Prioritization of Abandoned Mine Sites in California

by

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29 April 2016

Final Masters Project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment of Duke University
New Idria Abandoned Mercury Mine, San Benito County, CA, November 2015
ACKNOWLEDGEMENTS

I would like to thank both of my academic advisors, Dr. Deborah Gallagher and Dr. James Heffernan, for their careful reviews, thoughtful advice, and invaluable guidance through this process. I also thank my EPA colleagues, Kelly Manheimer and John Hillenbrand, for sharing their expertise and knowledge with me on this complex issue. Thanks as well to my Duke mentor, Michael Blum, whose valuable advice always offers insightful perspective.
EXECUTIVE SUMMARY

The massive scope of abandoned mines in California combined with the scientific and financial limitations to address them necessitates a sound ranking process. Abandoned mine sites threaten human and ecological communities with contamination impacts to groundwater, surface water, and soils. A prioritization system is needed in California to better account for the most environmentally hazardous of the state’s 47,000 abandoned mines (EPA Region 9, 2016). This study develops a cleanup priority recommendation for abandoned hardrock mining sites in California. Recommendation can help focus prioritization efforts on fewer sites for further review of transport and exposure pathways, and eventually lead to assessment and cleanup of the worst contaminated sites first among the many awaiting remediation in California.

To conduct this study, I first identified criteria that pose the most serious environmental contamination problems. The prioritization criteria I selected are as follows: the severity of contamination, persistence in the environment, cost of remediation, human health risks, and ecological toxicity. I applied the selected prioritization criteria to available scientific literature and studies related to abandoned mine sites in California. From this I was able to identify common themes in the literature review to form my framework for analysis of the existing mine site prioritization problem. Acid mine drainage (AMD), mercury, and arsenic contaminated abandoned mine sites best exemplify environmental concerns of the prioritization criteria in California. These types of sites should rise to the top of a prioritization scheme, and should be addressed first for assessment and cleanup.

Next I performed a review of the institutional management programs in place for abandoned mine lands in California, including staffing, budget, and authority that allow for an effective program. I also screened nine existing abandoned mine prioritization schemes of varying applicability to determine decision tools used in prioritizing sites and how these schemes relate to California’s top issues of AMD, mercury, and arsenic contaminated sites. Finally I make recommendations to start prioritization efforts with AMD, mercury, and arsenic sites.

The first two sections of the report break down the approach, goals, and drivers for mine prioritization with a discussion of overlapping agency authority and the extent of abandoned
mine contamination issues in the state. The third section of the report elaborates on the five environmental prioritization criteria selected and explains the development of how they were used in the literature study. An in depth discussion of AMD, mercury, and arsenic contamination and how they meet the five environmental criteria given the features of California is also included in this section. In the fourth section and Appendix I, I evaluate nine existing prioritization schemes and their applicability to AMD, mercury and arsenic contaminated sites. Conclusions and recommendations are discussed in the last two sections of the report, including the recommendation to conduct interviews of experienced mine remediation personnel to supplement the study’s findings, as well as discuss regulatory gaps and two proposed laws that directly impact the future of hardrock mining.

Using the results of the prioritization criteria, literature review, and existing prioritization scheme analysis, I made conclusions to better manage the abandoned mine lands in California, and progress in the prevention of further environmental degradation due to abandoned mine sites. Abandoned hardrock mining sites are the most potentially environmentally damaging and should be prioritized higher over other types of abandoned mine sites. Acid mine drainage is the most significant issue at abandoned hardrock mining sites due to adverse impacts to water quality and ability to mobilize heavy metals. Additionally the regenerative properties of AMD make it a difficult and expensive problem to tackle. Abandoned mine sites with mercury contamination ranks second, due to its ability to bioaccumulate in the food chain, reduce water quality, and methylate in aquatic environments. Abandoned mine sites with arsenic contamination ranks third, due to its carcinogenic properties, persistence in the environment, and threat to drinking water sources.

Additional drilldown is needed to further rank acid mine drainage, mercury, and arsenic sites according to exposure criteria to human and ecological receptors, and move sites toward assessment and cleanup. Preliminary site assessment data will be needed for each site in order to accomplish this. The CAMLAG mine prioritization effort, which currently is still under interagency development, is the most promising prioritization scheme to date for abandoned mine lands. CAMLAG will develop a standard, weighted formula for source-transport-receptor data, which can then be applied to each mine site to obtain an overall prioritization score.
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### Appendix I Evaluation of Existing Prioritization Schemes
I. INTRODUCTION

Approach and Methodology

This study develops recommendations to prioritize contaminated abandoned mine sites in California. Prioritization is necessary because the number of abandoned mine sites in California with environmental contamination far exceed available means to address them. It is the initial step in the process of cleaning up contaminated land to acceptable cleanup standards and returning it to reuse. Prioritization identifies the most seriously contaminated sites that must be assessed and cleaned up before the lesser contaminated ones. Prioritization allows regulators to better protect human health and the environment and prevent environmental damage in a cost effective manner.

