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# Update on South African Mining-Related Water Research, 21 June 2011

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The previous report to the Portfolio Committee (Appendix A) provided a description of the relevant activities of the Water Research Commission (WRC) up to that date. This report summarises developments since June 2010.

The previously available literature contained sufficient information of assessments of current impacts and predicted the imminent decant in the Witwatersrand as early as 1995 (Scott, 1995) and several times since then. In the second half of 2010 the WRC restructured its research areas within the Key Strategic Area of Water Use and waste Management to expand mine water research into a dedicated Thrust, containing five programmes (Appendix B).

Twelve projects have been completed and the new reports which have been released since the previous reports are listed below. We have investigated the scale-up of AMD treatment technologies to full scale, the prevention of unnecessary waste wand wastewater creation, and the prediction of future AMD generation and how to minimise it.

## Mine water treatment

1. Identification of arsenic resistance genes in microorganisms from maturing fly ash-acid mine drainage neutralised solids Authors: Cowan D; Musingarimi W; Tuffin M I; 2011/01/26; Research Report No.1655/1/10
2. Refinement of the decision support system for metalliferous mine residue disposal facilities Authors: Bezuidenhout N; Randell B; 2010/10/01; Research Report No.1735/1/10
3. Ambient Temperature Ferrite Process: Adapting the laboratory-scale process to treat acid mine drainage Authors: Alexander WV; Ristow N; 2011/11/19; Research Report
4. Kinetic development of oxidation zones in tailings dams with specific reference to the Witwatersrand gold mine tailings dams Authors: Yibas B; Pulles W; Nengovhela C; 2010/05/14; Research Report No.1554/1/10
5. Monitoring, evaluation and verification of long-term performance of the passive water treatment plant at Vryheid coronation colliery Authors: Molwantwa JB; Coetser SE; Heath R; Pulles W; Bowker M; 2010/05/03; Research Report No.1623-1-10

## Waste minimisation

6. The introduction of cleaner production technologies in the South African mining industry Authors: Trusler G; Mzoboshe S ; 2011/05/13; Research Report No.1553/1/11

**Prediction and minimisation of future AMD generation**

7. Assessment of how water quality and quantity will be affected by mining of the Waterberg coal reserves west of the Daarby fault Authors: Vermeulen PD; Bester M; Cruywagen LM; van Tonder GJ; 2011/01/01; Research Report No.1830-1-10
8. Geochemical sampling and analyses for environmental risk assessment using the Witwatersrand basin as a case study Authors: Zhao B; Pulles W; Chihobvu E; 2011/05/13; Research Report No.1624/1/10
9. Prediction of how different management options will affect drainage water quality and quantity in the Mpumalanga coal mines up to 2080 Authors: Coleman TJ; Usher B; Vermeulen D; Lorentz S; Scholtz N ; 2011/04/26; Research Report No.1628/1/10
10. Development of water balances for operational and post-closure situations for gold mine residue deposits to be used as input to pollution prediction studies for such facilities Authors: Pulles W; Yibas B; Lorentz S; Maiyana B; 2011/04/12; Research Report No.1460/1/11
11. Sensing as a tool for resource assessment towards the determination of the legal compliance of surface and groundwater use Authors: Gibson LA; Münch Z; Engelbrecht J; Petersen N; Conrad J; 2011/03/02; Research Report No.1690/1/09
12. Evaluation and validation of geochemical prediction techniques for underground coal mines in the Witbank/Vryheid regions Authors: Zhao B; Usher B; Yibas B; Pulles W; 2010/08/12; Research Report No.1249/1/10

We have also initiated four new projects to address the knowledge gaps identified by the Team of Experts in their report to Cabinet. (Full details are provided in Appendix C).

Further, a new project scheduled to start in the next cycle is being solicited in Programme 3, Minimising waste production, entitled "Detailed Acid-Base-Accounting study of the Karoo formations in the Waterberg coalfield." Coal mining has a pronounced impact on surface and groundwater quality and quantity. The Waterberg is the only remaining large area with proven reserves in South Africa and is being targeted for large scale mining in the foreseeable future. Most of this will be opencast mining, resulting in large volumes of spoils and discards being handled on surface. A detailed acid base potential study is required in order to determine how spoils should be handled, due to the complexity and volume of the spoils and discards. If handled correctly, acid generation can be minimised, possibly prevented.

