

Managing the Risk of Mine Sulphate Discharge to Downstream Ecosystems

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Abstract The discharge of mine water containing sulphate may pose potential ecological risk to receiving waters. In this paper, we demonstrated the application of a risk-based approach to managing sulphate discharge using a coal mine in the Bowen Basin (Australia) as a case study. This approach integrates information on sulphate concentration and its ecological impact to quantify the risk and evaluate the effectiveness of different scenarios in mitigating the risk. Findings in this study contribute a possible framework applicable to managing not only sulphate, but also other substances of potential concern in the mining industry, such as selenium and mercury.

Keywords sulphate, mine water discharge, risk-based approach, ecological risk

Introduction

Sulphate in mine water originates from the oxidation of sulfur-containing minerals, e.g. pyrite (Edwards et al. 2000, Davies & Hall 2007), and mine sites accessing waters that contain high concentrations of sulphate (Butler et al. 2008). The release of mine water with sulphate may cause large-scale pollution to receiving waters (Turbak et al. 1979, Bernhardt et al. 2012). Extensive research has been undertaken to gather information on sulphate aquatic toxicity. For example, the discharge of sulphate-polluted water into wetlands may lead to eutrophication and toxicity to the roots of aquatic plants, which are likely to induce major changes in vegetation composition (Lamers et al. 1998). Significant losses of many intolerant macro invertebrate taxa occur when as little as 2.2% of contributing catchments are converted to mining, which is correlated with ionic strength and sulphate concentrations in receiving streams within catchments (Bernhardt et al. 2012). Given the potential threat posed by sulphate to ecosystems, sulphate should be treated as a risk management exercise. According to the standardized risk management process (Department of Resources Energy and Tourism 2008), the ecological risk posed by sulphate is related to both the variation of its concentration (likelihood) and the magnitude of its toxicity (consequence), and should be determined by combining both pieces of information. In this study, we tested a risk-based approach as a framework to assist decision makers in understanding and managing the risk of sulphate release. This approach, which has been tested to manage water quality problems in mineral processing (Liu et al. 2011, Liu et al. 2013), integrates sulphate concentration variation with its toxicity to assess the likelihood of sulphate exceeding specific values where different levels of effects would occur, and evaluate the effectiveness of different strategies in mitigating the risk. The potential of this approach as a framework for managing sulphate discharge was demonstrated using a coal mine in Bowen Basin (Australia) as a case study.

Framework of the Risk-Based Approach

The proposed risk-based approach consists of two logical steps (Liu et al. 2011). The first step is to quantify the risk of sulphate to local ecosystems by combining two pieces of information: sulphate concentration variation and the magnitude of sulphate toxicity. The second step is to control the risk of sulphate by selecting various risk mitigation scenarios. This risk-based approach provides a mechanism to assist mine sites in proactively quantifying sulphate risk and making decisions in terms of whether treatment actions are required and the extent and nature of actions required.

Data Sources

The case study site is based on a coal mine located in the Bowen Basin in Central Queensland, Australia. There is a water impoundment on the mine from which mine water can be released into the Fitzroy River Basin. Electrical conductivity (EC) and sulphate concentrations in this impoundment (hereinafter referred to as ‘discharge dam’) were monitored from 2007-2011 (Dunlop et al. 2011). The continuous and intense monitoring of EC was from July 2010 to April 2011, which included the wet season of 2010-2011 when the region experienced heavy rainfall events. Because there were no biological effects-based data existing for sulphate in this region, Dunlop et al. conducted experiments to establish toxicity effect ranges of sulphate for local taxa under local conditions (Dunlop et al. 2011).

Results and Discussion

Fig. 1(A) shows the time series of EC monitored in the discharge dam over the study period from July 2010 to April 2011. From July to November, which is the dry season in Northern Australia, EC was higher, increasing from about 6.5 mS/cm in July to 10.0 mS/cm in November due to evaporation from the dam. In contrast, a pronounced decrease in EC was observed in late November, coincident with the major rainfall events at the beginning of the wet season. Sulphate concentration was not monitored as frequently as EC. Previous monitoring data from 2007 to 2011 was used to estimate the correlation between sulphate concentration and EC. Fig. 1(B) shows that there was a strong linear relationship between sulphate concentration and EC. Therefore, EC could be used as a proxy for sulphate concentration within this body of water.

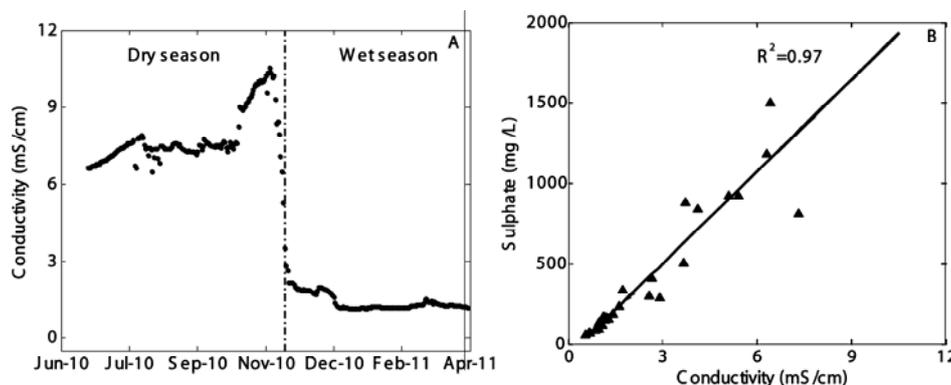


Fig. 1 (A) time series of electrical conductivity (EC) monitored in the discharge dam in the dry and wet seasons over the study period from July 2010 to April 2011; (B) correlation between EC and sulphate concentration based on data monitored in the discharge dam between 2007 and 2011

