CASE STUDIES OF COSTS AND LONGEVITIES OF ALKALI-BASED WATER-TREATMENT PLANTS FOR ARD[1]

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Abstract. This paper provides an approach for roughly estimating the capital and annual operating costs, and the longevities (time to substantial replacement or upgrade), of alkali-based water-treatment plants for ARD. Under most combinations of flow and acidities, these plants will be the only cost-effective option for long-term consistent adherence to water-quality restrictions.

Median and mean capital costs were roughly US$3.8 and $4.5 million, and there was a correlation with average annual flow rate. There were no strong correlations among total annual operating costs, flows, and acidity concentrations due to highly variable individual contributions from factors like power and reagents. Nevertheless, an average unit-volume treatment cost was US$0.27/$m^3$ for acidities less than 800 mg/L, and was US$2.24/$m^3$ for acidities above 4000 mg/L.

The reported longevity of these water-treatment plants is around twenty years, attributable to factors such as increasing chemical loadings, increasing flows, and improved technology. A replacement period of 20 years can have a significant, but not dominant, effect on net present value over 100 years.

Passive treatment systems and soil covers do not usually attenuate concentrations consistently to non-toxic discharge levels, so additional treatment can be required. If this involves a water-treatment plant, an interplay of combined costs, longevities, durations, and risks leads to a myriad of waste-management scenarios. For example, a soil cover that lessens annual acidity loadings can extend the number of years a treatment plant operates; thereby increasing (1) the length of time the mining company must maintain a site presence and thus (2) the risk posed by a greater probability of intense storm events or other problems leading to an accidental release of contaminated water.

Long-term costs for passive treatment systems, like wetlands, and soil covers are not as well defined. This can give the false impression that water-treatment plants are more expensive in the long term.

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Introduction

The most expensive aspects of some mining operations involve long-term water management and treatment, due to acidic pH and/or unacceptably high aqueous concentrations. The time period for such management and treatment can span many decades to centuries (e.g., Morin and Hutt, 1997 and 2001).

Prior to detailed engineering and costing, we have found that initial, rough estimates of water-treatment costs can be helpful in generally ranking mitigation options. This focusses subsequent efforts on the most viable options.

Over a large range of flow and acidity levels, the only consistently effective method of treating water is often an active water-treatment plant (Fig. 1). Consequently, the capital costs, annual operating expenses, and longevities of water-treatment plants are important in estimating future environmental costs for many minesites.

At this time, passive systems, such as wetlands and sulphate-reducing bacteria, can treat only relatively low flows and acidities at reasonably competitive costs (Taylor and Waters, 2003). Also, in most climates, soil covers can reduce the flow of water through a minesite component, but cannot completely eliminate the flow or reduce aqueous concentrations to non-toxic levels (e.g., Morin and Hutt, 1997 and 2001; Morin et al., 2003; Morin and Hutt, 2006). Additionally, significant uncertainties remain that affect the long-term performance and costs of soil covers (e.g., p. 62 of O'Kane Consultants, 2004). Therefore, the capital costs, annual operating expenses, and longevities of these other systems are important, but are relatively poorly defined under full-scale conditions at this time.

Objectives and Limitations

At minesites with acidic pH and/or elevated aqueous concentrations, a common treatment method involves pH adjustment with alkali (typically lime) followed by removal of the precipitated solids (sometimes called "sludge"). This is often done within an engineered structure that includes pumps, tanks, thickeners, and /or settling tanks. This type of treatment plant is the primary focus of this paper.

To obtain rough estimates of water-treatment costs, we have compiled case studies from minesites using alkali-treatment plants (predominantly using lime and in North America). We reviewed capital costs for construction as well as annual operating costs, searching for correlations with factors such as flow rate and aqueous acidity concentrations. We also considered the elapsed length of time ("longevity") before a treatment plant required major replacement or upgrade.

There are difficulties in comparing treatment-plant costs. For example, some costs are low when a minesite is operating, because these costs are considered part of mine operation. After a minesite closes, these costs can rise substantially - maintaining a power supply is a good example. Also, some minesites can dispose of sludge on-site with minimal capital and operating costs, whereas others may have to build and operate expensive shipping and secure disposal systems for sludge (e.g., Zinck, 2005). Therefore, we realize there are substantial site-specific differences among the plants, but we wish to develop generic rough guidelines for estimating costs.