To conduct this study, I first identified criteria that pose the most serious environmental contamination problems and applied those criteria to available scientific literature and studies related to abandoned mine sites in California. The prioritization criteria I selected are as follows: the severity of contamination, persistence in the environment, cost of remediation, human health risks, and ecological toxicity.

I applied the above prioritization criteria to an abandoned mine site literature review in order to determine what types of sites tend to present the greatest environmental problems. The literature review encompassed regulatory guidance, academic journals, and scientific studies pertaining to environmental contamination issues associated with abandoned mine sites. I was able to identify common themes in the literature review that formed my analysis framework for existing mine site prioritization. The types of abandoned mine sites that meet several of these criteria are the ones that rise to the top of a prioritization scheme, and should be addressed first for assessment and cleanup.

Next, I evaluated relevant existing prioritization schemes to assess how each managed the most significant types of contamination, and applied it to the abandoned mine prioritization problem in California. This exercise draws together the relevant components of past prioritization efforts and contextualizes it for abandoned mine sites in California. This process helped illustrate which existing ranking scheme is most applicable to the study focus, as well as evaluate how existing
schemes ranked the top three types of mine contamination issues in California, based upon my selected prioritization criteria.

In order to develop a meaningful prioritization plan that enables assessment and cleanup actions where most needed, California requires an effective regulatory program for prescriptive management. An effective agency must have an adequate budget to work on the mine prioritization problem, dedicated and qualified staff, authority to make needed changes and enforce rules, and a focused mission. I reviewed existing regulatory institutions according to these effectiveness criteria and found the need for much improvement. Current institutions are underfunded, understaffed, and overlap other regulatory and land-holding agency programs to address abandoned mine sites.

This study systematically analyzes qualitative data sets on overriding environmental criteria, relevant literature, and prioritization approaches to distill a recommendation on how to best prioritize the large backlog of California’s abandoned mine sites. Previous work most often considers three significant types of abandoned mine contamination at sites in California and elsewhere. Because a successful prioritization effort requires steady guidance and management from regulatory institutions, I also evaluated existing regulatory programs for their ability to provide continued support for an abandoned mine remediation program. Conclusions and recommendations for additional research and action are given based on the results of the analysis.

**Study Goals**

The objective of this study is to develop a well-reasoned qualitative recommendation for conducting abandoned mine prioritization in California. This project seeks to condense existing research, studies, and approaches, analyze them for relevance and applicability to California’s need for abandoned mine prioritization, and provides consideration factors that may assist California regulators in strategic planning. Study recommendations should aid decision-makers as they determine how to best solve a significant environmental problem.
Overview

United States abandoned mining sites pose enormous environmental challenges due to their sheer number and scope. By Environmental Protection Agency estimates, the state of California has 47,000 abandoned mine sites (EPA Region 9, 2016). The definition of an abandoned mine is a previously mined area and its associated waste units, processing plants, and other facilities that have not been reclaimed to a beneficial end use (California Technical Advisory Committee for Abandoned Mines, 1994).

The environmental impacts from United States abandoned mine sites require significant management and cleanup costs, well beyond foreseeable budgets. Expansive and detrimental impacts to groundwater, surface water, and soils are present on these sites. Direct contact, ingestion, and inhalation hazards due to mine waste threaten human health and ecological communities (California Department of Toxic Substances Control, 1999). A 2004 EPA study (Table 1) estimated costs to remediate all abandoned hardrock mines in the U.S at $20.4-$54.2 billion, which is unaffordable under current budget scenarios. Likewise, the scope and scale of abandoned mine sites in California is beyond the capacity of regulators and land-holding agencies to manage with current available funds. Therefore, a prioritization system is needed in California to better account for the most environmentally hazardous of the state’s abandoned mines.

