International ARD Treatment and Sludge Management Survey[1]

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ABSTRACT

Acid rock drainage (ARD) treatment and sludge management are two important facets of mine site environmental control practices. Most sites employ some form of treatment to address ARD issues. The type of treatment implemented varies from site to site. Previously there was no single, comprehensive database containing treatment and sludge management information for mine sites. CANMET-MMSL (Natural Resources Canada) has just completed an extensive survey of ARD treatment and sludge management practices at over 100 operations in Canada and around the world. A detailed questionnaire was developed and used to survey mining companies, government organizations, consulting firms and others. The information collected was compiled into an interactive database. This paper will discuss the results of this survey such as: operation type and site status; ARD sources, composition and flowrate; treatment methods; reagent usage; costing, treatment issues; novel and best practices. As well the paper will elucidate on sludge management options, including sludge production rates, composition and disposal methods in addition to sludge handling challenges and opportunities. The database will provide operators and regulators with the information necessary to make informed decisions regarding ARD treatment and sludge management practices.

Additional Key Words: acid mine drainage, lime, active treatment, disposal, metal recovery, costing.

INTRODUCTION

Most sites require treatment of surface, process and mine water prior to discharge. The type of treatment implemented varies from site to site. Some sites use chemical treatment, while other sites use biological or separation technologies. Information on various treatment applications is often limited and process specifics, especially cost data are often difficult to obtain. Previously there was no single, comprehensive database containing treatment and sludge management information for mine sites. At the request of the Mine Environment Neutral Drainage (MEND) Program, CANMET-MMSL (Natural Resources Canada) conducted a survey of acidic drainage treatment and sludge management practices and developed a comprehensive database.

Data Collection Process

A detailed survey was prepared that requested information such as site background and history, acidic drainage characteristics, type of treatment and reagents used, treatment issues, sludge composition, sludge management practices and issues.

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A list of contacts was developed including personnel from mining associations, companies, and federal, territorial and provincial governments. After which, introductory letters attached with a survey questionnaire were sent to the various contacts. The response from these questionnaires accounted for about 52% of the database. The remaining 48% of the data was extracted from technical papers, company press releases, website information, and government public releases. The data was compiled into an interactive database. This paper summarizes some the information contained in the database. The full report is available through MEND (Zinck and Griffith, 2009).

Site Information

Data on treatment practices and sludge management was collected on over 100 sites. Most sites are in Canada but other sites in USA, UK, Australia, Mexico, Peru, China, South Africa, New Zealand and Hungary also populate the database. Figure 1 shows the site locations.