The WRC continues to fund research that supports the aims of treating the AMD currently being generated, predicting future AMD generation, and preventing future AMD generation.

The WRC also produces the magazine, *The Water Wheel*, which has included several articles on the topics of the mine water threat, and how it can be treated, which are written for non-specialist readers.

All WRC reports and *Water Wheel* articles can be found using the Electronic Knowledge Hub on the WRC website (www.wrc.org.za), and full text can be downloaded free of charge. If a reader is not already registered s/he may go to www.wrc.org.za and click on register (quick and free):


He or she will then be able to obtain full text papers from *Water SA*, articles from *Water Wheel* and full research reports from the Knowledge Hub as PDFs… to do so, one navigates here on the website:


Checking the ‘Search inside docs’ box will come up with full text searching (instead of just title, subject area and keyword searching), and clicking on the blue and white jelly beans takes one to a tutorial on how to use the search engine.

## Appendix A: Report on South African Mining-Related Water Research, 21 July 2010

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### Summary

The South African Water Research Commission (WRC) is the newest member of the Global Alliance of research organisations, which support the activities of the International Network for Acid Prevention (INAP) and hence support world-class research into mining-related water issues in South Africa. This report provides an overview of research and other activities that have resulted in an improved ability to predict the likelihood of acid rock drainage, strategies to minimise the production and impact of acid drainage, advances with technologies to treat acid drainage and South African technology transfer activities.

### Introduction

The Water Research Commission (WRC) is a South African statutory body that was established in 1970 against the background of South Africa's water scarcity and the realisation that a lack of water is potentially the most important factor limiting its development. The WRC's mandate is to promote co-ordination, co-operation and communication in water research and development. The WRC thus endeavours to establish water research needs and priorities, which are then encouraged and funded. Furthermore, it strives to enhance knowledge and capacity building in the water sector and to promote effective transfer of new information and technology. The WRC decided not to build a research institution of its own, but instead promotes and expands existing research infrastructure by outsourcing, but actively managing, research projects. The WRC's research initiatives cover the whole spectrum of water related research. Mine water related research resides within the key strategic area dealing with water use and waste management.
Joining the Global Alliance in 2006, the WRC is the newest of the member research organisations, which support the activities of the International Network for Acid Prevention (INAP). The WRC views its membership of the Global Alliance as being on behalf of all South African activities that are of importance to the Alliance. The interaction between the WRC and the Mine Water Division (MWD) of the Water Institute of Southern Africa (WISA) plays an important role in this regard. The WRC is represented on the Management Committee of the MWD, where it regularly reports on Global Alliance activities and learns of mining activities of interest to the Alliance.

Prior to 1990 most South African mine water related research was conducted by the now disbanded Chamber of Mines Research Organisation. The WRC's involvement in mine water research was limited to determining the water requirements and pollution potential of gold and uranium mines. Between 1990 and 2000, research focused on the impact mining has on the surface environment, on treatment options for mine effluents and on the rehabilitation of mining spoils. Since 2000 the emphasis has shifted to the development of predictive tools and modelling techniques, with the focus on treatment options shifting to implementation and passive systems.

This paper briefly describes significant contributions from a South African perspective, with a specific focus on acid drainage.

**Improved Predictive Ability**

Two aspects of research related to improved predictive ability have received special attention: firstly, the ability to predict the generation of acid drainage, and secondly, the ability to predict the rise in water levels and/or time and point of decant when pumping associated with active mining stops.
In view of the plethora of techniques used to predict the likelihood of acid drainage, research targeted at opencast coal mining started in 1999 to standardise the methods used to quantify the potential and magnitude of acid rock drainage (ARD, or acid mine drainage, AMD). Based on an extensive testing of existing static methods, Usher et al. (2004) recommended standardised methods for measuring initial pH, neutralisation potential and acid potential of water. They describe and justify the reasons/advantages of the recommended methods. They also developed an easy to use spreadsheet tool, ABACUS, to standardise the interpretation of static Acid-Base Accounting (ABA) data and, where the suggested sampling methodology has been followed, to provide a method for extrapolation to the field through volume-weighted techniques. Although the project focused on ABA, it strived to define a suite of acid-drainage prediction tools. The researchers coined a new acronym, ABATE (derived from Acid-Base: Accounting, Techniques and Evaluation), for the approach that integrates a range of tools to predict the potential for acid generation. This also helps to prevent confusion from arising in the use of the term ABA, since most people associate ABA with the static test component of drainage chemistry prediction, rather than the entire suite of tools. Research is in progress regarding the use of geochemical modelling techniques to predict the evolution of ARD over time.

