METHODOLOGIES FOR THE CHARACTERIZATION OF HARD-ROCK MINE SITES [1]

by

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Abstract. As the population of the western United States has grown and the utilization of public and private lands has increased, once remote mining sites are beginning to significantly impact the daily lives of the general public. This paper outlines the methodologies and techniques used by the USEPA Region 6 Response and Prevention Branch (RPB) for the identification, assessment and mitigation of hard-rock mining sites. Topics addressed include: 1) site background information from ownership and archeological research; 2) development of site specific health and safety plans (HASP) and quality assurance sampling plans (QASP); 3) survey techniques such as Global Positioning System (GPS), total station and ecological surveys; 4) qualitative field techniques including field portable x-ray florescence (XRF), mercury vapor analyzer (MVA), reactive cyanide and saturated paste pH screening; and 5) sampling and analytical methods. The integration of survey, field screening, and analytical data, along with potential site remediation actions will also be discussed.

Additional Key Words: acid rock drainage, reclamation.

Introduction

During the post-Civil War hard-rock mining boom in the western United States, several small to medium-sized mines were opened and abandoned in a relatively short time frame. Most of these mines were processing metallic sulfide ore bodies on-site, utilizing various milling techniques. Upon abandonment of the mine, the sulfide based overburden and milling gangue were also abandoned without any type of engineering controls to prevent off-site migration of the mine wastes. Over the years, these sulfide based or "pyritic" mine wastes have become a major environmental problem in several areas of the western United States, primarily through the production of sulfuric acid (H_2SO_4) and subsequent mobilization of heavy metals, as rain water or snow melt percolates through these acidic mine wastes. This type of contaminated mine drainage is referred to as acid mine drainage (AMD) or acid rock drainage (ARD).

As the population of the western United States has grown and the utilization of public lands for recreation has increased, these once remote mining sites are beginning to frequently impact the daily lives of the general public. In addition, numerous privately owned residential properties (patented claims) are being developed for are use, often with limited knowledge of previous land use or potential hazards. As public contact has increased, so has the interest in evaluating, stabilizing and mitigating the potential impacts to public health and/or the environment from abandoned mine sites. The following paper presents an overview of the process used by the United States Environmental Protection Agency (EPA) Region 6, Response and Prevention Branch (RPB) and its contractors for the identification, assessment, and mitigation of heavy metal mine and mill sites, with an emphasis on ARD sites. While this outline can apply to any state, certain specifics are for New Mexico.

Site Background Investigation

Ownership and background searches related to turn-of-the-century mining properties are typically complex. Searches are conducted to provide information regarding current and previous owners and operators; patented versus unpatented mining claim(s); whether mineral rights are held separately from surface rights; years of operation and beneficiation process utilized; and historic leases of claim to third parties for mining or ore benefication. Useful sources for obtaining background information on inactive or abandoned mine sites include property title searches, reviews of Sandborn Fire Insurance maps, historical topographic maps, local

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historical society archives, aerial photographs and GIS digital files. Ownership information is used to obtain written access to the property from the current owner(s) and may also lead to interviews with former owners or workers, which can provide additional specific information on processes used at the site.

Site Characterization

Site assessment activities are conducted to evaluate the extent and composition of the waste materials present on an inactive or abandoned mine or mill site and the actual or potential threats to human health and/or the environment posed by these waste materials. Contaminant migrations pathways typically addressed include air, direct contact, surface water, and groundwater. In addition to assessing potential threats from a site, data collected during the site assessment process are also used to evaluate potential site specific remediation options that may be required to address the threats posed by the site. Standard Operating Procedures (SOPs) addressing most of the procedures used for the site assessment process discussed below are available through the USEPA Environmental Response Team (ERT) in either Edison, New Jersey or Cincinnati, Ohio.

As most of the metals associated with abandoned mine and mill sites are recognized as hazardous substances (i.e., lead, cadmium, and zinc) under the Comprehensive Environmental Response and Liability Act (CERCLA) the USEPA views these sites as a potential hazardous waste sites. Therefore, a site specific Health and Safety Plan (HASP) is generated prior to the initiation of field activities. This document is a requirement under the Occupational Safety and Health Act (OSHA), 29 CFR, Part 1910 and address all aspects of worker health and safety. Copies of a boiler-plate, menu-driven, MSDOS program for generating a HASP are available on floppy disks at no cost from EPA ERT.

