Mine Water Remediation at Large-Scale Metal Mines: Balancing Near-Term Expenditures for Source Control with Long-Term Expenditures for Collection and Treatment

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Abstract Mine water remediation at large-scale metal mines can be a technically challenging and expensive endeavor. Achieving an appropriate balance between near-term capital expenditures focused on source control and long-term expenditures focused on water treatment provides a means to achieve compliance with environmental laws and regulations, while managing capital expenditures by either private mining corporations or government agencies. Effective mine closure decisions can be supported through economic evaluations and consideration of other site management issues by project decision-makers and stakeholders.

Key Words mine closure, cost estimation, mine water treatment

Introduction

Remediation of large-scale metal mines presents tremendous challenges to decision-makers and stakeholders, including mining corporations, government representatives, and non-government organizations (NGOs). Often, goals of these stakeholders contrast markedly, which leads to disagreement regarding remediation strategies and investment of always-limited capital. In the mature environmental regulatory climate of the United States, a walk-away solution is seldom attained, and remediation commonly includes a combination of near-term expenditures to reduce mine water generation, and long-term expenditures to provide for mine water treatment. Achieving an appropriate balance between phased expenditures is an important consideration to efficiently remediate mine water issues at large-scale metal mines.

Decision-makers and stakeholders are often faced with an array of potential remediation strategies, which include various combinations of phased expenditures. Larger near-term expenditures are generally correlated with smaller long-term expenditures, because expenditures that reduce mine water generation rates decrease costs to collect and treat mine water. Present value analysis of potential remediation strategies displays short and long-term costs in a common monetary basis, and identifies the reduction in long-term mine water treatment costs that would be expected with a given level of near-term expenditure. Cost estimate risk analysis in conjunction with present value analysis evaluates cost uncertainties related to these expenditures. These are effective tools to identify strategies that are economically efficient, and thereby constrain the range of appropriate remediation strategies.

Additional site management issues are also important to consider during the process of assessing potential remedial strategies. These issues include human health and ecological risk, uncertainty in future environmental regulations, remedy performance risks, sustainability considerations, and funding considerations. These issues should be considered along with the results of economic evaluations to provide for mine remediation decisions that better meet the needs of all stakeholders.

Economic Evaluations

Present Value Analyses

Typically, to assess the payback period of a near-term expenditure, an engineering cost estimate is performed to evaluate the near-term capital cost associated with source control infrastructure in relation to long-term mine water collection and treatment costs. However, present value analysis can also be used to compare potential remedial strategies, and to evaluate whether proposed strategies are economically efficient considering both short- and long-term expenditures. For purposes of this discussion, economic efficiency is defined as expenditures by either private industry or government agencies that manage the environmental liability associated with mine water in an efficient manner.

Present value analysis is an established method to consider the value in current dollars of a series of future expenditures (EPA 2000). The present value (PV) is the amount of money that would need to be set aside today to provide for the planned series of future expenditures, assuming specific economic conditions. Where X_t is the payment in year t and i is the discount rate, PV is defined as:

$$PV_{total} = \sum_{t=1}^{t=n} \frac{X_t}{(1+i)^t}$$

The primary assumption regarding future economic conditions is the selected discount rate. The discount rate is similar to an interest rate, and accounts for the time value of money. The discount rate accounts for the productivity of capital if applied to alternative uses. For example, if capital is invested rather than expended, it would earn interest. Therefore, the current value of a dollar is higher than the value of a dollar that must be invested some time in the future. This is expressed in terms of a discount rate, which is a percentage generally in the range of 3 to 7 percent. A higher discount rate results in a lower present value of future investments, due to an increased amount of earned interest. Other assumptions that must be made for this estimate include the period of analysis (e.g. the duration of water treatment) and the water treatment costs.

Table 1 summarizes an example evaluation of the present value of long-term water treatment at a theoretical metal mine. For the purpose of this example, the cost of water treatment is assumed to be $3 per thousand liters, which is a reasonable value for high-density lime treatment at a closed metal mine. The volume of mine water treatment is assumed to be 400 million liters per year, and the capital cost of a water treatment plant is assumed to be $5 million. Although these are simple examples to facilitate discussion, each of these assumptions is a site-specific cost that could be estimated at a large-scale metal mine. The evaluation was conducted assuming a duration of water treatment of 100 years and discount rates of 3, 5 and 7 percent.

The 7 percent discount rate is a less conservative assumption of future economic conditions than the 3 percent discount rate assumption. The discount rate used in assessment of potential costs of long-term treatment should be considered on a site-specific basis with careful consideration of current and projected economic conditions. However, for this theoretical large-scale metal mine, remedies that focus on source control rather than water treatment would be less economically efficient if they are predicted to cost significantly more than $44 million dollars. This is because a similar level of environmental protectiveness for water quality could theoretically be achieved with treatment rather than source control.

Cost Estimate Risk Analysis

Cost estimate risk analysis is another economic evaluation tool that can be used to facilitate mine remediation decisions. Costs of potential mine closure strategies are generally estimated at several phases of a mine closure project, with various levels of accuracy as dictated by the stage of the mine closure design. These engineering cost estimates consist of a compilation of various costs, design quantities, and assumptions, all of which contain some level of uncertainty. The cost estimate risk analysis uses Monte Carlo simulation to propagate uncertainties associated with each of the inputs through the engineering cost estimate. This provides a probabilistic estimate of cost risk exposures that would be expected for a given remedial strategy based on the identified uncertainties (ASTM 2007).