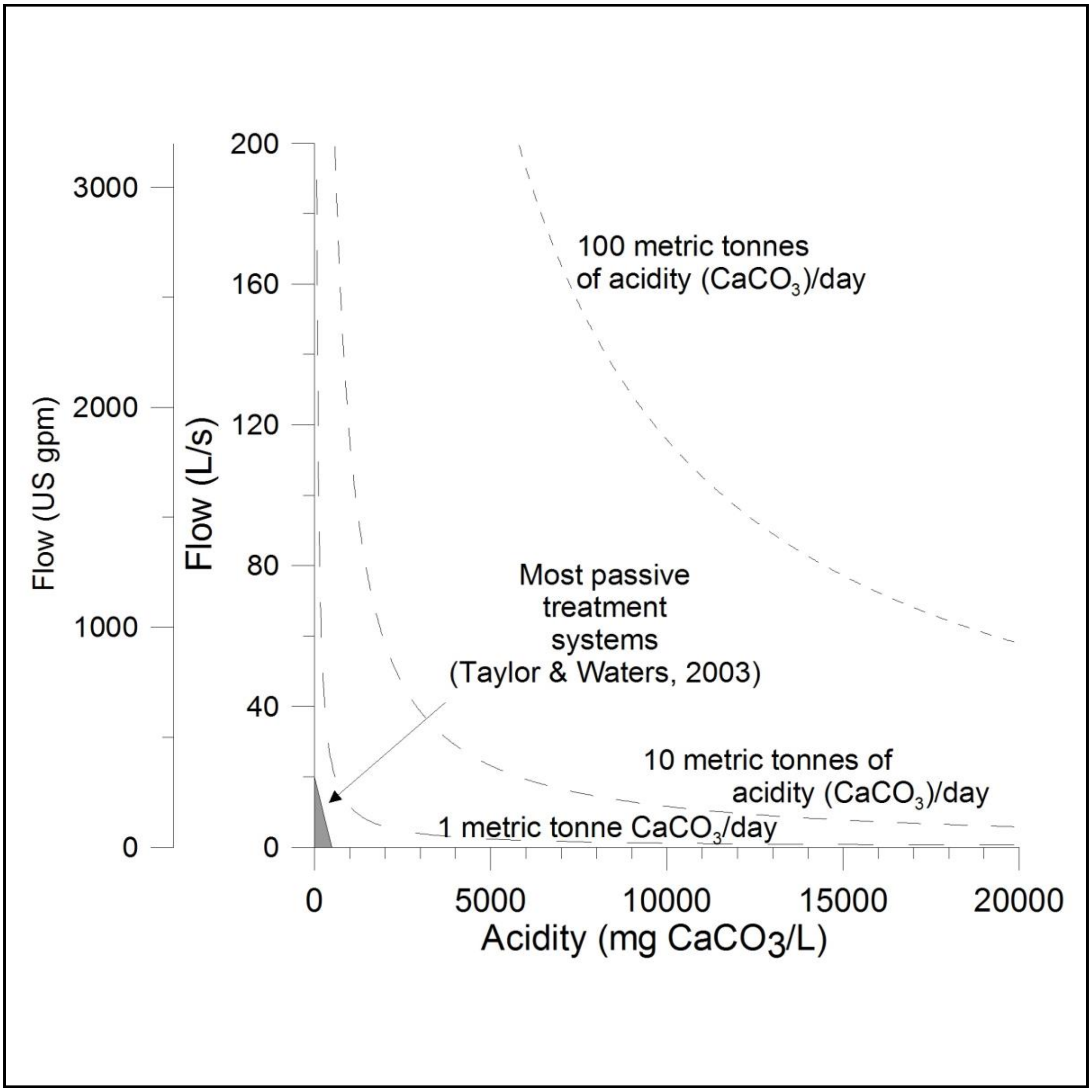

Figure 1. General Range of Flows and Acidities at Minesites, Plus the General Range Treatable by Passive Systems According to Taylor and Waters (2003).

Another difficulty is obtaining reliable costs. Rarely have we found capital costs, annual operating costs, hydrologic data, and geochemical analyses for a water-treatment plant all in one reference. Moreover, many plant owners are reluctant to release information on costs, perhaps because they represent long-term liabilities and potential stakeholder concerns. Therefore, we have assembled information from various sources, mostly confidential, yet for some plants we are still missing data on one or more aspects. Other factors affecting costs are (1) hydrologic wet and dry years, where a wet year may result in a much higher annual operating cost, and (2) year-round versus periodic (batch) operation of a treatment plant, which can lead to substantially different costs even if the same average annual volume of water is treated. For the costs we could locate, all were adjusted to 2005 U.S. dollars based on the Consumer Price Index (Sahr,

2005) and government-specified average-annual international exchange rates for those outside the USA.

Costs and Longevities of Alkali-Based Water-Treatment Plants

A compilation of capital costs for 21 alkali-based treatment plants at minesites, not including external costs such as storage ponds and pumps but including engineering and management, showed that capital costs ranged from approximately US$225,000 to nearly $12 million (2005 U.S. dollars). Costs generally correlated with the average annual flow of water requiring treatment (Fig. 2). Median and mean costs were roughly US$3.8 and $4.5 million.

