Las descargas contaminantes accidentales y deliberadas de grandes sitios mineros metálicos han causado daños medioambientales y sociales grandiosos. Las alternativas de remediación para la recuperación de minas inactivas o abandonadas han fracasado a menudo o han sido inadecuadas. El fracaso tiene una componente humana principal que puede ser minimizada, si no prevenida, a través de la práctica honesta, la humildad, la cooperación, y la revisión por pares de expertos de instituciones para una planificación y ejecución de la remediación de los principales sitios mineros metálicos. Científicos, ingenieros, agencias regulatorias, y la concurrencia juegan todos papeles importantes en esta restauración, pero estos grupos a menudo son de muy diferentes culturas con diferentes perspectivas que deben comprender y apreciar las perspectivas y restricciones de otros grupos para alcanzar la solución de remediación de mejor coste efectivo. La naturaleza experimental de la remediación estipula que la investigación es esencial para la remediación. Para sitios mineros complejos, aproximaciones iterativas para la remediación, por fases, con constante monitorización, funciona mejor.

Accidental and intentional contaminating discharges from large metal mine sites have caused tremendous environmental and social harm. Remedial options for restoration of inactive or abandoned mines have too often failed or have been found inadequate. Failure has a major human component which can be minimized, if not prevented, by practicing honesty, humility, cooperation, and instituting expert peer review for planning and executing remediation of major metal mine sites. Scientists, engineers, regulatory agencies, and the public all play important roles in this restoration but these groups are often very different cultures with different perspectives which must understand and appreciate the other group's perspectives and constraints to achieve the most cost-effective remedial solution. The experimental nature of remediation dictates that research is essential to remediation. For complex mine sites, phased, iterative approaches to remediation, with constant monitoring, work best.

Science, Engineering, and the Remediation of Metal Mine Sites

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INTRODUCTION

The remediation of metal mine sites, especially large-scale, abandoned or inactive mine sites, is a complex, challenging, and costly activity. There are five principal parties that can, and should, play an active role in this activity: the mining industry (or property owner), the regulatory agency, the consulting industry, academicians, and the public (particularly the local stakeholders). These five parties have substantial differences in background, education, and experience. Hence, negotiations and communications between these parties can be difficult and can add to the difficulties in achieving successful mine site remediation.

Three cultures underlie these differences: the scientific culture, the engineering culture, and the non-technical culture. The purpose of this paper is to describe how these cultural differences can affect successful remediation and to urge those participating in one of the five principal parties to respect the opinions and expertise of those from other parties to achieve a faster and more satisfactory goal.

ARE THOSE WHO DO NOT READ HISTORY BOUND TO REPEAT IT?

Several examples of mistakes made during mining or during remediation will help to remind us that human error can lead to tragic environmental, social, and human health consequences. Some of these mistakes could have been avoided if the right questions were asked, if the right expertise was sought, if effective oversight had been instituted, and if managers had read history. Some of these examples are known to regulatory agencies but they are not documented in the published literature. Hence, citations are often absent.

Approximately 84 million metric tons of mine tailings were discharged into Calancun Bay between 1975 and 1988 from mining and processing the Mt. Tapian copper ore deposit on Marunduque Island, Phillipines. Local residents insisted that this discharge must stop because of the serious harm to the coast and its aquatic life. Since 1993, approximately 20 million cubic meters of tailing were discharged into the Tapian Pit. Failures occurred in 1996 that led to 2-3 million cubic meters of tailings release into the Makulapnit-Boac River drainage system within 4-5 days. The river water quality, aquatic life, many hectares of cropland, and road crossings and connections were destroyed. The UN mission team declared these rivers to be significantly degraded and an environmental disaster (UNEPOCHA, 1996).