Table 1 *Example of present value evaluations for long-term mine water treatment*

Annual Mine Water Treatment Volume (liters)	Mine Water Treatment Cost ($ per 1000 liters)	Initial Treatment Plant Capital Cost	Discount Rate	Present Value of Mine Water Treatment (100 year duration)
400 million	$ 3.00	$ 5 million	7 percent	$ 23.3 million
400 million	$ 3.00	$ 5 million	5 percent	$ 30.0 million
400 million	$ 3.00	$ 5 million	3 percent	$ 44.1 million

Monte Carlo simulation considers that each of the various inputs to the closure cost estimate have some uncertainty associated with them. For example, the future diesel fuel cost even 1 year from now is generally unknown. In Monte Carlo simulation, the future diesel fuel cost is expressed as a probability distribution that defines a most likely value as well as a range of potential values and the probability of those other values. The specific probability distributions for various inputs can be developed based on historical values adjusted for inflation, estimates of the range of uncertainty associated with quantities such as volume estimates, or professional judgment. During the Monte Carlo simulation, a computer program selects a random value for each of the inputs from the defined probability distributions, and then re-calculates the overall cost estimate. The computer program repeats this process thousands of times, and develops a probability distribution that defines the probability that the cost will be below some value at a selected level of certainty. For example, the effort may determine that the cost of a potential closure strategy has a 50 percent probability to be below $75 million dollars, but a 95 percent probability to be less than $95 million.

Risk analysis using Monte Carlo simulation provides a confidence interval associated with an engineering estimate. It can also facilitate comparison of costs related to various mine closure strategies using a standard probability level and identify critical elements that are "drivers" to the overall cost risk. For example, a cost estimate associated with a large-scale earthmoving and geosynthetic cover installation project would have cost risks related to petroleum costs, because of the use of petroleum in manufacture of both diesel fuel and geosynthetic products. An alternative mine closure option focused on long-term water treatment may be less dependent on petroleum costs, but more dependent on chemical reagent costs, electrical power, and labor. Analysis of risks associated with cost estimates facilitates better comparison of costs for different closure strategies, and facilitates better mine closure decisions.

Other Site Management Considerations

Although the economic evaluation tools described above are valuable to facilitate appropriate mine closure decisions, there are additional site management issues that also require consideration. These issues are additional mine closure decision inputs, which can affect the weight that is applied to purely cost-based economic analyses. The priority of these issues in mine remediation and closure decisions may be viewed differently by various stakeholders such as mining corporations, government representatives, and NGOs.

Human Health and Ecological Risk

Protection of human health and the environment is a major goal of large-scale metal mine closure. Although mine water remediation is a particularly challenging aspect of mine closure, additional risks to human health and the environment may be present (EPA 2001). For example, risks related to direct inhalation, ingestion, or wind dispersion of fine grained mine wastes may be important. Mitigation of these types of risks may require near-term expenditures to cover or stabilize fine grained mine waste, regardless of the results of economic analyses focused on mine water remediation.

Uncertainty in Future Regulatory Requirements

Uncertainty in future regulatory requirements is an additional consideration in selecting appropriate mine closure strategies. In the United States, surface water quality standards are reviewed every 3 years and revised if necessary, based on new water pollutant toxicity information. Although this practice facilitates protection of human health and the environment, it creates difficulties during closure of large-scale metal mines. These difficulties arise because the water quality standards that a closed mine must meet in the future are strictly unknown. Strategies focused on long-term mine water treatment are somewhat less subject to this risk, because less capital is expended in the short-term. Modifications to a water treatment system can be implemented in the future, if necessary, to address changing water quality standards.

Remedy Performance Risks

Risks that a remedy will not perform as designed should also be evaluated during the mine closure decision-making process. These risks are highest for remedial strategies focused on source control, because these strategies often require high near-term capital investments. This risk is lower for strategies focused on long-term water treatment, because short-term capital costs to implement the strategy are lower than strategies focused on source control.

Sustainability Considerations

The principles of sustainable development are being applied to mine closure projects by private industry and government agencies. Potential sustainable development considerations for mine closure projects include environmental, social, health, safety, cultural, political and spiritual issues (ICMM 2008). Energy efficiency, use of alternative energy sources, re-use and recycling are also considerations to improve the sustainability of mine closure projects.

Funding Considerations

The source of funding for capital expenditures and competing needs for that capital are also important considerations in selecting appropriate remediation strategies. When mine closures are conducted by private industry, competing needs for near-term capital are critical issues, because the capital could be invested in other ways if an alternative strategy is selected that requires a lower near-term capital investment. Large near-term capital investments may also adversely affect shareholder earnings for publically-traded mining companies.

This is also a critical issue in government-funded mine closures, because competing needs for available government funding are commonly present. Government funding of large-scale mine closure projects in the United Sates is conducted in numerous ways, and the ability of government agencies to fund mine closure is sometimes dependent on whether expenditures are related to near- or long-term expenditures. In the event that mine closure is implemented by near-term government funding mechanisms, it may be appropriate to select remedial strategies focused on source control even if a remedy focused on long-term treatment would be a good option based solely on economic analyses. Government representatives may also prefer remedies focused on source control, because of uncertainties in future funding for long-term mine water treatment.

Conclusion

Closure of large-scale metal mines in the modern U.S. regulatory environment is often a technically challenging and expensive endeavor. Achieving an appropriate balance between near-term capital expenditures focused on source control and long-term expenditures focused on water treatment provides a means to achieve the requirements of environmental laws and regulations, while managing the level of capital expenditures for either private mining corporations or government agencies. It is helpful to consider both cost-based economic evaluations and additional site-management issues during the process of selecting the best remedial strategies for mine closure. Although disagreements regarding appropriate remediation strategies may occur between mining corporations, government representatives, and other potential stakeholders (e.g. NGOs), consideration of both the economic evaluations and site-management issues described in this paper will support mine closure decisions that protect human health and the environment, while providing for efficient and effective expenditure of either private or government funding sources.

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