenary Session – Overview of plant analysis findings | Evans L. |
| 2005 | Plants for People Annual Review and Planning Workshop | Perth, WA | Feb | Horticulture of Indigenous Plants | Woodall G. |

| NATIONAL/INTERNATIONAL RESEARCH CONFERENCE, WORKSHOP AND SEMINAR PRESENTATIONS | | | | | |
|---|---|---|---|---|---|
| 2005 | Desert Knowledge CRC-wide Conference | Alice Springs, NT | Feb | Plants for People | Evans L. |
| 2005 | Recording Indigenous Knowledge in Electronic Databases | Alice Springs, NT | Feb | Welcome and introduction – Plants for People program | Evans L. |
| 2004 | 43rd Australian Society for Limnology Congress | Adelaide, SA | Nov-Dec | Mine lakes - more than just acidic, toxic scars on the landscape | Lund M.A. |
| 2004 | Pit Lakes 2004 | Reno, Nevada, USA | Nov | Mine lake environmental and social sustainability research in Western Australia | Evans L. |
| 2004 | Pit Lakes 2004 | Reno, Nevada, USA | Nov | Aqueous geochemistry of the coalmine pit lakes Collie Basin, Western Australia | Salmon U. |
| 2004 | Pit Lakes 2004 | Reno, Nevada, USA | Nov | Hydrodynamics processes in a Western Australian coal mine pit lake | Ivey G. |
| 2004 | Pit Lakes 2004 | Reno, Nevada, USA | Nov | Predicting long term water quality in pit lakes | Oldham C. |
| 2004 | Marine Aquaculture Conference | Singapore | Oct | Mariculture in inland saline water | Fotedar R. |
| 2004 | Second New Crops Conference | Brisbane, QLD | Sep | New vegetable crops from the mega-diverse South West Botanical Province of Australia | Woodall G. |
| 2004 | Acid Sulfate Soils Workshop: Focus on Aquatic Impact Assessment and Management | Mandurah, WA | Sep | Fluidised limestone reactor technology in acid sulphate soil remediation | Evans L. |
| 2004 | Acid Sulfate Soils Workshop: Focus on Aquatic Impact Assessment and Management | Mandurah, WA | Sep | Metal toxicity in ameliorated mine lake water: case study of a fish kill in Collie | Storer T. |
| 2004 | Australasian Aquaculture | Sydney, New South Wales | Sep | Can inland saline water be used to rear post larvae of black tiger prawn, *Penaeus monodon* Fabricus? | Tantalu U. |
| 2004 | Australasian Aquaculture | Sydney, NSW | Sep | Blood osmolality and body moisture of Murray Cod *Maccullochella peelii peelii* (Mitchell 1839) juveniles reared in inland saline waters | Mellor P. |
| 2004 | Capitalising on Natural Resources and Indigenous Knowledge Workshop | Broome, WA | Aug | Mining for Country | Evans L. |
| 2004 | Muresk Institute Biothon | Bentley, WA | Jul | Influence of a potential predatory threat on the interaction behaviour between an indigenous and an invader crayfish species | Storer T. |

| NATIONAL/INTERNATIONAL RESEARCH CONFERENCE, WORKSHOP AND SEMINAR PRESENTATIONS | | | | | |
|---|---|---|---|---|---|
| 2004 | Muresk Institute Biothon | Bentley, WA | Jul | Interaction between Murray cod (*Maccullochella peelii*) and marron (*Cherax tenuimanus*): translocation impacts and polyculture potential in Western Australia | Storer T. |
| 2004 | Muresk Institute Biothon | Bentley, WA | Jul | Total ammonium nitrogen (TAN) removal from water with zeolite treatment | Ingram M. |
| 2004 | WA Chamber of Minerals and Energy | Perth, WA | Jun | Centre for Sustainable Mine Lakes overview | Evans L. |
| 2004 | AJM Water Management in Mining Conference | Perth, WA | Jun | Water quality and usage of water in mine voids | Ivey G. |
| 2004 | Indigenous Mining Training and Employment Task Force (IMTEF) meeting | Borroloola, NT | May | WA Indigenous Enterprise Development Project: Mining for Country | Evans L. |
| 2004 | International Conference on Indigenous Knowledge and Bioprospecting | Macquarie, NSW | Apr | Plants for People: A community based approach to recording and protecting Indigenous knowledge about plants | Evans L. |
| 2004 | 15th Symposium of the International Association of Astacology | London, UK | Mar | Impact of crayfish polyculture on pond production and ecology | Whisson G. |
| 2004 | 15th Symposium of the International Association of Astacology | London, UK | Mar | Do visual and chemical predator cues affect competition for shelter between native (Cherax tenuimanus) and invasive (Cherax albidus) crayfish in Western Australia? | Storer T. |
| 2004 | Indigenous Mining Training and Employment Task Force (IMTEF) meeting | Tennant Creek, NT | Feb | Traditional knowledge enterprises and the mining industry | Evans L. |
| 2003 | 42nd Australian Society for Limnology and 36th New Zealand Limnological Society joint congress | Warrnambool, VIC | Dec | Managing the acidity of mine lakes in the Collie Region (WA) using organic matter and phosphorous | Yuden |
| 2003 | MCA Sustainable Development Conference | Brisbane, QLD | Nov | Beneficial end uses for open cut mine sites: planning for optimal outcomes | Evans L. |
| 2003 | Annual Queensland Redclaw Conference | Gympie, QLD | Oct | Crayfish polyculture systems (keynote address) | Whisson G. |
| 2003 | ACMER workshop on water quality issues in final voids and temporary streams | Brisbane, QLD | Jul | Mine lake research – water quality prediction, amelioration and use with emphasis on aquaculture | Fotedar R. |
| 2003 | Indigenous Mining Training and Employment Task Force | Darwin, NT | June | End uses for mine sites and mine lakes - sustainable initiatives | Evans L. |

| NATIONAL/INTERNATIONAL RESEARCH CONFERENCE, WORKSHOP AND SEMINAR PRESENTATIONS | | | | | |
|---|---|---|---|---|---|
| | (IMTEF) meeting | | | | |
| 2003 | ACMER workshop on water quality issues in final voids, salt lakes and ephemeral streams | Perth, WA | May | Emerging technologies in modelling void water quality | Ivey G. |
| 2003 | ACMER workshop on water quality issues in final voids, salt lakes and ephemeral streams | Perth, WA | May | International case study | Oldham C. |
| 2003 | ACMER workshop on water quality issues in final voids, salt lakes and ephemeral streams | Perth, WA | May | CSML Research programs and mine lake water treatment systems | Evans L. |
| 2003 | ACMER workshop on water quality issues in final voids, salt lakes and ephemeral streams | Perth, WA | May | Data requirements for predicting and monitoring final void water quality | Ivey G. |
| 2002 | 14th Symposium of the International Association of Astacology | Queretaro, Mexico | Aug | Utilising ameliorated water from acidified mining lakes for polyculture in Western Australia | Storer T. |

# 5. MANAGEMENT

## ADVISORY BOARD

The CSML Advisory Board determines policy on all matters relating to the achievement of the objectives of the Centre; monitors and assesses the performance of management and research teams; receives and approves annual budgets; and monitors and assesses the financial management of Centre funds. The Board has the power to admit new members to the collaborative venture in accordance with relevant clauses of the Joint Venture Agreement. Executive Officer services are provided through the office of the Executive Director of the Centre. The CSML Advisory Board met on one occasion during the 2006/2007 reporting period. The composition of the CSML Advisory Board in the funding period was:

| | |
|---|---|
| Dr Hilda Turnbull | Chairperson |
| Dr Tim Morrison | Murdoch University |
| Professor Louis Evans | Executive Director, CSML |
| Mr Ian Pigott | Griffin Coal |
| Professor Greg Ivey | The University of Western Australia |
| Dr Tony Tate | Curtin University of Technology |
| Mr Patrick Warrand | Wesfarmers Premier Coal |
| Professor Patrick Garnett | Edith Cowan University |
| Mr Matt Platell | Department of Premier and Cabinet |

## EXECUTIVE MANAGEMENT COMMITTEE

The Executive Management Committee (EMC) manages the operation and financial affairs of the Centre and implements Centre policy, as directed by the CSML Advisory Board. The Committee assesses and approves all staff appointments to the Centre; reviews and refers proposed annual budgets to the Advisory Board for approval; reviews progress in research programs; and monitors income and expenditure of the Administration and Research Sections. The duties of the EMC are delegated to the CSML Executive Director for the day-to-day management of the Centre. Between April 2006 and March 2007 the EMC met on bi-monthly intervals. The composition of the EMC was as follows:

| | |
|---|---|
| Professor Louis Evans | Chairperson |
| Professor Greg Ivey | Deputy Chairperson |
| Dr Hilda Turnbull | CSML Advisory Board delegate |
| Mr Peter Ashton | Wesfarmers Premier Coal |
| Professor Mark Lund | Edith Cowan University |
| Professor Alan Lymbery | Murdoch University |
| Professor Carolyn Oldham | The University of Western Australia |
| Mr Ian Pigott/ Mr David Bills | Griffin Coal |
| Ms Trisha Becker | Curtin University of Technology |

# PERSONNEL

Since the previous annual report to the State Government, the following personnel changes occurred:

Ms Renata Bitencourt

- Administrative Officer; resigned July 2005

Ms Andrea Duncan

- Business and Communications Manager; resigned November 2006
- Employed as Communications Officer, May 2007

Ms Lisa Forward

- Administrative Officer; employed July 2005, resigned November 2006

Trisha Becker

- Administrative Officer; employed November 2006, resigned July 2007

Dr Robert Doupé

- Research Fellow; resigned mid 2006

Dr Geoffrey Wake

- Research Fellow; resigned June 2006

# MILESTONES

This section lists the achievements of the Centre between April 2006 and March 2007 against the key milestones listed in the research proposal submitted to the State Government in 2001. Milestones that were achieved in the previous reporting period are not included in this section.

## Advisory Board Meeting, Annual Review

*Complete by December all years from 2002*

- The last CSML Advisory Board meeting was held on 14th August 2007.
- The second CSML Scientific Review was held on March 20th 2007 at Wesfarmers Premier Coal, Collie WA. The seminar attracted 34 delegates from the mining industry, government, and Indigenous community interested in research outcomes during the past five years.

## Continuing Research Programs

*Complete by June and December, all years*

Progress within individual research projects is reviewed regularly by the EMC. The committee has endorsed a standardised format for research project reports and requested that reports be submitted on a bi-annual basis. The standard format includes statements on the project milestones that are to be reviewed by a sub-committee, along with the report on research conducted. A report on this review is considered by the EMC twice a year.

## Annual Reporting Cycle

*Complete by June all years*

There are two reports required to be prepared for CSML research projects – the quarterly reports to ACARP and the annual report to the State Government, due in March of each year. The former were all completed on time and the latter, this report which is inclusive of final reporting information, is overdue.

## Marketing of Centre

*Complete by June and December, all years from 2002*

The major marketing activities of the Centre during this reporting period have centred on attracting the support and ongoing commitment of industry for the Centre's core activities, and generating awareness of the Centre's research capacity through collaborative workshops and seminars. Business development activities have involved the Executive Director continuing to meet with representatives from numerous mining companies across Australia to discuss opportunities for CSML projects in the mine lake water quality, mine lake water remediation, and beneficial end uses of mine lake areas.

## Annual Funding Application Cycle

*Complete by June all years from 2004*

- Refer to the section Highlights and Breakthroughs showing the CSML research project teams that have been successful in obtaining grants, awards, contracts or new partnerships.
- Refer to the section Grant Funding for a comprehensive list of competitive grants and contracted research/consultancies secured across the State Government funding Agreement.
- About 30% of additional income through competitive grants, contract research and consulting assignments was secured during the 2006/2007 funding period. This high figure is reflective of the assertion that until the Centre had published results and gained a solid reputation in the mine lakes management and research area, the ability of researchers to successfully win such additional funding would be restricted.

## Subsequent International Visitor

*Complete by June all years from 2004*

Researchers within CSML have developed international research links and collaborations with a number of individuals and organisations interested in the separate and overarching project findings, as shown in the following table:

| INTERNATIONAL RESEARCH LINKS | | |
|---|---|---|
| **Contact** | **Organisation/ Association** | **Country** |
| Dr Rene Froemicchen | Helmholtz Centre for Environmental Research - UFZ | Germany |
| Dr Martin Schultze | Helmholtz Centre for Environmental Research - UFZ | Germany |
| Dr Matthias Koschorreck | Helmholtz Centre for Environmental Research - UFZ | Germany |
| Dr Katrin Wendt-Potthoff | Helmholtz Centre for Environmental Research - UFZ | Germany |
| Prof. Stefan Peiffer | Helmholtz Centre for Environmental Research - UFZ | Germany |
| Prof. Helmut Klapper | Helmholtz Centre for Environmental Research - UFZ | Germany |
| Dr Devin Castendyk | Dept. of Earth Sciences - State University of New York | USA |
| Dr James Ranville | Dept. of Chemistry and Geochemistry - Colorado School of Mines | USA |
| Prof. Jannie Maree | Faculty of Science - Tshwane University of Technology | South Africa |
| Dr Phillip Sibrell | Leetown Science Center - US Geological Survey Program | USA |
| Prof. Ernö Pretsch | Institute of Biogeochemistry and Pollutant Dynamics ETH Zürich – Swiss Federal Institute of Technology | Switzerland |
| Prof. Eric Bakker | Dept. of Chemistry - Purdue University | USA |
| Dr David Marcogliese | Environment Canada | Canada |

## Contract Research/Consulting

*Complete by June and December, all years from 2004*

- Refer to the section Highlights and Breakthroughs showing the CSML research project teams that have been successful in obtaining contract research and consultancies during the 2006/2007 reporting period.
- Refer to the section Grant Funding for a comprehensive list of contract research and consultancies secured across the State Government funding Agreement.
- Of the 15 new contract research and consulting projects secured by CSML researchers across the State Government funding Agreement, nine were secured during the 2006/2007 reporting period, amounting to further additional income of $300,748 and representing 50% of total industry funding and consultancies obtained.

## Training Program

*Complete by June and December, all years.*

- Refer to the section Education and Community Service for a comprehensive report on achievements against this milestone.

## CSML Original Key Milestones Chart

Original key milestones are summarised in the following chart:

| Achievement | 2002 | | 2003 | | 2004 | | 2005 | | 2006 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Half year** | **1** | **2** | **1** | **2** | **1** | **2** | **1** | **2** | **1** | **2** |
| Appoint Board and Director | | ⇔ | | | | | | | | |
| Establish MOUs with Participating Universities | | | ⇔ | | | | | | | |
| Advisory Board Meeting, Annual Review | | ⇔ | | ⇔ | | ⇔ | | ⇔ | | ⇔ |
| Refurbish Collie Buildings | | ⇔ | ⇔ | | | | | | | |
| Appoint Research Fellows | | ⇔ | ⇔ | | | | | | | |
| Appoint Research Associates and Other Support Staff | | ⇔ | ⇔ | | | | | | | |
| Install Premier Coal Site Security | ⇔ | | | | | | | | | |
| Create Griffin Wetlands | ⇔ | ⇔ | ⇔ | | | | | | | |
| Establish Aqua/Horticulture Facility | | | | | ⇔ | ⇔ | | | | |
| Commence Research Programs 1 to 3 | | ⇔ | | | | | | | | |
| Continuing Research Program | | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | |
| Annual Reporting Cycle | | ⇔ | | ⇔ | | ⇔ | | ⇔ | | ⇔ |
| Marketing of Centre | | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ |
| Commence Funding Applications | | ⇔ | ⇔ | ⇔ | | | | | | |
| Annual Funding Application Cycle | | ⇔ | | ⇔ | | ⇔ | | ⇔ | | |
| First Postgraduate Students in Centre | | ⇔ | | | | | | | | |
| First Undergraduate Students at Field Sites | | ⇔ | | | | | | | | |
| First Conference | | | | | | ⇔ | | | | |
| First International Visitor | | | ⇔ | | | | | | | |
| Subsequent International Visitor | | | | ⇔ | | ⇔ | | ⇔ | | |
| Contract Research/Consulting | | | | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | | |
| Training Program | | | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | | |
| CoE Funds Terminate | | | | | | | | | ⇔ | |

## CSML Revised Key Milestones Chart

Revised key milestones are summarised in the following chart (revised milestones indicated by solid blocks):

| Achievement | 2002 | | 2003 | | 2004 | | 2005 | | 2006 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Half year** | **1** | **2** | **1** | **2** | **1** | **2** | **1** | **2** | **1** | **2** |
| Appoint Board and Director | | | ⇔ | | | | | | | |
| Establish MOUs With Participating Universities | | | | ⇔ | | | | | | |
| Advisory Board Meeting, Annual Review | | ⇔ | | ⇔ | | ⇔ | | ⇔ | | ⇔ |
| Refurbish Collie Buildings | | | ⇔ | ⇔ | | | | | | |
| Appoint Research Fellows | | | ⇔ | ⇔ | | | | | | |
| Appoint Research Associates and Other Support Staff | | | ⇔ | ⇔ | | | | | | |
| Install Premier Coal Site Security | ⇔ | | | | | | | | | |
| Create Griffin Wetlands | ⇔ | ⇔ | ⇔ | | | | | | | |
| Establish Aqua/Horticulture Facility | | | | | | | | | | ⇔ |
| Commence Research Programs 1 to 3 | | ⇔ | | | | | | | | |
| Continuing Research Program | | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | |
| Annual Reporting Cycle | | | ⇔ | | ⇔ | | ⇔ | | ⇔ | |
| Marketing of Centre | | | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ |
| Commence Funding Applications | | | ⇔ | ⇔ | ⇔ | | | | | |
| Annual Funding Application Cycle | | | | | ⇔ | | ⇔ | | ⇔ | |
| First Postgraduate Students in Centre | | ⇔ | | | | | | | | |
| First Undergraduate Students at Field Sites | | ⇔ | | | | | | | | |
| First Conference | | | | | | | ⇔ | | | |
| First International Visitor | | | | ⇔ | | | | | | |
| Subsequent International Visitor | | | | | ⇔ | | ⇔ | | ⇔ | |
| Contract Research/Consulting | | | | | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | |
| Training Program | | | | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | ⇔ | |
| CoE Funds Terminate | | | | | | | | | ⇔ | |

# 6. FINANCE

## SUMMARY

In 2006 CSML submitted a request to alter the utilisation of State Government funds along with a request to vary the State Government funding schedule. The request to vary the funding schedule was due to higher than expected project expenditures in the 2004 and 2005 reporting periods compared to State Government funding received.

CSML received confirmation in August 2006 from the Office of Science, Technology and Innovation (OSTI) that the revised CSML expenditure of State Government funds had been approved by the A/Deputy Director General, OSTI, whereby all of the proposed changes which dealt with the redistribution and utilisation of COE investment to support the employment of five new research fellows was officially approved.

The request to vary the funding tranche schedule however was not approved and thus remained as it was in its already revised form from the previously approved request to vary the funding tranche schedule. This outcome led to a situation where by 31st March 2007 all projects supported by COE funds had been completed, and all anticipated expenditure of State Government funds expended.

CSML expects to receive the fifth tranche ($162K) from the State Government on submission and acceptance of this final report which is an annual report for the final year of the Agreement and an overview of the entire period of the Agreement. However as no further expenditure against approved expenditures items will be incurred after 31st March 2007 the funds will be used to offset expenditures in previous years.

As this is the final report from CSML, OSTI has advised CSML to request that this report also triggers the $10K final tranche originally anticipated for February 2008.

CSML's 2006 reporting period Actual Expenditure of State Government Funds Summary (1st April 2006 – 31st March 2007) is shown in Table 1 with documentation supporting expenditure acquittal included in Appendix 1. A total of $285K was expended on expenditure items comprising Research Fellow salaries, capital equipment, and salaries relating to the project management of asset construction. The anticipated budgeted expenditure was also $285K.

The full and final expenditure of State Government funds to CSML is shown in Table 2.

