Development and application of water quality criteria for reliable management of off-site risk

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Abstract The development and application of water quality criteria (guidelines) for mine water discharges and downstream receiving waters is critical to the management life-of-mine off-site risk for mining operations. While regulatory requirements may cover compliance risk, they may not protect all receiving environment values and may be under or over protective in different regulatory and climatic circumstances. International sets of water quality guidelines and management approaches are reviewed including those of the US, Canada, Australia, Europe (EC) and southeast Asia. The authors provide recommendations with respect to understanding the risks managed by industry best practice approaches to water quality criteria development.

Keywords guidelines, water quality, criteria, management, discharge.

Introduction

Setting quantitative water quality targets or criteria for mine discharges is a common requirement for proposed, active and closed mining operations. These criteria are required for both regulatory and engineering purposes, the former to establish a level of acceptable impact and the latter for feasibility, design and cost calculations. While "motherhood" statements about the intended level of impacts to social and environmental values may provide social and political acceptance for a project, quantitative targets will need to be established to put these statements into practice. Typically the targets will be set in terms of measurable parameters which are monitored over time to establish compliance with the level of impact agreed to by the project stakeholders.

In most developed nations the regulatory requirements for the quality of mine water discharges are clearly defined, if often complicated. The requirements in many developing nations can be less well defined as well as not protective of stakeholder values either locally to the project or internationally. In any case project proponents or operators should recognize the difference between regulatory compliance and risk mitigation. It is important to understand the level of risk mitigation achieved through implementing regulatory water quality criteria and to have considered the adoption of more stringent project specific criteria where residual risk would be unacceptable to the project.

Methods

This paper was developed through years of consulting experience in the field of mine water quality management and impact assessment by the authors as well as a literature review. Literature was sought outlining the philosophy behind the setting of water quality criteria in a suite of developed nations/regions (Australia, Canada, European Union and the US) and developing nations (China, Indonesia, Papua New Guinea and the Philippines). In order to restrict the scope to a manageable size, only criteria/guidelines for aquatic ecosystem protection have been formally referenced. There are many other water quality values that are often protected within the same or parallel frameworks in any given national guidance (*e.g.* recreational, drinking water, stock water, industrial supply).

Discussion

Background

The developed nations reviewed displayed a common approach with respect to setting numerical water quality criteria for the protection of aquatic ecosystems in that all placed ecotoxicity tests as a corner-stone in the process (ANZECC/ARMCANZ 2000, Environment Canada 1987, EU 2008, USEPA 1985). However, there were distinct differences in the level of standardization and scientific method used. Despite default criteria being largely derived from assessment of ecotoxicity testing data, almost universally there were alternate methods established in the guidance to allow regional, catchment wide and site specific criteria to be developed (*e.g.* ANZECC/ARMCANZ 2000, USEPA 1985, CCME 2007, MacDonald Environmental Services Ltd 1997). A common alternative to default guidelines is to allow an acceptable variance from the baseline conditions in the receiving waters as well as conducting ecotoxicity testing on local organisms for the substance of concern. In contrast, the EU has adopted a set of Environmental Quality Standards (EQS) that are common to all member states and which do not allow for regional variation (EU 2008).

There are variations around how substance toxicity data is applied to real-world management, which mirrors the complexity of transposing largely laboratory derived results to diverse aquatic ecosystems. In addition there are mitigating factors (*e.g.* water hardness, complexing molecules and organism adaptation) and antagonistic factors (*e.g.* stress from multiple toxic substances as well as pathogens) which are partially incorporated into criteria application in some national guidance (*e.g.* ANZECC/ARMCANZ 2000, CCME 2003) and not in others (*e.g.* EU 2008). It is common for guidance on criteria selection to be directed at water use (objective/value) with ecological protection being one of a number of categories of “use”, each of which has its own set of numerical water quality criteria. Further, within the category of environmental protection most guidance has incorporated two or more levels of protection based around either the length of time exposed to pollutants (chronic or acute; CCME 1999, CCME 2012, USEPA 2012) or the sensitivity of the ecosystem (ANZECC/ARMCANZ 2000).