The processes and procedures commonly used by the Region 6 RPB to characterize abandoned mine or mill sites are illustrated in the following subsections of this paper. The reader should note, however, that this paper does not represent or attempt to address all characterization techniques. The actual techniques used during an assessment is dependent on site conditions, amount of background information obtained, and assessment objectives.

Reconnaissance Field Surveys

Reconnaissance field surveys are conducted as the initial step in the field investigation of an abandoned mine or mill site. This type of survey is typically done by a two (2) person field team collecting basic information on the site utilizing visual observations and basic field screening tests. Key observational indicators of the presence of ARD include: a strong sulfur smell, especially on wet tailings; discolored or "tea-colored" run off; the presence of highly oxidized (deep orange) tailings material; abundance of pyrite in waste rock or ore associated with the mine or mill area; precipitation of salts on the surface of the tailings or in the drainage area downstream of the tailings; and stressed or an absence of vegetation on the tailings pile or near run off areas. Several "quick and dirty" field tests can be used to verify these field observations. Results from field test are then used to develop the scope and potential magnitude of any further characterization required at a specific ARD mine or mill site. Saturated Paste pH screening is a simple agricultural test used to document soil pH levels. Liquid samples (surface water, shaft water or leachate) are easily tested for pH, dissolved oxygen, electrical conductivity, and dissolved solids using readily available probes, pens, and papers.

Mercury (Hg) contamination is a potential problem at most processing sites, where some form of mercury amalgamation is suspected as a form of ore beneficiation. All gold and silver operations prior to World War I should be screened for mercury. A mercury vapor analyzer (MVA) is used to screen for mercury contamination. The MVA is designed as an ambient air analyzer, however, procedures have been developed to adapt the instrument to screen for soil Hg. In general, jars with a septa are filled to approximately 75-80% full with collected soil, leaving a headspace at the top of the container. After heating the sealed jar to approximately 65°C, a headspace vapor sample is taken and analyzed with the MVA. Correlations between headspace concentrations and soil concentration do exist but the MVA screening technique is primarily used by the Region 6 RPB to establish the presence or absence of Hg in soils. The JEROME™ 431-X Gold Film MVA, manufactured by Arizona Instrument Corporation, is used by the Region 6 RPB.

Gold and silver processing sites that operated after World War I, primarily used sodium cyanide (NaCN) or potassium cyanide (KCN) heap leaching processes for ore beneficiation. At such sites, it is necessary to address cyanide during assessment activities. Several field screening test are available to identify the presence of cyanide. The Region 6 RPB typically uses a method employing rhodamine and silver nitrate solutions, which yields a "Prussian Blue" colored solution in the presence of cyanide. It must be remembered that cyanides are not stable in acidic conditions.

In addition to assessing the presence of ARD and evaluating the need for a more extensive characterization of the site, valuable information on logistics (i.e., . proximity to access roads, accessability, etc.) can be obtained in the initial survey. Another important element of these initial surveys is to obtain a preliminary evaluation of any potential target or susceptible populations or environments. To begin to assess the risks potentially posed by a site, it is important to establish the location of the nearest residence, residential area, potable water wells, area population, surface water uses, other significant features or environments, and any physical evidence that the site is being utilized by humans or wildlife.

An ecological survey is a key component of the reconnaissance survey. This survey not only assesses the general condition and health of the general ecology of a site, it provides key information on environmental risk assessment decisions and evaluation of potential revegetation reclamation options. Observations noted include surface water run-off effects, utilization by wildlife (especially fossorial and piscivorous species) and botanical identification of existing endemic grasses and shrubs. Such botanical information could also be used to develop a revegetation seeding mix for the site. In addition, endemic plants could contribute "volunteer" seeds to the potential revegetation area. As part of the ecological survey, any Federal or State endangered or protected species or its habitat should be identified for the area around the site. This information can be critically important in assessing the overall threat and selection of a mitigative action for a site. While no endangered or protected species may be present on the site, they may be depredating those species that do. This was the case with Terrero Mine in Pecos, New Mexico. Prey species living in and around the mine spoil areas had metal levels that were near and/or exceeded the acceptable raptor protection levels established by U. S. Fish and Wildlife Service (USFWS).