**Table 1.**

Centre of Excellence for Sustainable Mine Lakes CSML

## 2006 Actual Expenditure of State Government Funds Summary

*01/04/06 to 31/03/07*

| Description | Budgeted Expenditure | Actual Expenditure | Underspend | Overspend |
|---|---|---|---|---|
| *Laboratory fitout and upgrade* | 0.00 | 0.00 | 0.00 | $0.00 |
| **Laboratory fitout and upgrade sub total** | **$0.00** | **$0.00** | **$0.00** | **$0.00** |
| *Program 1 - Prediction Modelling* | | | | |
| Research Fellow A1 - Hydrodynamics (Wake) | 17,000.00 | 7,011.00 | 9,989.00 | 0.00 |
| Research Fellow A2 - Ecological Modeller (Hipsey) | 48,000.00 | 34,560.00 | 13,440.00 | 0.00 |
| Research Fellow A3 - Software Engineering (Imerito) | 0.00 | 0.00 | 0.00 | 0.00 |
| Research Fellow B - Biogeochemistry (Salmon) | 82,000.00 | 106,326.00 | 0.00 | 24,326.00 |
| Equipment - Prediction Modelling | 0.00 | 0.00 | 0.00 | 0.00 |
| Equipment - New Technology | 0.00 | 0.00 | 0.00 | 0.00 |
| **Program 1 - Prediction Modelling sub total** | **$147,000.00** | **$147,897.00** | **$23,429.00** | **$24,326.00** |
| *Program 2 - Water Treatments* | | | | |
| Research Fellow C - Biological Remediation (McCullough) | 61,000.00 | 61,207.54 | 0.00 | 207.54 |
| Research Fellow D - Ecotoxicology (Tsvetnenko) | 0.00 | 0.00 | 0.00 | 0.00 |
| Research Fellow E - Environmental Acidity (Green) | 0.00 | 0.00 | 0.00 | 0.00 |
| Equipment - Water Treatments Study | 4,000.00 | 0.00 | 4,000.00 | 0.00 |
| Equipment - Fluidised Limestone Reactor Treatment Study | 19,000.00 | 16,643.44 | 2,356.56 | 0.00 |
| **Program 2 - Water Treatments sub total** | **$84,000.00** | **$77,850.98** | **$6,356.56** | **$207.54** |
| *Program 3 - Beneficial End Uses* | | | | |
| Research Fellow F - Ecosystem Health (Doupé) | 16,000.00 | 17,253.27 | 0.00 | 1,253.27 |
| Aquaculture Ponds | 0.00 | 0.00 | 0.00 | 0.00 |
| Security System - Aqua/Hort | 0.00 | 0.00 | 0.00 | 0.00 |
| Equipment - Aqua/Hort | 38,000.00 | 41,998.75 | 0.00 | 3,998.75 |
| **Program 3 - Beneficial End Uses sub total** | **$54,000.00** | **$59,252.02** | **$0.00** | **$5,252.02** |
| **2005 GRAND TOTALS** | **$285,000.00** | **$285,000.00** | **$29,785.56** | **$29,785.56** |

| | |
|---|---|
| **2006 TOTAL BUDGETED EXPENDITURE** | **$285,000.00** |
| **2006 TOTAL ACTUAL EXPENDITURE** | **$285,000.00** |
| **2006 TOTAL OVERSPEND/UNDERSPEND** | **$0.00** |

# EXPENDITURE RECONCILIATION

Documentation supporting the acquittal of State Government funds for the period 1st April 2006 – 31st March 2007 is provided in Appendix 1.

As shown in Table 1, the overspend for the 2006 reporting period was $29,785.56 and underspend $29,785.96. Explanations for the greater than or less than anticipated expenditures are outlined below.

## Program 1 – Prediction Modelling

*Overspend and underspend on Research Fellow Salaries*

In the 1st April 2006 – 31st March 2007 reporting period, Program 1 experienced increasing reliance on Research Fellow Salmon and decreasing reliance on Research Fellows Wake and to a lesser extent Hipsey. Wake's decreasing involvement was flagged in the 2005 and 2006 Annual Reporting, and his departure in 2006 from UWA to work in industry curtailed his involvement in the project. However by the time Wake left, he had set up the hydrodynamic model for continued work by Salmon and therefore his departure did not compromise our achievement of Project 1 milestones.

In addition, the software development as foreshadowed in the 2005 and 2006 reporting was completed more rapidly than expected, and thus less of Research Fellow Hipsey's time was used than budgeted. The scenario testing could therefore be explored in far more detail by Research Fellow Salmon. The over-expenditure on Salmon's salary highlights increasing reliance on her to assume responsibilities for progress with the modelling, as well as salary increases over the life of the project, greater than originally budgeted. All milestones as stated in the original proposal have been achieved with the above strategy.

In summary, while in 2007 the balance of expenditure across Program 1 Research Associates was slightly changed, the project progressed extremely well and have achieved all expected outcomes.

## Program 2 – Water Treatments

*Underspend on Equipment – Fluidised Limestone Reactor Treatment Study*

Lower than expected equipment costs relating to this study led to an underspend of $2,356.56. This underspend enabled the slightly higher overspend in program 1, and greater than anticipated Research Fellow (Doupé) salary cost to be off-set.

## Program 3 – Beneficial End Uses

*Overspend on Research Fellow F – Ecosystem Health*

The slightly higher than expected expenditure on Research Fellow F salary resulted from an unexpected rise in salaries for all Murdoch University staff. As indicated above, this overspend has been off-set by the underspend in the equipment budget of the FLR treatment study.

*Overspend on Aquaculture/Horticulture equipment*

In the original CSML proposal to the State Government $150,000 was budgeted towards establishing an aquaculture facility at the Collie Aquafarm as part of CSML project 3.1. The total capital cost to build the Aquafarm hatchery was $138,841 plus $15,223 to employ a project manager to oversee the construction of the capital asset, which equates to a total overspend of $4,064.

As outlined in the 2005 report to the State Government, anticipated significant rises in construction and associated labour costs prompted CSML to purchase the majority of equipment and materials earlier than expected. The remaining Aquafarm hatchery components however were unable to be purchased and constructed until 2006. CSML was therefore required to purchase equipment and contract labour at greater than expected amounts, in-line with price hikes across the construction industry.

On the whole CSML views a <10% overspend in this item across five years as an achievement in project management as across the past five – six years costs have risen substantially throughout the whole building sector.

This $4,000 overspend was subsequently off-set by the $4,000 underspend on equipment in the Water Treatments Study outlined above.

# CASH CONTRIBUTION RECONCILIATION

The cash contributions provided by CSML research groups at the four participating universities and industry sponsors for the period 1st April 2006 to 31st March 2007 is shown below.

## Cash Income

Given the finalisation of the majority of CSML projects in December 2006, there was minimal cash income from CSML participating universities, industry and other sponsors during this reporting period. Pending final acceptance of ACARP project C11053, CSML expects to receive $147K from ACR Ltd. A further $15K was received from Murdoch University in-line with the University's agreed contribution to CSML.

## Full and Final Expenditure Reconciliation

Table 2 below shows CSML's actual expenditure across all reporting periods.

**Table 2.**

## CSML Total Actual Expenditure Schedule of State Government Funds

| Item | #2003 | ^2004 | ^2005 | ^2006 | 2007 | 2008 | Budgeted 2006 | Totals actual (2002-2007) | Totals budgeted (2002-2007) |
|---|---|---|---|---|---|---|---|---|---|
| | $000 | $000 | $000 | $000 | $000 | $000 | $000 | $000 | $000 |
| Laboratory Fitout and Upgrade | 29 | 13 | 0 | **0** | | | 0 | 42 | 42 |
| *Program 1 - Prediction Modelling* | | | | | | | | | |
| Research Fellow A1 - Hydrodynamics (Wake) | 0 | 54 | 49 | **7** | | | 17 | 110 | 147 |
| Research Fellow A2 - Ecological Modeller (Hipsey) | 0 | 0 | 48 | **35** | | | 48 | 83 | 61 |
| Research Fellow A3 - Software Engineering (Imerito) | 0 | 0 | 0 | **0** | | | 0 | 0 | 14 |
| Research Fellow B - Biogeochemistry (Salmon) | 7 | 65 | 75 | **106** | | | 82 | 253 | 223 |
| Equipment - Prediction Modelling | 111 | 57 | 47 | **0** | | | 0 | 215 | 215 |
| Equipment - New Technology | 0 | 9 | 25 | **0** | | | 0 | 34 | 34 |
| *Program 2 - Water Treatments* | | | | | | | | | |
| Research Fellow C - Biological Remediation (McCullough) | 12 | 69 | 71 | **61** | | | 61 | 213 | 213 |
| Research Fellow D - Ecotoxicology (Tsvetnenko) | 88 | 58 | 39 | **0** | | | 0 | 185 | 185 |
| Research Fellow E - Environmental Acidity (Green) | 0 | 36 | 25 | **0** | | | 0 | 61 | 61 |
| Equipment - Wetland Treatment Study | 0 | 24 | 17 | **0** | | | 4 | 41 | 45 |
| Equipment - Fluidised Limestone Reactor Treatment Study | 0 | 13 | 8 | **17** | | | 19 | 38 | 40 |
| *Program 3 - Beneficial End-uses* | | | | | | | | | |
| Research Fellow F - Ecosystem Health (Doupé) | 0 | 43 | 69 | **17** | | | 16 | 129 | 128 |
| Aquaculture Ponds | 0 | 73 | 0 | **0** | | | 0 | 73 | 73 |
| Security System - Aqua/Hort | 48 | 0 | 0 | **0** | | | 0 | 48 | 48 |
| Equipment - Aqua/Hort | 0 | 0 | 112 | **42** | | | 38 | 154 | 150 |
| **Total expenditure** | **295** | **514** | **585** | **285** | **0** | **0** | **285** | **1679** | **1679** |
| **OSTI approved funding tranches** | **573** | **236** | **376** | **322** | **162** | **10** | | | |

*# Year 2003 reporting is from 1st September 2002 to 31st March 2004*

*^ Year 2004, 2005 and 2006 reporting is from 1st April of a given year to 31st March the following year*

# 7. GRANT FUNDING

## SUMMARY

This section details the overall value of the State Government grant in terms of the aims of the Centres of Excellence in Science and Innovation Program.

To support the establishment of CSML and leverage matching State Government funding, substantial sponsorship of $1.679m across a three to four-year period was pledged from leading WA mining companies, the Australian Coal Association Research Program (ACARP), WA universities and other sponsors.

Funding was sought from the State Government's Centres of Excellence in Science and Innovation Program to encourage, enable and leverage opportunities to expand, enhance and generate scientific knowledge and technologies relating to sustainable mine lake management to better inform mine closure decision-making within the WA mining industry.

Without the State Government's funding support, CSML sponsors Wesfarmers Premier Coal and the Griffin Coal Mining Company could not have progressed with their commitment to finding innovative solutions for problems associated with mine closure that would provide environmental, social and economic benefits to the Shire of Collie and the State's south west.

To this end, the Centre concentrated its research on an understanding of the development of final water quality in mine lakes and the means of managing or using that water in a way that, where possible, adds value to the water body for the community.

The funding submission for CSML was developed in consultation with ACARP to ensure research gap areas were addressed. Funding approval for a contribution from ACARP of $150,000pa across three years (later revised to four) was granted in June 2002.

By March 2007, CSML had been successful in attracting a further $2m in income beyond the initial funding support by industry and the State Government to establish the Centre. This figure comprises $1.44m in competitive grants and $560K in industry funding and consultancies and represents a 2.3:1 ratio of additional research monies attracted into the Centre compared to State Government funding provided.

## INITIAL AND ACTUAL SPONSORSHIP

Initial funding support other than COE funds to CSML was to be derived from four main sources (Table 3).

In the first three years of operation the Minerals and Energy Industry was to contribute $930,000 cash as well as in-kind support through ACARP centrally, Griffin Coal and Premier Coal at Collie and Sons of Gwalia at Greenbushes.

The four universities were to provide a combined contribution of $645,000 with the major contributor being Curtin, then UWA.

The community was to contribute $54,000 through the Shire of Collie and the Collie Mine Workers Welfare Group, making the total of cash funds for the first four years match COE funding of $1,679,000.

With Sons of Gwalia moving into liquidation mid-way through the funding period, effectively reducing the company's contribution by $10K and an increase of Murdoch University's funding commitment by $25K, the actual income from CSML initial sponsors other than the COE program was $1,694,000 (Table 4).

Table 3.

| INITIAL INCOME COMMITTED TO SUPPORT THE ESTABLISHMENT OF CSML IN ANTICIPATION OF STATE GOVERNMENT FUNDING SUPPORT | | | | | |
|---|---|---|---|---|---|
| **Universities** | **Year 1** $000 | **Year 2** $000 | **Year 3** $000 | **Year 4** $000 | **Total** $000 |
| Curtin University R&D Office | 60 | 60 | 60 | - | **180** |
| Curtin University Divisions | 60 | 60 | 60 | - | **180** |
| UWA Central Funds | 10 | 10 | 10 | - | **30** |
| UWA Faculty Eng/Math Sc. | 50 | 50 | 50 | - | **150** |
| Edith Cowan Central Funds | 25 | 25 | 25 | - | **75** |
| Murdoch University | 10 | 10 | 10 | - | **30** |
| | 215 | 215 | 215 | - | **645** |
| | | | | | |
| **Industry** | **Year 1** $000 | **Year 2** $000 | **Year 3** $000 | **Year 4** $000 | **Total** $000 |
| Griffin Coal Mining Company | 100 | 100 | 100 | - | **300** |
| Wesfarmers Premier Coal | 50 | 50 | 50 | 50 | **200** |
| Sons of Gwalia | 10 | 10 | 10 | - | **30** |
| Shire of Collie | 4 | 10 | 10 | - | **24** |
| Collie Mine Workers Welfare Group | 10 | 10 | 10 | - | **30** |
| ACARP | 150 | 150 | 150 | - | **450** |
| | 324 | 330 | 330 | 50 | **1,034** |
| | | | | **GRAND TOTAL** | **1,679** |

**Table 4.**

| ACTUAL INCOME FROM INITIAL CENTRE FUNDING SUPPORTERS | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Universities** | **2002** $000 | **2003** $000 | **2004** $000 | **2005** $000 | **2006** $000 | **2007** $000 | **Total** $000 |
| Curtin University R&D Office | - | 65 | 65 | 65 | - | - | **195** |
| Curtin University Divisions | - | 55 | 55 | 55 | - | - | **165** |
| UWA Central Funds | - | 10 | 10 | 10 | - | - | **30** |
| UWA Faculty Eng/Math Sc. | - | 50 | 50 | 50 | - | - | **150** |
| Edith Cowan Central Funds | - | 25 | 25 | 25 | - | - | **75** |
| Murdoch University | - | 10 | 15 | 15 | 15 | - | **55** |
| | - | 215 | 220 | 220 | 15 | - | **670** |
| | | | | | | | |
| **Industry** | **2002** $000 | **2003** $000 | **2004** $000 | **2005** $000 | **2006** $000 | **2007** $000 | **Total** $000 |
| Griffin Coal Mining Company | 100 | - | 100 | 100 | - | - | **300** |
| Wesfarmers Premier Coal | 50 | 50 | 50 | 50 | - | - | **200** |
| Sons of Gwalia | 10 | 10 | - | - | - | - | **20** |
| Shire of Collie | 4 | 10 | 10 | - | - | - | **24** |
| Collie Mine Workers Welfare Group | 10 | 10 | 10 | - | - | - | **30** |
| ACR (previously ACARP) | - | 101 | 101 | 101 | 147 | - | **450** |
| | 174 | 181 | 271 | 251 | 147 | - | **1,024** |
| | | | | | | **GRAND TOTAL** | **1,694** |

## COMPETITIVE GRANTS

By March 2007, CSML researchers had been awarded $1.44m in competitive grant funding for projects that expanded on CSML research resulting from initial State Government, university, and industry funding.

About 30% of additional income through competitive grants was awarded during the 2006/2007 reporting period ($340K). This high figure is reflective of the assertion that until the Centre had published results and gained a solid reputation in the mine lakes management and research area, the ability of researchers to successfully win such additional funding would be restricted.

Table 5 provides a summary of the ten competitive grants CSML researchers received across the CSML State Government funding Agreement.

## INDUSTRY FUNDING AND CONSULTANCIES

A significant number of new research projects funded through industry contracts and consultancies were also initiated during the CSML State Government funding Agreement. Of the 15 new research projects nine were secured during the 2006/2007 reporting period, amounting to further additional income of $300,748 and representing 50% of total industry funding and consultancies obtained. Once again this figure is indicative of CSML's strong research results in mine lakes management and the mineral and regulatory industry's strong support for CSML.

## WORKSHOP INCOME AND WORKSHOP FUNDING SUPPORT

In addition to competitive grants and new industry contracts, CSML received additional income through workshops and workshop funding support totalling $44,640 (Table 7).

**Table 5.**

| COMPETITIVE GRANTS | | | | |
|---|---|---|---|---|
| **Period** | **Project Title** | **Funding Body** | **Recipients/ CSML Collaborators** | **Amount Received** |
| 2006-07 | Fluidised Limestone Reactors for the Remediation of Acidic Drainage (ACARP project C15041) | Australian Coal Research Ltd | Evans L., Tsvetnenko Y., Tade M., Curtin | $121,430 |
| 2006-07 | P4P Multimedia Pilot Project – A new paradigm in science and mathematics education | Department of Education Science and Training | Evans L., Curtin | $85,000 |
| 2006-09 | Integrating inland saline aquaculture and livestock production (EFM06-22) | Rural Industries Research and Development Corporation | Lymbery A., Murdoch | $93,428 |
| 2006-07 | Sustainable weed control and habitat restoration in the Collie region | NHT envirofund | Evans L., Curtin; Collie Weed Action Group; Ngalang Boodja Council | $41,210 |
| 2005 | Sulfate and pH limitations to passive bacterial remediation of acid mine lakes | ECU Small Grant Scheme | McCullough C.D., Lund M., ECU | $4,820 |
| 2005-06 | Remediation of acid coal mine lakes using biological processes and organic material (ACARP project C14052) | Australian Coal Research Ltd | Lund M., McCullough C.D., ECU | $134,974 |
| 2004-06 | Development of new root vegetable crops from southern Western Australia's diverse tuberous flora (50% of total grant $144,134) | Rural Industries Research and Development Corporation | Woodall G., Curtin | $72,067 |
| 2004-06 | Are acidic mine lakes usable as regional water resources? | ARC-Linkage | Oldham C., Ivey G., Schultze M., UWA | $435,000 |
| 2004-06 | Plants for People | Desert Knowledge - CRC | Evans L., Curtin | $427,298 |
| 2004-06 | DK-CRC Bush Foods | Desert Knowledge - CRC | Evans L., Curtin | $26,000 |
| | | | **TOTAL** | $1,441,227 |

**Table 6.**

| INDUSTRY FUNDING AND CONSULTANCIES | | | | |
|---|---|---|---|---|
| **Period** | **Project Title** | **Funding Body** | **Recipients/ CSML Collaborators** | **Amount Received** |
| 2007 | CSML Collie Aboriginal integrated aquaculture project | Department of Agriculture, Fisheries and Forestry | Evans L., Curtin; Ngalang Boodja Council | $27,200 |
| 2007 | Review of CSML research of Lake Kepwari and recommendations for water quality management | South West Development Commission | Evans L., Tsvetnenko Y. Neil L., Curtin; Oldham C. & Salmon U., UWA; McCullough C.D., ECU | $40,750 |
| 2007 | Scoping project for Dalwallinu Shire wattle feasibility study | Wheatbelt Development Commission | Evans L., Curtin | $10,000 |
| 2006-07 | Mine lake aquaculture interim project | Wesfarmers Premier Coal | Whisson G., Storer T., Curtin | $34,000 |
| 2006 | Review of water quality limits for Collie industrial saline water discharge into the ocean | Devereaux Holdings Pty Ltd | Tsvetnenko Y., Evans L., Curtin; Oldham C., UWA | $11,022 |
| 2006 | Protocols for the monitoring and prediction of water quality in mine lakes | ACMER | Oldham C., Salmon U., UWA | $79,000 |
| 2006 | Simple prediction of water quality in Chicken Creek mine lake | WA Department of Environment and Conservation | Oldham C., Salmon U., UWA | $25,000 |
| 2006 | Regional mining and other Agreements review | Goldfields Land and Sea Council | Cronin D., Evans L., Curtin | $43,776 |
| 2006-09 | Cultivation of seaweed in inland saline water | BHP Billiton | Fotedar R., Curtin | $30,000 |
| 2005 | Potential of pit lakes as a positive post-mining option – examples, issues and opportunities | Rio Tinto | Evans L., Cronin D., Tsvetnenko Y. & Hunt D., Curtin; Doupé R. & Lymbery A., Murdoch; McCullough C.D., ECU | $20,000 |
| 2005-08 | Plants for People Wongatha Wonganara Partnership Project | AngloGold Ashanti Australia Limited | Evans L., Curtin | $150,000 |
| 2005 | The toxicity of commercial fungicide SWITCH to juvenile marron | Denmoore Charolais | Tsvetnenko Y., Evans L., Curtin | $11,038 |
| 2005 | Development of an innovative treatment system for acidity problems in an urban lake (Spoonbill Lakes) resulting from Acid Sulfate Soils | Stirling City Council<br><br>ECU-Industry Collaboration Scheme | Lund M., McCullough C.D., ECU<br><br>Collaborating with Tsvetnenko Y., Evans L., Watkins R., Curtin | $40,000<br><br>$28,300 |
| 2003 | Evaluation of Eneabba West Mine Void Stage 2 for mine lake aquaculture | Iluka Resources Ltd | Fotedar R., Curtin | $8,002 |
| 2002-03 | Toxicity and hazard assessment of water from Eneabba West mine void | Iluka Resources Ltd | Tsvetnenko Y., Curtin | $4,606 |
| | | | **TOTAL** | $562,694 |

**Table 7.**

| WORKSHOP INCOME AND WORKSHOP FUNDING SUPPORT | | | | |
|---|---|---|---|---|
| **Period** | **Project Title** | **Funding Body** | **Recipients/ CSML Collaborators** | **Amount** |
| 2007 | Laverton AngloGold Ashanti Plants for People Project Artsource Workshop | Artsource | Evans L., Curtin | $2,850 |
| 2006 | Kalgoorlie Aboriginal Wild Harvest and Land Management Seminar | Desert Knowledge - CRC | Evans L., Curtin | $1,700 |
| 2006 | Reclamation of traditional Indigenous knowledge of the South West Noongar Indigenous community (Collie, WA) | Department of Indigenous Affairs ENRICH Grant | Evans L., Curtin | $2,590 |
| 2006 | Titjikala field trip – Haydn Williams Fellow | Tapatjatjaka Community Government Council, Titjikala | Evans L., Curtin | $7,500 |
| 2004 | Acid Sulfate Soils Workshop: Focus on Aquatic Impact Assessment and Management | Department of Environment<br><br>Participant income | Evans L., Curtin | $6,000<br><br>$24,000 |
| | | | **TOTAL** | $44,640 |

# 8. CONCLUSIONS

The framework for mine closure by the Australian and New Zealand Minerals and Energy Council and Minerals Council of Australia (ANZMEC 2000) stresses the importance of a mine closure process that leaves a decommissioned mine as a self-sustaining ecosystem. The water captured in open cut pits following mine closures is a sustainability issue that is gaining increasing attention. What can the mining industry do to make mine lakes an asset rather than a burden on the community?