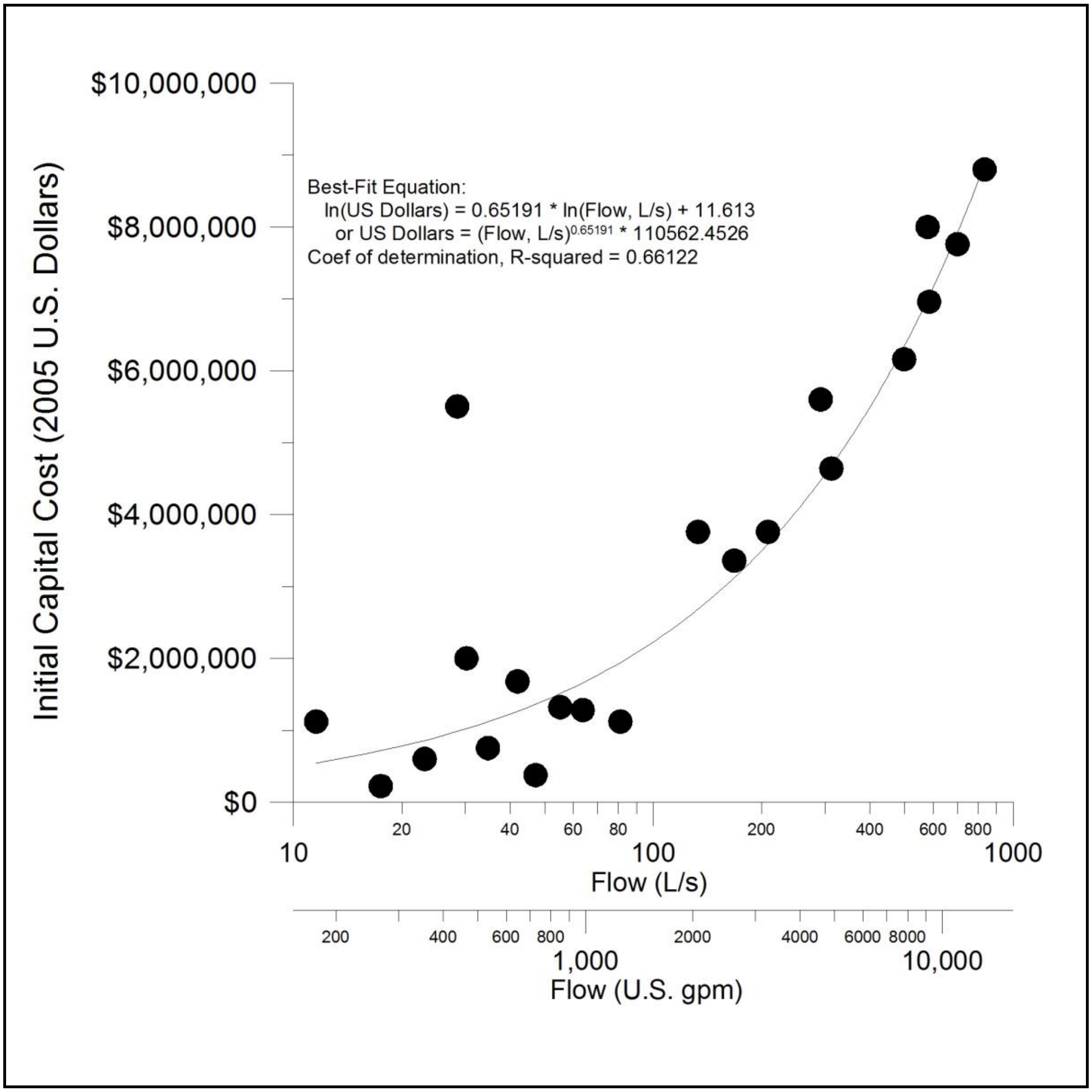

Figure 2. Initial Capital Costs vs. Average Annual Treatment Flows for 21 Alkali-Based Water-Treatment Plants.

A compilation of annual operating costs at 10 alkali-based treatment plants, with flows below 500 L/s, showed that their annual costs are typically less than US$1.4 million/yr (Fig. 3). There were no good correlations of annual cost with either acidity concentration or flow rate. However, greater annual flows generally cost less to treat on a unit m^3 basis (Fig. 4), probably due to economy of scale. Some relationship to acidity concentrations can also be seen in Fig. 4, with an average unit-volume cost of US$0.27/$m^3$ for acidities less than 800 mg/L, and an average unit-volume cost of US$2.24/$m^3$ for acidities above 4000 mg/L. We expect that multi-dimensional correlations exist among acidity concentrations, flow, and treatment costs, but we have too few datapoints to determine this.