The Mammoth Mine in northern California was the site of a small massive sulfide deposit in Devonian rhyolite from which Cu, Zn, Au, and Ag were extracted between 1905 and 1925 (Kinkel and Hall, 1952). The current owner, Mining Remedial Recovery Company, sealed the main portal for remediation in the 1980s. The water backed up and approached a higher level portal which also was plugged. More than 100 m of mine pool head was created and then the system appeared to be hydraulically stable. Within two years, seepage of acid water and a landslide in the next catchment was discovered. The newly formed mine pool found a permeable fault zone that cut across the watershed divide and seeped into the next drainage. The problem was aggravated by the destabilization of a plug. The end result was that the metal loading into the receiving waters had not changed substantially, just moved location, and further remediation to meet regulatory discharge requirements is much more difficult. A final plan to mitigate this site is still under discussion today.

palabras clave: Restauración minera, buenas prácticas, implicaciones sociales, ambientales y científicas

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In the late 1980s the Eagle Mine Superfund Site, Colorado, underwent several remediation projects. One component was plugging of the main tunnel. Within 2 years, seepage waters from the mine pool were contaminating the Eagle River. Large volumes of acid, metal-contaminated water were issuing from several locations. At this time, the metal loading was worse than any time before or since. Following this failure, the regulators required those responsible to dewater the mine pool as far as possible. Many other measures (cap and treat tailings piles, water diversions, etc.) were also employed and the resultant water quality has gradually improved ever since. Remediation and monitoring continues.

In late December of 1991, the Nangiles Mine portal plug at the Wheal Jane in Cornwall, UK, unexpectedly burst and released 50,000 m^3 of acid mine drainage, and sent colorful plume into the Fal Estuary (Banks et al., 1997).

On April 24-25, 1998 an oversized tailings impoundment at the Aznacollar-Los Frailes Mine complex failed and released 6 million m^3 of acid water and pyritic fines into the Guadiamar River threatening the wildlife and bird migratory refuge at Doñana National Park. Thousands of hectares of farmland, river banks, and the river channel were ruined (Grimalt and Macpherson, 1999).

On January 30, 2000 a major cyanide and heavy metal spill from a 4 km impoundment entered the Sasar River from the Aurul gold extraction plant near Baia Mare in northwestern Romania (Souren, 2000; UNEP/OCHA, 2000a). One hundred thousand m^3 of cyanide-rich water moved down to the Lapus River, then to the Tisza, and finally the Danube all the way to the Black Sea. Approximately 1200 tons of fish were killed from this spill, bird life was affected, thousands of fishermen were out of work, and water supplies for several towns and rural communities were badly contaminated. Another smaller spill occurred a week later. On March 10 a tailings impoundment failed and 20,000 metric tons of sludge from the Baia Borsa lead-copper-zinc mine spilled (UNEP/OCHA, 2000b). Again the Tisza and Danube Rivers were severely polluted. Unexpected torrential rains were blamed for the dam failures.

HOW TO MINIMIZE FAILURES

Minimizing any type of mistake begins with ethics. The first rule of failure minimization is to be honest. Planners, policy-makers, engineers, and scientists must be honest about the reasons for any mine site activities that affect the environment, local residents, land usage, etc. Rational and responsible planning has to be transparent to those who are affected by these decisions. Engineers must admit that they cannot calculate or predict what the consequences of a remedial measure on a mine site will be in the same sense that they can calculate what the failure probability is for a bridge that carries traffic across a river or for constructing a skyscraper. The hydrobiogeochemical processes in the environment are complex and not known to the same degree and level of certainty that stress-strain relations are known for mechanical structures.

The second rule of failure minimization is to have proper and adequate oversight. The Aznalcollar disaster happened in spite of monthly inspections of the impoundment. Clearly such inspections were inadequate and there was insufficient understanding of what might happen to increased loading of an acid slurry impoundment built on a marl foundation. Had there been an independent oversight committee for the impoundment siting and development, and had that committee been composed of the right mix of engineering, geological, and geochemical expertise, the probability of dam failure could have been minimized and likely prevented.

The third rule of failure minimization is to learn from our mistakes and those of others. This rule is a rather hard one because we don’t like to admit our own mistakes and because there is a huge lack of information on the mistakes of others when it comes to mine-site remediation. How many readers know about all 6 of the above-mentioned examples of accidental or intentional discharges? Would knowing about these failures make a difference to those who plan and manage mining or remediation activities at future sites? It should.