CSML research has appealed to mining companies interested in not just rehabilitating a mine site according to legal requirements, but who are focused on providing a positive legacy that will add value for future generations — demonstrating that mining can be truly sustainable.

CSML research into water quality prediction, off take water treatment systems and beneficial end uses has all tremendous results, and outcomes from CSML projects has identified research gaps and opened doors to new research opportunities.

This section summarises the benefits accruing from CSML as described in this report, both in the context of acquired new knowledge and an assessment of the usefulness of information obtained.

## CSML PERFORMANCE AGAINST KEY OBJECTIVES

| PROPOSED KEY OBJECTIVES | ACHIEVEMENT AGAINST PROPOSED KEY OBJECTIVES |
|---|---|
| Recruit a champion to lead the centre, with the right skills and networks and then provide support through quality staff, PhD students, Research Fellows and International Visitors. | Professor Louis Evans was recruited as CSML Executive Director in 2002 as the champion to lead the Centre forward and progress its aims and objectives. Professor Evans was instrumental in channelling the energy and support for better strategies and solutions to sustainable mine lake management, that had its beginnings during 2000 at meetings and workshops in Collie with the Collie mining industry and community, into the creation of a Centre of Excellence with strong and ongoing support from the minerals industry, universities, vocational education and the government.<br><br>Based at Curtin University of Technology since 1975, Professor Evans held the positions of Associate Professor within the School of Biomedical Sciences, and later at Muresk Institute of Agriculture. It was whilst within Muresk that Professor Evans established the Aquatic Science Research Unit and later was awarded a Personal Chair in Aquatic Sciences. As Executive Director of the CSML, Professor Evans supervised and co-supervised postgraduate research projects focused on crustacean post harvest technology, Indigenous traditional knowledge and enterprise, aquatic ecotoxicology, and mine lake aquaculture.<br><br>As a member of the European Association of Fish Pathologists; the International Astacology Association; the Western Australian Marron Growers Association; and the World Aquaculture Society, combined with the connections and networks built within Curtin and other WA universities since 1975, and a strong reputation for securing project funding, Professor Evans was considered the most suitable person to lead the Centre. |
| Establish an appropriate supporting structure including the Advisory Board and | The structure and roles of the CSML Advisory Board, Management Committee and administration section were formulated during the planning discussions prior to submission of the Centre proposal. The structures and roles described within this document were ratified at the |

| | |
|---|---|
| Management Committee and necessary staff (research and administrative). | first meeting of the CSML Advisory Board held in March, 2003. |
| Attract the support and ongoing commitment of industry, the universities and the Department of Industry and Technology. | Funding commitments from mining companies, ACARP, the four universities involved in CSML, local government, and community organisations were secured prior to submission of the final Centre proposal and were instrumental in securing the State Government grant for the Centre. These funding commitments were all honoured over the five year period of operation except for the final payment of one of the mining companies. This payment was not made as the company went into liquidation mid-way through the funding period. |
| Ensure certainty of funding for the first four years of operation. | Funding provided through the original sponsor commitments, along with additional funding obtained through research grants, consultancies and contracts, ensured that all of the Centre's research commitments were fulfilled. |
| Develop the intellectual capital by the Centre through its academic staff, graduate students and networks. | At the completion of the State Government funding period CSML had significant intellectual capital in the form of staff, graduate students and networks. Unfortunately, the winding down of the Centre has eroded this capital with several of the research fellows having to leave the organisation to seek other employment. None-the-less, there remains a strong commitment and on-going activity in mine lake research in each of the four participating universities and the State will continue to benefit from this intellectual capital created by the establishment of CSML. |
| Deliver real benefit to the industry from the research conducted by the Centre, acting as a catalyst for change. | The science of mine lake management is still in the early stages of development. Beneficial end uses of mine lakes being trialled in Collie are on the leading edge of mine lake research. The aquaculture facility at Wesfarmers Premier Coal, for example, was the first successful mine lake aquaculture development in Australia. Mine lake aquaculture has the potential to create significant employment and enterprise in Collie and, by example, throughout the state. The awarding of a scholarship for mine lake aquaculture project by BHP Billiton to a CSML research group was the direct result of information presented at a CSML seminar attended by a BHP representative. As another example of benefit to industry and the state, Lake Kepwari is now being opened up as a recreational centre in Collie. The final decision to relinquish the site to the State Government was strongly influenced by information provided to decision makers by CSML researchers. Enquiries now being received from mining companies and researchers throughout Australia and from overseas about mine lake management and development are illustrative of the degree to which CSML is seen as a catalyst for change in closure planning for mine lakes. |
| Establish and maintain credibility with the mining industry. | Although CSML is winding down due to the completion of State Government funded research, contracts with mining companies for mine lake research or technology applications is continuing. This continued support is indicative of the credibility that has been developed with not only mining companies but also with government agencies. As an example of this credibility, CSML has been asked to conduct a one-day seminar on mine lake science for government agencies managing the recently announced salinity study in the Collie Basin and a half-day seminar on closure and beneficial end uses of mine lakes at a mining industry environmental conference to be held in Perth in February, 2008. |
| Establish self-funding mechanism in the medium term through scholarships, industry | CSML research groups within each of the participating universities are continuing to pursue their interests in mine lake research through student projects, industry contracts and funded university-based research. However, the benefits and value of having a central group coordinating these efforts and encouraging collaboration between |

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| funds, and university support. | different universities has been significantly affected by the decision of the Centre Agent, Curtin University to cease support of the management and administration of the centre. |
| Develop and enhance inter-disciplinary and international linkages. | As detailed elsewhere in this report, all CSML research groups have established international and inter-disciplinary linkages as a result of the establishment of CSML and are expected to continue these associations in the future |

## CSML PERFORMANCE AGAINST KEY OUTPUTS

| PROPOSED KEY OUTPUTS | ACHIEVEMENT AGAINST PROPOSED KEY OUTPUTS |
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| Local graduates at the undergraduate and postgraduate level with expertise in mine lake management and downstream uses. | Since CSML was established in 2002, university partners in the Centre have continued to attract and retain high calibre students interested in pursuing PhD, Masters, and undergraduate degrees in the diverse fields that encompass the study and management of mine lakes and downstream uses.<br><br>Local graduates from engineering, environment, agriculture and aquatic sciences have chosen to continue their education through undertaking postgraduate studies directly applicable to the mining, water, and fisheries industries. The first student to receive a PhD relating to CSML research into mine lake management issues graduated in 2006, and is now applying his expertise in aquatic ecosystems impacted by acid sulphate soils to the estuarine environment through his appointment to the WA Department of Water. To date, four students have completed postgraduate degrees relating to CSML research, with a further nine in progress. Nine final-year undergraduate projects (Honours) have also been completed. Research undertaken by these students has contributed to the global understanding of mine lake mechanics and management, particularly in the areas of mine lake environmental fluid dynamics, aquatic ecosystem dynamics, mine lake ecotoxicology and beneficial end uses. |
| A research and education presence in Collie and potentially in other regional centres. | The CSML headquarters was established in the Collie TAFE in 2003. CSML researchers located in this facility developed and conducted the first year of an undergraduate science course focused on aquaculture and environmental management and continued to tutor students enrolled in this program until the course was withdrawn at the end of 2006 as a result of the closure of the CSML headquarters.<br><br>A bridging course for Aboriginal students was also conducted through the Collie TAFE facility. Both these educational programs were managed by Curtin's Centre for Regional Education.<br><br>The education and training program commenced by CSML and offered to members of the Collie Aboriginal community is continuing, with a Certificate 1 in Leadership Development being conducted in the second half of 2007 through a collaborative arrangement between the Collie TAFE and the Ngalang Boodja Council Aboriginal Corporation (NBCAC). Facilities in the Collie TAFE previously leased through CSML are now being leased by the NBCAC using funding obtained by grant applications submitted to funding agencies by the NBCAC with assistance from CSML mentors. Enrolment of students from this course in a Murdoch University Diploma in University Studies, a one-year bridging course for Aboriginal students wishing to pursue a higher education, is planned for 2008.<br><br>A mine lake aquaculture development project at the Collie Aquafarm conducted by NBCAC with advice and assistance of an expertise based Leadership Group is presently being scoped. The CSML Executive Director, |

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| | Professor Louis Evans, has been nominated to lead this project. Sponsorship funds for the project have been offered by Wesfarmers Premier Coal and additional funding is being sought from government agencies.<br><br>Over the course of the five-year funding period CSML assisted the NBCAC in funding applications to NHT (2), SW Development Commission (1), ILC (2), DIA (1), DEST (1), Collie Shire (1), SW Area Consultative Committee (1) and the Australian Government Department of Agriculture Forestry and Fisheries (1) resulted in five successful outcomes and have led to the employment of eight community members as part time Teachers Associates and natural resource management project officers.<br><br>Building on the experience gained in the partnership activities conducted by CSML researchers with the NBCAC a new Aboriginal enterprise, education and employment project has commenced at Laverton sponsored by AngloGold Ashanti. This five-year project is in its second year and is having outstanding success with the establishment of a bush dye enterprise conducted by a group of Wongatha Wonganara community members. The education and training component of the project is planned to commence in 2008. The CSML Executive Director, Professor Louis Evans, was contracted by AngloGold Ashanti to lead this project and has been invited to continue with this work following the closure of the CSML Administration section. |
| Research reports and papers that lead to an enhanced understanding of mine lake management. | A number of publication avenues have been utilised to maximise the outreach of CSML research outcomes:<br><br>• Refereed journal papers<br>• Non-refereed papers<br>• Book chapters<br>• Conference papers and industry articles<br>• Conference posters<br>• Research grant and consultancy reports to client groups<br>• Editorialships<br><br>When the last submitted and accepted paper is printed, a total of 103 research output materials will have been published by CSML researchers for the benefit of industry and future mine lake research. This total includes 26 refereed journal papers; three book chapters; 35 conference papers and industry articles; 24 research grant and consultancy reports to client groups; and five Editorialships. A further 12 thesis papers have been published by postgraduate students who completed research projects relating to CSML research.<br><br>As the majority of CSML projects were completed by December 2006, the 2006/2007 funding period in particular has seen significant publishing activity. The majority of CSML researcher refereed journal papers appeared in publications in 2006 and a high number of papers are due to be published later this year or early 2008. |
| Conferences, case studies and seminars on mine lake management. | In addition to the publication of research results, transfer of CSML research outcomes to the broader community of mine lake management information has been through national and international conferences, workshops and seminar presentations.<br><br>Two CSML Scientific Review Seminars and associated research field trips across the State Government funding period to showcase mine lake research were conducted by the Centre. The last CSML Scientific Review Seminar was held in March 2007 at Wesfarmers Premier Coal, Collie WA. The seminar attracted 34 delegates from the mining industry, government, and Indigenous community interested in research outcomes during the past five years.<br><br>In the last funding period alone, CSML researchers prepared and |

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| | delivered twenty two presentations to industry and government agencies interested in research results stemming from the Centre. Since the establishment of the Centre, close to 100 presentations have been delivered.<br><br>An indication of the importance and value of CSML research results to the broader community is the high number of presentations by CSML researchers at key national and international conferences and symposiums, including: Water in Mining Conference 2006; Mine Closure 2006; INTERACT 2006; ICARD conferences; International Association of Astacology symposiums, MCA Sustainable Development conferences; Pit Lakes 2004; and World Aquaculture Society conference 2005.<br><br>The CSML Executive Director has been invited to give a plenary presentation on mine lake management and closure options and coordinate a half day workshop by CSML researchers at a mining industry national conference to be held in Perth in February, 2008. Professor Evans was recently invited by the WA Department of Water to convene a one day seminar in late 2007 on CSML mine lake research to inform government agencies involved in management of acid sulphate soils, acid mine drainage and water quality and salinity research. |
| Improved market and research networks. | The CSML website and research seminars have enabled networks to be established throughout Australia and beyond. As a direct result of these marketing tools CSML researchers have been invited to contribute to international conferences (USA EPA Pit Lakes Conference 2004, Nevada; 2007 International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production), provide a guest editorial for the journal, International Journal of Mining, Reclamation and Environment; contribute to the INAP-ADTI Pit Lakes Workbook and present at a number of national and local conferences, seminars and symposia. Examples to illustrate the market reach and establishment of research networks, details of which are provided elsewhere in this report, are the ACMER grant to write the protocols for long-term prediction and monitoring of mine lake water quality, the convening of a three-day UWA workshop on mine lake modelling that involved three researchers from Germany and the participation of a leading acid mine drainage treatment researcher from South Africa in the acid sulphate soils workshop conducted in Mandurah in 2004. These collaborations have led to participation of these research groups in grant applications to ARC and other agencies for mine lake research projects as well as to contract research with government agencies and mining companies. |
| An enhanced reputation for the State as a manager of mine lakes and for approaches to mine closure. | By March 2007, CSML had been successful in attracting a further $2m in income beyond the initial funding support by industry and the State Government to establish the Centre. This figure comprises $1.44m in competitive grants and $560K in industry funding and consultancies and represents a 2.3:1 ratio of additional research monies attracted into the Centre compared to State Government funding provided.<br><br>About 30% of additional income through competitive grants, contract research and consulting assignments was gained during the 2006/2007 funding period. This high figure is reflective of the assertion that until the Centre had published results and gained a solid reputation in the mine lakes management and research area, the ability of researchers to successfully win such additional funding would be restricted.<br><br>Indicative of the high reputation WA researchers have in mine lakes and mine closure, in 2006 CSML researchers across all three research programs were invited to contribute to an international workbook on the management of metal mine and metallurgical process drainage. Three chapters have been accepted for publication, relating to regulatory requirements and planning required to develop successful beneficial end uses, successfully rehabilitated pit lake examples, and |

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| | mine lake water quality modelling have been submitted for inclusion in the INAP-ADTI Pit Lakes Workbook and are currently in review. Research outcomes relating to mine lake research at Wesfarmers Premier Coal features strongly in these chapters. This book is an international effort to synthesise current knowledge on pit (mine) lakes, and is intended for use as a worldwide handbook for the mining industry on pit lakes and the issues surrounding them. The acceptance of CSML researchers' chapters for inclusion in the publication is a strong indication that CSML is leading the way in mine lake research. |

## THE FUTURE OF CSML

The Centres of Excellence funds are recognised as catalytic and time bound. From the on-set CSML set out to ensure certainty of funding beyond the five-year Centres of Excellence funding period and initial Centre sponsorship, to guarantee its own sustainability.

As reported last year, an expression of interest (EoI) for a new Centre of Excellence in Mine Closure and Sustainable Resources was submitted to the State Government in October 2005. The EoI followed a strategic planning review of CSML, extensive discussions with various government and university personnel, a review of responses of attendees at the CSML Research Seminar held in May 2005, and an analysis of the needs of industry. The EoI captured the need to maintain a focus on mine lake research to address research gaps, and branch into related research areas of importance and relevance to resource and urban development industries. Unfortunately the EoI was not approved to go to the full project application phase.

Discussions regarding the future of CSML aimed at building support for on-going funding for the administration of the Centre were held between various parties and reviewed at a subsequent CSML Advisory Board meeting. The Board noted that commercialisation of the outcomes of CSML research was a high priority and was actively pursued by CSML researchers in the different partner universities, through competitive grant funds, contract research and consultancy income are also being actively pursued by CSML researchers.

The CSML Advisory Board has agreed that a statement will be placed on the CSML website to the effect that the Centre is no longer being actively managed but the research is continuing at the partner universities by research groups involved in CSML. The statement will include information on links to these research groups. It was also agreed that the joint venture, due to expire in 2010, would be maintained as a legal agreement but that there would be no funding allocated for maintenance of either the website or a point of contact for future enquiries on mine lake research.

## FUTURE DIRECTIONS IN MINE LAKES RESEARCH

### *Review of ongoing mine lake research*

Information on current directions in mine lake research was obtained by examination of the spread and nature of presentations at Pit Lakes 2004 Conference, Reno, Nevada, November 16-18, 2004. Presented papers covered six broad category areas – policy, key issues and science overviews (8), characterisation (hydrogeology/geochemistry)(5), environmental modelling (8), bioremediation (4), closure studies (2), and future directions (3).

Overall, there is currently little direction for either mining companies or regulatory bodies over many aspects of mine lake water quality and hydrology. Environmentally acceptable geochemical, biogeochemical and ecological cycles for rehabilitated mine lakes, and suitable indicators of such, have yet to be identified. Many knowledge gaps remain in the science and management of mine lakes.

Knowledge gaps and requirements for future research are in the areas of: 1) detection and monitoring of potential environmental impacts; 2) water quality criteria for mine lakes and proposed approaches to monitoring water quality; 3) selection of preferred test species for ecotoxicological evaluations of toxic effluents and treatment outcomes; 4) development of standard approach to using chemical analyses and bioassays in the assessment and regulation of toxic effluents from mine lakes; 5) mine lake remediation technologies; 6) modelling of water quality changes in mine lakes; and 7) regulatory approaches and beneficial end uses of mine lakes.

### *Prioritisation of research gaps*

Based on the identified knowledge gaps, priorities for mine lake research are:

- Harmonising regulatory measures across Australian states, identifying agreed success criteria for which sign off can be obtained, and developing agreed approaches whereby both government (local and/or state) and industry share the long term liability risks.
- Developing cost-effective and sustainable approaches to remediating water quality problems in mine lakes.
- Characterising the geochemical, biogeochemical and ecological cycles of mine lake ecosystems.
- Developing reliable indicators for long term monitoring and management of mine lakes and predictive capability of likely remediation outcomes.
- Evaluation of commercially viable options for beneficial end uses of mine lakes.

### *The way forward*

The central goal of all stakeholders in any mine lake development is to minimise the risk of long-term ecological degradation, whilst maximising the opportunity for public and community benefit (sustainability). The way forward in achieving this goal is for government, industry, academe and community to work together to identify and trial cost-effective options for end uses of mine lakes. In order for this goal to be achieved, the following areas need urgent attention:

- Development of a uniform set of closure criteria and closure processes that minimise the risk of failure of remediation and rehabilitation strategies, whilst allowing for an equitable sharing of this risk between industry, government and community.
- Increased understanding of the structural and functional characteristics of post-mining ecosystems, and the need for regulators to recognise that post mining environments will not be the same as existed before mining commenced.
- Establishment of demonstration sites of mine lake developments for evaluation and long-term monitoring of state of the art remediation technologies and the use of these demonstration lakes, and their monitoring data, for validation of water quality models and optimal remediation strategies.
- Research on sustainable approaches to minimising environmental problems in mine lakes and the impacts they might have on surrounding ecosystems, and on identifying appropriate indicators or criteria of success.
- Research into on-going changes to void water biogeochemistry and their modelling to provide greater certainty to community and regulators on the likely future water quality conditions and risk to land use / void options.