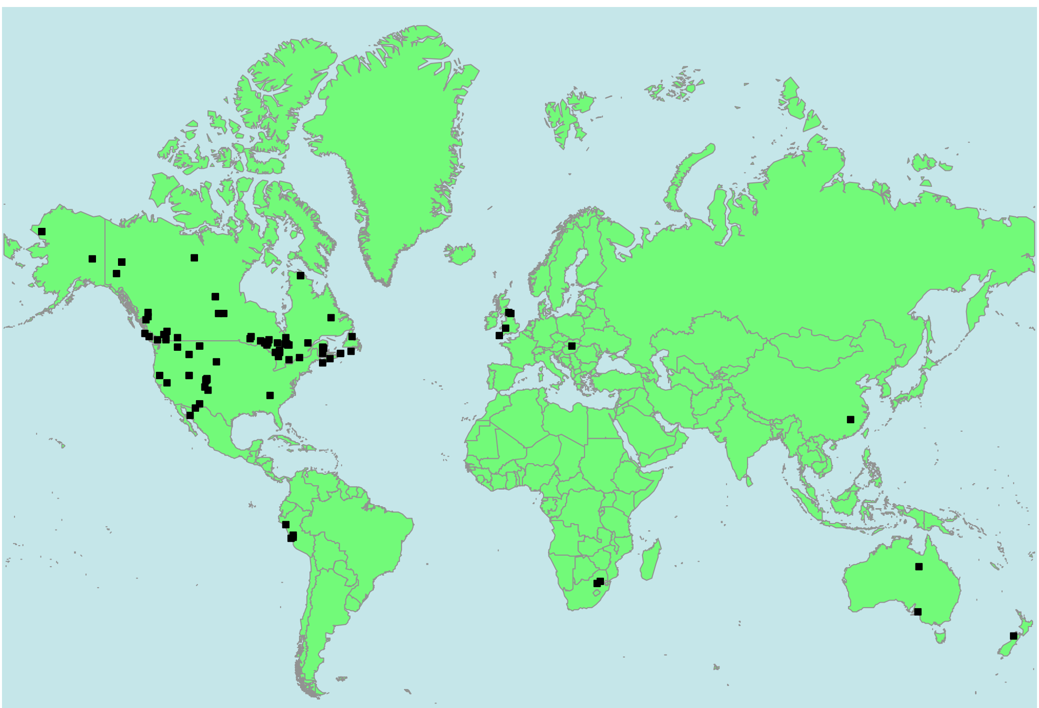

Figure 1. Locations of treatment sites in database.

Of the over one hundred sites in the database the majority are base and precious metal sites. Figure 2 graphically displays this information. Half of the sites are in operation, while the others are orphaned, abandoned or closed sites (Figure 3).

The survey focused on the treatment of acidic drainage; however several sites reported the treatment of a variety of contaminated waters including process, surface and mine waters as well as neutral drainage. The database captured information on the composition and flowrate of these waste streams, as well as information on the effluent receiving environment.

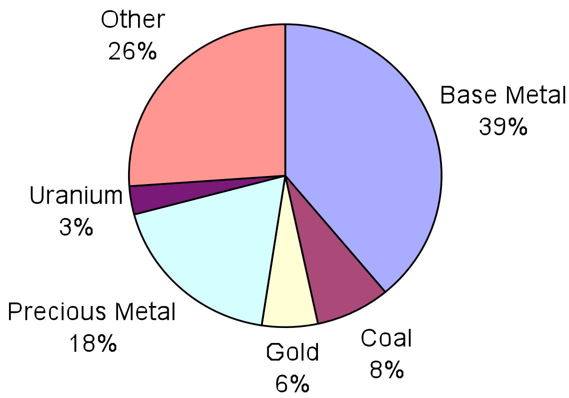

Figure 3. Mine site status

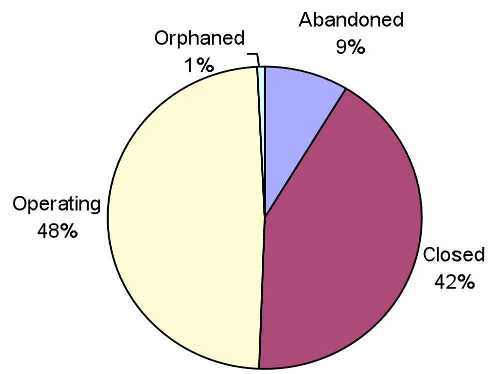

Figure 2. Type of mine operation

TREATMENT PRACTICES

The majority of sites surveyed reported that they expect to treat *in perpetuity* and as such their choice of treatment is critical for not only economic but environmental reasons. There are a variety of treatment processes that can be applied either in isolation or in combination to remove metals and neutralize acidity (MEND 5.4.2e, 2000; Aubé and Zinck, 2003).

Process Components

Figure 4 presents an array of treatment processes that were reported in the survey. Active treatment processes are most prevalent with chemical treatment processes more common than physical (membrane) and biological treatment processes combined. Roughly the same number of basic (simple) treatment processes as high density sludge (HDS) processes are in used. Many sites are moving towards HDS processes that employ mechanical agitation, flocculation, and sludge recycle to optimize treatment performance, increase sludge density and reduce reagent consumption. Other sites plan to modify their basic treatment systems to improve performance without investing in the high capital cost of a high density sludge treatment systems. For example, some sites will utilize reactors without sludge recycle to enhance mixing and precipitation; while others will add a simple sludge recycle line back to the start of their process. Treatment is generally site specific, and what works for one site may not be suited for another.