Table 1: 2004 Nationwide Cleanup Estimates Far Exceed Available Budgets

<table>
<thead>
<tr>
<th>Type of Site</th>
<th>Number of Sites</th>
<th>Average Cost Per Site ($Millions)</th>
<th>Cost ($Billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water contamination</td>
<td>14,400</td>
<td>1 - 3</td>
<td>14.4 - 43.2</td>
</tr>
<tr>
<td>Groundwater contamination</td>
<td>500</td>
<td>7.5 - 12.5</td>
<td>2.5 - 7.5</td>
</tr>
<tr>
<td>Superfund Mega sites</td>
<td>20</td>
<td>100</td>
<td>2.0</td>
</tr>
<tr>
<td>Superfund Non-mega sites</td>
<td>70</td>
<td>22c</td>
<td>1.5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>20.4 - 54.2</td>
</tr>
</tbody>
</table>

Source: US EPA OSWER (Sept 2004)
Antiquated mining laws in effect today in the United States still do not account for the true environmental cost of mining. The General Mining Act of 1872 was established in the United States primarily to foster settlement of the west, not necessarily to protect human health and the environment. In 1872, environmental degradation caused by active and former mining activities was largely unknown or ignored. Individuals and companies with mine claims still are not required to fully demonstrate methods used to prevent environmental contamination from their mining activities, nor are they required to demonstrate financial viability to conduct clean up and reclamation of lands following mining. Modern mining activities can still add to the burgeoning backlog of orphaned mine sites, which further justifies the need for prioritization.

Prioritization can allow regulators to better understand and communicate the extent of the abandoned mining problem to justify funds needed, actions taken, and time to address sites. Unfortunately, most of the operators and companies responsible for the environmental impacts due to mining activities are long gone, leaving regulators with the burden of abandoned sites and the many unknowns surrounding them. The majority of California mining sites ceased operations by the middle of the twentieth century, leaving little documentation on how mines were drilled and oriented, how and where tailings and wastes were treated, or how mining operations altered surface and subsurface hydrologic channels. Prioritization is essential due to the sheer size and scope of the abandoned mine problem.

Like the rest of the U.S., most of the abandoned mine sites in California are not characterized for the extent of environmental pollution caused, much less been cleaned up or reclaimed. As the EPA and State agencies struggle to account for and characterize the environmental hazards of known abandoned mines, adequate protections to stop more mines from being orphaned are not in place. Lack of comprehensive mining policies in the U.S. that account for environmental protection is the most important issue to tackle in order to prevent more sites from becoming contaminated and orphaned due to ongoing and future mining activities. Solving this problem will require new measures to be passed into law by Congress, and is beyond the scope of this study.

Because the scope and scale of abandoned mine assessments and cleanups in California is beyond the capacity of most other state and federal agencies, the bulk of the burden to protect
human health and the environment falls on EPA Region 9. California has more abandoned mines than any other state; absent more comprehensive mining laws, EPA Region 9 has a documented need for a prioritization system in California to better account for the most environmentally hazardous abandoned mines. Business as usual budget scenarios will not allow regulators to characterize and clean up all abandoned mine lands (AMLs) in the state. Having a system in place to better account for the biggest environmental threats and budgeting for obstacles can better position the agency to address the “worst first” cases and ensure funds are applied expeditiously to achieve the best possible results. Additionally, better means of predicting and avoiding another mine spill like the Gold King Mine disaster in Silverton, Colorado in August 2015 is in the country’s best interests.

Importance of Prioritization

Because the number of abandoned mine sites in the state far exceed available dollars, staffing, technology, and time to address them all, it is essential to assess and rank sites to enable cleanup at the most contaminated sites first. The EPA and various State of California regulators together are tasked with protecting human health and the environment. Prioritization can maximize this potential to manage abandoned mine sites given resource constraints. This “worst first” methodology allows for strategic allocation of limited resources to ensure that the most contaminated, highest risk sites get addressed first. Using a worst first approach requires a standardized site evaluation which most heavily weights protection of human health and the environment above other factors, such as cost, ease of execution, and political influence.

A scientifically sound and standardized prioritization approach by regulators allows for unbiased action to get the most critical environmental cleanup work done, and is most defensible if challenged by stakeholders. Because most of the responsible parties that created and profited from damage to the environment during mining operations are now deceased or insolvent, the burden of funding cleanups of these orphaned mine sites falls on the public. State and federal regulators have a fiscal responsibility to spend public funds in a manner that is transparent and has explainable rationale.
The California Department of Commerce Abandoned Mine Lands Program (DOC AML) advocates the need for abandoned mine prioritization in the state on the basis of a four-pronged approach (Figure 1). DOC AML recognizes the need to rank mine sites based on relative risk to human health and the environment, and then relative to each other. Transparency and collaboration are essential tools for efficient decision-making. Likewise, the reality of limited available resources to address abandoned mines necessitates strategic planning through a prioritization system, as well as a means for budget requests and justification.

Prioritization is a critical step toward cleaning up California’s worst abandoned mine sites. Increasing human populations and encroaching development are straining California’s freshwater resources. California ranks third in the U.S. for total land area and first in population. In addition, California has an increasing population and a largely arid, Mediterranean climate. Abandoned mine sites are a large source of contamination to valuable surface water and groundwater resources, and can continually pollute by adding acidity, metals and nutrient loadings, sediment, and toxins to scarce water supplies.