Another key element of the reconnaissance survey, especially for federal agencies is an archeological survey. If based on the preceding elements of the reconnaissance survey it appears that further delineation and/or mitigation of the threats posed to the public health and/or the environment are required for the site, then an archeological survey must be conducted. All federally funded actions that may have an impact on a site of potential historical significance, must meet the regulatory criteria established in Section 106 of the National Historic Preservation Act of 1966. A Phase I archeological survey is conducted, followed by a consultation with the State Historic Preservation Officer (SHPO) to determine if a site is eligible for inclusion on the National Register of Historic Places. If a site is determined to be eligible, a more extensive Phase II archeological survey is performed to maximize available information for the site. This information is then used to determine if the proposed corrective actions taken on the site will have an "adverse effect" or "no adverse effect" on the historical resources. Mitigation of an "adverse effect" is very rare in New Mexico. Since all available historic information on the site is usually obtained during the Phase II survey, the SHPO generally makes a finding of "no adverse effect".

Extent of Contamination Survey

After completion and review of the data obtained from the general observations and simple field tests conducted in the reconnaissance survey, several decisions must be made. These decisions include: 1) does this site have the characteristics of ARD; 2) are materials actively or potentially migrating off-site; and 3) does this site pose an actual or potential threat to the general public health and/or the environment. If the answer to any or all of these questions is "yes", then a more comprehensive extent of contamination survey should be conducted. Extent of contamination surveys expands upon the information from the reconnaissance survey and provide a detailed evaluation of the actual and/or potential effects of the site on the general public health and/or the environment. This type of survey is much more labor intensive than the reconnaissance survey and generally forms the basis for an informed decision on the potential remediation or reclamation of the wastes on the site.

Because this type of survey is used as a decision making tool, the of quality assurance/quality control (QA/QC) needs to be of a higher quality than that required during the reconnaissance survey. For surveys of this type, a Quality Assurance Sampling Plan (QASP) is developed for the site. The QASP documents site assessment and sampling strategies, data use objectives, and sample quality assurance requirements. The EPA requires a QASP for all site work. Copies of a boiler-plate, menu-driven, MSDOS program for generating a QASP (QASPER) are available on floppy disk at no charge from the EPA ERT in either Edison, New Jersey or Cincinnati, Ohio.

Site Mapping

In an extent of contamination survey, no element is more critical to the success of the survey than the production of a detailed, and accurate base map of the site. Global Positioning System (GPS) surveys are conducted to obtain site specific topographic and geographic data, and to position structural features and sample or field screening locations. Both GPS static and kinematic surveys are utilized during assessment activities. GPS control points are established based on standardized GPS benchmarks are present in most states in the U.S. Information on control point locations is generally available from State transportation or geographic information agencies. The Region 6 EPA RPB uses the Trimble 2000SE GPS unit for this type of surveying. A limitation of GPS is that mapping using this method requires minimal overhead obstructions (i.e., . sparse tree canopy cover, few rock ledges, etc.) for proper satellite down linking. A Total Station survey unit is the preferred alternative for mapping locations not conducive to GPS applications.

Field Portable X-Ray Florescence (XRF)

Over the years, the EPA RPB has found that one of the most important field screening and analytical tools for assessing abandoned mine and/or mill sites is the field portable XRF unit. XRF spectroscopy is a nondestructive analytical technique which allows qualitative and quantitative screening for the elemental composition of a sample. With the proper x-ray source selection and instrument calibration, samples can be screened for most metallic elements. Advantages of the field portable XRF unit include rapid data acquisition and reduction in the number of laboratory analyses required to evaluate a site. XRF screening can be performed on-site *in situ* or off-site *ex situ*. For *ex situ* screening, a sample is collected and placed in an XRF cup. This allows for information to be obtained during inclement weather or from locations inaccessible to the unit (i.e., soil borings, steep slopes, etc.) or allows samples to be collected and screened at a later date. The *ex situ* method provides the highest level of QA/QC, and usually has a correlation coefficient of 0.95 or higher to laboratory data. However, this method can also be very time consuming compared to the *in situ* method. *In situ* data generally have correlation coefficients of 0.6 to 0.8 with laboratory data, with generally low bias. The EPA RPB typically uses a mixture of both *in situ* and *ex situ* methods during an extent of contamination survey.