Membrane separation and biosulphide treatment are also practiced at several sites. The adoption of these relatively new technologies is increasing as regulations for lower effluent discharge criteria and demand for 'zero discharge' are on the rise.

If ferrous concentrations are significant (>100-200 mg/L), aeration is often required to oxidize the iron to a more stable ferric form. About 10% of the sites reported using aeration as an addition to their processes. Aeration is a common component in HDS systems and in this case aeration would not be considered an add-on.

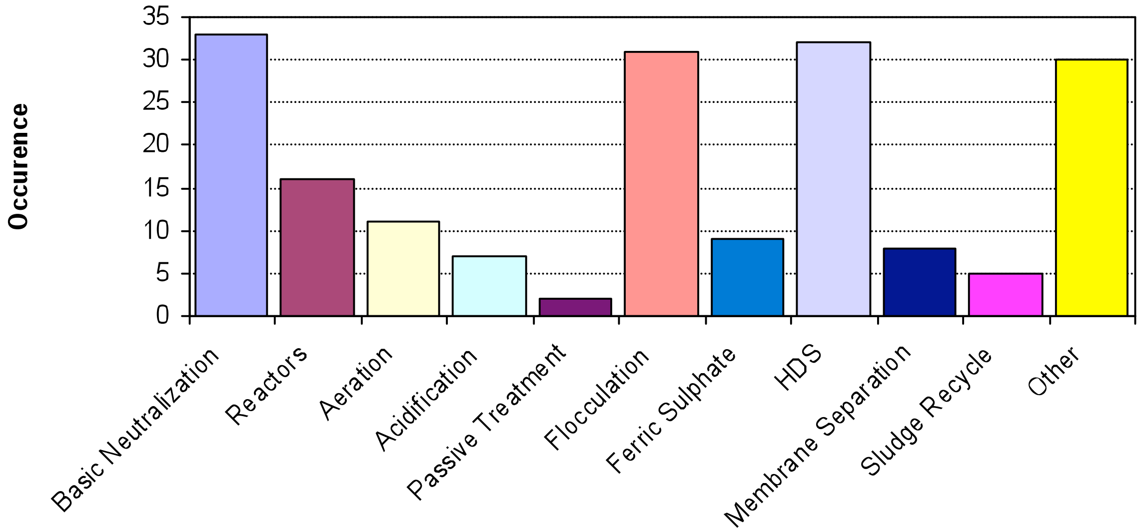

Figure 4. Range of treatment processes reported. Other includes biosulphide process, pipe reactor, pit lake treatment, Rotating Cylinder Treatment System™ RCTS technology.

Reagents

Lime is the most prominent reagent used for sites that apply chemical treatment. Lime was used in one of three forms: quicklime (CaO, without slaking) – 6%; hydrated lime ($Ca(OH)_2$) – 59%; and slaked lime ($Ca(OH)_2$ slaked on site) – 35%. Slaked lime can be prepared with either a ball mill, paste or slurry slakers. In the database, slurry slakers were most frequently recorded. More information on lime slaking can be found in Zinck and Aubé (2000) and Hassibi (1999). Caustic soda ($NaOH$) is also used for hydrolysis and acidity neutralization. Caustic soda is very efficient and reacts rapidly; however it is almost ten times more expensive than lime and sludge densification is more challenging. Limestone is also used for hydrolysis and neutralization, but its application is limited as it armours easily and can only neutralize to pH ~7. Figure 5 shows the reagents used for treatment.