The fact that most guidances on setting of water quality criteria are based on scientific testing of the toxicity of specific substances indicates that this is a best practice mechanism for assessing the risk from these substances in the environment. However, there are complications in applying these test data to managing aquatic ecosystems which have diversified the guidelines in this regard. While the more mature and resourced environmental regulatory bodies in developed nations have attempted to address this complexity to some degree, many if not most developing nations do not. The developing nations reviewed all had water quality criteria that was relative to the designated use of a water body (*e.g.* drinking, recreation, irrigation) though were universally less sophisticated in addressing acute/chronic toxicity issues, mitigating/antagonistic factors, ecosystem sensitivity or other issues with setting static numerical criteria (DENR 1990a and 1990b, ROI 2001, ROI 2003, ROI 2010, PRC 1984, PNG 2000 and 2002).

A common issue with the developing nation water quality criteria reviewed was that it was either not specific to ecosystem protection (*e.g.* ROI 2001 and DENR 1990) as well as it contained values that were well above what is considered protective by “best practice” ecotoxicity risk based guidelines (*e.g.* DENR 1990, ROI 2006, PNG 2002). Older style guidelines often set water quality criteria based on the ability to detect the substance of concern using available standard methods and instrumentation at the time of development and in general usage in laboratories within each country. As the instrumentation improved to be able to detect orders of magnitude lower concentrations the guideline criteria were not similarly amended. This may be a reflection of the often basic and aged instrumentation available in developing nation government labs in the past and the slow pace of adoption of new technologies where funds are insufficient for environmental laboratories to purchase as well as operate them. The authors are aware of instances of donations of new analytical instruments to developing nation environmental laboratories by overseas aid agencies only for the instrumentation to sit unused due to the lack of funding for supplies, maintenance or training of staff in their operation.

There are numerous issues with the application of numerical water quality criteria to specific aquatic environments which have recently been highlighted by the attempts of the United Nations to derive "international" guidelines (UN-Water 2011, UNEP/IWAG-TU 2012). In Australia and Canada the indigenous (first nations) cultural and spiritual values around water have been acknowledged if not smoothly integrated with the scientific management approach (CAGS 2013, DSEWPC 2012, CCME 1999). This is in nations with the financial and institutional resources to attempt to address these issues. In many developing nations the use of water has strong cultural links and perception of impact is as important to stakeholders as any scientific attempt to quantify it. These developing nations have, in general, fewer resources to manage water quality which in turn leads to less certainty on the level of risk to all water related values including cultural, ecosystem protection and economic uses.

Implications for managing mine water discharges

While in developed nations it may be acceptable for mining projects to meet the local criteria for water discharge quality as being arguably "best practice", this is often not the case for projects in developing nations. Multinational mining companies operating in developing countries have to respond to shareholder and international stakeholder expectation for management of environmental risks as espoused in the International Council on Mining and Metals Sustainable Development Framework, which may push them towards implementing water quality objectives that are more stringent than the national regulations require. National companies may also follow this path due to ethical as well as moral considerations, external stakeholder pressure, a desire to work to international best practice or the need to satisfy the requirements of funders and other stakeholders. In order to satisfy international funding (*e.g.* IFC 2012) risk management requirements, as well as corporate image/governance policy, mining companies are drawn to meet international best practice for projects in developing nations where regulatory requirements may not. Putting aside the moral implications of spending project funding on meeting standards that the developing nation may not have asked you to meet (and thereby reducing tax revenue), the issue then becomes what criteria should the project apply? As noted above, developing water quality criteria is complicated but choosing a set of criteria that are more stringent than those of the local legislation and then applying them is even more so.

Once a mining project starts down the path of setting its own water quality criteria it can choose to adopt default values from a "best practice" developed nation (IFC 2007), develop a table of criteria from a range of different but scientifically defensible sources as well as establish the baseline conditions for the receiving waters to propose an acceptable change over natural variability. This process may or may not involve establishing the values requiring protection within the receiving waters, based on stakeholder engagement as well as expert review. A critical point is that compliance with the local regulatory requirements in developing nations may not remove the risk to the project of being liable for unforeseen impacts. The same may well be true in developed nations, but the greater rigor of the regulatory framework shifts more of the burden of responsibility for the risk to the government as agency for the wider stakeholders.