Researchers in WA universities, that have been integral to the CSML research platform of fostering the creation mine lakes of value to the community, environment and economy, will continue to work in partnership with government and industry to deliver scientific information towards these areas that need urgent attention.

# APPENDIX 1: CSML 2006 REPORTING PERIOD: ACTUAL EXPENDITURE OF STATE GOVERNMENT FUNDS SUMMARY, ITEMISED PROGRAM EXPENDITURE REPORTS, AND DOCUMENTATION SUPPORTING THE ACQUITTAL OF STATE GOVERNMENT FUNDS

- CSML 2006 Actual Expenditure of State Government Funds Summary
- CSML 2006 Program 1 Itemised Expenditure Report
- CSML 2006 Program 1 Expenditure Documentation:
    - Research Fellow Salaries
    - Equipment – Prediction Modelling
    - Equipment – New Technology
- CSML 2006 Program 2 Itemised Expenditure Report
- CSML 2006 Program 2 Expenditure Documentation:
    - Research Fellow Salaries
    - Equipment – Water Treatments Study
    - Equipment – Fluidised Limestone Reactor Treatment Study
- CSML 2006 Program 3 Itemised Expenditure Report
- CSML 2006 Program 3 Expenditure Documentation:
    - Research Fellow Salary
    - Equipment – Aquaculture/Horticulture

# 2006 Actual Expenditure of State Government Funds Summary

*01/04/06 to 31/03/07*

| Description | Budgeted Expenditure | Actual Expenditure | Underspend | Overspend |
|---|---|---|---|---|
| *Laboratory fitout and upgrade* | 0.00 | 0.00 | 0.00 | $0.00 |
| **Laboratory fitout and upgrade sub total** | **$0.00** | **$0.00** | **$0.00** | **$0.00** |
| *Program 1 - Prediction Modelling* | | | | |
| Research Fellow A1 - Hydrodynamics (Wake) | 17,000.00 | 7,011.00 | 9,989.00 | 0.00 |
| Research Fellow A2 - Ecological Modeller (Hipsey) | 48,000.00 | 34,560.00 | 13,440.00 | 0.00 |
| Research Fellow A3 - Software Engineering (Imerito) | 0.00 | 0.00 | 0.00 | 0.00 |
| Research Fellow B - Biogeochemistry (Salmon) | 82,000.00 | 106,326.00 | 0.00 | 24,326.00 |
| Equipment - Prediction Modelling | 0.00 | 0.00 | 0.00 | 0.00 |
| Equipment - New Technology | 0.00 | 0.00 | 0.00 | 0.00 |
| **Program 1 - Prediction Modelling sub total** | **$147,000.00** | **$147,897.00** | **$23,429.00** | **$24,326.00** |
| *Program 2 - Water Treatments* | | | | |
| Research Fellow C - Biological Remediation (McCullough) | 61,000.00 | 61,207.54 | 0.00 | 207.54 |
| Research Fellow D - Ecotoxicology (Tsvetnenko) | 0.00 | 0.00 | 0.00 | 0.00 |
| Research Fellow E - Environmental Acidity (Green) | 0.00 | 0.00 | 0.00 | 0.00 |
| Equipment - Water Treatments Study | 4,000.00 | 0.00 | 4,000.00 | 0.00 |
| Equipment - Fluidised Limestone Reactor Treatment Study | 19,000.00 | 16,643.44 | 2,356.56 | 0.00 |
| **Program 2 - Water Treatments sub total** | **$84,000.00** | **$77,850.98** | **$6,356.56** | **$207.54** |
| *Program 3 - Beneficial End Uses* | | | | |
| Research Fellow F - Ecosystem Health (Doupé) | 16,000.00 | 17,253.27 | 0.00 | 1,253.27 |
| Aquaculture Ponds | 0.00 | 0.00 | 0.00 | 0.00 |
| Security System - Aqua/Hort | 0.00 | 0.00 | 0.00 | 0.00 |
| Equipment - Aqua/Hort | 38,000.00 | 41,998.75 | 0.00 | 3,998.75 |
| **Program 3 - Beneficial End Uses sub total** | **$54,000.00** | **$59,252.02** | **$0.00** | **$5,252.02** |
| **2005 GRAND TOTALS** | **$285,000.00** | **$285,000.00** | **$29,785.56** | **$29,785.56** |

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| **2006 TOTAL BUDGETED EXPENDITURE** | **$285,000.00** |
| **2006 TOTAL ACTUAL EXPENDITURE** | **$285,000.00** |
| **2006 TOTAL OVERSPEND/UNDERSPEND** | **$0.00** |

# CSML Program 1 - Prediction Modelling

## 2006 Itemised Expenditure Report

*01/04/06 to 31/03/07*

| ITEM | | AMOUNT (GST Exc.) |
|---|---|---|
| ***Research Fellow Salaries*** | | |
| ***1*** | Research Fellow A1 - Hydrodynamics (Geoffrey Wake) | 7,011.00 |
| ***2*** | Research Fellow A2 - Ecological Modeller (Matthew Hipsey) | 34,560.00 |
| ***3*** | Research Fellow B - Biogeochemistry (Ursula Salmon) | 106,326.00 |
| | **2006 TOTAL EXPENDITURE PROGRAM 1 - PREDICTION MODELLING** | **$147,897.00** |

# CSML Program 1 – Prediction Modelling
# 2006 Expenditure Documentation

## Research Fellow Salary Items

Item 1: Research Fellow A1 - Hydrodynamics (Geoffrey Wake)
Item 2: Research Fellow A2 - Ecological Modeller (Matthew Hipsey)
Item 3: Research Fellow B - Biogeochemistry (Ursula Salmon)

Salary Report - Geoffrey Wake
Program 1 Research Fellow A1 - Hydrodynamics
2006 State Government Reporting Period
01/04/06 to 31/07/07

| Division | School | JrnlID | JrnlDate | JrnlHdrDesc | Amt |
|---|---|---|---|---|---|
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0603047 | 3/04/2010 | 00031529-WAKE, GEOFFREY WILLIA | 690.77 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0603047 | 3/04/2010 | 00031529-WAKE, GEOFFREY WILLIA | 41.11 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0603047 | 3/04/2010 | 00031529-WAKE, GEOFFREY WILLIA | 40.27 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0603047 | 3/04/2010 | 00031529-WAKE, GEOFFREY WILLIA | 6.95 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0606661 | 17/04/2010 | 00031529-WAKE, GEOFFREY WILLIA | 494.55 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0606661 | 17/04/2010 | 00031529-WAKE, GEOFFREY WILLIA | 41.27 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0606661 | 17/04/2010 | 00031529-WAKE, GEOFFREY WILLIA | 29.47 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0606661 | 17/04/2010 | 00031529-WAKE, GEOFFREY WILLIA | 4.95 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0610007 | 1/05/2010 | 00031529-WAKE, GEOFFREY WILLIA | 494.54 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0610007 | 1/05/2010 | 00031529-WAKE, GEOFFREY WILLIA | 41.28 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0610007 | 1/05/2010 | 00031529-WAKE, GEOFFREY WILLIA | 29.47 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0610007 | 1/05/2010 | 00031529-WAKE, GEOFFREY WILLIA | 4.96 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0614252 | 15/05/2010 | 00031529-WAKE, GEOFFREY WILLIA | 458.55 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0614252 | 15/05/2010 | 00031529-WAKE, GEOFFREY WILLIA | 41.27 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0614252 | 15/05/2010 | 00031529-WAKE, GEOFFREY WILLIA | 27.49 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0614252 | 15/05/2010 | 00031529-WAKE, GEOFFREY WILLIA | 4.59 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0618199 | 29/05/2010 | 00031529-WAKE, GEOFFREY WILLIA | -458.55 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0618199 | 29/05/2010 | 00031529-WAKE, GEOFFREY WILLIA | -41.27 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0618199 | 29/05/2010 | 00031529-WAKE, GEOFFREY WILLIA | -27.49 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0618199 | 29/05/2010 | 00031529-WAKE, GEOFFREY WILLIA | -4.59 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0631143 | 10/07/2010 | 00031529-WAKE, GEOFFREY WILLIA | 2,621.72 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0635326 | 24/07/2010 | 00031529-WAKE, GEOFFREY WILLIA | 494.56 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0639406 | 7/08/2010 | 00031529-WAKE, GEOFFREY WILLIA | 494.56 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0645043 | 21/08/2010 | 00031529-WAKE, GEOFFREY WILLIA | 494.56 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0649371 | 4/09/2010 | 00031529-WAKE, GEOFFREY WILLIA | 148.36 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0631143 | 10/07/2010 | 00031529-WAKE, GEOFFREY WILLIA | 254.80 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0635326 | 24/07/2010 | 00031529-WAKE, GEOFFREY WILLIA | 77.96 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0639406 | 7/08/2010 | 00031529-WAKE, GEOFFREY WILLIA | 77.96 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0645043 | 21/08/2010 | 00031529-WAKE, GEOFFREY WILLIA | 77.96 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0649371 | 4/09/2010 | 00031529-WAKE, GEOFFREY WILLIA | 23.39 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0631143 | 10/07/2010 | 00031529-WAKE, GEOFFREY WILLIA | 158.23 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0635326 | 24/07/2010 | 00031529-WAKE, GEOFFREY WILLIA | 31.49 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0639406 | 7/08/2010 | 00031529-WAKE, GEOFFREY WILLIA | 31.49 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0645043 | 21/08/2010 | 00031529-WAKE, GEOFFREY WILLIA | 31.49 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0649371 | 4/09/2010 | 00031529-WAKE, GEOFFREY WILLIA | 9.45 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0631143 | 10/07/2010 | 00031529-WAKE, GEOFFREY WILLIA | 4.95 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0635326 | 24/07/2010 | 00031529-WAKE, GEOFFREY WILLIA | 4.95 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0639406 | 7/08/2010 | 00031529-WAKE, GEOFFREY WILLIA | 4.95 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0645043 | 21/08/2010 | 00031529-WAKE, GEOFFREY WILLIA | 4.95 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0649371 | 4/09/2010 | 00031529-WAKE, GEOFFREY WILLIA | 1.49 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0631143 | 10/07/2010 | 00031529-WAKE, GEOFFREY WILLIA | 26.26 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0635326 | 24/07/2010 | 00031529-WAKE, GEOFFREY WILLIA | 4.95 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0639406 | 7/08/2010 | 00031529-WAKE, GEOFFREY WILLIA | 4.95 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0645043 | 21/08/2010 | 00031529-WAKE, GEOFFREY WILLIA | 4.95 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0649371 | 4/09/2010 | 00031529-WAKE, GEOFFREY WILLIA | 1.49 |

2006 REPORTING PERIOD SALARY TOTAL, GEOFFREY WAKE $7,011

Salary Report - Matthew Hipsey
Program 1 Research Fellow A2 - Ecological Modeller
2006 State Government Reporting Period
01/04/06 to 31/07/07

| Division | School | JrnlID | JrnlDate | JrnlHdrDesc | Amt |
|---|---|---|---|---|---|
| Engineering Computing & Maths | Environmental Systems Eng | INT0006051 | 31/05/2010 | CRG TIMESHEET CHARGES MAY06 | 4,050.00 |
| Engineering Computing & Maths | Environmental Systems Eng | INT0006176 | 7/06/2010 | CRG TIMESHEET CHARGES MAY06 | 2,319.00 |
| Engineering Computing & Maths | Environmental Systems Eng | 0000613194 | 10/05/2010 | TFR FROM BU 00640 APR 06 BAL | 5,461.69 |
| Engineering Computing & Maths | Environmental Systems Eng | 0064000955 | 4/05/2010 | Mining Lakes | 3,942.30 |
| Engineering Computing & Maths | Environmental Systems Eng | 0000613194 | 10/05/2010 | TFR TO BU 00645 APR 06 BAL | -5,461.69 |
| Engineering Computing & Maths | Environmental Systems Eng | INT0006764 | 19/07/2010 | CRG TIMESHEET CHARGES JUN06 | 9,276.00 |
| Engineering Computing & Maths | Environmental Systems Eng | INT0006176 | 11/07/2010 | CRG TIMESHEET CHARGES MAY06 | 2,319.00 |
| Engineering Computing & Maths | Environmental Systems Eng | INT0007335 | 17/08/2010 | CRG TIMESHEETS JULY06 | 773.00 |
| Engineering Computing & Maths | Environmental Systems Eng | INT0009835 | 20/12/2010 | CRG TIMESHEET FOR NOV06 -MINEL | 2,974.00 |
| Engineering Computing & Maths | Environmental Systems Eng | INT0009365 | 18/11/2010 | CRG TIMESHEET FOR OCT06 -MINEL | 4,692.00 |
| Engineering Computing & Maths | Environmental Systems Eng | INT0008951 | 28/10/2010 | CWR TIMESHEET- AUG06 MINELAKES | 2,628.20 |
| Engineering Computing & Maths | Environmental Systems Eng | INT0010597 | 25/01/2011 | CRG TIMESHEET CHARGES DEC06 | 661.00 |
| Engineering Computing & Maths | Environmental Systems Eng | INT0010865 | 8/02/2011 | CRG TIMESHEET JAN07- MINE LAKE | 925.00 |

2006 REPORTING PERIOD SALARY TOTAL, MATTHEW HIPSEY $34,560

Salary Report - Ursula Salmon
Program 1 Research Fellow B - Biogeochemistry
2006 State Government Reporting Period
01/04/06 to 31/07/07

| Division | School | JrnlID | JrnlDate | JrnlHdrDesc | Amt |
|---|---|---|---|---|---|
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0603047 | 3/04/2010 | 00054085-SALMON, SALLY URSULA | 2,375.58 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0603047 | 3/04/2010 | 00054085-SALMON, SALLY URSULA | 403.85 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0603047 | 3/04/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0606661 | 17/04/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0610007 | 1/05/2010 | 00054085-SALMON, SALLY URSULA | 23.77 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0614252 | 15/05/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0618199 | 29/05/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0622318 | 12/06/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0626719 | 26/06/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0603047 | 3/04/2010 | 00054085-SALMON, SALLY URSULA | 152.87 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0603047 | 3/04/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0606661 | 17/04/2010 | 00054085-SALMON, SALLY URSULA | 2,375.58 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0606661 | 17/04/2010 | 00054085-SALMON, SALLY URSULA | 403.85 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0606661 | 17/04/2010 | 00054085-SALMON, SALLY URSULA | 152.87 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0606661 | 17/04/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0610007 | 1/05/2010 | 00054085-SALMON, SALLY URSULA | 2,375.58 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0610007 | 1/05/2010 | 00054085-SALMON, SALLY URSULA | 403.85 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0610007 | 1/05/2010 | 00054085-SALMON, SALLY URSULA | 152.89 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0610007 | 1/05/2010 | 00054085-SALMON, SALLY URSULA | 23.77 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0614252 | 15/05/2010 | 00054085-SALMON, SALLY URSULA | 2,375.58 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0614252 | 15/05/2010 | 00054085-SALMON, SALLY URSULA | 403.85 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0614252 | 15/05/2010 | 00054085-SALMON, SALLY URSULA | 152.87 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0614252 | 15/05/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0618199 | 29/05/2010 | 00054085-SALMON, SALLY URSULA | 2,375.58 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0618199 | 29/05/2010 | 00054085-SALMON, SALLY URSULA | 403.85 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0618199 | 29/05/2010 | 00054085-SALMON, SALLY URSULA | 152.87 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0618199 | 29/05/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0622318 | 12/06/2010 | 00054085-SALMON, SALLY URSULA | 2,375.58 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0622318 | 12/06/2010 | 00054085-SALMON, SALLY URSULA | 403.85 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0622318 | 12/06/2010 | 00054085-SALMON, SALLY URSULA | 152.87 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0622318 | 12/06/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0626719 | 26/06/2010 | 00054085-SALMON, SALLY URSULA | 2,375.58 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0626719 | 26/06/2010 | 00054085-SALMON, SALLY URSULA | 403.85 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0626719 | 26/06/2010 | 00054085-SALMON, SALLY URSULA | 152.87 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0626719 | 26/06/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0631143 | 10/07/2010 | 00054085-SALMON, SALLY URSULA | 7,579.26 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0635326 | 24/07/2010 | 00054085-SALMON, SALLY URSULA | 26,141.10 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0639406 | 7/08/2010 | 00054085-SALMON, SALLY URSULA | 2,375.58 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0645043 | 21/08/2010 | 00054085-SALMON, SALLY URSULA | 2,375.58 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0649371 | 4/09/2010 | 00054085-SALMON, SALLY URSULA | 2,375.58 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0653302 | 18/09/2010 | 00054085-SALMON, SALLY URSULA | 2,411.21 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0631143 | 10/07/2010 | 00054085-SALMON, SALLY URSULA | 1,288.44 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0635326 | 24/07/2010 | 00054085-SALMON, SALLY URSULA | 4,444.01 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0639406 | 7/08/2010 | 00054085-SALMON, SALLY URSULA | 403.85 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0645043 | 21/08/2010 | 00054085-SALMON, SALLY URSULA | 403.85 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0649371 | 4/09/2010 | 00054085-SALMON, SALLY URSULA | 403.85 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0653302 | 18/09/2010 | 00054085-SALMON, SALLY URSULA | 409.91 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0631143 | 10/07/2010 | 00054085-SALMON, SALLY URSULA | 487.69 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0635326 | 24/07/2010 | 00054085-SALMON, SALLY URSULA | 1,682.20 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0639406 | 7/08/2010 | 00054085-SALMON, SALLY URSULA | 152.87 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0645043 | 21/08/2010 | 00054085-SALMON, SALLY URSULA | 152.87 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0649371 | 4/09/2010 | 00054085-SALMON, SALLY URSULA | 152.87 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0653302 | 18/09/2010 | 00054085-SALMON, SALLY URSULA | 155.17 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0631143 | 10/07/2010 | 00054085-SALMON, SALLY URSULA | 75.78 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0635326 | 24/07/2010 | 00054085-SALMON, SALLY URSULA | 261.47 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0639406 | 7/08/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0645043 | 21/08/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0649371 | 4/09/2010 | 00054085-SALMON, SALLY URSULA | 23.76 |