To treat low strength waters (low total dissolved solids (TDS)), sites will often apply a coagulant such as ferric sulphate to improve metal removal by surface adsorption and co-precipitation. The iron sulphate quickly dissolves and causes the iron to re-precipitate as ferric hydroxide/ferrihydrite. Ferric sulphate serves to agglomerate the precipitates and also to adsorb any metals remaining in solution. Larger particles are formed by combining with the ferric hydroxide and settle much faster than the smaller particles. Ferric sulphate was used by 9% of the sites (Figure 5). Barium chloride is used for radium-226 removal and accounted for a fraction of the reagent usage.

Depending on the contaminants to treat and the pH set-point, the effluent pH may require adjustment prior to discharge. Most sites sparge carbon dioxide to decrease the pH prior to discharge while a few sites use sulphuric acid or a combination of both (Figure 5).

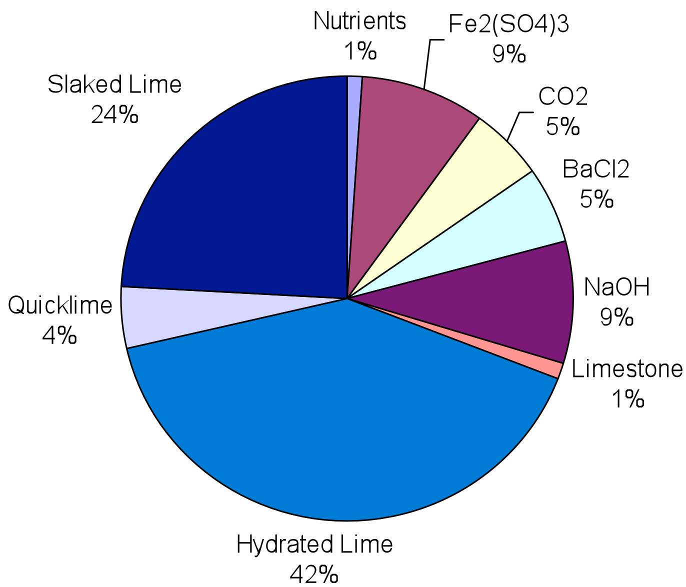

Figure 5. Type of reagents used for treatment.

Flocculation

The primary purpose of flocculation is to agglomerate the finer particles and enhance settling to obtain a clear effluent. Flocculation aids in clarification by promoting the formation of flocs which settle more rapidly. The flocculant type and concentration have a major impact on effluent quality and sludge properties and typically account for 2-5% of treatment costs (Zinck and Aubé, 2000). Flocculant was used in approximately 32% of the treatment operations (Figure 5) and a range of flocculant types were recorded (Table 1). Magnafloc 10 was the most common flocculant used. It is a non-toxic high molecular weight anionic polyacrylamide flocculant.

Table 1: Various types of flocculant used in mine water treatment.

Name	Number of sites
Amerifloc 300	1
Flomin SNF	1
GE Betz Polyfloc 1103	1
Golden West 1883A	1
Magnafloc 10	10
Magnafloc 155	1
Magnafloc 156 (E10)	3
Magnafloc 338	5
Magnafloc 1011	4
Polyclear 2748	1
Polyfloc AE 1125	1
Potassium Permanganate	1
Powerfloc 3056 SH	1
Super Floc A110	1

Solid/Liquid Separation
Solid/liquid separation is a critical step in any water treatment processes whether it is simple gravity separation or more sophisticated mechanical separation. All sites with active treatment have some type of solid/liquid (S/L) separation. The types of S/L separation used, as recorded by the survey, are shown in Figure 6. Over 50% of respondents used a conventional thickener/clarifier while six sites reported using lamella clarifiers. Settling ponds were also commonly used. For enhanced sludge dewatering, some sites reported using filter presses or centrifugation. To improve effluent quality and to reduce turbidity, sites employ polishing ponds and sand filters (Figure 6).