There are about 270 gold mine tailings covering 180 $km^2$. Continued efforts to remine and consolidate the tailings into mega-dumps, the contamination and reclamation of the footprint beneath them (Rosner et al., 2001; Hattingh et al., 2003) and the degree to which tailing properties and time affect the depth and rate of weathering of typical tailings dams, have been investigated. An empirical model was developed to predict the likely period over which tailings dams will produce acidic drainage (Bezuidenhout and Rousseau, 2005). Efforts are currently underway to develop a coherent process to facilitate transparent and effective regulatory decision-making regarding the sustainable design, operation and closure of residue disposal facilities. A preliminary Decision Support System to facilitate decision-making has recently been completed (Rademeyer et al., 2008), while a refinement of the system is nearing conclusion.

The ability to predict the rise in water levels, and hence when and where decant to surface would take place after the cessation of mining, has received considerable attention. This ability is particularly important in view of the recovery of water levels in deep gold mines and the seepage of ARD from old shafts. Pioneering research in this regard was undertaken by Scott (1995) who investigated the flooding of Central and East Rand gold mines which have become largely interconnected through mining activities. Scott identified the controls over the inflow rate and water quality and was able to predict the future decant points and timeframes for different scenarios. A series of collaborative research projects (Grobbelaar et al., 2004 and Vermeulen et al., 2005) between the WRC and Coaltech (a non-profit research organisation funded by coal mining companies) captured the mine plans and coal seams in a three dimensional GIS, enabling the mines to determine decant points and the extent of intermine flow within the Mpumalanga coal fields. This ability is currently used to determine the position and capacity of plants to treat the ARD emanating from the coal fields.

**Minimising The Production And Impact Of Acid Rock Drainage**

Several approaches have been evaluated in an attempt to reduce the production and impact of ARD associated with mining.

A regional closure strategy was developed (Pulles et al., 2005) and is being implemented by the regulating authorities (van Tonder et al., 2008) to ensure the orderly and responsible closing of mines which exploit the same ore body. This represents a fundamental change from the previous dispensation where the approach to address mine closure from the perspective of individual mines, resulted in the last mine standing in an area to be saddled with the responsibility for the combined decant and ARD pollution potential of interconnected neighbouring mines.

Under experimental conditions the use of soil to cover acid generating discard material was found to be effective in reducing the ingress of oxygen and water and thus the volume and strength of ARD percolate (Vermaak et al., 2004). However, under field conditions, where large discard dumps had to be covered, it proved difficult to source sufficient soil for an effective cover thickness and to prevent erosion reducing cover depth on side slopes (Wates et al., 2006).
An evaluation and modelling of the impact that the release to surface streams of stored saline neutralised ARD during high flow conditions would have on water quality (Coleman et al., 2003) contributed to the development of a strategy whereby ARD from Mpumalanga coal mines is released periodically during years with above average runoff.

Several research projects have highlighted the benefits in the form of reduced volumes of water that would accumulate in underground mines if the ingress of water through surface cracks and fissures could be reduced. The Department of Minerals and Energy initiated a multimillion Rand project through the Council of Geoscience to identify and close these ingress points as a priority (Coetzee, 2009).

Two interesting projects aimed at minimising the impact or production of ARD are currently being conducted. The first is assessing the viability of extracting good quality groundwater in aquifers overlying deep mines in order to reduce the percolation of good quality water into the mines. The potential benefit is to prevent the subsequent contamination of this good quality water with ARD and in the reduction of the volume of ARD requiring mitigation. The second is an investigation into the feasibility of either removing or accelerating the oxidation of pyrites associated with mining. In this way mining may be able to deal with ARD problems during the lifespan of a mine, so that mines would not have a post-closure ARD legacy.

**Treatment Technologies**

In contrast with water-rich mining regions, South Africa faces not only the high acidity and dissolved metal problems associated with ARD, but the limited dilution potential associated with low rainfall exacerbates the contribution of salinity associated with ARD (and also with neutralised ARD) to the salinisation of water resources. For example, it has been calculated that effluents from gold mines contribute 35% of the salt load while contributing approximately 6% of the water flow at the Barrage in the Vaal River (the major water source of the industrial heartland of South Africa, Pilson et al., 2000). For this reason, much of the research into treatment technologies focused on developing technology that would remove sulphate in addition to metals and the neutralisation of acidity.