| | | | | | |
|---|---|---|---|---|---|
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0653302 | 18/09/2010 | 00054085-SALMON, SALLY URSULA | 24.11 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000638305 | 1/08/2010 | TFR FROM BU 00640 AT 31/7/06 | 3,289.26 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000638305 | 1/08/2010 | TFR FROM BU 00640 AT 31/7/06 | 370.49 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000638305 | 1/08/2010 | TFR FROM BU 00640 AT 31/7/06 | -194.72 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000638305 | 1/08/2010 | TFR FROM BU 00640 AT 31/7/06 | 201.28 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000638305 | 1/08/2010 | TFR FROM BU 00640 AT 31/7/06 | 32.96 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000638305 | 1/08/2010 | TFR FROM BU 00640 AT 31/7/06 | 360.00 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000638305 | 1/08/2010 | TFR FROM BU 00640 AT 31/7/06 | 32.40 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000638305 | 1/08/2010 | TFR FROM BU 00640 AT 31/7/06 | 21.58 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000638305 | 1/08/2010 | TFR FROM BU 00640 AT 31/7/06 | 3.60 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000685087 | 22/12/2010 | 00054085-SALMON SALLY URSULA | -1,515.42 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0657383 | 2/10/2010 | 00054085-SALMON, SALLY URSULA | 2,411.21 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0661317 | 16/10/2010 | 00054085-SALMON, SALLY URSULA | 2,411.21 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0665374 | 30/10/2010 | 00054085-SALMON, SALLY URSULA | 2,411.21 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0669879 | 13/11/2010 | 00054085-SALMON, SALLY URSULA | 2,411.21 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0673952 | 27/11/2010 | 00054085-SALMON, SALLY URSULA | 2,423.27 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0679418 | 11/12/2010 | 00054085-SALMON, SALLY URSULA | 3,271.42 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0684221 | 25/12/2010 | 00054085-SALMON, SALLY URSULA | 2,423.27 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0657383 | 2/10/2010 | 00054085-SALMON, SALLY URSULA | 409.91 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0661317 | 16/10/2010 | 00054085-SALMON, SALLY URSULA | 409.91 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0665374 | 30/10/2010 | 00054085-SALMON, SALLY URSULA | 409.91 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0669879 | 13/11/2010 | 00054085-SALMON, SALLY URSULA | 409.91 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0673952 | 27/11/2010 | 00054085-SALMON, SALLY URSULA | 411.96 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0679418 | 11/12/2010 | 00054085-SALMON, SALLY URSULA | 411.96 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0684221 | 25/12/2010 | 00054085-SALMON, SALLY URSULA | 411.96 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0657383 | 2/10/2010 | 00054085-SALMON, SALLY URSULA | 155.17 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0661317 | 16/10/2010 | 00054085-SALMON, SALLY URSULA | 155.17 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0665374 | 30/10/2010 | 00054085-SALMON, SALLY URSULA | 155.17 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0669879 | 13/11/2010 | 00054085-SALMON, SALLY URSULA | 155.17 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0673952 | 27/11/2010 | 00054085-SALMON, SALLY URSULA | 155.94 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0679418 | 11/12/2010 | 00054085-SALMON, SALLY URSULA | 202.59 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0684221 | 25/12/2010 | 00054085-SALMON, SALLY URSULA | 155.94 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0657383 | 2/10/2010 | 00054085-SALMON, SALLY URSULA | 24.11 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0661317 | 16/10/2010 | 00054085-SALMON, SALLY URSULA | 24.11 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0665374 | 30/10/2010 | 00054085-SALMON, SALLY URSULA | 24.11 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0669879 | 13/11/2010 | 00054085-SALMON, SALLY URSULA | 24.11 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0673952 | 27/11/2010 | 00054085-SALMON, SALLY URSULA | 24.23 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0679418 | 11/12/2010 | 00054085-SALMON, SALLY URSULA | 24.23 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0684221 | 25/12/2010 | 00054085-SALMON, SALLY URSULA | 24.23 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0657383 | 2/10/2010 | 00054085-SALMON, SALLY URSULA | 24.11 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0661317 | 16/10/2010 | 00054085-SALMON, SALLY URSULA | 24.11 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0665374 | 30/10/2010 | 00054085-SALMON, SALLY URSULA | 24.11 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0669879 | 13/11/2010 | 00054085-SALMON, SALLY URSULA | 24.11 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0673952 | 27/11/2010 | 00054085-SALMON, SALLY URSULA | 24.23 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0679418 | 11/12/2010 | 00054085-SALMON, SALLY URSULA | 32.71 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0684221 | 25/12/2010 | 00054085-SALMON, SALLY URSULA | 24.23 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000685087 | 22/12/2010 | TFR FROM BU 00640 APR 06 BAL | 52.54 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000685087 | 22/12/2010 | TFR FROM BU 00640 AT 31/7/06 | -77.88 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000686819 | 2/01/2011 | ACCRUE 50% PAYRUN 07-01-2007 | -1,211.64 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000686819 | 2/01/2011 | ACCRUE 50% PAYRUN 07-01-2007 | -205.98 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000686819 | 2/01/2011 | ACCRUE 50% PAYRUN 07-01-2007 | -78.00 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000686819 | 2/01/2011 | ACCRUE 50% PAYRUN 07-01-2007 | -10.60 |
| Engineering Computing & Maths | Environmental Sys Engineering | 0000686819 | 2/01/2011 | ACCRUE 50% PAYRUN 07-01-2007 | -481.50 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0686212 | 8/01/2011 | 00054085-SALMON, SALLY URSULA | 2,423.27 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0686212 | 8/01/2011 | 00054085-SALMON, SALLY URSULA | 411.96 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0686212 | 8/01/2011 | 00054085-SALMON, SALLY URSULA | 155.99 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0686212 | 8/01/2011 | 00054085-SALMON, SALLY URSULA | 21.19 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0686212 | 8/01/2011 | 00054085-SALMON, SALLY URSULA | 24.21 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0691024 | 22/01/2011 | 00054085-SALMON, SALLY URSULA | 2,423.27 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0691024 | 22/01/2011 | 00054085-SALMON, SALLY URSULA | 411.96 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0691024 | 22/01/2011 | 00054085-SALMON, SALLY URSULA | 155.94 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0691024 | 22/01/2011 | 00054085-SALMON, SALLY URSULA | 18.17 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0691024 | 22/01/2011 | 00054085-SALMON, SALLY URSULA | 24.23 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0694609 | 5/02/2011 | 00054085-SALMON, SALLY URSULA | 1,938.62 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0694609 | 5/02/2011 | 00054085-SALMON, SALLY URSULA | 329.57 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0694609 | 5/02/2011 | 00054085-SALMON, SALLY URSULA | 124.75 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0694609 | 5/02/2011 | 00054085-SALMON, SALLY URSULA | 14.54 |
| Engineering Computing & Maths | Environmental Sys Engineering | SAL0694609 | 5/02/2011 | 00054085-SALMON, SALLY URSULA | 19.38 |

2006 REPORTING PERIOD SALARY TOTAL, URSULA SALMON $106,326

# CSML Program 2 - Water Treatments

## 2006 Itemised Expenditure Report

*01/04/06 to 31/03/07*

| ITEM | | AMOUNT (GST Exc.) |
|---|---|---|
| ***Research Fellow Salaries*** | | |
| ***1*** | Research Fellow C - Biological Remediation (Clint McCullough) | 61,207.54 |
| | **Research Fellow Salaries sub total** | **61,207.54** |
| ***Equipment - Fluidised Limestone Reactor Treatment Study*** | | |
| ***1*** | Construction and supply of cone to specifications - Hawke Bros | 2,400.00 |
| ***2*** | Supply and delivery of bushmans tanks - Tank Master | 5,036.36 |
| ***3a*** | Materials to construct asset (PVC) - Bunnings | 34.97 |
| ***3b*** | Materials to construct aset (PVC/solvent/tape/pipe) - Bunnings | 37.46 |
| ***4*** | Materials (various) to construct asset - TBS Rural and Hardware | 80.45 |
| ***5*** | Materials to construct asset - TBS Rural and Hardware | 8.05 |
| ***6*** | Materials to construct asset - TBS Rural and Hardware | 19.32 |
| ***7*** | Lime sand - CIM | 260.00 |
| ***8*** | Soak well - Tradelink | 245.26 |
| ***9a*** | Materials to construct asset (spray paint/ degreaser) - Bunnings | 14.50 |
| ***9b*** | Materials to construct asset (bucket/battery/silicone/rain gauge/hose) - Bunnings | 42.20 |
| ***9c*** | Irrigation materials to construct asset - Watershed Water Systems | 33.30 |
| ***10a*** | Concrete mix - Bunnings | 43.15 |
| ***10b*** | Materials transport costs - Gull | 13.65 |
| ***10c*** | Materials transport costs - Coles Express | 13.65 |
| ***11*** | Electronic components to construct asset - Jaycar Electronics | 68.45 |
| ***12*** | Hatchery earthworks - Cardinal Contractors | 2,900.00 |
| ***13*** | # Water Treatments: Salary cost to manage construction of new asset and trial equipment (Paul Irving) | 5,392.67 |
| | **Equipment - Fluidised Limestone Treatment Study sub total** | **16,643.44** |
| | **2006 TOTAL EXPENDITURE PROGRAM 2 - WATER TREATMENTS** | **$77,850.98** |

Notes:

# Paul Irving's total salary, as shown on the supporting salary report, was $12,832.21 for the 2006 reporting period. Of this amount only $5,392.67 is to be supported by State Government funding with the remainder supported by other CSML sponsors.

# CSML Program 2 – Water Treatment
# 2006 Expenditure Documentation

## Research Fellow Salary Item

Item 1: Research Fellow C - Biological Remediation (Clint McCullough)

Item 1

EDITH COWAN UNIVERSITY

JOONDALUP CAMPUS

100 Joondalup Drive,
Joondalup
Western Australia 6027
Telephone 134 328
Facsimile (08) 9300 1257

ABN 54 361 485 361

CRICOS IPC 00279B

Andrea Duncan
Curtin University of Technology
Centre for Sustainable Mine Lakes (CSML)
1 Turner Ave, Bldg 611
Technology Park
Bentley WA 6012

Thursday 14 June 2007

Dear Andrea,

Re: Centre for Sustainable Mine Lakes (CSML) Research Project

Thank you for your email requesting a salary report for Clinton McCullough for the above project for the period 1 April 2006 – 31 March 2007.
I have been advised by our Human Resources Department and ECU's Office of Research and Innovations that salaries are confidential information and as such I am unable to provide a salary report as requested.

However I have been permitted to provide specific salary details required to submit the report to the State Government in order to confirm that the $61,000 State Government Funding for Clinton McCullough's salary was fully expended for the period stated.

Total salary paid for 1 April 2006 to 31 March 2007 was $61207.54. This includes $47766.28 paid to Clinton and $13441.26 employment oncosts. Clint McCullough commenced work on this project on 30 December 2005.

Travel and Vehicle costs for the project for this period was $1750.

If you have any queries relating to this information, please do not hesitate in contacting me.

Yours sincerely

Dr Mark Lund
Head of School
School of Natural Sciences

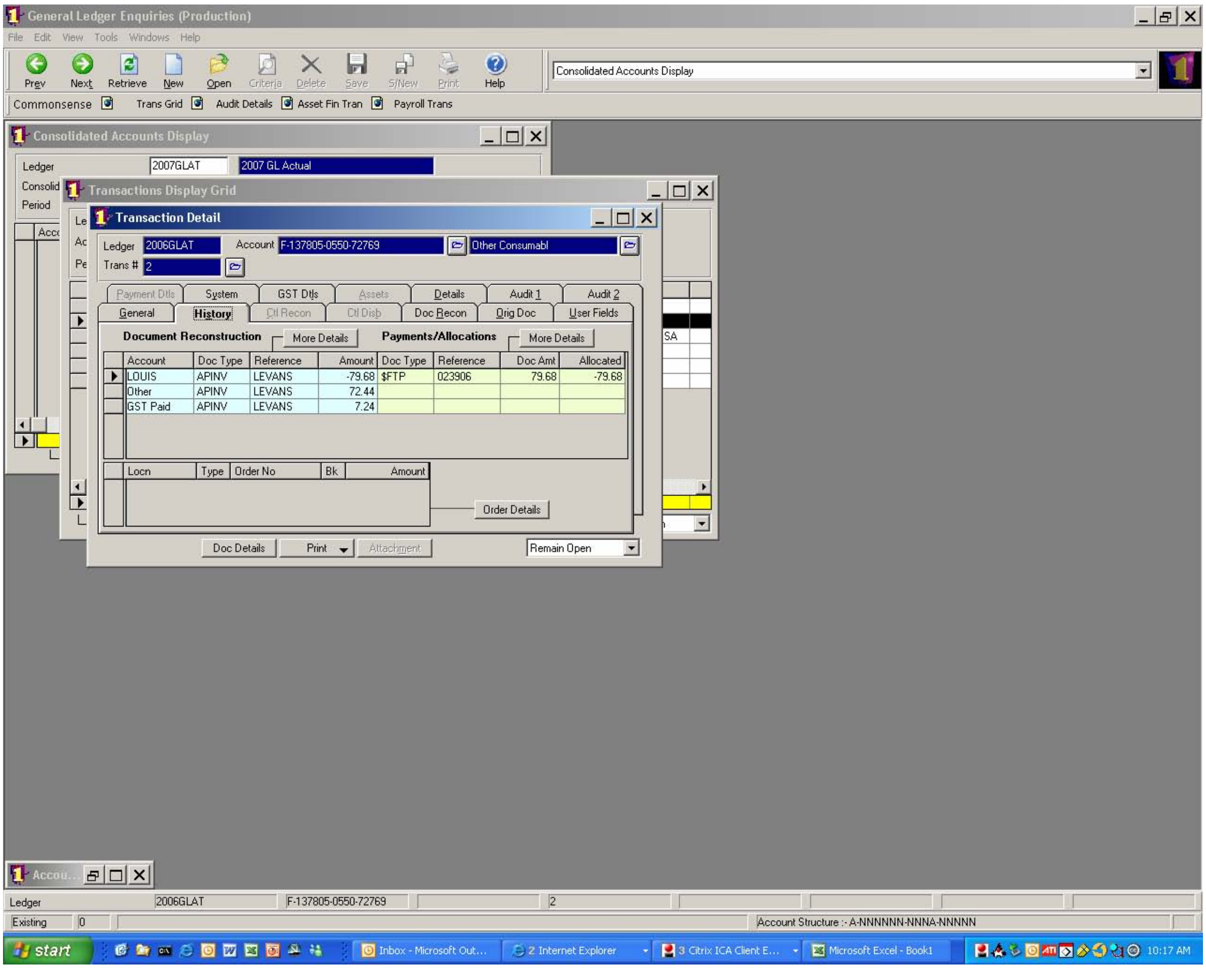
Ph: 08 6304 5644
Fax: 08 6304 5070
Email: m.lund@ecu.edu.au

# CSML Program 2 – Water Treatments
# 2006 Expenditure Documentation

## Equipment - Fluidised Limestone Reactor Treatment Study

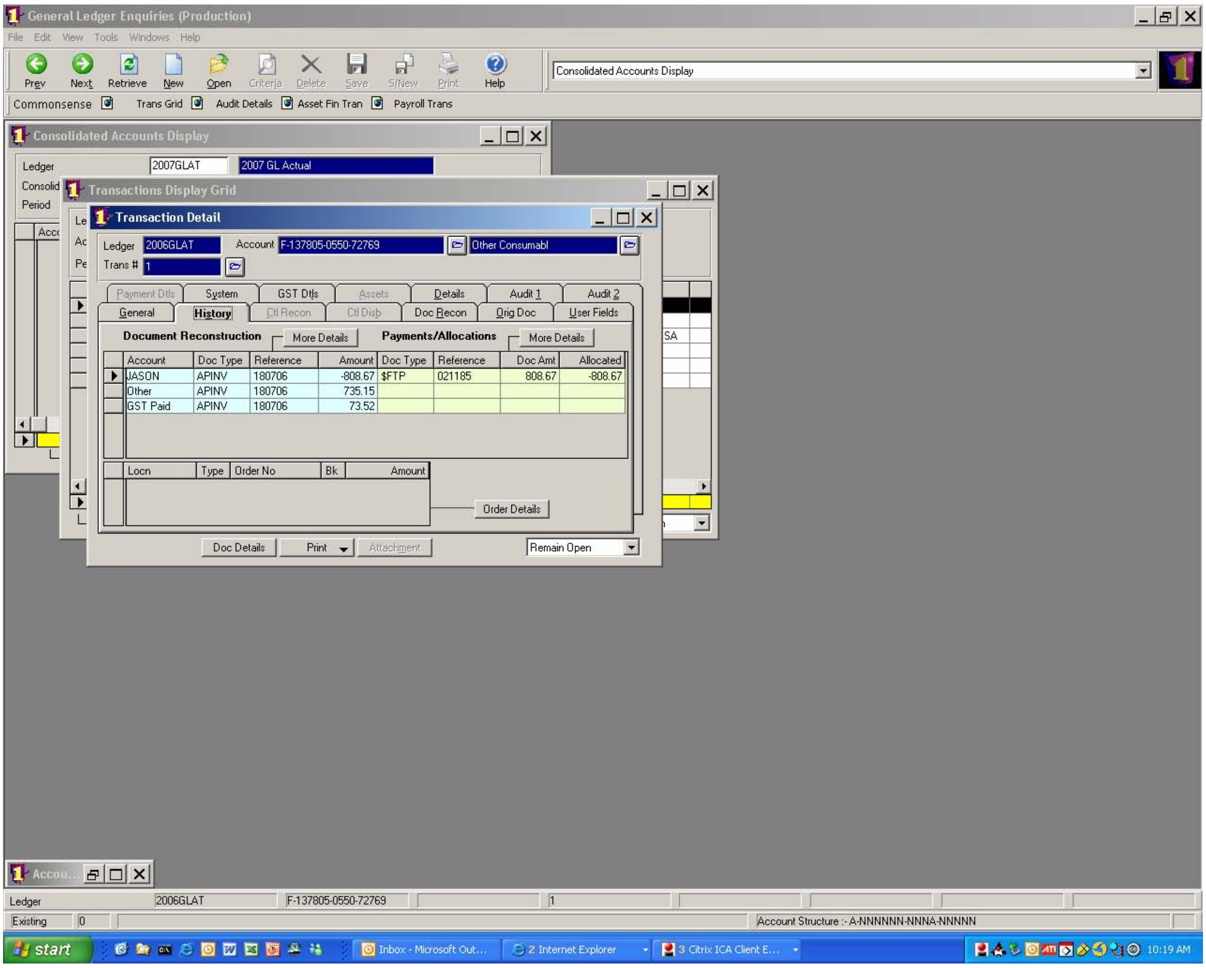
| | |
|---|---|
| Item 1: | Construction and supply of cone to specifications – Hawke Bros |
| Item 2: | Supply and delivery of bushmans tanks – Tank Master |
| Item 3a: | Materials to construct asset (PVC) – Bunnings |
| Item 3b: | Materials to construct asset (PVC/ solvent/ tape/pipe) – Bunnings |
| Item 4: | Materials to construct asset (PVC) – TBS Rural and Hardware |
| Item 5: | Materials to construct asset (PVC) – TBS Rural and Hardware |
| Item 6: | Materials to construct asset (tape) – TBS Rural and Hardware |
| Item 7: | Lime sand - CIM |
| Item 8: | Soak well - Tradelink |
| Item 9a: | Materials to construct asset (spray paint/ degreaser) - Bunnings |
| Item 9b: | Materials to construct asset (bucket/battery/ silicone/rain gauge/hose) – Bunnings |
| Item 9c: | Irrigation materials to construct asset - Watershed Water Systems |
| Item 10a: | Concrete mix - Bunnings |
| Item 10b: | Materials transport costs - Gull |
| Item 10c: | Materials transport costs – Coles Express |
| Item 11: | Electronic components to construct asset - Jaycar Electronics |
| Item 12: | Hatchery earthworks – Cardinal Contractors |
| Item 13: | Water Treatments: Salary costs to manage construction of new asset and trial equipment (Paul Irving) |

Items 3a - 3b



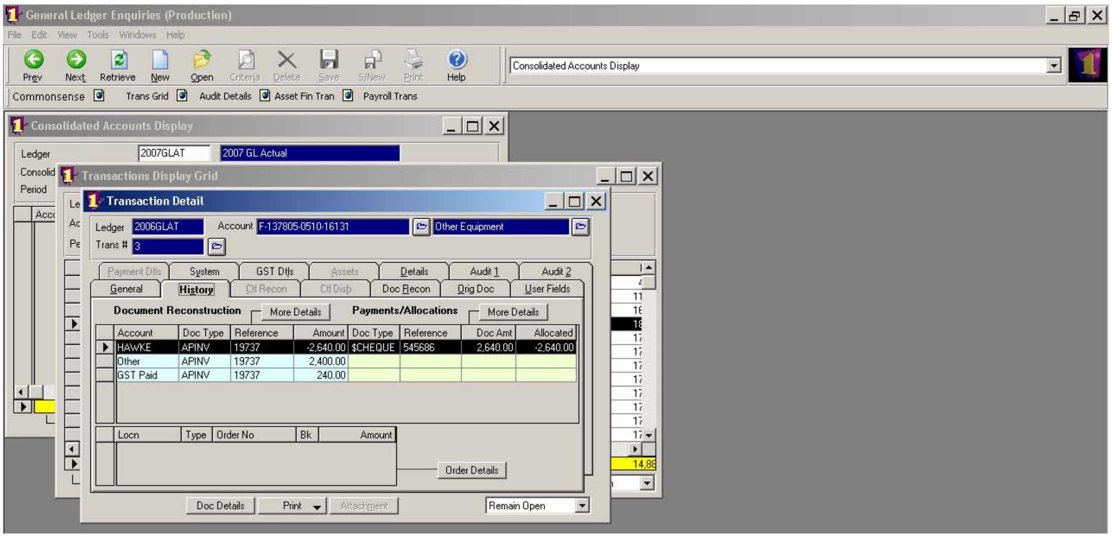

Curtin Transaction Display Grid showing reimbursement to Louis Evans for equipment purchases under CSML Fluidised Limestone Reactor Treatment Study (items 3a – 3b of CSML Program 2 – Water Treatments; 2006 Itemised Expenditure Report)