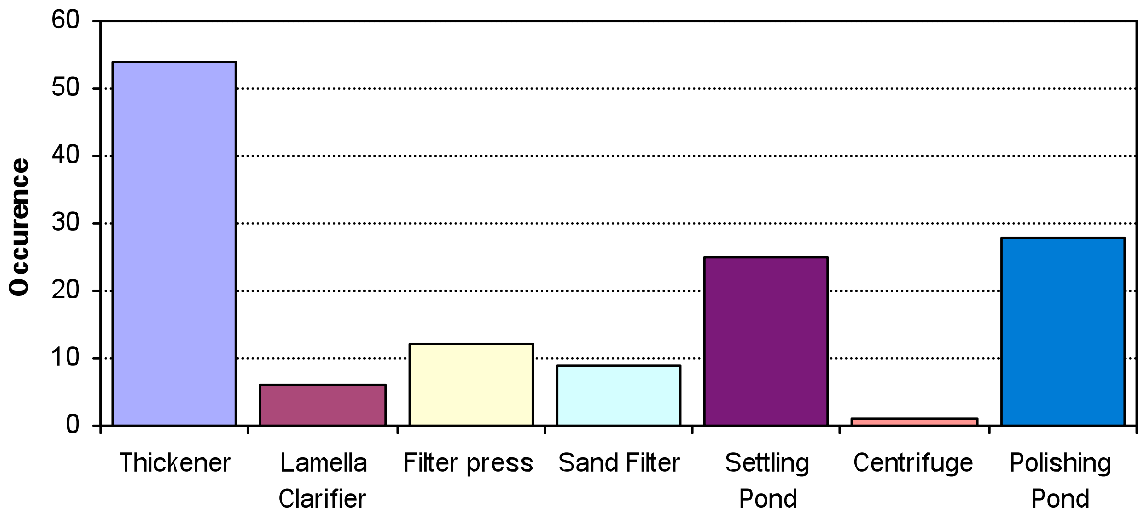

Figure 6. Solid/liquid separation methods used.

Treatment Costs
The database contains details on capital and operating treatment costs. Some sites recorded treatment costs as low as \$0.02 US/m^3 for basic treatment and \$0.06 US/m^3 for HDS treatment. Passive and semi passive treatment costs were variable while no costs per cubic metre were given for either membrane treatment or biosulphide precipitation. Sites were asked to provide a breakdown of annual operating costs (e.g. labour, reagents, power, etc.). The averaged breakdown for all sites reporting is given in Figure 7. The majority of the costs are for reagents and labour.

Treatment Issues
As part of the survey, respondents were invited to list treatment issues. Many respondents listed gypsum scaling of the process equipment and lime slurry lines as their major concern. Some noted that the application of sludge recycle/HDS treatment reduced scaling. Other issues noted were: the control of total suspended solids (TSS) in the final effluent, managing high flows, algal blooms in collection ponds, poor settling, lime handling and mixing, polymer mixing during winter months, difficulty in maintaining high density sludge, inefficient mixing, and acidity in the water due to residual thiosulfate (S_2O_3) derived from the mill processing.