The research into water treatment technology is currently being implemented and evaluated at a range of pilot and operational scales at a number of locations. In a joint venture Anglo Coal and BHP Billiton constructed a 20 ML/d reverse osmosis plant at 99% water recovery to produce potable water from ARD. The treated water is sold to the neighbouring town to supplement its water supply (Gunther, 2008). Two similar plants are planned for the treatment of ARD form the Mpumalanga coal mines. The Rhodes BioSure process whereby sewage sludge is used as energy source for the biological reduction and removal of sulphates from ARD has been implemented at ERWAT's Ancor Waste water treatment works, which had been rebuilt to accommodate the BioSure process. Ten ML/d of ARD from the Grootvlei Gold Mine is treated in this way (Joubert et al., 2009). The Western Utilities Corporation, established to treat the ARD from four basins in the Witwatersrand gold fields, is planning to treat 75 ML/d of ARD from gold mines using the Council for Scientific and Industrial Research's ABC (Alkali-Barium-Calcium) desalination process, which use barium to precipitate sulphates. A pilot plant utilising the degrading packed bed reactor, that overcame the failure that is commonly experienced with passive sulphate removal systems once the easily oxidisable organic material has been depleted, and that significantly improved the efficiency of passive systems, is currently being constructed (Pulles, 2009). The cost saving associated with using limestone (calcium carbonate) rather than lime (calcium hydroxide), and the effectiveness of the technology for the neutralisation of acid waters, have been demonstrated in a number of applications.

**Technology Transfer (Best Practice Guidelines and Conferences)**

The Department of Water Affairs (DWA) recently completed a series of Best Practice Guidelines for Resource Protection in the South African Mining Industry. Four of these deal with aspects of the Department's water management hierarchy, viz. Integrated mine water management, Pollution prevention and minimisation of impacts, Water reuse and reclamation and Water Treatment. Five of the series deal with general water management strategies, techniques and tools, namely Storm Water Management, Water And Salt Balances, Water Monitoring Systems, Impact Prediction and Water Management Aspects For Mine Closure. Six of the series deal with specialised mining activities or aspects, specifically: Small-Scale Mining, Water Management For Mine Residue Deposits, Water Management In Hydrometallurgical Plants, Pollution Control Dams, Water Management For Surface Mines and Water Management For Underground Mines.

The MWD of WISA in collaboration with DWA and the South African Chamber of Mines hosted two well attended Symposia (24-25 October 2007 and 11-12 February 2009). A Workshop to discuss the Global Acid Rock Drainage Guide was held on 13 October 2008. The 3rd International Seminar on Mine Closure (Mineclosure2008) with the theme From Waste to Resource: Revaluation of Mining Operations, land and Residue Deposits in a Changing World was held from 14 to 17 October 2008. Almost 400 participants from 28 countries attended to hear the 90 speakers. The MWD together with the International Minewater Association will host an International Minewater Conference from 19 to 23 October 2009.

## Conclusion

South African activities have made significant contributions on several fronts in the quest to deal with the problems associated with ARD emanating from mining activities.

## Acknowledgements

The authors wish to thank the many researchers and practitioners who contributed to the progress that has been reported here. It is only a limitation on space that resulted in the exclusion of many interesting other developments from being reported upon. The authors also wish to thank the South African Water Research Commission for permission to present this report.

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## Appendix B: KSA3 Thrust 5: Mine Water Treatment and Management