A more successful approach to mine site remediation will incorporate the necessary research, it will use a phased, iterative approach to remediation, and it should consider recycling or re-extraction of mine wastes as technology improves and metal prices increase.

There are other rules that could be mentioned but they tend to be corollaries of these three. It all boils down to be honest, especially about what you don’t know, and subject projects to independent, expert peer review. Numerous examples of more serious “lethal arrogance” in other contexts are only too well-known and could have been avoided with some common sense and honesty (Dumas, 1999).

SCIENCE AND REGULATORY PRACTICE: THE SEARCH FOR CERTAINTY

The following is extracted and modified from a progress report (Nordstrom, 1998) on the 10-year Abandoned Mine Lands Initiative (1997-2007) which is now completed and available online as USGS Professional Paper 1651 (Church et al., 2007).

Questions are often raised during the regulation and remediation of hazardous waste sites on how best to go about it, and scientists, engineers, and regulators are not always in agreement. The classic assertion is that regulators often think that scientists just want to do another study and that these studies are self-promoting, whereas scientists often think that regulators and remediation teams always want to rush the cleanup of a site before they have defined the problem and considered the consequences. Let’s be honest – there is truth to both of these claims. Scientists do like to study problems out of pure curiosity and for prestige, and regulators do work with limited information, limited time, limited funding, and frequently with considerable political pressure to show results. Part of the problem stems from a misunderstanding of what science is, and another part stems from a misunderstanding of what is involved with regulation and remediation.

Science is a way of understanding the physical world based on testing hypotheses with empirical evidence subject to open debate and peer review. Without science, there is no basis for regulation, or remediation, or testing remedial effectiveness. Remediation is the activity of correcting, curing, or ameliorating an unwanted problem.

Environmental remediation is directed

at specific sites with specific issues for which specific scientific knowledge is needed within a specific legal-political agenda. For complex sites, remediation is often experimental and needs focused scientific research that must be communicated to politicians and the public.

The important questions are:

Is the problem well-defined? This question addresses ultimately the known or potential risk to human and environmental health, but it also addresses what is known about contaminant sources, mobility, and fate.

Has the right science been applied to the problem? The concern here is whether the appropriate scientific (medical, economic, and social as well as physical, chemical, biological, geological, hydrological, and ecological) disciplines have been used in a prioritized manner to emphasize the most relevant issues.

Have we got the science right? This question refers to adequacy and reliability of the data, consideration of multiple working hypotheses, testability of hypotheses, plausibility of assumptions, and the magnitude and character of the uncertainties.

Have we got the right stakeholder participation? This question addresses whether all parties who have some stake in the deliberative process have been included so that all important perspectives can be considered.

Have we got the participation right? This question pertains to the adequacy and appropriateness of the response to the stakeholders and the improvement of trust.

Have we developed balanced, informative syntheses? Overemphasis on analytical aspects can lead to failure without the synthesis of information communicated to the non-technical public and decision-makers.

Is there a defensible and consensual goal? Rational environmental problem-solving will succeed if all parties involved share a common understanding of concepts, assumptions, remedial alternatives, potential consequences, and costs that are defensible and adequately constrained by empirical evidence. These guidelines, extracted from several publications on risk assessment, should minimize uncertainty and promote effective decision-making.

Concluding remarks

Often, engineers, regulators, and policy makers do not understand the need for research or the vital role it can play in achieving restoration of mine sites. Nor do they understand how expensive and time-consuming site characterization and remediation planning can be. They simply wish to see the site cleaned up quickly. Similarly, researchers are often more interested in the scientific aspects of site characterization and publishing scientific results than in the remediation. Both parties must respect each other's perspective, remember that the final goal is environmental restoration, that the restoration can be extremely complicated, that a broad range of expertise and oversight may be needed, and that only by bringing together all of our knowledge and technology, applying a patient and deliberative process, can mine sites be effectively remediated.

Remediation or environmental restoration of mine sites has a large experimental component, unlike the construction of buildings and bridges. Hence, some research is essential and must be incorporated into the planning before construction. A phased, iterative approach to remediation will lead to a great probability of success and a combination of remedial measures with an eye toward possible further extraction will ultimately benefit society.

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