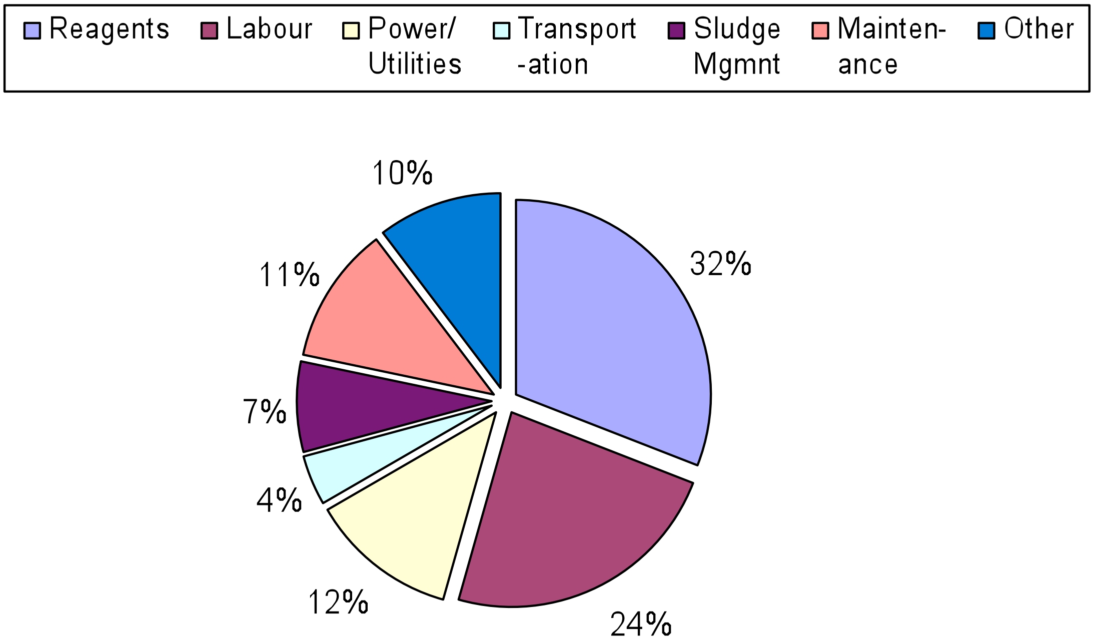

Figure 7. Annual treatment cost breakdown.

SLUDGE MANAGEMENT

Most treatment processes will require some type of residue management whether it be iron-metal-gypsum sludge from lime treatment, residue from treating membrane concentrate, uneconomic residuals from biosulphide treatment or the substrate from passive treatment systems.

Sludge Disposal Practices

Figure 8 presents the type of sludge management practices reported. Details on these and other sludge disposal and management options are available in MEND 3.42.3 (Zinck, 2005).

The majority of the sites surveyed utilize sludge ponds for dewatering and permanent sludge disposal. Disposal in a pond can minimize potential remobilization as the sludge is isolated from the acidic waste. However, many sites prefer to have one waste disposal area and choose to dispose of their sludge with tailings. There are several methods to co-dispose sludge with tailings. One method involves mixing the sludge with tailings (~ 2-5% sludge in tailings) prior to disposal in the tailings pond. More commonly, sites will utilize the sludge as an alkaline rich cover over acidic tailings, while other sites will simply dispose of the sludge in the pond (neither mixed nor as a cover). Some sites, such as NBCoal, have had success disposing of their sludge in their waste rock dumps (Coleman and Butler, 2004).

If site availability, mine capacity and configuration are appropriate, sludge disposal in abandoned mine workings offers an excellent sludge management strategy. Benefits of this option include potential for the sludge to assist in mine water neutralization and minimization of surface reclamation. Six sites reported sludge disposal in mine workings.

Disposal in an abandoned open pit is one of the most economical solutions for sludge storage, if a pit is within a reasonable pumping distance from the treatment plant. Many companies frequently take advantage of open pits available on site as an appropriate short or long-term sludge disposal option. McNee (2004) found that disposing sludge in a pit lake could cause increased suspended solids, productivity, dissolved oxygen and entrainment in the pit lake and ultimately could result in whole-lake mixing. Six sites reported using pits for sludge disposal. Landfill disposal is necessary for some sites that do not possess sufficient area for on-site disposal. No sites noted reprocessing their sludge at this time.