In a typical *in situ* XRF survey, transects or grids are established at the site. At each node, multiple (3 - 5) readings are taken. The concentrations and the standard deviations values are averaged to obtain a value for each metal of interest. This method is used to circumvent some of the problems associated with the natural variability of the mineral content of mine/mill waste. Basic geostatistics are used to determine the optimal number and distance between nodes. The Spectrace™ 9000 XRF, manufactured by Texas Nuclear Technologies, Inc. is used by the Region 6 EPA RPB. A standard operating procedure (SOP) specifically describing Spectrace 9000 applications and the basic geostatistics used is available at no cost from EPA ERT.

To confirm the accuracy of the XRF results, it is necessary to perform conventional laboratory analysis on at least 10 percent of the XRF nodes. Confirmation samples are typically analyzed for the twenty three (23) target analyte list (TAL). Differences between XRF and laboratory results are typically due to application or user errors and not to instrument precision. Common errors include chemical matrix interferences, physical matrix interferences, and soil moisture content. Further, the XRF unit does not work reliably under temperature extremes. Because of chemical matrix interferences, all field portable XRF units tend to have problems accurately quantifying arsenic (As), mercury (Hg), and cadmium (Cd) levels. At the Cleveland Mill site near Silver City, New Mexico, interferences from rubidium (Rb) resulted in inaccurate lead values during XRF screening.

Sampling and Analysis

Soil, air and/or water samples are typically collected during the extent of contamination survey of abandoned mine sites. It is important that all quality assurance requirements as outlined in the QASP are maintained during sampling. In addition, the laboratory results should be subjected to a data validation process prior to use in site evaluation. Because of the cost of laboratory analysis, field screening techniques are often used to reduce the total number of samples analyzed.

The Region 6 EPA RPB has used both high volume and high flow air sampling techniques primarily at abandoned mine sites that are on or near residential areas or show evidence of off-site migration via air dispersion. Air samples are analyzed for specific metals and total suspended particulates (TSP). Air sample results are compared to published EPA National Ambient Air Quality Standards (NAAQS) or EPA exposure based "action levels". Dust (total and respirable) particles suspended in air can also be monitored using real-time air monitoring (RAM) units.

Surface water, ground water (including shaft water), and waste material leachate samples are often analyzed to characterize abandoned mine sites. This type of sampling measures a critical part of the overall risk posed by a site in areas of high snow fall or heavy snow run off. Numerous techniques are used to collect such samples. The technique used is dependent on the site conditions and type of sample to be collected. Water samples are typically analyzed for metals content and compared to Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCL), or state-specific water quality standards that are based on water resource utilization [e.g., Water Quality Standards for Interstate and Intrastate Streams in New Mexico (WQCC 91-1)].

Both surface and subsurface soil samples are used to characterize abandoned mine sites. The Region 6 RPB often uses hand-operated soil recovery probes or truck mounted Geoprobe™ units to collect subsurface samples. Soil samples are typically analyzed for TAL metals. As mentioned in the field-portable XRF subsection above, TAL metals analysis of tailings/soil samples is also the preferred methodology for confirmation of XRF data. In addition to establishing the precision and accuracy of the XRF results, the laboratory results are necessary to provide values for As, Hg and Cd, for which the XRF is unreliable. It is important to know arsenic levels of any potential ARD material prior to alkaline treatment, since the mobility of arsenic increases with increasing pH.

Acid/Base Accounting and Soil Fertility Assessment

An acid/base accounting assessment should be done as part of the extent of contamination survey to effectively determine the neutralization and acid generating potential of the mine waste materials. In standard acid/base accounting analytical tests, results are reported in units of tons $CaCO_3$/kiloton material (approximately tons/acre over a six inch depth). The net neutralization potential (NNP) is given by the neutralization potential (NP) (usually positive for calcareous materials) + the acid potential (AP) (usually negative for acid generating mine waste). An ARD neutralization assessment for a mine waste site includes: exchangeable acidity (EXA), AP, and NP analyses. Mine waste rock and tailings with NNP values less than -20 tons of $CaCO_3$/kiloton and with an AP:NP greater than 3:1 are considered to be potentially acid generating.

For revegetation and reclamation considerations existing soil nutrient levels, including macro (especially phosphorus) and micro nutrients (especially boron and molybdenum), water holding capacity, and soil organic matter levels are required. Soluble metals concentrations, including both water and DPTA extractable, are used to indicate the potential for plant tissue uptake.