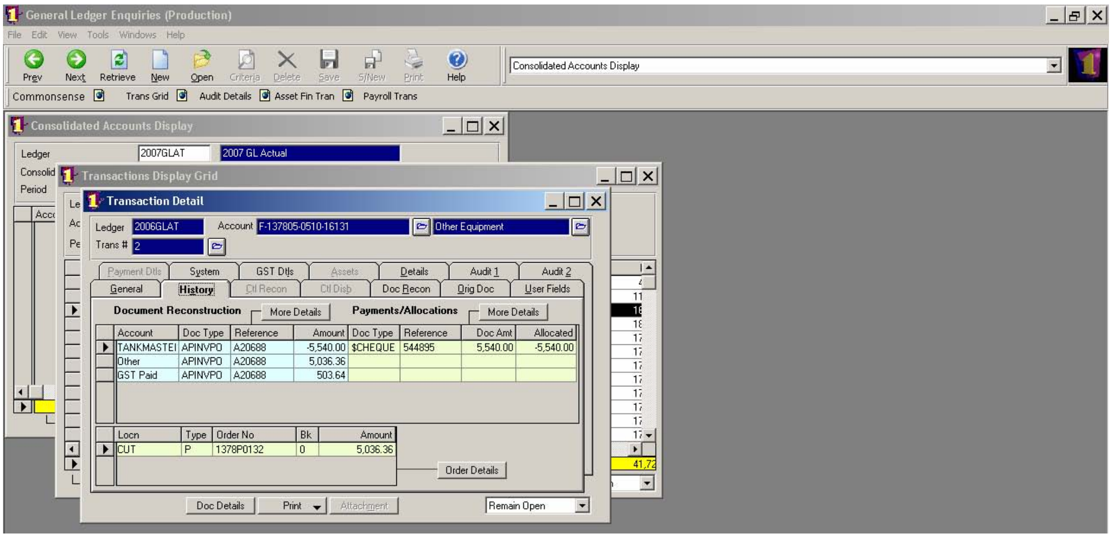
Items 7-11

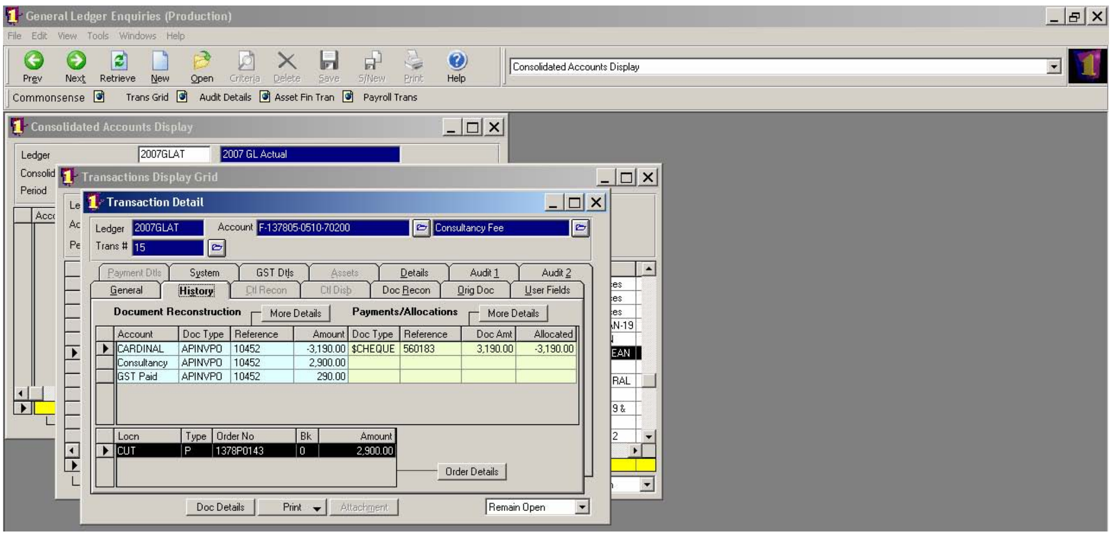



Curtin Transaction Display Grid showing reimbursement to Jason Milne for equipment purchases under CSML Fluidised Limestone Reactor Treatment Study (items 7 – 11 of CSML Program 2 – Water Treatments; 2006 Itemised Expenditure Report)

Items 1, 2, 12

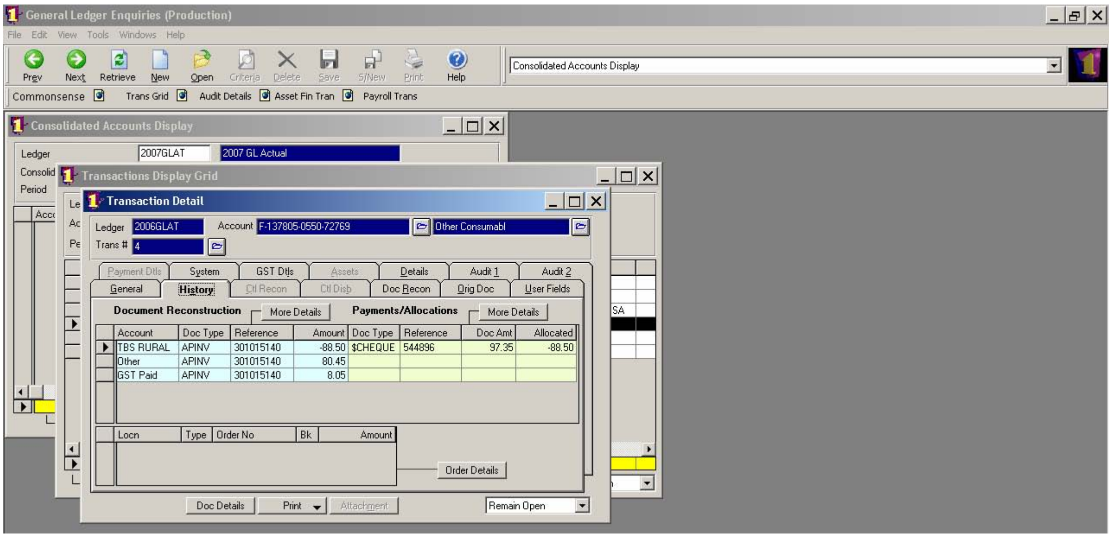


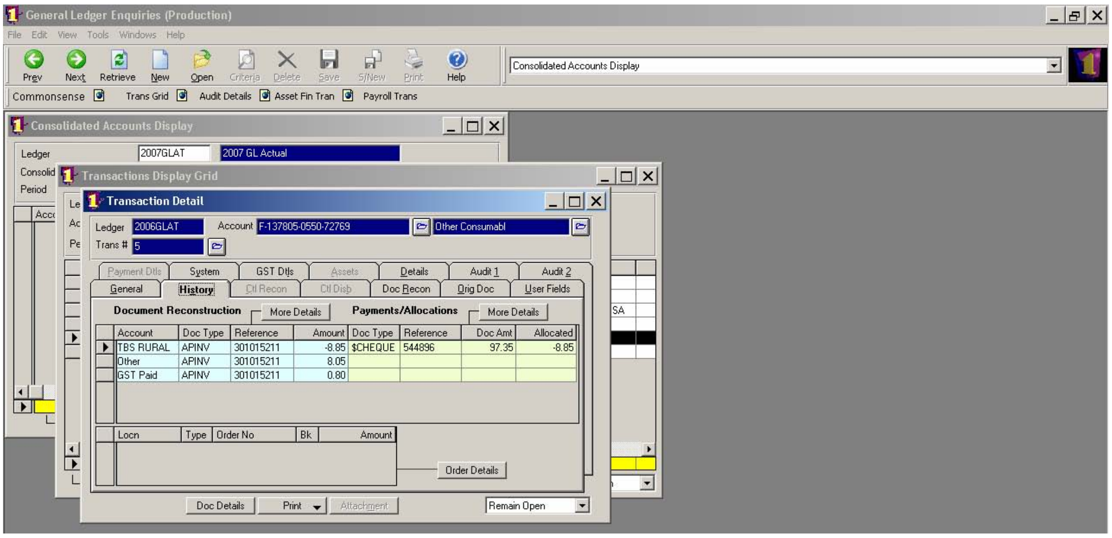



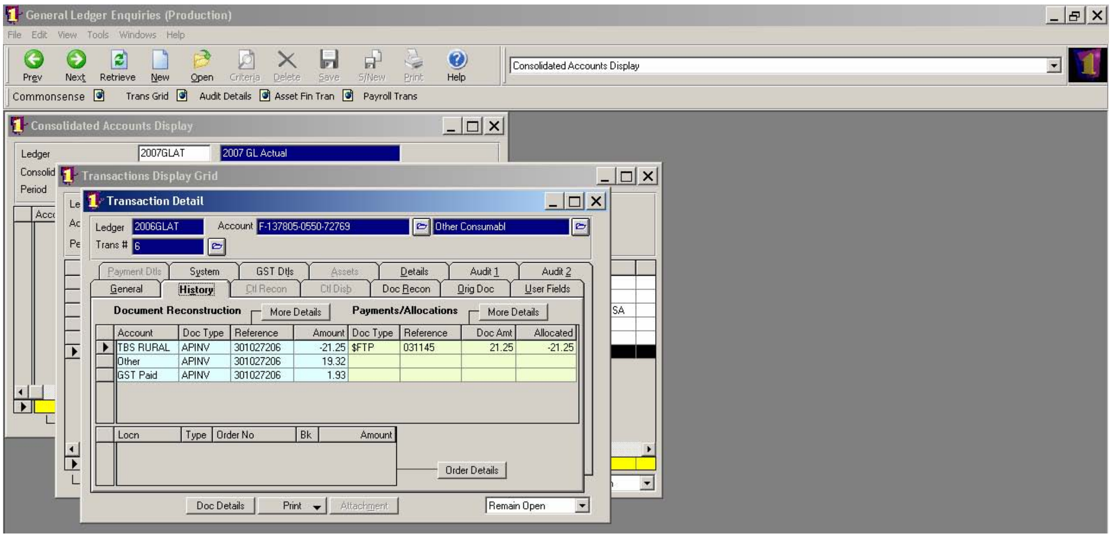




Curtin Transaction Display Grid showing equipment purchased under CSML Fluidised Limestone Reactor Treatment Study (items 1, 2 and 12 of CSML Program 2 – Water Treatments; 2006 Itemised Expenditure Report)

Items 4,5,6




Curtin Transaction Display Grids showing equipment purchased under CSML Fluidised Limestone Reactor Treatment Study (items 4, 5 and 6 of CSML Program 2 – Water Treatments; 2006 Itemised Expenditure Report)

[redacted]

[redacted]

Item 1

ATT Andrea Duncan

21 Frobisher Street,
Osborne Park WA 6017

PHONE (08) 9242 2111
FAX (08) 9443 2448
EMAIL sales@hawke.com.au

**TAX INVOICE**

19737

In Account With... Curtain University
Centre for Sustainable mine Lakes
GPO BOX U1987
Perth WA 6845

**Hawke**
**BROS. PTY. LTD.**

ABN 93 008 768 929 Est. 1962

Date: 27 9 06

Order No.: Jason Milne

ABN Number:

**Manufacturers and Suppliers of all Fibreglass Products**

| | | | | |
|---|---|---|---|---|
| 1 | only | 2.500m long Cone | | |
| | | /320m x 110m | | |
| | | in olive Green To Drawing | | |
| | | as supplied as quoted | 2400 | 00 |
| | | | | |
| | | | | |
| | | Andrea Duncan | | |
| | | spoonbill lakes FLR | | |
| | | F 137805 0510 | | |

No claims allowed unless made in writing within 10 days after delivery.
Materials specially processed, packed or machined to customer's order are not returnable.
**Interest will be charged on all overdue accounts**
Ownership of this merchandise remains the property of HAWKE BROS Pty. Ltd. until payment in full has been received.

| | | |
|---|---|---|
| Cartage | | |
| GST | 240 | 00 |
| TOTAL $ | 2640 | 00 |

A.B.N. 79 038 329 914

# Tank Master

www.tankmaster.com.au

Item 2

337 Great Eastern Hwy (Cnr Great Eastern and Roe Hwy) Midland WA

**PO Box 310 Glen Forrest WA 6071**

**Telephone: 08 9274 7000 Fax: 08 9250 4422**

Email: sales@tankmaster.com.au

**Date:** 24/08/2006

# TAX INVOICE

**Invoice No:** A20688

**Invoice To:**

Curtain University of Technology - CSML
Andrea Duncan
1 Turner Ave
BENTLEY WA 6845

**Deliver To:**

CSML Curtain University
Andrea Duncan
1 Turner Ave

| Description | Amount |
|---|---|
| 2 x bushmans 27,000ltr beige to be delivered to Curtin Uni - Collie | $5,036.36 |

6/9/06

Your Purchase Order Number: 1378PO132

**Terms: COD**

| | |
|---|---|
| **Subtotal:** | $5,036.36 |
| **Freight:** | $0.00 |
| **GST:** | $503.64 |
| **Total Inc GST:** | **$5,540.00** |
| **Amount Paid:** | $0.00 |

Payments can be made electronically to Tankmaster's bank account at Bank West.
BSB: 306 041 A/C: 0776879
Please make reference to the invoice number being paid in payee details and notify Tankmaster of your transfer by fax or email.

Item 3

BUNNINGS WAREHOUSE
MIDLAND
Ph: 08 9274 5666
A.B.N. 26 008 672 179

Sale
** TAX INVOICE **

3140714 9319841038570 PRESS-PVC BARREL UNION
PVU25 25MM
NET 2 @ $14.31 $28.62

5070658 9319841028441 VALVE-BALL PVC
VBS25 25MM SOLVENT WELD
1 @ $9.85 $9.85

2 @ SubTotal: $38.47

Total $ 38.47
GST INCLUDED IN THE TOTAL $3.50
EFT $38.47

TERMINAL: 16094102
CARD NO: 00045094-2656
CREDIT
TOTAL AUD $38.47
APPROVED

Change $ 0.00

*** "NO GST" INDICATES NON TAXABLE ITEM(S) ***
29/04/2006 15:07:06

R2 P283 S2180 C164375 #200051716

Thank you for shopping with Bunnings
*** TRADING HOURS ***
Everyday 7AM - 7PM
Thursday 9PM

--- Please retain receipt for refund ---

BUNNINGS WAREHOUSE
MIDLAND
Ph: 08 9274 5666
No. 72769
A.B.N. 26 008 672 179

Sale
** TAX INVOICE **

3142562 9319841038396 PRESS-PVC TEES FAUCET
PVT2525F 25MM X 1 INCH
NET 1 @ $4.64 $4.64

3141304 9319841036507 PRESS-PVC ELBOW 90DEG
SS PVE25 25MM
NET 3 @ $1.06 $3.18

3140756 9319841035968 PRESS-PVC COUPLING
SS PVC025 25MM COUPLING
NET 3 @ $0.99 $2.97

3143631 9319841038815 PRESS-PVC PLUG THREADED
PUSP25 25MM
NET 1 @ $3.23 $3.23

3140471 9319841035722 PRESS-PVC CAP (END)
PVC25 25MM CAP
NET 1 @ $1.29 $1.29

3146621 9318858207009 PRIMER-PVC
125ML PRIMER
NET 1 @ $4.91 $4.91

3145099 9318858104162 CEMENT-SOLVENT PRESSURE PIPE
TYPE P 125ML
NET 1 @ $6.56 $6.56

4929206 TAPE-TEFLON
12MM X 75 10MTR TEFLON TAPE
1 @ $0.45 $0.45

3143932 9311381338011 PIPE-PRESSURE CLASS 9 2M LEN
PPP0925B 25MM
NET 3 @ $4.66 $13.98

9 @ SubTotal: $41.21

Total $ 41.21
GST INCLUDED IN THE TOTAL $3.75
EFT $41.21

TERMINAL: 16177704
CARD NO: 00045094-2656
CREDIT
TOTAL AUD $41.21
APPROVED

Change $ 0.00

*** "NO GST" INDICATES NON TAXABLE ITEM(S) ***
29/04/2006 12:05:06

R9 P483 S2180 C172865 #900050284

($ 72.44)

Item 4

# TBS RURAL & HARDWARE PTY

No. 72769

24 FORREST STREET

COLLIE WA 6225
ACN 113 811 233 ABN 83 252 167 135
Tel:(08) 9734 1744 Fax:(08) 9791 2926

12 OCT 2006

## Tax Invoice

| *Invoice To* | *Deliver To* |
|---|---|
| CURTIN UNIVERSITY OF TECHNOLOGY<br>CENTRE SUSTAINABLE MINE LAKES<br>PO BOX U1987<br>PERTH WA 6845<br>ACN ABN | CURTIN UNIVERSITY OF TECHNOLOGY<br>CENTRE SUSTAINABLE MINE LAKES<br>PO BOX U1987<br>PERTH WA 6845 |

| *Date* | *Invoice No.* | *Account* | *Customer Order No.* | *Sales Tax No.* | *Staff* | *Page* |
|---|---|---|---|---|---|---|
| 15/09/2006 | 301027206 | 9521 | 3.1 | | Stone, Vanessa | 1 |

| Item Code | Description | Quantity Units | Ex Tax Price | Discount | GST | Line Total |
|---|---|---|---|---|---|---|
| HT870515 | TAPE BARRICADE DANGER 50MT | | | | | |
| | | 1.00 EACH | 19.32 | | 10.00% | 21.25 |

RH L

| | *Sub Total* |
|---|---|
| | 21.25 |
| *GST Included* | 1.93 |
| Total Includes GST *Total Due* | **21.25** |

( # 19.32 )

Item 5

# TBS RURAL & HARDWARE PTY No. 72769

24 FORREST STREET

COLLIE WA 6225
ACN 113 811 233 ABN 83 252 167 135
Tel:(08) 9734 1744 Fax:(08) 9791 2926

## Tax Invoice

| *Invoice To* | *Deliver To* |
|---|---|
| CURTIN UNIVERSITY OF TECHNOLOGY<br>CENTRE SUSTAINABLE MINE LAKES<br>PO BOX U1987<br>PERTH WA 6845<br>ACN ABN | CURTIN UNIVERSITY OF TECHNOLOGY<br>CENTRE SUSTAINABLE MINE LAKES<br>PO BOX U1987<br>PERTH WA 6845 |

| *Date* | *Invoice No.* | *Account* | *Customer Order No.* | *Sales Tax No.* | *Staff* | *Page* |
|---|---|---|---|---|---|---|
| 08/08/2006 | 301015211 | 9521 | PROJECT 3.1 | | Moloney, Jamie | 1 |

| Item Code | Description | Quantity Units | Ex Tax Price | Discount | GST | Line Total |
|---|---|---|---|---|---|---|
| 135050 | ELBOW PVC 50MM x 90 DEG CAT 13 | 3.00 EA | 2.68 | | 10.00% | 8.85 |

FLK project

| | | |
|---|---|---|
| | *Sub Total* | 8.85 |
| | *GST Included* | 0.80 |
| Total Includes GST | *Total Due* | **8.85** |

($ 8.05)

Item 6

# TBS RURAL & HARDWARE PTY

No. 72769

24 FORREST STREET

COLLIE WA 6225
ACN 113 811 233 ABN 83 252 167 135
Tel:(08) 9734 1744 Fax:(08) 9791 2926

12 OCT 2006

## Tax Invoice

| Invoice To | Deliver To |
|---|---|
| CURTIN UNIVERSITY OF TECHNOLOGY<br>CENTRE SUSTAINABLE MINE LAKES<br>PO BOX U1987<br>PERTH WA 6845<br>ACN ABN | CURTIN UNIVERSITY OF TECHNOLOGY<br>CENTRE SUSTAINABLE MINE LAKES<br>PO BOX U1987<br>PERTH WA 6845 |

| Date | Invoice No. | Account | Customer Order No. | Sales Tax No. | Staff | Page |
|---|---|---|---|---|---|---|
| 15/09/2006 | 301027206 | 9521 | 3.1 | | Stone, Vanessa | 1 |

| Item Code | Description | Quantity Units | Ex Tax Price | Discount | GST | Line Total |
|---|---|---|---|---|---|---|
| HT870515 | TAPE BARRICADE DANGER 50MT | 1.00 EACH | 19.32 | | 10.00% | 21.25 |

| | | Sub Total |
|---|---|---|
| | | 21.25 |
| | GST Included | 1.93 |
| Total Includes GST | Total Due | **21.25** |

( $ 19.32)

Item 7

**CIM**
ACN 008 756 278 QEC2883

CUTLER ROAD, JANDAKOT 6164
TELEPHONE: (08) 9417 1111
EMAIL: info@cim-pl.com.au

ABN 80 008 756 278
FAX: (08) 9417 3684

**ADJUSTMENT NOTE**
**00067838**

Sold To:
Jason Milne

DATE 1/06/2006

ORDER NO: No. 72769

C/R Comp.(Initials): ($ 735.15)

| QTY | UNIT | GOODS DESCRIPTION | PRICE | TOTAL EXC. GST | |
|---|---|---|---|---|---|
| 40 | Bag | Lime Sand -850um Approx 20kg Bags | $6.00 | $240.00 | GST |
| 1 | Each | Pallet CIM Supplied | $20.00 | $20.00 | GST |

PAID
- 1 ... 2006
CASH $286.00.

TAX CODE APPLICABLE: G = 10% GST F = GST FREE

Our Delivery ends at the edge of the road, if requested to take the goods onto your property, we accept no responsibility for damage incurred by our vehicles.
Received the above goods in good order and condition.