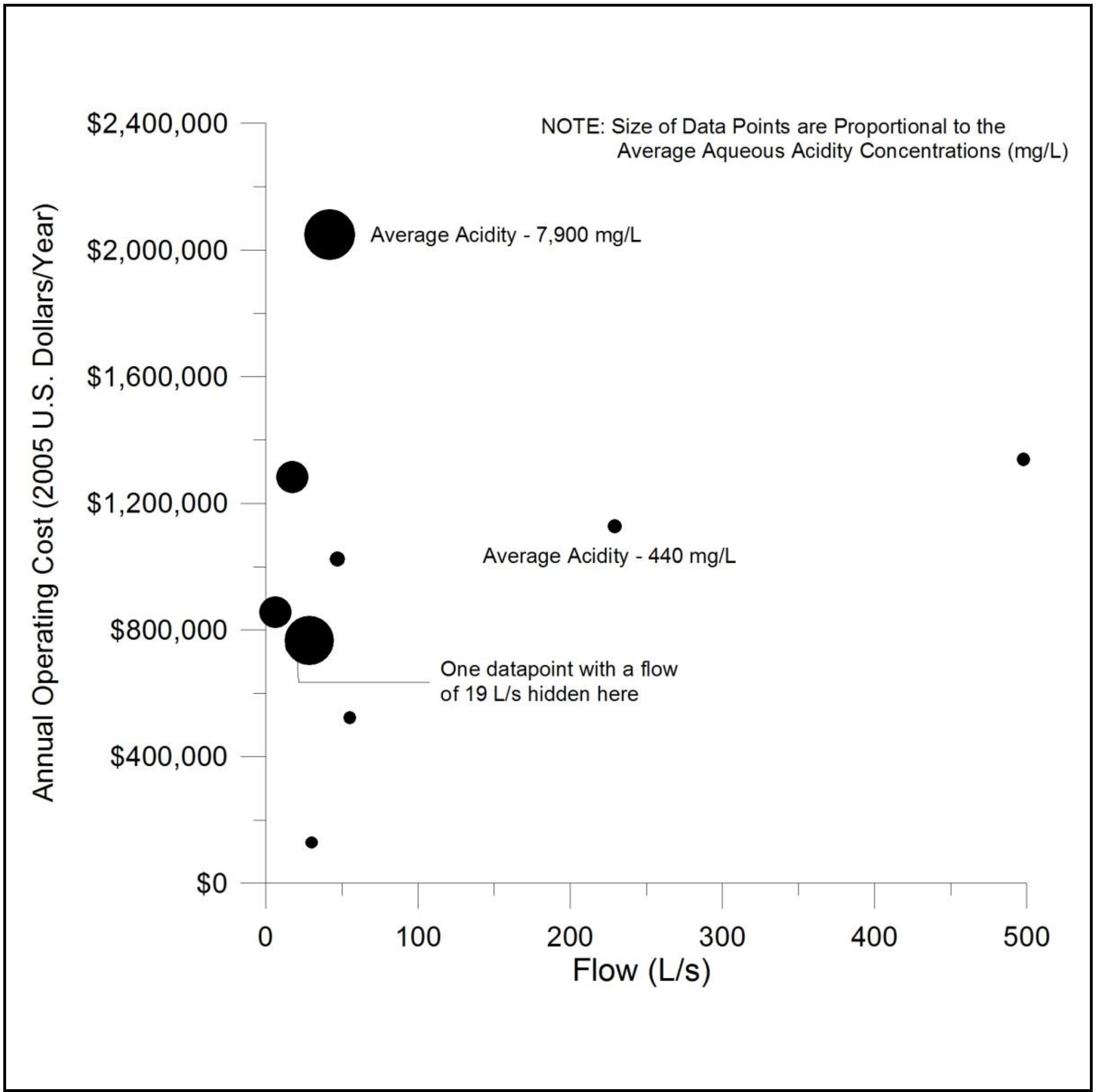

Figure 3. Compilation of Annual Operating Costs vs. Treatment Flows and Acidity Concentration for 10 Alkali-Based Water-Treatment Plants.

The annual operating cost reflects the sum of a number of individual costs such as labour, alkali (e.g., often costing around US$130-250/tonne delivered to a minesite in Canada), maintenance, power, and sludge disposal (Fig. 5). In our compilation, there was no one individual cost that consistently dominated all others, although the alkali cost was often dominant for higher flows with higher acidity concentrations. Thus, estimating annual operating costs using simple correlations such as flow (as shown in Figs. 3 and 4) is not highly reliable.