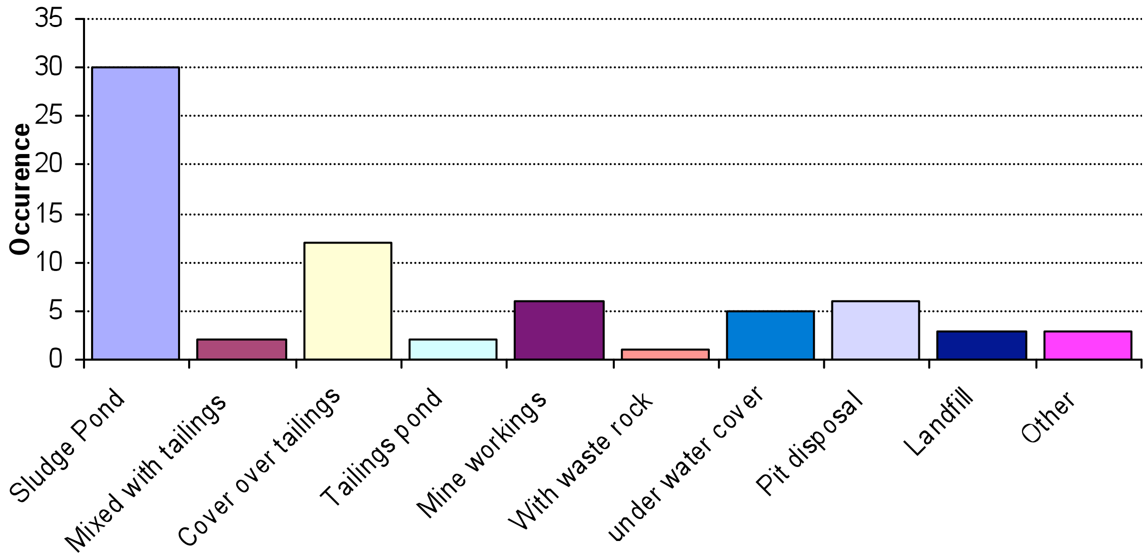

Figure 8. Sludge management practices. “Other”– includes heap leach pad, and hazardous waste disposal.

Sludge Characteristics and Production

The database includes information on the chemical composition and to a lesser extent the mineralogy of the sludge produced. Some sites indicate that leach testing had been performed on the sludge. If completed, the leach tests tended to be batch type tests (TCLP- Toxicity Characteristic Leaching Procedure, SWEP- Special Waste Extraction Procedure). Much of the data on sludge characteristics originates from earlier MEND work (Zinck et al., 1997).

The annual sludge production rate and long term storage capacity were also captured by the survey. Figure 9 presents the sludge production rate for some site in dry tonnes per year. One site not recorded on the graph produced 135,000 dry t/y. It is important to note that considering the high water content in many sludges, volumes (m^3) are frequently 20-30 times that of recorded tonnages.

Disposal Costs

The costs associated with sludge disposal are not well recorded. The survey found that only a fraction of sites examined had disposal cost data. Many disposal costs are hidden within other treatment and operation costs. The annual costs recorded in this survey ranged from ~$10k to >$100k per annum (Figure 10). However, other sites have been known to spend over $1M per annum on sludge dredging costs alone. This inconsistency in data highlights the need to better quantify the true costs associated with sludge disposal. Figure 7, presented earlier, showed that on average sludge disposal accounts for about 7% of the overall treatment cost.