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| ***Thrust 5 Scope****:* The usage of water in mining and mineral processing/refining produces high volumes of solid wastes and liquid effluents. Some mining activities generate acid mine drainage (AMD) or other mining-impacted waters. This thrust aims to provide appropriate, innovative and integrated solutions to water use and waste management in the mining sector. Future operations will almost exclusively take place in water scarce regions (e.g. Waterberg, Eastern Limb) and their development will require reallocation of already stretched resources through e.g. improved water demand and water conservation management. Additional priorities will include brine handling, biological sulphur compound transformation and aversion of future impacts. | |
| ***Programme 1: Water use and waste production*** | ***Scope*****:** This programme focuses on investigations into quantification of water used and waste produced by the sector currently, and into predicting and quantifying the short, medium and especially long term impacts the wastes generated will have. The environmental consequences of mining activity are almost always long term in nature, with impacts that last for centuries. These long lasting effects were often not fully understood in the past, and consequently not properly considered. In the present regulatory environment it is increasingly expected of waste producers to quantify the present and future environmental impacts of their past and present operations and to indicate how these will be remedied, as well as how such consequences can be avoided when planning future operations. |
| ***Programme 2: Regulatory, management and institutional arrangements*** | ***Scope*****:** The creation of sustainable arrangements (e.g. public-private partnerships) that enable the mitigation and prevention of the environmental, social and economic legacies of the mining and minerals industries is complex. Priorities include addressing the treatment and supply of bulk water using acid mine drainage (AMD), a realistic estimate of non point source pollution relating to the waste discharge charge system and determining the price elasticity for water use of the sector (determine the potential to decrease water use through tariff increases). This programme interrogates such aspects from the perspective of the mining sector (note: Policy Development falls under KSA1). |
| ***Programme 3: Minimising waste production*** | ***Scope*****:** This programme focuses on investigations into developing technologies and methods to decrease / minimise the generation of waste products in the mining sector, either through cleaner production, by-product generation and life cycle analysis or through applying other risk assessment methodologies. The programme incorporates novel mining methods and mining-impacted water prevention strategies. Waste minimisation at the national, regional, (catchment), complex or single site scale is considered. Identification of opportunities to convert liabilities into assets and holistic, long term research into the beneficial use and recovery of brines, their solutes, and other waste products are also included. |
| ***Programme 4: Mining in the 21st century*** | ***Scope*****:** The emerging challenges related to avoiding recreating the legacies of past operations call for emerging solutions. Programme 4 will investigate the prediction and avoidance of long-term water impacts and implications associated with establishing new operations within different geographical areas. It will also actively pursue beneficiation initiatives, remining of wastes, etc. (especially innovative ideas and piloting / scale-up). |

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| ***Programme 5: Low volume mined products*** | ***Scope:*** Much research attention has been paid to coal and gold mining, however other quarried or mined products such as radionuclides and platinum group metals also require consideration and in some cases they present unique challenges. Water use and demand management, water-conserving metallurgical and extraction processes and investigation of the impacts and amelioration of mine discards specific to these products will be addressed in this programme. |

**Appendix C: New WRC projects initiated since July 2010**

| Project no. | Project title | Contractor | Start and end dates | Project summary |
|---|---|---|---|---|
| **K5/2107** | Toxicity evaluation of metals and metal oxides nanoparticles to aquatic invertebrates and algae species | Council for Science and Industrial Research | 01/04/2011 31/03/2014 | Nanotechnology has matured from laboratory based research and development phase into full commercialization of nanoproducts since the beginning of 1990s. For example, there are numerous novel consumer products and industrial applications of nanotechnology including: nanoelectronics, molecular assemblies, tissue engineering, biomedicine, nanocomposites, cosmetics, paints, pesticides and water purification modules. Analyses of the distribution of nanomaterials used in the nanoproducts reported are metals and metals oxide nanoparticles. Therefore, among the nanomaterials with high potential of release in large quantities into the aquatic environments are metals and metal oxides. In view of the rapidly increasing quantities of nanomaterials into different environmental compartments - especially water and sediments - it is imperative that the potential risks that may be associated with nanomaterials attract attention to ensure long-term safe, responsible, and sustainable development of this novel technology for optimal benefit of the society. Due to limited data on potential risks of nanomaterials to the aquatic organisms which can support practical risk assessment and risk management after entry into the environment, this project will investigate the effects of nanomaterials on organisms at different trophic levels. Secondly, the mechanism of how nanomaterials cause toxic effects to the receptor organisms will be explored through use of DNA, reactive oxygen species (ROS) generation techniques. |