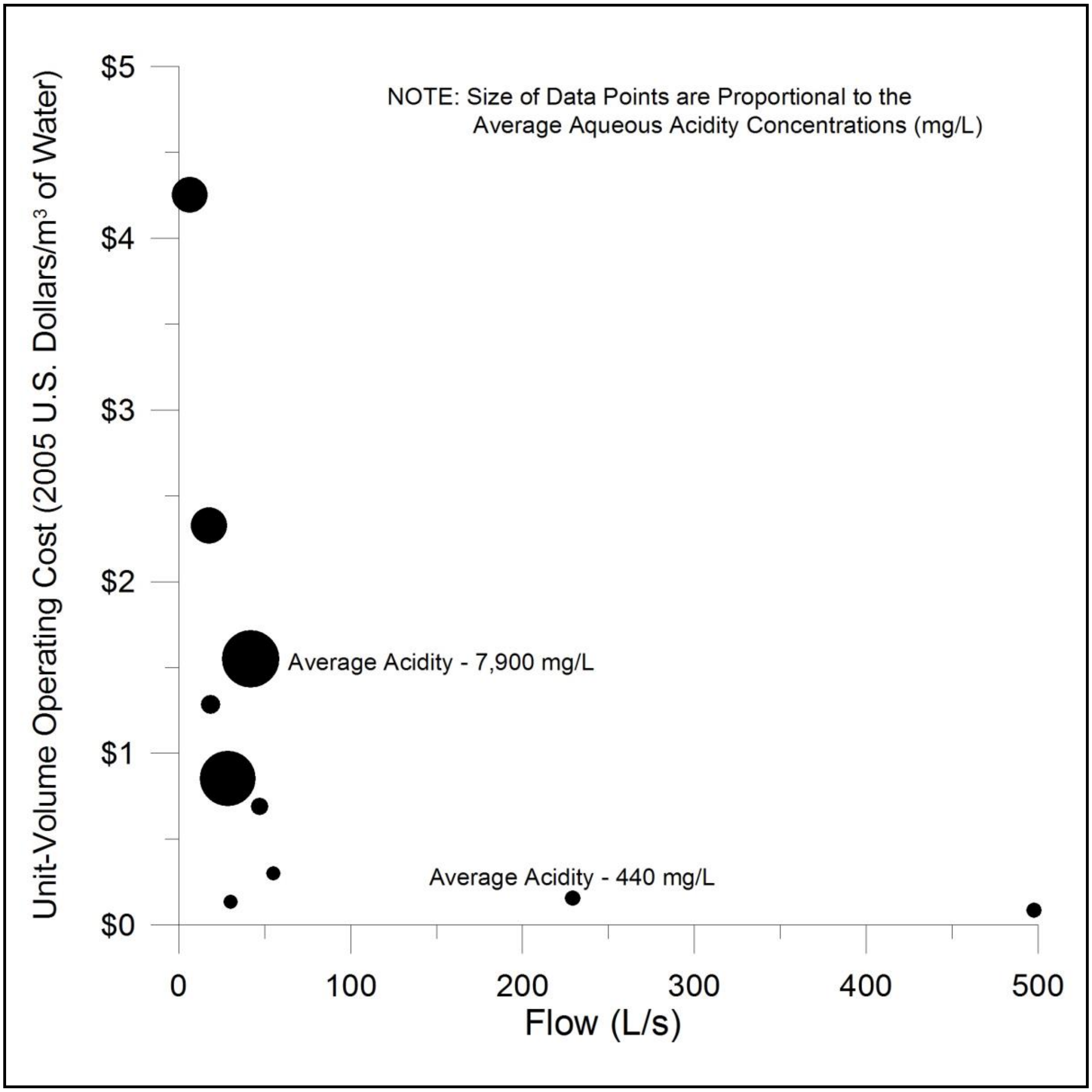

Figure 4. Compilation of Operating Costs per m3 of Water vs. Treatment Flows and Acidity Concentration for 10 Alkali-Based Water-Treatment Plants.