The time series and histogram of sulphate concentration are shown in figs. 2(A) and (B). In the wet season sulphate concentration clustered within a narrow concentration interval. In contrast, sulphate concentration in the dry season was more variable. Therefore, a frequency distribution was fitted for the dry season (solid line in fig. 2B). This frequency distribution was approximated to a normal distribution. Sulphate concentrations for 80%, 90%, 95% and 99% levels of species protection were derived as per the standardized method (ANZECC/ARMCANZ 2000). Level of species protection is the percentage of species that should be theoretically protected at a given sulphate concentration. Fig 2C shows that the relationship between the level of species protection and sulphate concentration could be described as linear. A sulphate concentration of less than 440 mg/L would be equivalent to a 100% level of species protection, meaning that no damage to the ecosystem would occur. As

sulphate concentration was increased, the level of species protection decreased, indicating that the magnitude of the toxic effect of sulphate on the ecosystem increased.

The risk of sulphate to the ecosystem was quantified by combining the above two pieces of information: the variation of sulphate concentration (Fig. 2B), and the magnitude of sulphate toxicity (Figure 2C). The risk plot, shown in Fig 2D, shows the time percentage for which each level of species protection was exceeded. For the wet season there was no ecological threat from discharging this water to the local streams, because sulphate concentration was consistently below the critical value of 440 mg/L. Therefore, the risk plot was the vertical straight line, meaning that 100% of the time the level of species protection was 100%. In contrast, the risk plot for the dry season (solid line) shows that the discharge would pose risks to the local ecosystem. For example, 80% of the time the level of species protection was around 60%.

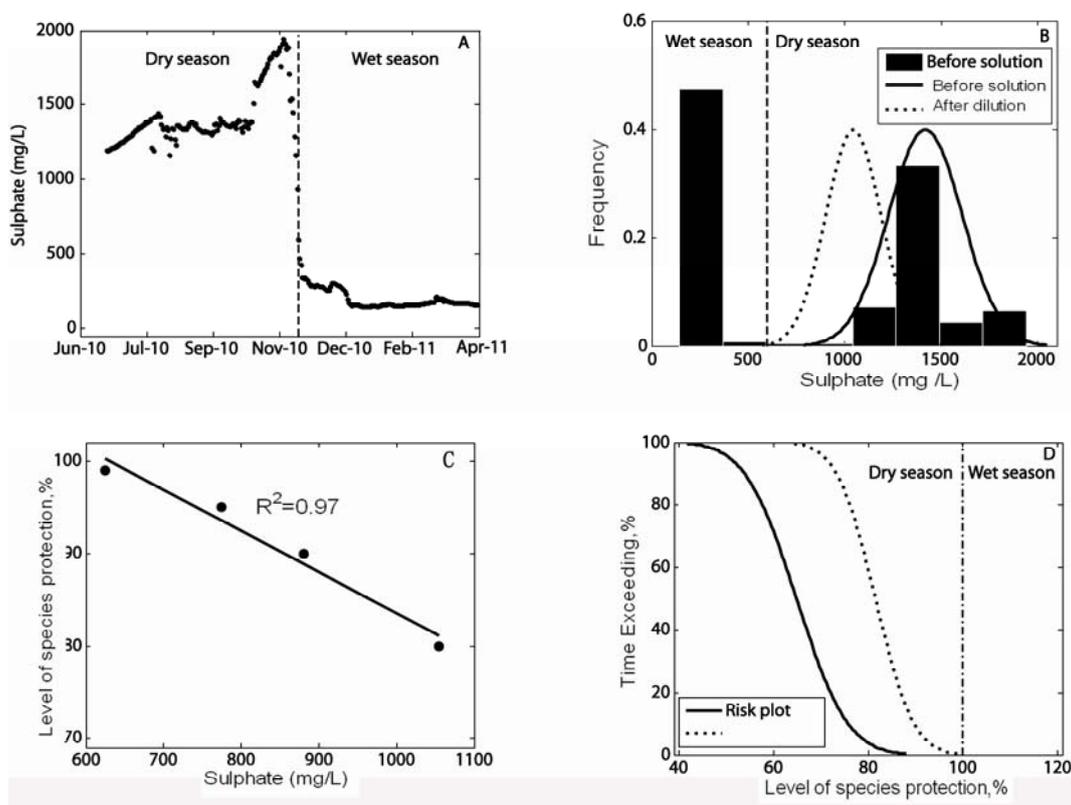


Fig. 2 The risk-based approach for the study site: (A) time series of sulphate concentration; (B) histogram (bars) and frequency plot of sulphate concentration, and new frequency plot after proposed dilution; (C) correlation between level of species protection and sulphate concentration; (D) risk plot before and after proposed dilution in the dry season

The aim of risk control is to reduce the ecological risk of sulphate to acceptable levels, which may be different depending on the current status of the ecosystem being considered. For example, the Australian and New Zealand water quality guideline provide three levels of protection (ANZECC/ARMCANZ 2000). These levels are: (1) high conservation ecosystems where the default is to protect 100% of species, (2) slightly to moderately modified ecosystems where the default is to protect 95% of species, and (3) highly modified ecosystems where the default is to protect between 80 to 90% of the species.