DRIVER Jason Milne TRANSPORT COMPANY

SIGNATURE JSMilne DATE DELIVERED/COLLECTED 1/6/06

| | |
|---|---|
| Total Exc. GST | $260.00 |
| GST | $26.00 |
| Total Inc GST | $286.00 |

1. WHITE - CUSTOMER 2. PINK - DELIVERY 3. WHITE - WORKS 4. YELLOW - FILE

Item 8

# TAX INVOICE

CRANE DISTRIBUTION LIMITED
ABN 29000003832
94 BELGRAVIA STREET BELMONT WA 6104
Internet:.

**Tradelink**

**SOLD TO:** 5885173
MILNE JASON
STIRLING
PH - 0403 760 010
STIRLING WA 6104

**Mobile**

**DELIVER TO:** 5885173
MILNE JASON
STIRLING
PH - 0403 760 010
STIRLING WA 6104

**Invoice Number:** RI 14854911
**Invoice Date:** 07/06/06
**Cust Order Number:**

**Originating Branch** 6612
**Our Order Number:** SO 10176074
**Page:** 1
**User ID:** TLDANPOR

| Requested Date | Requested Time | Supplied From | Branch Phone | Branch Fax | Branch Email |
|---|---|---|---|---|---|
| 07/06/06 | 1230 | BELMONT | (08)92774488 | (08)92777485 | belmont@tradelink.com.au |

| Item Code | Item Description | UOM | Qty Order | Qty Balance | Qty Deliv | Unit Price Excl GST | Ext Price Excl GST |
|---|---|---|---|---|---|---|---|
| FREIGHT | DELIVERY FEE | EA | 1.00 | | 1.00 | 30.00 | 30.00 |
| 096209 | BODY SOAK WELL CONCRETE 600 X 600MM DEEP | EA | 4.00 | | 4.00 | 45.48 | 181.92 |
| 096207 | COVER SOAK WELL STANDARD CONCRETE 700MM DIA | EA | 2.00 | | 2.00 | 16.67 | 33.34 |

MAPP IS ATTACHED

Del: BY 1.00pm

EFTPOS FROM WESTPAC
CRANE DISTRIBUTION
94 BELGRAVIA ST
BELMONT WA 6104
MID: 18171272
TID: 21948168 ROC:001206
========================
450949 656(M)
CREDIT A/C
VISA 11/07
JUN 07,06 11:51
SALE
APPROVED 08
APPROVAL CODE 397696
AMOUNT AUD $269.78
TOTAL AUD $269.78
CUSTOMER COPY
PLEASE RETAIN AS RECORD
OF PURCHASE

Paid by:

| | |
|---|---|
| Total Exclusive of GST $ | 245.26 |
| GST$ | 24.52 |
| Rounding$ | |
| Total Incl. GST$ | 269.78 |

Signature ........................................ Print Name ........................................

I acknowledge that I have received the afore mentioned goods in the quantities stated at the specified date and time:

R529 (01.12)

Item 9a

BUNNINGS WAREHOUSE
MIDLAND
ABN 26 008 672 179
Ph: 08 9274 5666

Sale
** TAX INVOICE **

9312566021094 W/KNIGHT SPRAY PAINT
310G SQUIRTS MOCHA
2 @ $6.98 $ 13.96
& 9305363000072 DEGREASER-AUSTRALIAN EXPO
EX001 400G AEROSOL $ 1.98

2 @ SubTotal: $ 15.94

Total $ 15.95
GST INCLUDED IN THE TOTAL $ 1.45
Cash $ 50.00

Change $ 34.05
--- "&" INDICATES NETT PRICED ITEM(S) ---
--- "*" INDICATES NON TAXABLE ITEM(S) ---
18/06/2006 18:49:44

R5 P645 S2180 C172865 #500020703

Thank you for shopping with Bunnings.
*** TRADING HOURS ***
Everyday 7AM - 7PM
Thursday 9PM

Please retain receipt for proof of purchase

Item 9b

BUNNINGS WAREHOUSE
MIDLAND
ABN 26 008 672 179
Ph: 08 9274 5666

Sale
** TAX INVOICE **

& 9415829027212 BUCKET-PLASTIC
BB12L BUNNINGS BRANDED SQ $ 1.50
& 9325086001460 BARBECUE ACCESSORY-S & D
OM2017-1B AC/DC BATTERY $ 24.94
9300697100092 SILICONE-WET AREA SELLEYS
75G WHITE $ 6.84
& 9310070109604 GAUGE-RAIN NYLEX
RG500 NYLEX 500 $ 9.50
& 9315199009101 WATERING HOSE
VT081 8MM CLEAR VINYL TUB $ 3.64

5 @ SubTotal: $ 46.42

Total $ 46.42
GST INCLUDED IN THE TOTAL $ 4.22
EFT $ 46.42

TERMINAL: 16093803
CARD NO: 00045094-2656
CREDIT
TOTAL AUD $46.42
APPROVED

Change $ 0.00
--- "&" INDICATES NETT PRICED ITEM(S) ---
--- "*" INDICATES NON TAXABLE ITEM(S) ---
01/07/2006 10:22:02

R7 P358 S2180 C177061 #700008391

Thank you for shopping with Bunnings.
*** TRADING HOURS ***
Everyday 7AM - 7PM
Thursday 9PM

Please retain receipt for proof of purchase

COMMONWEALTH BANK
EFTPOS
THE WATERSHED WATER
SYSTEMS MIDLAND WA
TERMINAL: 86041200

CUSTOMER COPY

CARD NO.: 450949-656
EXPIRY DATE: 11/07
CREDIT 053698
PURCHASE 37.00
TOTAL AUD37.00

01 JUL 2006 10:49
ANZ AFFINITY CARD 1

APPROVED 08

Item 9c

THE WATERSHED
WATER SYSTEMS
146 Great Eastern Hway
MIDLAND WA 6056
TAX INVOICE

01-07-'06 SAT 10:25AM
11849 CLERK 03
IRRIGATION 1 37.00
VISA 37.00
Dave
ABN 48 064 791 519
Total Includes GST

99.3

Item 10a

BUNNINGS WAREHOUSE
BALCATTA
ABN 26 008 672 179
Ph: 08 9344 4333

Sale
** TAX INVOICE **

0768505 CONCRETE MIX
031161 CONCRETE DRYMIX 30KG
6 @ $7.91 $ 47.46

SubTotal: $ 47.46

Total $ 47.45
GST INCLUDED IN THE TOTAL $ 4.31
Cash $ 50.00

Change $ 2.55
--- "&" INDICATES NETT PRICED ITEM(S) ---
--- "*" INDICATES NON TAXABLE ITEM(S) ---
08/06/2006 14:02:01

R17 P253 S2010 C169710 #1700097166

Thank you for shopping with Bunnings.
*** TRADING HOURS ***
Everyday 7AM - 7PM
Thursday Until 9PM

Please retain receipt for proof of purchase



Item 10b

TAX INVOICE
RFMC PTY LTD
T/As GULL KIARA
A.C.N. 088 963 231
157 MORLEY DRIVE
KIARA
ABN 83 390 164 335
* CASH SALE R 08/06/06 17:06 2 6391
2 P:1 H:2 UNLEADED T2
DISC: 0.00 11.20Lx$/L1.339 $15.00G
CASH 15.00
REF. GST 1.36 TOT $15.00
TENDERED $15.00

# ITEMS 1
G = ITEMS INCLUDE G.S.T.
THANK YOU - PLEASE CALL AGAIN
TOTAL INCLUDES G.S.T.
GULL PETROLEUM - PURE ENERGY

Item 10c

EUREKA OPERATIONS PTY LT
ABN: 78 104 811 216
COLES EXPRESS UPPER SWAN
1333 GREAT NORTHERN HWY
UPPER SWAN W.A 6056

TERMINAL ID 00016056001 URN 0218
GST
Unleaded G PUMP 01
10.80L 138.9c/L 15.00+
Due 15.00
Cash 20.00
Change 5.00
GST Included in the Transaction 1.36

01/06/06 15:21 02 0906
Receipt No. 007689
*** TAX INVOICE ***

PH 9296 1310
FAX 9296 1662
www.colesexpress.com.au

Item 11

# JAYCAR ELECTRONICS

ACN 000 087 936 · ABN 65 000 087 936 · A DIVISION OF JAYCAR PTY. LTD.

100 SILVERWATER RD SILVERWATER NSW 2128
Postal Address: P.O. Box 6424 Silverwater NSW 1811
Telephone: **(02) 9741 8538** Fax: **(02) 9741 8559**
Email: techstore@jaycar.com.au
Web Site: www.jaycar.com.au

Quality System
Quality Endorsed Company

## TECHSTORE (MAIL ORDER) TAX INVOICE

DATE 22/06/2006

INVOICE TO
JASON MILNE
18 ALL SAINTS WAY
CHURCHLANDS 6018

DELIVER TO
JASON MILNE
18 ALL SAINTS WAY
CHURCHLANDS 6018

INVOICE No. MO143188

| ACCOUNT No. | ORDER NUMBER | | DELIVERED BY |
|---|---|---|---|
| J39061-1 | TSN46537 | | EXPRESS POST 0.50KGS |

| PART No. | DESCRIPTION | QTY. ORD. | QTY B/ORD. | QTY SUPPLIED | PRICE | PER | NET | | EXTENSIONS |
|---|---|---|---|---|---|---|---|---|---|
| SK0960 | SWITCH ROCKER SPST 6A@250VA | 1 | | 1 | 1.80 | | 1.80 | | 1.80 |
| PS0524 | SKT PNL DC 2.5MM BULKHEAD | 2 | | 2 | 2.65 | | 5.30 | | 5.30 |
| PP0130 | PLG LINE 3.5MM STEREO BLK P | 2 | | 2 | 1.00 | | 2.00 | | 2.00 |
| KA1797 | KIT - LOW VOLTAGE ADPT 08/9 | 1 | | 1 | 6.95 | | 6.95 | | 6.95 |
| INS | INSURANCE | 1 | | 1 | 1.00 | | 1.00 | | 1.00 |
| AA0093 | ADDITIONAL FREIGHT & HANDLI | 1 | | 1 | 6.60 | | 6.60 | | 6.60 |

Paid by C/CARD $76.07

*** GST INCLUDED ***

| ASSEMBLED BY | PACKED BY | DESPATCH DATE | CARRIER | CONSIGNMENT NOTE No. |
|---|---|---|---|---|
| 50 | 70 | 22/06/2006 | . | |

No claim regarding this Invoice will be recognised unless received within 14 days of invoice date.

Freight on returns to be prepaid.

| | |
|---|---|
| SUB TOTAL | 76.07 |
| | |
| | |
| TOTAL | 76.07 |

CREDIT CARD ORDERS

FREE CALL 1800 022 888

# CARDINAL CONTRACTORS PTY. LTD.

Item 12

A.B.N. 45 008 686 097
P.O. BOX 25, COLLIE, W.A. 6225
TEL. (08) 9734 1622 or FAX (08) 9734 5988

Specialists in:
★ Earthworks/Landclearing ★ Bulk Haulage ★ Heavy Haulage ★ Crusher Stockpile Management

## TAX INVOICE NO. 10452

| Invoice To |
|---|
| Curtin University of Technology<br>43 Wittenoom Street<br>Collie WA 6225<br>CARDINAL.00 |

| | |
|---|---|
| Date | 30/11/2006 |
| Your Order No: | 1378P0143 |

COPY
faxed as requested 12/3

| Description | Hr/Qty | Rate (Ex GST) | Amount (Ex GST) |
|---|---|---|---|
| Attention: Tim Storer | | | |
| Hire excavator to clean marron ponds at Premier Mine | 12.5 | 160.00 | 2,000.00 |
| Mob/Demob | | 600.00 | 600.00 |
| Supply and delivery of sand 30m³ 29-11-06 | 30 | 10.00 | 300.00 |
| F1378050510 ~~70~~200 0520 | | $3,190-00 C | 2290.91. 2520 |

| Terms | |
|---|---|

Dog'original
PO 11/4/07

| | |
|---|---|
| Total Charges | $2,900.00 |
| GST | $290.00 |
| **Total Invoice** | **$3,190.00** |

EFT Information
Bankwest Bunbury
BSB: 306-004
A/c No. 0704270

No Statement will be issued, please pay on Invoice

COPY

Brad Gardiner, Managing Director

**Remittance Advice**

| From |
|---|
| Curtin University of Technology<br>43 Wittenoom Street<br>Collie WA 6225 |

| Invoice No | Due Date |
|---|---|
| 10452 | 8/12/2006 |
| Amount Payable | $3,190.00 |

| Mail To: |
|---|
| Cardinal Contractors Pty Ltd<br>PO Box 25, COLLIE WA 6225 |

| Amount Paid | |
|---|---|

Employee Line Item, Pay Code Report

Item 13

Employees Paid in Cost Centre F-137805-0510-

Between 01 APR 2006 and 31 MAR 2007

Irving, Paul 224804B 02

06 APR 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 540.72 |
| 62201 | PTAX | 221 | Basic Pay | 29.74 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 2.68 |
| 63201 | WCOMP | 221 | Basic Pay | 5.41 |
| 64234 | | SG404 | APP (9% ) - General Staff | 48.67 |
| 65221 | LSL | 221 | Basic Pay | 16.23 |
| 67221 | AL | 221 | Basic Pay | 57.59 |
| 68221 | PL | 221 | Basic Pay | 11.25 |
| | | | Pay Total | 712.29 |

20 APR 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 548.75 |
| 62201 | PTAX | 221 | Basic Pay | 30.19 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 2.71 |
| 63201 | WCOMP | 221 | Basic Pay | 5.49 |
| 64234 | | SG404 | APP (9% ) - General Staff | 49.39 |
| 65221 | LSL | 221 | Basic Pay | 16.47 |
| 67221 | AL | 221 | Basic Pay | 58.43 |
| 68221 | PL | 221 | Basic Pay | 11.41 |
| | | | Pay Total | 722.84 |

04 MAY 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 548.75 |
| 62201 | PTAX | 221 | Basic Pay | 30.19 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 2.71 |
| 63201 | WCOMP | 221 | Basic Pay | 5.49 |
| 64234 | | SG404 | APP (9% ) - General Staff | 49.39 |
| 65221 | LSL | 221 | Basic Pay | 16.46 |
| 67221 | AL | 221 | Basic Pay | 58.44 |
| 68221 | PL | 221 | Basic Pay | 11.41 |
| | | | Pay Total | 722.84 |

18 MAY 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 548.75 |
| 62201 | PTAX | 221 | Basic Pay | 30.18 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 2.72 |
| 63201 | WCOMP | 221 | Basic Pay | 5.49 |
| 64234 | | SG404 | APP (9% ) - General Staff | 49.39 |
| 65221 | LSL | 221 | Basic Pay | 16.46 |
| 67221 | AL | 221 | Basic Pay | 58.44 |
| 68221 | PL | 221 | Basic Pay | 11.41 |
| | | | Pay Total | 722.84 |

# Employee Line Item, Pay Code Report

## Employees Paid in Cost Centre F-137805-0510-

Between 01 APR 2006 and 31 MAR 2007

Irving, Paul 224804B 02

01 JUN 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 548.67 |
| 62201 | PTAX | 221 | Basic Pay | 30.18 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 2.72 |
| 63201 | WCOMP | 221 | Basic Pay | 5.49 |
| 64234 | | SG404 | APP (9% ) - General Staff | 49.38 |
| 65221 | LSL | 221 | Basic Pay | 16.46 |
| 67221 | AL | 221 | Basic Pay | 58.44 |
| 68221 | PL | 221 | Basic Pay | 11.41 |
| | | | Pay Total | 722.75 |

15 JUN 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 548.73 |
| 62201 | PTAX | 221 | Basic Pay | 30.18 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 2.71 |
| 63201 | WCOMP | 221 | Basic Pay | 5.49 |
| 64234 | | SG404 | APP (9% ) - General Staff | 49.39 |
| 65221 | LSL | 221 | Basic Pay | 16.47 |
| 67221 | AL | 221 | Basic Pay | 58.43 |
| 68221 | PL | 221 | Basic Pay | 11.41 |
| | | | Pay Total | 722.81 |

29 JUN 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 548.73 |
| 62201 | PTAX | 221 | Basic Pay | 30.18 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 2.72 |
| 63201 | WCOMP | 221 | Basic Pay | 5.49 |
| 64234 | | SG404 | APP (9% ) - General Staff | 49.39 |
| 65221 | LSL | 221 | Basic Pay | 16.46 |
| 67221 | AL | 221 | Basic Pay | 58.44 |
| 68221 | PL | 221 | Basic Pay | 11.41 |
| | | | Pay Total | 722.82 |

13 JUL 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 54.87 |
| 61221 | | 611 | Workplace Reform Bonus | 111.90 |
| 62201 | PTAX | 221 | Basic Pay | 3.02 |
| 62201 | PTAX | 611 | Workplace Reform Bonus | 6.15 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 0.27 |
| 63201 | WCOMP | 221 | Basic Pay | 0.55 |

# Employee Line Item, Pay Code Report

## Employees Paid in Cost Centre F-137805-0510-

Between 01 APR 2006 and 31 MAR 2007

Irving, Paul — 224804B — 02

13 JUL 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 64234 | | SG404 | APP (9% ) - General Staff | 4.94 |
| 65221 | LSL | 221 | Basic Pay | 1.65 |
| 67221 | AL | 221 | Basic Pay | 5.84 |
| 68221 | PL | 221 | Basic Pay | 1.14 |
| | | | Pay Total | 190.33 |

27 JUL 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 1,042.59 |
| 62201 | PTAX | 221 | Basic Pay | 57.34 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 5.16 |
| 63201 | WCOMP | 221 | Basic Pay | 10.43 |
| 64234 | | SG404 | APP (9% ) - General Staff | 93.84 |
| 65221 | LSL | 221 | Basic Pay | 31.28 |
| 67221 | AL | 221 | Basic Pay | 111.04 |
| 68221 | PL | 221 | Basic Pay | 21.68 |
| | | | Pay Total | 1,373.36 |

10 AUG 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 548.73 |
| 62201 | PTAX | 221 | Basic Pay | 30.18 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 2.72 |
| 63201 | WCOMP | 221 | Basic Pay | 5.49 |
| 64234 | | SG404 | APP (9% ) - General Staff | 49.39 |
| 65221 | LSL | 221 | Basic Pay | 16.46 |
| 67221 | AL | 221 | Basic Pay | 58.44 |
| 68221 | PL | 221 | Basic Pay | 11.41 |
| | | | Pay Total | 722.82 |

24 AUG 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 548.73 |
| 62201 | PTAX | 221 | Basic Pay | 30.18 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 2.72 |
| 63201 | WCOMP | 221 | Basic Pay | 5.49 |
| 64234 | | SG404 | APP (9% ) - General Staff | 49.39 |
| 65221 | LSL | 221 | Basic Pay | 16.46 |
| 67221 | AL | 221 | Basic Pay | 58.44 |
| 68221 | PL | 221 | Basic Pay | 11.41 |
| | | | Pay Total | 722.82 |

Employee Line Item, Pay Code Report

Employees Paid in Cost Centre F-137805-0510-

Between 01 APR 2006 and 31 MAR 2007

Irving, Paul 224804B 02

07 SEP 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 548.73 |
| 62201 | PTAX | 221 | Basic Pay | 30.18 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 2.72 |
| 63201 | WCOMP | 221 | Basic Pay | 5.49 |
| 64234 | | SG404 | APP (9% ) - General Staff | 49.39 |
| 65221 | LSL | 221 | Basic Pay | 16.46 |
| 67221 | AL | 221 | Basic Pay | 58.44 |
| 68221 | PL | 221 | Basic Pay | 11.41 |
| | | | Pay Total | 722.82 |

21 SEP 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 548.73 |
| 62201 | PTAX | 221 | Basic Pay | 30.18 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 2.72 |
| 63201 | WCOMP | 221 | Basic Pay | 5.49 |
| 64234 | | SG404 | APP (9% ) - General Staff | 49.39 |
| 65221 | LSL | 221 | Basic Pay | 16.46 |
| 67221 | AL | 221 | Basic Pay | 58.44 |
| 68221 | PL | 221 | Basic Pay | 11.41 |
| | | | Pay Total | 722.82 |

05 OCT 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 329.24 |
| 62201 | PTAX | 221 | Basic Pay | 18.11 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 1.63 |
| 63201 | WCOMP | 221 | Basic Pay | 3.29 |
| 64234 | | SG404 | APP (9% ) - General Staff | 29.63 |
| 65221 | LSL | 221 | Basic Pay | 9.88 |
| 67221 | AL | 221 | Basic Pay | 35.06 |
| 68221 | PL | 221 | Basic Pay | 6.85 |
| | | | Pay Total | 433.69 |

19 OCT 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 787.43 |
| 62201 | PTAX | 221 | Basic Pay | 43.30 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 3.89 |
| 63201 | WCOMP | 221 | Basic Pay | 7.87 |
| 64234 | | SG404 | APP (9% ) - General Staff | 70.87 |
| 65221 | LSL | 221 | Basic Pay | 23.62 |
| 67221 | AL | 221 | Basic Pay | 83.86 |
| 68221 | PL | 221 | Basic Pay | 16.38 |
| | | | Pay Total | 1,037.22 |