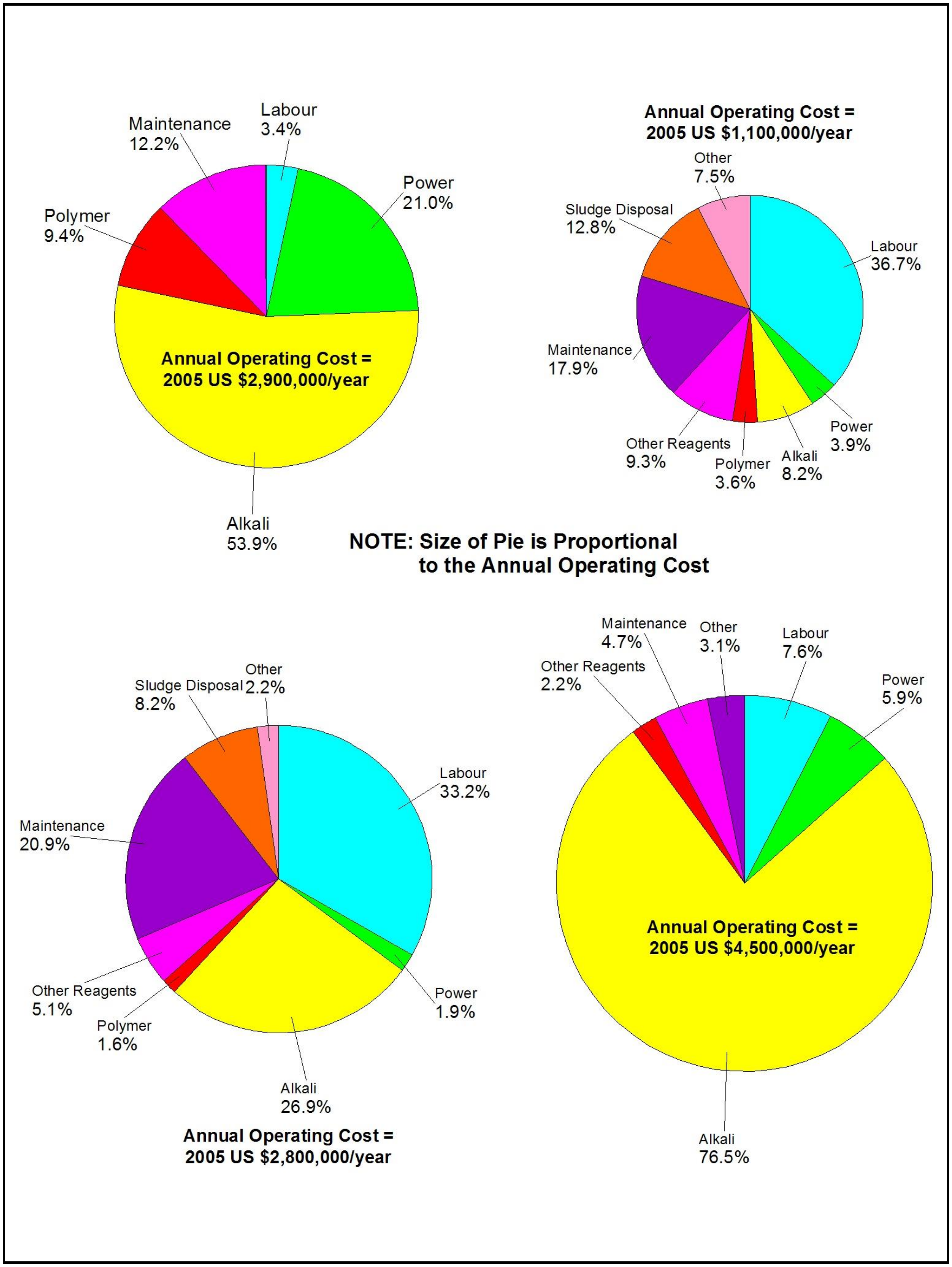

Figure 5. Examples of Individual Costs Contributing to the Annual Operating Costs of Four Alkali-Based Treatment Plants (size of pie is proportional to total annual operating cost and individual costs are percentages of total annual cost).

Not apparent in these costs are the longevities of the treatment plants. A design life of, for example, 20-25 years can be assumed for a lime-treatment plant (e.g., Higgs, 2002; Koehnken et al., 2003). In our experience, this is a reasonable assumption, because a number of plants have been replaced after roughly 20-25 years due to factors such as increasing chemical loadings, increasing flows, and improved cost-effective technology. Therefore, the assumption that an alkali-based water treatment plant requires replacement every 20-25 years is reasonable based on available information.

Effects of Longevities and Replacement Costs on Net Present Value

As shown above, the overall cost of treatment-and-control of minesite drainage involves not just original capital cost, but also annual operating costs and periodic replacement. Interestingly, annual costs, which can significantly increase long-term cumulative costs, have often been initially estimated for treatment plants (e.g., Fig. 5), but have often been omitted in initial cost estimates for passive systems and soil covers. This lack of annual costs and periodic replacement or upgrade, combined with their typically higher risk of periodic non-compliance, often makes passive systems and soil covers incorrectly appear more attractive economically. Put simply, the ability to estimate better the relatively high costs of water-treatment plants does not mean the currently less accurate, typically lower estimates of other systems automatically make them viable alternatives.

