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Groundwater remediation using a coal washery discard permeable reactive wall

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GROUNDWATER REMEDIATION USING A COAL WASHERY DISCARD PERMEABLE REACTIVE WALL

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CERTIFICATION

I, Stuart C. Gray, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Engineering, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Stuart C. Gray

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Abstract

Groundwater remediation has become increasingly necessary for environmental sustainability in industrial, agricultural and urban settings. One reason for this need has been the emplacement of rock waste materials (e.g. coal washery discard (CWD) and blast furnace slag (BFS)) from mining and metallurgical industries in areas such as the Illawarra region of New South Wales. Since there has been a lack of rigorous research into the potential for these emplacements to pollute groundwater, the majority of these emplacements were constructed without the installation of engineering leachate controls. Indeed, until research over the last 15 to 20 years proved the contrary, available evidence suggested that these rock wastes were inert and would not threaten groundwater quality. Therefore, there is a need to identify the environmental impacts of these rock waste emplacements and develop groundwater remediation strategies at existing emplacement sites, as well as develop economically and environmentally sustainable utilisation technologies for these rock waste materials.

This thesis presents a field study of a BFS emplacement located within the Illawarra region of New South Wales. High pH groundwater (pH 12-13) has been found to be migrating from this emplacement into an adjacent coastal saline lake, resulting in severe impacts on fish and benthic fauna. An innovative engineering solution, which involves the installation of a low pyrite CWD permeable reactive wall at the site, has been proposed and tested. Depending on the particle size, the equilibrium pH of this CWD material ranges from about 7.5 to over 9.0.

Field monitoring has been conducted to assess the hydraulic performance and reactivity of the CWD wall. A consistent and significant pH drop across the wall has been observed; the pH at the effluent end of the wall averaged 7.2 over the 825 day monitoring period. In addition, the wall was not found to impede natural groundwater flow. A three-dimensional MODFLOW model of the site and the wall reveals that flow through the wall conforms to fundamental flow equations.

Laboratory batch and column tests have been conducted to develop a conceptual model of the chemical interactions within the CWD wall. According to this model, the primary pH reduction mechanism is the deprotonation of reactive amphoteric oxygen sites at the clay edge surfaces and gibbsite basal surfaces within the CWD. This is an acid-base controlled reaction in which protons are drawn into solution by the concentration of hydroxide ions. Deprotonation of clay surfaces results in negatively charged surfaces that attract and adsorb available cations (primarily calcium) from solution.

The conceptual model has been used to develop a quantitative PHREEQC geochemical model of the wall. This model has been thoroughly tested using column test data and found to be valid. It is used to show that exhausted CWD is chemically stable and that the worst-case reactive life of the CWD permeable reactive wall at the BFS emplacement site will be 3.23 years. Under average rainfall conditions, the life of the wall should exceed 60 years.

This solution is shown to be an efficient and economical engineering application of clay surface chemistry. It simultaneously addresses three issues relevant to groundwater remediation: the need for groundwater remediation strategies at existing rock waste

emplacements, the need to develop economical and environmentally sustainable utilisation technologies for rock waste and the need for new field applications for permeable reactive walls.

Acknowledgements

I give thanks and praise to the Lord for providing me with everything that I have needed to complete this thesis. May this research and qualification be for His glory and be used for His service.

Now to him who is able to do immeasurably more than all we ask or imagine, according to his power that is at work within us, to him be glory in the church and in Christ Jesus throughout all generations, for ever and ever! Amen. (Ephesians 3:20-21).

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List of Publications

Gray, S.C. and Sivakumar, M. (peer reviewed and re-submitted). 'Remediation of High pH Groundwater with a Coarse Coal Washery Discard Reactive Wall'. Submitted to *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE.

Gray, S.C., Indraratna, B. and Yassini, I. (1999). 'Contaminant Transport through a Coal Washery Discard Reactive Wall'. *Environmental Engineering 1999: Proceedings of the ASCE-CSCE National Conference on Environmental Engineering*, Norfolk, Virginia. Schafran, G.C. (Ed.). pp. 757-765.

Gray, S.C., Morris, C.E. and Sivakumar, M. (2000). 'Laboratory Evaluation of the Treatment of Alkaline Leachate with Coal Washery Discard'. *Proceedings 4th Australia New Zealand Young Geotechnical Professionals Conference*, Perth. House, A. and Watson, P. (Eds.). pp. 99-104.

Gray, S.C., Morris, C.E. and Sivakumar, M. (2000). 'Groundwater Neutralisation with Coal Washery Discard'. *GeoEng2000: An International Conference on Geotechnical and Geological Engineering*, Melbourne.

Gray, S.C., Sivakumar, M. and Morris, C.E. (2001). 'The Coal Washery Discard Permeable Reactive Wall: An Engineering Application of Clay Deprotonation'. *GeoEnvironment 2001: Proceedings 2nd Australia New Zealand Conference on GeoEnvironmental Engineering*, Newcastle.