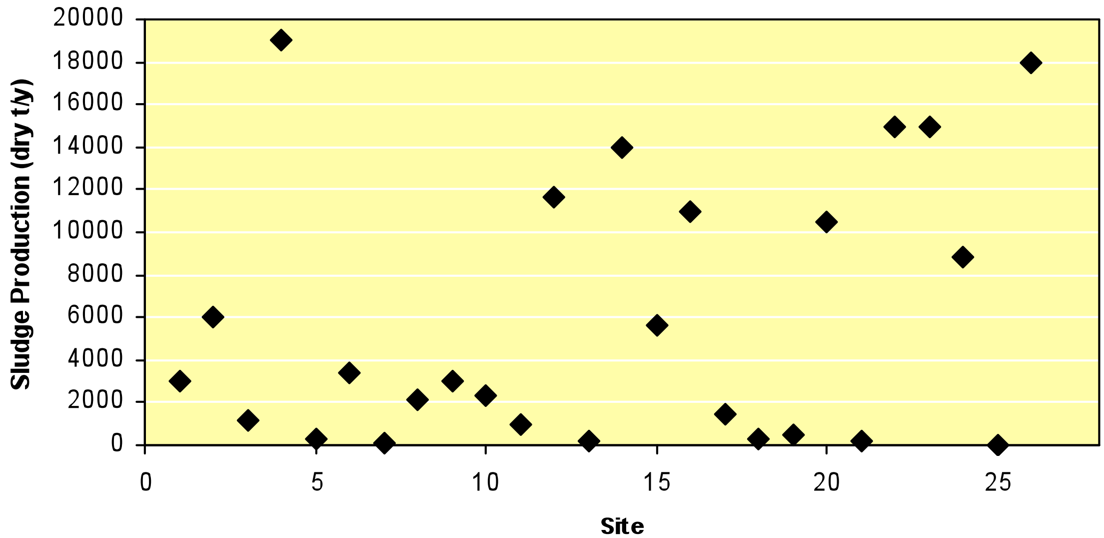

Figure 9. Sludge production rates (dry t/y) recorded through the survey.

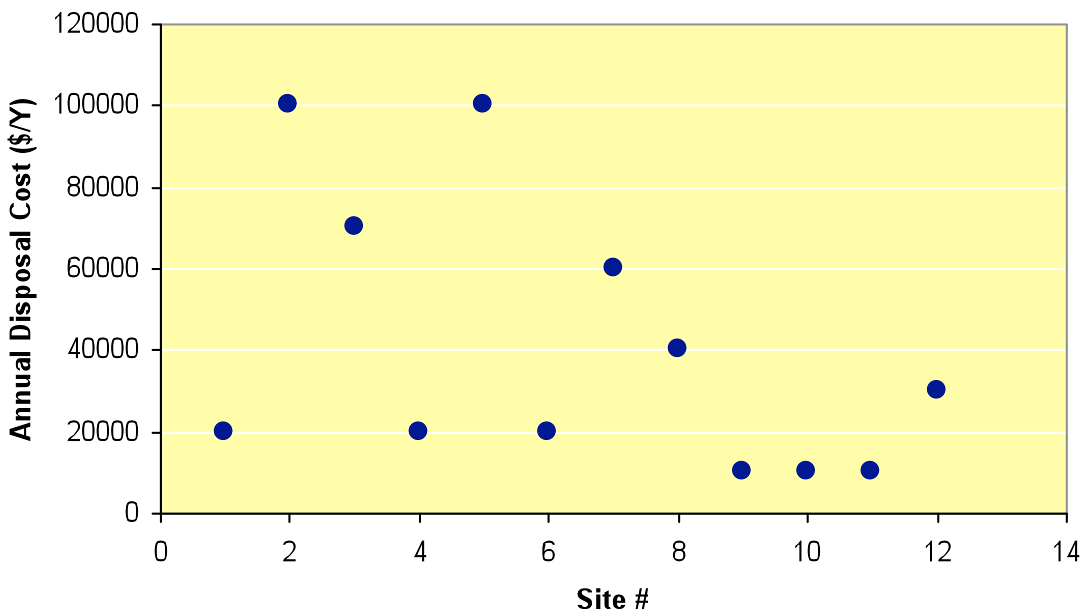

Figure 10. Sludge disposal costs ($US/y) recorded through the survey.

Sludge Management Issues

Several issues associated with disposal and management of the treatment sludge were highlighted during the survey. Sludge desiccation, dusting, and the inability to drive machinery on the sludge for dust control were noted. Some sites noted 'running out of room' to dispose the sludge and difficulty in dredging sludge ponds. High disposal costs and the stability of the sludge were also noted as issues.

CONCLUSIONS

The database contains valuable information on various aspects related to mine water treatment and the management of the resultant sludge. The database will serve as a clearinghouse for relevant treatment information and provide information on best practices and novel strategies. The data can be used to draw useful correlations between treatment parameter with the intent to improve treatment performance in terms of economic and environmental performance. While the data contained in the database has been summarized for this paper, additional details can be found in MEND report 3.43.1 (Zinck and Griffith, 2009). The database will be continually updated with new site data. The electronic version of the database will be managed by Natural Resources Canada.

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