To assess overall cost, organizations may consider estimates of "net present value" of the treatment-and-control system selected for a minesite. "Net present value" is the current value of all capital, annual operating, periodic maintenance, and longer-term replacement costs that are expected to be incurred for some specified period into the future. Basically, net present value reflects the amount of money needed today (2005 dollars), based on anticipated future rates of inflation and interest, to pay for all future costs. The approach used here to calculate net present value is (e.g., British Columbia Ministry of Water, Land and Air Protection, 2003):

$$\sum_{n=0}^{term} \{[(CC_n + OC_n)*(1+IF)^n]*[1/(1+IT)^n]\} \tag{1}$$

where n = year (0 to selected number of years as the "term")

term = time span of present-value calculation (years)

CC_n = Capital Cost, if any, in Year n ($)

OC_n = Annual Operating Cost in Year n ($)

IF = Inflation Rate (e.g., 0.02 or 2%)

IT = Interest Rate (e.g., 0.04 or 4%)

For example, a hypothetical water-treatment plant for ARD has an initial capital cost of US$3 million (2005 dollars) and an annual operating cost of $600,000/yr. Based on an annual inflation rate of 2% and an interest rate of 4%, the net present value of this system over a 100-year period would be nearly $30 million (Fig. 6).

If the plant is replaced every twenty years at a cost of $3 million each time, then the present value rises to more than $35 million, or an increase of 18% (Fig. 6). Therefore, estimates of longevities and long-term replacement costs of treatment plants can significantly affect the net present value of treatment.

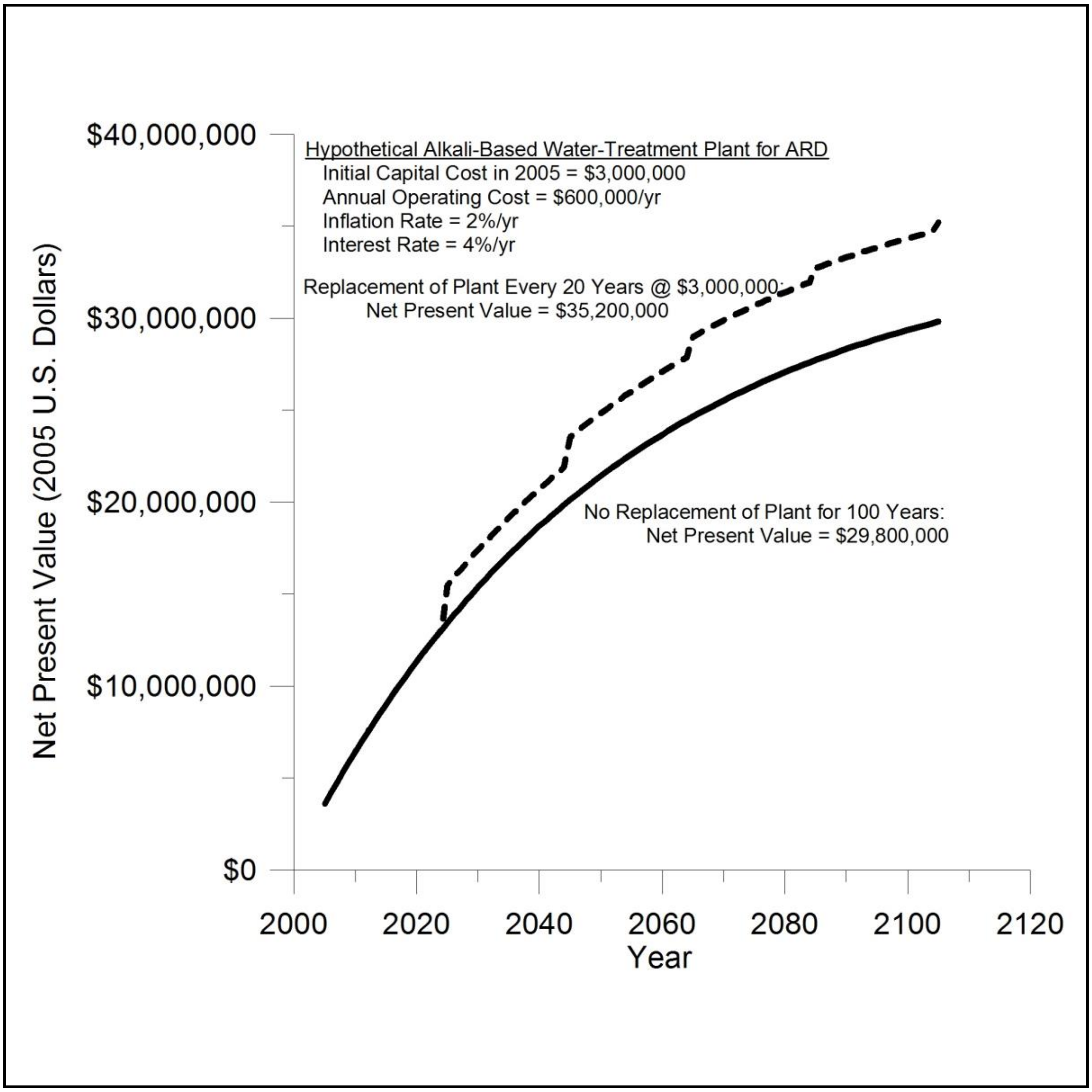

Figure 6. Net Present Value of a Hypothetical Water-Treatment Plant Up to 100 Years, With and Without Replacement Every Twenty Years.