| Project no. | Project title | Contractor | Start and end dates | Project summary |
|---|---|---|---|---|
| **K5/2108** | Removal of Metal Ions from Industrial Effluents and Acid Mine Drainage by Metal Sulphide Precipitation | University of Cape Town | 01/04/2011 31/03/2013 | The main aim of the research is to further the understanding of the precipitation of metal sulphides in the treatment of acid mine drainage via sulphate reduction and metal precipitation. The project will characterise the effect of operating conditions on the physical characteristics of the formed metal sulphide precipitate by investigating the effect of metal to sulphide ratio on precipitation behaviour, the effect of the operating pH on the precipitation process and using a technique based on moment transformations of the number density function n(L) to make inferences about the mechanisms involved in the particle formation processes. The project will also investigate the factors affecting the solid-liquid separation characteristics of the formed particles. The effects of the processing conditions on solid-liquid separation characteristics of the formed precipitates will be quantified using particle size distribution measurements, settling characteristics and zeta potential measurements for surface charge determination. These studies will be carried out on a number of model metal systems. Finally, the project will investigate factors that potentially influence the solid-liquid separation characteristics of the formed particles. As a result of the investigations carried out, it should be possible to identify a number of factors, possibly different additives that would influence the separation characteristics of the formed precipitates. Thus the effect of these ions (as well as other additives) on coagulation and aggregation phenomenon will be quantified by measuring their effect on particle size distribution, surface charge and settling characteristics of the precipitate. |

| Project no. | Project title | Contractor | Start and end dates | Project summary |
|---|---|---|---|---|
| **K5/2109** | Development of a toolkit to enable quantitative microbial ecology studies of sulphate reducing and sulphide oxidising systems | University of Cape Town | 01/04/2011 31/12/2013 | The catastrophic effects of untreated mine water discharges are well known and several high profile events have been documented. Mine water has traditionally been treated using oxidation-neutralisation-precipitation which effectively removes metal but the treated stream still contains sulphate. Biological treatment systems, based on the activity of sulphate reducing bacteria have received considerable attention. Their widespread application has been constrained by the provision of a carbon source/electron donor and the management of the sulphide containing effluent. Both these issues are addressed in the Integrated Passive Treatment System (IMPI) technology which makes use of a mixture of complex, lignocellulosic carbon sources and incorporates a sulphide oxidation step. Both the sulphide oxidation and sulphate reduction processes are catalysed by a consortium of different microorganisms. Different components of the consortium have different tolerances to sulphate, sulphide and heavy metals. As a consequence, changes in feedstock can lead to major changes in the microbial community. This may have catastrophic effects on system performance. Until recently these changes were poorly understood and system management was based on empirical rules of thumb. The advent of molecular biology techniques has facilitated qualitative microbial ecology studies. While these have been useful in confirming the presence or absence of species or groups of species they provide limited information on dynamic changes in population structure, which could be extremely useful in predicting the response of a system to specific perturbations. This project will develop a molecular toolkit for performing quantitative microbial ecology work in sulphate reducing and sulphide oxidising systems. The toolkit will initially be used to characterise the microbial populations in the IMPI demonstration plant at Middleburg Mine. This technology has the potential to effectively treat mine water effectively and economically over a sustained period of time |

| Project no. | Project title | Contractor | Start and end dates | Project summary |
|---|---|---|---|---|
| **K5/2110** | Addressing the challenges facing biological sulphate reduction as a strategy for AMD treatment through analysis of the reactor stage: raw materials, products and process kinetics | University of Cape Town | 01/04/2011 31/03/2014 | Mine waters generated during active mining or resulting from groundwater rebound at abandoned sites have major environmental and economic implications. Active chemical treatment of the waters is the most widely employed technology. Recently there has been increasing interest in active and passive biological treatment processes. These systems rely on naturally occurring biological and geochemical processes to improve water quality with minimal operational and maintenance requirements. Biological sulphate reduction is a well understood and efficient process that has been frequently demonstrated at laboratory and pilot scale. However, its full scale implementation has been limited. The challenges facing sulphate reduction systems have been identified as: provision of a cost effective carbon source; enhancing reaction kinetics when complex carbon sources are used; and management of the resulting sulphide. This study will undertake a critical review of existing technologies, from a technological and economic perspective. Furthermore the feasibility of using micro algal biomass as a carbon source/electron donor will be investigated. The study will also evaluate the requirements for algal cultivation at the scale required to sustain the SRB process. To address the issue of enhanced reaction kinetics the effect of decoupling the hydrolysis and acidogenesis reactions from the sulphate reduction will be investigated. The study will include a review of available technologies and investigate the application of cross-flow microfiltration membranes to recover and recycle biomass to both the hydrolysis/acidogensis and sulphate reduction reactors. |