Geotechnical Assessment

Reclamation and mitigation techniques generally require the use of heavy equipment on and around the site. Because of the physical characteristics of waste rock or tailings piles (i.e., sand, interbedded sands and slimes, etc.), it is necessary to address the slope stability on sites with large waste rock and/or tailings piles. Information obtained from stability studies can be used to evaluate the current physical risk and proposed remedial designs.

Factors to consider during stability studies include: the volume of waste material; existing slope angles; embankment heights; water retention capacity; physical characteristics of the waste material; and the type of the soil or rock underlying the waste. Mine waste piles can be stable under static conditions, but fail under dynamic loads; therefore, it is also important to consider the site location relative to U.S. earthquake zones. These zones are established relative to damage and intensity, not the probability of occurrence. Several computer programs are available to evaluate the stability of the waste material based on geotechnical parameters data. The current conditions, as well as various constant slope remedial designs, can be analyzed. Program models help to identify probable failure locations and resulting factor of safety (FOS) values.

Integration of Survey and Field Screening Data

The integration of the field and laboratory data into a comprehensive report format is the ultimate goal of the characterization of any mine or mill site. The information from these integrated reports, forms the basis for evaluating the potential scope and costs associated with any potential remediation options for the site. Computer gridding, contouring, and mapping programs are used to integrate GPS and/or total station data with XRF and screening or analytical data from the site. Isopleth or concentration contour maps are created through the use of geostatical modeling and kriging. These maps are used to identify the magnitude and extent of contamination for selected metals at the site. Volume estimates of the contaminated waste materials can be obtained by integrating the topographic and isopleth maps generated from the field data. Several contouring and mapping programs are commercially available.

Geographical Information System (GIS) computer software are also useful for the integration of all data from the site, especially large site or sites involving multiple property owners. Recent advances in feature positioning systems, such as GPS, total station survey instruments and other portable laser mapping devices, as well as field portable computers, digital cameras, video interfaces and real-time mapping software, now provide the tools to build fully integrated GIS databases in the field. The EPA Region 6 RPB is currently field testing the use of these integrated GIS systems on an abandoned mine/mill site in southeastern New Mexico.

Summary and Conclusions

Development of the scope and costs for any potential remediation options for a site are based upon the information and data obtained during site characterization activities, and present in the integrated reports for the site. As such, the necessity of performing a thorough site characterization cannot be over emphasized. If the required information was not obtained or if the data collected cannot be verified and defended, then additional time and money will have to be expended to correct the situation.

Potential remediation actions implemented at an abandoned ARD site includes: no action; off-site removal; and on-site treatment or disposal. For some sites a combination of these options may be required. Off-site removal typically involves the complete excavation and disposal of the site wastes. Limiting factors for this option include: volume of the waste material; waste characteristics; and site location. Because of the costs incurred during transportation and disposal, off-site removal is not often selected as a remediation option on sites with large waste volumes or a remote location.

Until recently, on-site treatment or disposal has consisted primarily of"treat and cap" or "cap" methodologies. Site wastes were treated as necessary, relocated to an on-site repository and capped with clay and/or "clean" fill dirt. While this method has been used successfully on many sites throughout the U.S, it has certain inherent drawbacks (i.e., high maintenance) that make it difficult and cost prohibitive to implement on all sites. This situation led to research into a method of achieving the same end result at a lower cost and with easier implementation. The most promising of these alternative methods is, geochemical treatment and phytostabilization (revegetation). This method involves decreasing the acid generating potential and heavy metal solubility of the mine wastes through additions of buffering or neutralizing agents. After the ARD waste material is buffered or neutralized, organic and fertilizer amendments are added to enhance the ecological fertility of the waste material, and native grasses and shrubs are seeded into the treated waste material.

There are several useful information sources that address issues related to geochemical treatment and revegetation of mine sites, including Munshower, (1994) and the Streambank Tailings and Revegetation Studies-STARS (Reclamation Research Unit, et al. 1989; Schafer and Associates et al. 1989; and Schafer and Associates, and Reclamation Research Unit, 1993), which was conducted for the Montana Department of Health and Environmental Sciences, Helena, Montana with EPA oversight and review.

Geochemical and vegetative stabilization was recently implemented by the EPA Region 6 RPB as the preferred mitigation method in a Superfund removal action at the Mammoth Lode site in Piños Altos, New Mexico.

Notice

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