Long-Term Costs of Other Treatment Systems and Soil Covers

Interestingly, similar analyses of other passive systems and of soil covers show that their long-term costs can sometimes approach those of a water-treatment plant. More importantly, if another system does not fully alleviate the need for additional treatment under all on-site conditions, then a treatment plant may still be needed. At some sites, the success and long-term costs of other treatment systems and of soil covers may not be initially considered, because of poorly defined capital costs, annual operating costs, longevities, frequencies of exceedances of water-quality criteria, and environmental risks. These poorly defined factors can give the false impression that water-treatment plants are more expensive in the long term. Hicks (2003) presents a good example of this for ARD at a non-mining site.

For example, if both a soil cover and a water-treatment plant are required, dual long-term costs arise in some non-linear proportional manner. A cover that lessens the annual operating cost of the plant, by lessening the annual acidity loading, will extend the number of years that the plant must operate until all substantial acidity is depleted. For time periods longer than 100-200 years, this will have only a small effect on the net present value, but larger effects on (1) the length of time the mining company must maintain a site presence and thus (2) the risk posed by a greater probability of intense storm events or other problems leading to an accidental release of contaminated water.

This interesting interplay of costs, longevities, durations, and risks, combined with other mitigation options, lead to a myriad of waste-management scenarios for any one minesite. For alkali-based water-treatment plants, this paper has provided an approach for roughly estimating in advance their capital and annual operating costs, and their longevities, allowing an initial ranking with other mitigation options to focus more intensive work.

Tools, like AMDTreat (Office of Surface Mining, 2005), combined with realistic site-specific estimates, will eventually lead to more consistent and standardized cost comparisons of waste-management options.

Conclusion

This paper provides an approach for roughly estimating the capital and annual operating costs, and the longevities, of alkali-based water-treatment plants for ARD. During initial studies, this allows a ranking against other mitigation options to focus subsequent work. Under most combinations of flow and acidities, treatment plants will be the only cost-effective option for long-term consistent adherence to water-quality restrictions.

For capital costs, median and mean costs were roughly US$3.8 and $4.5 million, and there was a correlation with average annual flow rate. For annual operating costs, the individual contributions from labour, power, reagents, sludge disposal, and other factors were highly variable among the plants, so that there were no strong correlations among total annual operating costs, flow, and acidity concentrations. Nevertheless, an average unit-volume treatment cost was US$0.27/m^3 for acidities less than 800 mg/L, and was US$2.24/m^3 for acidities above 4000 mg/L.

Case studies show that alkali-based water-treatment plants at minesites can require replacement after approximately twenty years, at capital costs similar to original values. Thus, the typical longevity of these water-treatment plants is around twenty years, attributable to factors such as increasing chemical loadings, increasing flows, and improved technology.

To illustrate the effect of longevity on net present value, a hypothetical water-treatment plant has a capital cost of US$3 million (2005 dollars) and an annual operating cost of US$600,000/yr, which is not unusual for ARD. Based on an annual inflation rate of 2% and an interest rate of

4%, the net present value of this system over a 100-year period would be nearly $30 million. If the plant is replaced every twenty years at a cost of $3 million each time, then the net present value rises to more than $35 million, or an increase of 18%.

Passive treatment systems and soil covers do not usually attenuate concentrations consistently to non-toxic discharge levels, but can reduce annual volumes of contaminated water. As a result, additional treatment can be required. If this involves a water-treatment plant, an interplay of combined costs, longevities, durations, and risks leads to a myriad of waste-management scenarios. For example, a soil cover that lessens annual acidity loadings will extend the number of years a treatment plant operates; thereby increasing (1) the length of time the mining company must maintain a site presence and thus (2) the risk posed by a greater probability of intense storm events or other problems leading to an accidental release of contaminated water.

This paper provided some rough cost estimates for treatment plants. However, such costs for passive treatment systems, like wetlands, and soil covers are not as well defined and thus poorly estimated for initial rankings. This can give the false impression that water-treatment plants are more expensive in the long term. Detailed, long-term case studies of passive treatment systems and their costs, combined with tools like AMDTreat, will eventually lead to more consistent and standardized cost comparisons of waste-management options.

Acknowledgments

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