In this study, a hypothetical scenario was used to demonstrate the application of the risk-based approach in assessing the effectiveness of risk mitigation options, namely dilution with

low-sulphate water. Sulphate concentration in the discharge dam was reduced hypothetically by 50% through implementing this option in the dry season. Fig. 2B (dashed line) shows the corresponding change of the frequency plot of sulphate concentration. Note that the standard deviation of sulphate frequency distribution was assumed to be the same before and after dilution. The mean value was reduced by 50% by implementing the hypothetical dilution. The corresponding change of the risk plot is shown in Fig. 2D (dashed line). Dilution by low-sulphate water would control the risk by maintaining a high level of species protection for a higher percentage of the time. For example, the level of species protection was 80% for 80% of the time, as opposed to only 60% of the time prior to dilution.

Conclusion

This study tested the potential of the risk-based approach as a framework to manage sulphate discharge from mining activities. There is significant potential for this approach to be applicable to other industries that generate sulphate-contaminated water, and other contaminants, such as selenium and mercury. The effective application of this approach depends on a good understanding of the concentration variation of a contaminant and its ecological toxicity. Although this study was conducted with a constituent that behaves reasonably conservative with respect to salinity, this method could easily be applied to non-conservative constituents as long as the behavior of the constituent of concern in relation to another constituent (e.g., EC) is well characterized.

Acknowledgements

Funding for this study was provided by Australian Research Council linkage project (LP0883872) "Impact of recycled and low quality process water on sustainable mineral beneficiation practices", which is part of AMIRA project P260E. Collection of water quality and ecotoxicity data was funded by Australian Coal Association Research Program (ACARP C18033) "Development of ecosystem protection trigger values for sodium sulphate in seasonally flowing streams of the Fitzroy River Basin".

References

- ANZECC/ARMCANZ (2000) Australian water quality guidelines for fresh and marine waters, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand
- Bernhardt ES, Lutz BD, King RS, Fay JP, Carter CE, Helton AM, Campagna D, Amos J (2012) How many mountains can we mine? assessing the regional degradation of Central Appalachian Rivers by surface coal mining. *Environ. Sci. Technol* 46: 8115-8122
- Butler BA, Ranville JF, Ross PE (2008) Observed and modeled seasonal trends in dissolved and particulate Cu, Fe, Mn, and Zn in a mining-impacted stream. *Water Res* 42: 3135-3145
- Davies TD, Hall KJ (2007) Importance of calcium in modifying the acute toxicity of sodium sulphate to *Hyalella azteca* and *Daphnia magna*. *Environ. Toxicol. Chem* 26: 1243-1247
- Department of Resources Energy and Tourism (2008) Leading practice sustainable development program for the mining industry-risk assessment and management, Australian Government: Department of Resources Energy and Tourism
- Dunlop J, Hobbs D, Mann R, Nanjappa V, Smith R, Vardy S, Vink S (2011) Development of ecosystem protection trigger values for sodium sulphate in seasonally flowing streams of the Fitzroy River Basin, Department of Environment and Resource Management
- Edwards KJ, Bond PL, Gihring TM, Banfield JF (2000) An archaeal iron-oxidizing extreme Acidophile important in acid mine drainage. *Science* 287: 1796-1799
- Lamers LPM, Tomassen HBM, Roelofs JGM (1998) Sulphate-induced eutrophication and phytotoxicity in freshwater wetlands. *Environ. Sci. Technol* 32: 199-205
- Liu W, Moran CJ, Vink S (2011) Quantitative risk-based approach for improving water quality management in mining. *Environ. Sci. Technol* 45: 7459-7464
- Liu W, Moran CJ, Vink S (2013) Managing the potential risks of using recycled water in mineral processing to protect freshwater *Environ. Sci. Technol* 47: 6582-6588

- Turbak SC, Olson GJ, McFeters GA (1979) Impact of western coal mining—I. Chemical investigations of a surface coal mine sedimentation pond. *Water Res* 13:1023-1031
- approach for improving water quality management in mining. *Environ. Sci. Technol.* 45: 7459-7464
- Liu W, Moran C J, Vink S. (2013) .Managing the potential risks of using recycled water in mineral processing to protect freshwater *Environ. Sci. Technol.* 47: 6582-6588
- Turbak S C, Olson G J, McFeters G A. (1979). Impact of western coal mining—I. Chemical investigations of a surface coal mine sedimentation pond. *Water Res.* 13: 1023-1031