It is typically hard to justify combining water quality criteria from multiple sets of national guidelines unless the required parameter suite is not available from a single guidance document. The Australian, Canadian and USEPA guidelines all have standardized approaches to setting numerical criteria which are slightly different from each other. In addition, using criteria meant to be protective of one use to manage a different receiving body water use objective is unlikely to be acceptable. An example of this would be using the drinking water criteria for metals where ecological criteria are not available. The human health risk from many metals is much lower than the aquatic ecological risk due to the different pathways of uptake and detoxification for humans, particularly the lack of gill and general body surface uptake pathways.

The Australian guidelines allow the setting of numerical water quality criteria based on an allowed variance from the existing of baseline conditions for the substance of concern. In its default form this approach requires the median concentrations of the impacted (post mine discharge) waters to be below the 80th percentile of the baseline or non-impacted waters (ANZECC/ARMCANZ 2000). This approach uses existing conditions as a guide though has timing issues where the baseline is highly variable and the mine discharge more constant. It also assumes that all substances of concern have the same linear risk increase with respect to increases over baseline concentrations, which is not always the case. Using a combination of the default numerical criteria (which are ecotoxicity based) and acceptable variance from baseline, lowers the risk that existing system will not be unacceptably impacted.

The highest cost, though potentially lowest residual risk approach is to conduct whole effluent or direct toxicity assessment (WET or DTA in the different guidances) where various concentrations of the mine water discharge is mixed with the receiving water under laboratory conditions to assess the toxicity to specific aquatic organisms. This approach covers several of the issues with default trigger values including assessing the mitigating and antagonistic effects of constituents of both the discharge and receiving waters. It also informs potential cumulative impacts as a range of dilutions are tested allowing for assessment of changes in the relative ratios of discharge and receiving waters. The results from WET/DTA testing still require expert ecotoxicological interpretation as the laboratory conditions can never fully replicate the receiving environment, including complex food webs, chronic bioaccumulation/sediment storage and biogeochemical transformation processes (ANZECC/ARMCANZ 2000, USEPA 1985).

A multiple-lines-of-evidence approach is likely to provide the best assessment of the risk from any given mine water discharge. Having an understanding of the hydrology, ecology and physico-chemical characteristics of the receiving environment, including the variability of each aspect, allows for the identification of higher risk conditions. An example would be a river system that has periods of very low flow, anoxia and high water temperatures which could be improved in terms of physiological stress to aquatic organisms by a constant mine discharge of high water quality or the naturally stressed ecosystem could be catastrophically impacted by a water quality discharge that would be considered of minor water quality implications under other circumstances.

Understanding factors such as the sensitivity of the aquatic flora and fauna to any substance of concern can promote adaptive management approaches including lowering or avoiding discharge during critical life-stages. Mining projects can collect valuable information during baseline studies, suitable for ecotoxicity assessment of planned discharges, with relatively minor additional cost. Parameters such as water hardness, major ion concentrations, dissolved organic carbon (mitigates some metal toxicity), sediment particle size and organic carbon content, periphyton coverage (algae that grows on submerged rocks) and flow volume variability can be added to existing water quality monitoring programs for relatively minor additional cost over those of the parameters of potential concern.

Conclusions

The development and application of water quality criteria for the reliable management of off-site risk requires going beyond default guidelines, regardless of the international standing of those guidelines. While the major international guidelines are typically risk assessment based, they also contain considerable guidance and recommendations on going beyond the default criteria they provide. This is the reason that even within Australia, Canada, the EU and the US there are regional and even water body specific guidelines developed under the national frameworks. If different aquatic ecosystems within the same region require their own numerical water quality criteria to be protective (*i.e.* mitigate the risk of adverse impacts) then it is reasonable to assume that the same may be true of the receiving waters for any mine discharge. This is particularly true when the mine is in a different country and even bio-climatic region. In developing countries with less protective water quality regulation frameworks, simple compliance may not adequately manage environmental risk, and international funding requirements and stakeholder expectations will often drive the need to take a more risk-based approach to water quality management and assessment.

Mining operations can significantly reduce the risk of unacceptable impacts to receiving water ecological values by implementing a set of risk based criteria systematically derived from ecotoxicity data such as those from Australia, Canada or the US. However, the degree of residual risk should be at least assessed as acceptable through understanding of the limitations of the chosen default criteria in the context of the local receiving ecological system.

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