Irving, Paul 224804B 02

02 NOV 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 562.45 |
| 62201 | PTAX | 221 | Basic Pay | 30.93 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 2.78 |
| 63201 | WCOMP | 221 | Basic Pay | 5.62 |
| 64234 | | SG404 | APP (9% ) - General Staff | 50.62 |
| 65221 | LSL | 221 | Basic Pay | 16.87 |
| 67221 | AL | 221 | Basic Pay | 59.90 |
| 68221 | PL | 221 | Basic Pay | 11.70 |
| | | | Pay Total | 740.87 |

16 NOV 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 562.45 |
| 62201 | PTAX | 221 | Basic Pay | 30.93 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 2.78 |
| 63201 | WCOMP | 221 | Basic Pay | 5.62 |
| 64234 | | SG404 | APP (9% ) - General Staff | 50.62 |
| 65221 | LSL | 221 | Basic Pay | 16.87 |
| 67221 | AL | 221 | Basic Pay | 59.90 |
| 68221 | PL | 221 | Basic Pay | 11.70 |
| | | | Pay Total | 740.87 |

30 NOV 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 221 | Basic Pay | 56.25 |
| 62201 | PTAX | 221 | Basic Pay | 3.09 |
| 62201 | PTAX | SG404 | APP (9% ) - General Staff | 0.28 |
| 63201 | WCOMP | 221 | Basic Pay | 0.56 |
| 64234 | | SG404 | APP (9% ) - General Staff | 5.06 |
| 65221 | LSL | 221 | Basic Pay | 1.69 |
| 67221 | AL | 221 | Basic Pay | 5.99 |
| 68221 | PL | 221 | Basic Pay | 1.17 |
| | | | Pay Total | 74.09 |

28 DEC 2006

| Line | Oncost | Paycode | | Amount |
|---|---|---|---|---|
| 61221 | | 132T | Retire/Resign Leave Load (Post 93) Taxed | 173.11 |
| 61221 | | 251 | Public Holiday (Termination) | 112.49 |
| 62201 | PTAX | 132T | Retire/Resign Leave Load (Post 93) Taxed | 9.52 |
| 62201 | PTAX | 251 | Public Holiday (Termination) | 6.19 |
| | | | Pay Total | 301.31 |

Irving, Paul 12,832.21

# CSML Program 3 - Beneficial End Uses

## 2006 Itemised Expenditure Report

*01/04/06 to 31/03/07*

| ITEM | | AMOUNT (GST Exc.) |
|---|---|---|
| ***Research Fellow Salaries*** | | |
| ***1*** | Research Fellow F - Ecosystem Health (Robert Doupé) | 17,253.27 |
| | **Research Fellow Salaries sub total** | **17,253.27** |
| ***Equipment - Aqua/Hort*** | | |
| ***1*** | Clear site and provide sand pad - Tilbrook Developments | 8,598.00 |
| ***2*** | Supply of fill for tank foundations - Tilbrook Developments | 600.00 |
| ***3*** | Supply and installation of retaining wall - Tilbrook Developments | 1,922.25 |
| ***4*** | Relocation of clean sand fill - Tilbrook Developments | 2,405.00 |
| ***5*** | Supply and lay concrete floor plus drainage - Chad Tilbrook | 20,014.50 |
| ***6*** | *Hatchery construction: Project manager salary to oversee construction of asset (T. Storer) | 8,459.00 |
| | **Equipment - Aqu/Hort sub total** | **41,998.75** |
| | **2006 TOTAL EXPENDITURE PROGRAM 3 - BENEFICIAL END USES** | **$59,252.02** |

Note:

* Dr Tim Storer's total salary, as shown on supporting salary report, was $9,637.58 for the 2006 reporting period. During this period a portion of Dr Storer's time was spent supervising CDEP workers employed in the DAFF project to develop the horticulture component of the hatchery. As such only $8,459 is to be supported by State Government funding.

# CSML Program 3 – Beneficial End Uses
# 2006 Expenditure Documentation

## Research Fellow Salary Item

Item 1: Research Fellow F - Ecosystem Health
(Robert Doupé)

20-JUN-2007, 09:05am MURDOCH HRMS (production)
Page 1
TED327

Account Charges
ACCOUNT MUVETR560 FROM 01-APR-2006 to 07-JUL-2006

| NAME | ACCOUNT | UNIT | PAYCOD | PAY DATE | AMOUNT |
|---|---|---|---|---|---|
| Doupe, Robert Gerard | MUVETR560SFN | 75 | SAL | 14-APR-2006 | $2,248.53 |
| | | 75 | | 28-APR-2006 | $2,248.53 |
| | | 75 | | 12-MAY-2006 | $2,248.53 |
| | | 75 | | 26-MAY-2006 | $2,248.53 |
| | | 75 | | 09-JUN-2006 | $2,248.53 |
| | | 75 | | 23-JUN-2006 | $2,248.53 |
| | | 37.5 | | 07-JUL-2006 | $1,128.76 |
| | MUVETR560SFNL | 0 | SAL | 14-APR-2006 | $61.83 |
| | | 0 | | 28-APR-2006 | $61.83 |
| | | 0 | | 12-MAY-2006 | $61.83 |
| | | 0 | | 26-MAY-2006 | $61.83 |
| | | 0 | | 09-JUN-2006 | $61.83 |
| | | 0 | | 23-JUN-2006 | $61.83 |
| | | 0 | | 07-JUL-2006 | $31.04 |
| | MUVETR560SFNT | 0 | SAL | 14-APR-2006 | $123.67 |
| | | 0 | | 28-APR-2006 | $123.67 |
| | | 0 | | 12-MAY-2006 | $123.67 |
| | | 0 | | 26-MAY-2006 | $123.67 |
| | | 0 | | 09-JUN-2006 | $123.67 |
| | | 0 | | 23-JUN-2006 | $123.67 |
| | | 0 | | 07-JUL-2006 | $62.08 |
| | MUVETR560SFNW | 0 | SAL | 14-APR-2006 | $22.49 |
| | | 0 | | 28-APR-2006 | $22.49 |
| | | 0 | | 12-MAY-2006 | $22.49 |
| | | 0 | | 26-MAY-2006 | $22.49 |
| | | 0 | | 09-JUN-2006 | $22.48 |
| | | 0 | | 23-JUN-2006 | $22.49 |
| | | 0 | | 07-JUL-2006 | $11.28 |
| | MUVETR560SFSS | 0 | TESST | 14-APR-2006 | $202.37 |
| | | 0 | | 28-APR-2006 | $202.37 |
| | | 0 | | 12-MAY-2006 | $202.37 |
| | | 0 | | 26-MAY-2006 | $202.37 |
| | | 0 | | 09-JUN-2006 | $202.37 |
| | | 0 | | 23-JUN-2006 | $202.37 |
| | MUVETR560SFST | 0 | TESST | 14-APR-2006 | $11.13 |

Item 1

| | | | | | |
|---|---|---|---|---|---|
| | | 0 | | 28-APR-2006 | $11.13 |
| | | 0 | | 12-MAY-2006 | $11.13 |
| | | 0 | | 26-MAY-2006 | $11.13 |
| | | 0 | | 09-JUN-2006 | $11.13 |
| | | 0 | | 23-JUN-2006 | $11.13 |
| ****************************** | ********************** | | ****** | *********** | ------------ |
| sum | | | | | $17,253.27 |
| | | | | | ------------ |
| sum | | | | | $17,253.27 |

40 rows selected.

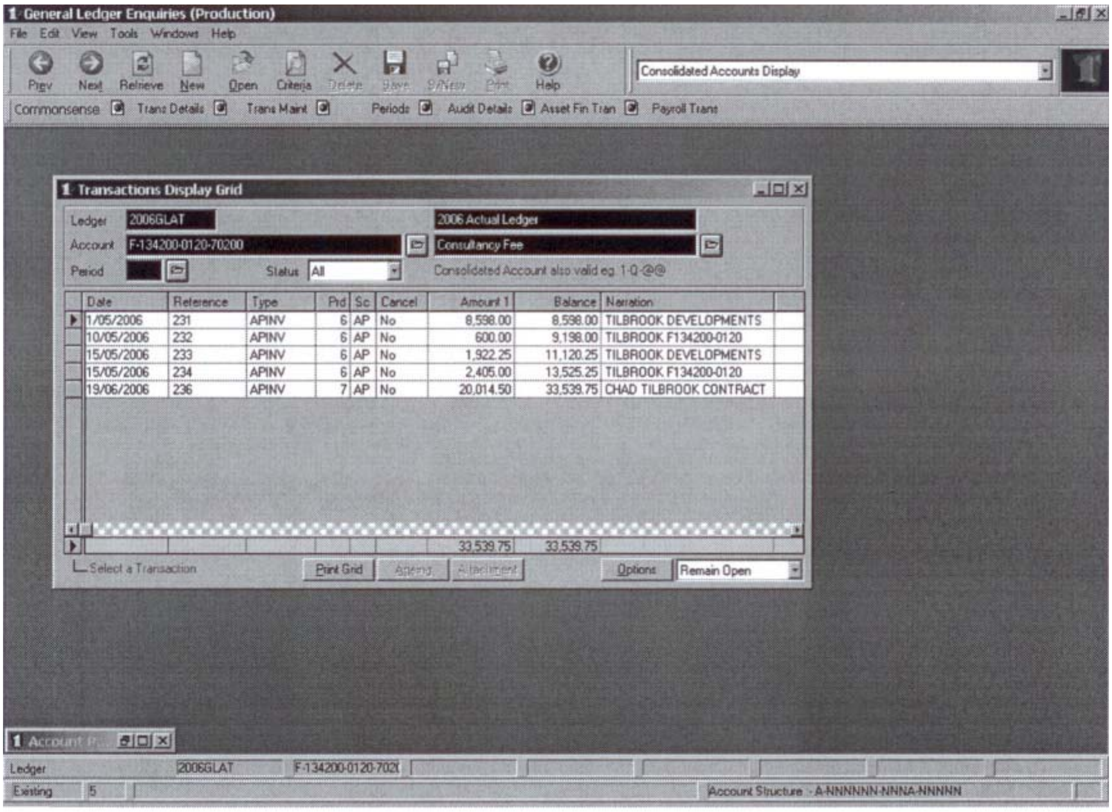
End of Report

# CSML Program 3 – Beneficial End Uses
# 2006 Expenditure Documentation

## Equipment – Aquaculture/Horticulture Item

Item 1: Clear site and provide sand pad - Tilbrook Developments
Item 2: Supply of fill for tank foundations - Tilbrook Developments
Item 3: Supply and installation of retaining wall - Tilbrook Developments
Item 4: Relocation of clean sand fill - Tilbrook Developments
Item 5: Supply and lay concrete floor plus drainage - Chad Tilbrook
Item 6: Hatchery construction: Project manager salary to oversee construction of asset (T. Storer)

Transaction report items 1-5




| Date | Reference | Type | Prd | Sc | Cancel | Amount 1 | Balance | Narration |
|---|---|---|---|---|---|---|---|---|
| 1/05/2006 | 231 | APINV | 6 | AP | No | 8,598.00 | 8,598.00 | TILBROOK DEVELOPMENTS |
| 10/05/2006 | 232 | APINV | 6 | AP | No | 600.00 | 9,198.00 | TILBROOK F134200-0120 |
| 15/05/2006 | 233 | APINV | 6 | AP | No | 1,922.25 | 11,120.25 | TILBROOK DEVELOPMENTS |
| 15/05/2006 | 234 | APINV | 6 | AP | No | 2,405.00 | 13,525.25 | TILBROOK F134200-0120 |
| 19/06/2006 | 236 | APINV | 7 | AP | No | 20,014.50 | 33,539.75 | CHAD TILBROOK CONTRACT |
| | | | | | | 33,539.75 | 33,539.75 | |

Item 1

Mobile: 0407 981 599
Fax: (08) ~~9734 2514~~ 97345651

*In account with:*

**TILBROOK DEVELOPMENTS PTY LTD**
ABN 13 103 964 572
**CARPENTRY CONTRACTORS**
**Commercial Second Fixing Specialists**
Lot 1433 Preston Road COLLIE WA

74 STEERE ST
~~PO Box 446~~
Collie WA 6225

To: CURTIN UNIVERSITY — 1 / 5 / 06
ATT: PAUL IRVING
Job: CLEAR SITE + PROVIDE SAND PAD
Job No.

| DATE | DESCRIPTION | AMOUNT | |
|---|---|---|---|
| | CLEAR VEGETATION FROM SITE + LEVEL GROUND. | | |
| | SUPPLY CLEAN SAND FILL, LEVEL + COMPACT TO SHED AREA. | | |
| | AS PER QUOTE Nº 205 | | |
| | F-134200-0120-70800 | | |
| | "I certify that this Account is correct in respect of Treasurer's instruction 305, and University Policies & Procedures". | | |
| | Signature (Incurring Officer) — Date 11/7/06 | | |

E. & O. E.
Please pay on this Tax Invoice

"I certify that this Account is correct within the meaning of Section 33 of the Financial Administration and Audit Act 1985".

Signature (Certifying Officer) Date

231

| | | |
|---|---|---|
| TOTAL | 8,598 | 00 |
| GST | 859 | 80 |
| AMOUNT OWING (Including GST) | 9,457 | 80 |

Item 2

Mobile: 04
Fax: (

**TAX INVOICE**
*In account with:*
**TILBROOK DEVELOPMENTS PTY LTD**
ABN 13 103 964 512
**CARPENTRY CONTRACTORS**
**Commercial Second Fixing Specialists**
Lot 1433 Preston Road COLLIE WA

74 STERRE ST
~~PO Box 446~~
Collie WA 6225

To CURTIN UNIVERSITY 10.5.06
ATT. PAUL IRVING.
Job
Job No.

| DATE | DESCRIPTION | AMOUNT | |
|---|---|---|---|
| | SUPPLY OF 50 $m^3$ OF CLEAN | | |
| | SAND FILL FOR TANK FOUNDATIONS. | $600 | 00 |
| | F-134200-0120-70200 | | |
| | "I certify that this Account is correct in respect of Treasurer's instruction 305, and University Policies & Procedures". | | |
| | Signature (Incurring Officer) 4/2/06 Date | | |

E. & O. E.
Please pay on this Tax Invoice

"I certify that this Account is correct within the meaning of Section 33 of the Financial Administration and Audit Act 1985".
Signature (Certifying Officer) 13.7.06 Date

232

| | | |
|---|---|---|
| TOTAL | $600 | 00 |
| GST | $ 60 | 00 |
| AMOUNT OWING (Including GST) | $660 | 00 |

Item 3

TAX INVOICE

TAX INVOICE

*In account with:*

**TILBROOK DEVELOPMENTS PTY LTD**

ABN 13 103 964 512

**CARPENTRY CONTRACTORS**

**Commercial Second Fixing Specialists**

Lot 1433 Preston Road COLLIE WA

Mobile: 0407 981 599
Fax: ~~(08) 9734 2514~~ 97345659

74 STEERE ST.
~~PO Box 446~~
Collie WA 6225

To CURTIN UNIVERSITY 15.5.06
ATT: PAUL IRVING
SUPPLY + INSTALL RETAINING

Job No.

| DATE | DESCRIPTION | AMOUNT | |
|---|---|---|---|
| | SUPPLY LIMESTONE BLOCKS, REMOVE SAND FROM BETWEEN PAD + FENCE TO ALLOW BLOCKS TO BE LAID. LAY BLOCKS IN PLACE, REPLACE SAND, RE-COMPACT + LEVEL. | | |
| | | $1,922 | 25 |
| | F-134800-0120-70200. "I certify that this Account is correct in respect of Treasurer's instruction 305, and University Policies & Procedures". Signature (Incurring Officer) 11/7/06 Date | | |

E. & O. E.
Please pay on this Tax Invoice

"I certify that this Account is correct within the meaning of Section 33 of the Financial Administration and Audit Act 1985".

Leanne Ross 13.7.06
Signature (Certifying Officer) Date

233

| | | |
|---|---|---|
| TOTAL | $1,922 | 25 |
| GST | $ 192 | 22. |
| AMOUNT OWING (Including GST) | $2,114 | 47 |

Item 4

# TAX INVOICE

*In account with:*

**TILBROOK DEVELOPMENTS PTY LTD**

ABN 13 103 964 512

**CARPENTRY CONTRACTORS**

**Commercial Second Fixing Specialists**

Lot 1433 Preston Road COLLIE WA

☎ 0407 981 599
(08) ~~9734 2514~~ 97245654

74 STEERE S
~~PO Box 4~~
Collie WA 62

To: CURTIN UNIVERSITY 15, 5, 0

ATT: PAUL IRVING

Job

Job No.

| DATE | DESCRIPTION | AMOUNT | |
|---|---|---|---|
| | RELOCATION OF CLEAN SAND FILL. | | |
| | IN TO SITE DUE TO ACCESS 4 | | |
| | LARGER MACHINERY. | | |
| | TRUCK. 13 hrs @ $95.00 | $1,235 | 00 |
| | LOADER 13 hrs @ $90 00 | $1,170 | 00 |
| | "I certify that this Account is correct in respect of Treasurer's instruction 305, and University Policies & Procedures". | | |
| | Signature (Incurring Officer) Date 11/7/06 | | |

E. & O. E.
Please pay on this Tax Invoice

"I certify that this Account is correct within the meaning of Section 33 of the Financial Administration and Audit Act 1985".

Signature (Certifying Officer) Date

234

| | | |
|---|---|---|
| TOTAL | $2,405 | 00 |
| GST | $ 240 | 50 |
| AMOUNT OWING (Including GST) | $2,645 | 50 |

Item 5

TOTAL P.02

ENTERED

BY ~~[signature]~~ MUA02460

28 JUN 2006

CURTIN - MURESK FINANCE RECEIVED

**TAX INVOICE**

In account with:-

Mobile: 0407 981 599
Fax: (08) 9734 2514

# CHAD TILBROOK

ABN: 29 880 643 242

CONTRACT CARPENTER

Lot 1433 Preston Road, Collie

PO Box 446
Collie WA 6225

To CENTRE FOR SUSTAINABLE MINE LAKES. 19, 6, 06

ATT. MR PAUL IRVING.

Job AQUACULTURE FACILITY CONCRETE FLOOR.

Job No.

| DATE | DESCRIPTION | AMOUNT | |
|---|---|---|---|
| | SUPPLY + LAY CONCRETE FLOOR TO | | |
| | AQUACULTURE FACILITY AS REVISED | | |
| | WITH PAUL IRVING DUE TO BUDGET | | |
| | RESTRICTIONS. @ APPROX 2/3 OF SHED | | |
| | AREA. | | |
| | INSTALL DRAINAGE AS PER QUOTE. | | |
| | Nº 203 | | |
| | "I certify that this Account is correct in respect of ~~Treasurer's instruction 305~~, and University Policies & Procedures". | | |
| | Signature (Incurring Officer) Date | | |

E. & O. E.
Please pay on this Tax Invoice

236

| | | |
|---|---|---|
| TOTAL | $20,014 | 50 |
| GST | $2,001 | 45 |
| AMOUNT OWING | $22,015 | 95 |

Item 6

University of Technology Western Australia

# Employee Line Item, Pay Code Report

## Employees Paid in Cost Centre F-137805-0510-

**Between 06 APR 2006 and 24 AUG 2006**

**Storer, Timothy Jarrad Iain** 211286F 06

| | Paycode | Oncost | Amount |
|---|---|---|---|
| F-137805-0510-61221 | 221 | | 7,172.25 |
| F-137805-0510-61221 | 611 | | 180.00 |
| F-137805-0510-62201 | 221 | PTAX | 394.50 |
| F-137805-0510-62201 | 611 | PTAX | 9.90 |
| F-137805-0510-62201 | SG404 | PTAX | 35.49 |
| F-137805-0510-63201 | 221 | WCOMP | 71.70 |
| F-137805-0510-64234 | SG404 | | 645.48 |
| F-137805-0510-65221 | 221 | LSL | 215.19 |
| F-137805-0510-67221 | 221 | AL | 763.84 |
| F-137805-0510-68221 | 221 | PL | 149.23 |
| | | | 9,637.58 |

**Grand Total 9,637.58**

CSML research projects are collaborative partnerships between mining companies and WA's four public universities:

By contacting CSML you will have access to a unique hub of expertise, and current models and tools, for use in mine lake planning and environmental operations.

Enquiries can be directed to:

**Professor Louis Evans**
Executive Director, CSML
**Email:** l.evans@curtin.edu.au
**Web:** www.csml.curtin.edu.au