Prioritizing the inventory of abandoned mine sites is essential for proactive planning and response to prevent mine waste accidents. The recent Gold King Mine spill near Silverton, Colorado has renewed interest in the environmental legacy of the many abandoned mines throughout the U.S. In the case of the Gold King spill, EPA drilling activities triggered a release of acid and metals-laden mine water to Cement Creek and the Animas River. The parties responsible for creating the environmental contamination at Gold King are long gone, leaving the State of Colorado and EPA left with site cleanup responsibility. The State of Colorado, which originally objected to EPA listing Gold King on the Comprehensive Environmental Response, Compensation, and Liabilities Act (CERCLA) National Priorities List, eventually realized that the scope of the problem was beyond their capacity to handle. When EPA was called in to help, time and funds were not available to do comprehensive testing. According to the EPA Gold King Mine web site, the Animas River already suffered many fish kills due to decades of
continued acid and metals releases from multiple draining abandoned mines into the watershed (EPA, 2015). Nonetheless, the public, politicians, and tribes were outraged at the accident and expect proactive preventions to be enacted in order to prevent a similar event from happening again (Neuhauser, 2015). Following the Gold King Spill, California’s regulators are now being asked for a plan to strategically assess its many abandoned mine sites, and a site ranking and comprehensive abandoned mine inventory list does not yet exist.

**Drivers for Prioritization**

Prioritization of abandoned mine sites is a first step in cleaning up contaminated waste land and putting it back into use. The large number of abandoned mine sites in California necessitates prioritization to fully understand the breadth of the environmental contamination problem, and make decisions on how to pragmatically protect human health and the environment given resource constraints. This study aims to provide recommendations on how to begin prioritization efforts by focusing on the types of abandoned mine sites that are most potentially damaging in California. Following this study, further examination and re-ranking of sites on the prioritization list is needed to get a manageable number of highest rank sites—two or three hundred.

The second step in reclaiming abandoned mine sites is site assessment, which is out of the scope of this study. The site assessment process is where specific human health and ecological risk factors are compared to site contamination levels. Site specific data on soil and groundwater contamination is needed for this step, in addition to knowledge of geology, hydrogeology, transport mechanisms for contaminants, and viable pathways present that could impact receptors. Information from the site assessment step will clarify and refine the prioritized site list to better reflect the sites that pose the biggest hazards. For example, a site that has a clear source of contamination from an abandoned mine site, a viable transport mechanism for contaminants (drainage from the site to a surface water body), and a clear pathway to a human receptor (via drinking water intakes in that surface water body) is a high priority. Sites with documented contamination sources from abandoned mines but lacking a transport mechanism for contaminants to reach receptors are lessor priorities. Human receptors are weighted more heavily than ecological receptors in all prioritization and assessment strategies. Contamination impacts to surface water and groundwater are also heavily weighted due to the potential for use
as a drinking water source, and increased likelihood of contaminants mobilizing and impacting other areas. Protection of surface water and groundwater is especially important in California, due to prolonged drought, expanding human population, and sensitive ecosystems throughout the state.

The third step in reclaiming abandoned mines is remediation and preparation for reuse of the site, which is also outside the scope of this study. Following site assessment activities to characterize contamination and consider appropriate cleanup risk factors, sites are cleaned up with appropriate end-use goals in mind. Since resources are limited and some sites cannot be reasonably remediated to allow for unrestricted use, engineering controls and institutional controls are utilized at the remediation stage to allow for controlled site use and protectiveness.

Prioritization is the least expensive of the three-step process toward cleanup and reuse of abandoned mine sites, but it is also one of the most important. Site assessments and remediation are often very costly; it is unlikely that the lowest priority sites will be addressed for many decades. Site assessment and remediation are predicated on the need to address the most critical areas first, which comes to light during the prioritization step.

The recommendations made in this study are a result of applying the standard measures used to evaluate most types of environmental contamination on abandoned mine site prioritization. Five criteria are used to evaluate priorities among types of abandoned mine sites. Protection of human health is the primary goal for most site cleanups. Abandoned mine prioritization must consider human health risks posed by mine contamination, including ingestion, inhalation, and direct contact exposure routes. Second, risks to ecological receptors are important to preserve natural communities. Typically, site evaluation requires a sense of scale in regard to the contamination; the size and severity of contamination posed by a site is indicative of its priority ranking. Cost of remediation is also a good indicator of the extent of the seriousness of an environmental contamination problem, so I used it as one of the five criteria. Lastly, persistence of a contaminant released to the environment is considered in ranking mine sites; persistent contaminants are difficult to remediate and present long term hazards to receptors.
II. BACKGROUND

Context of Study—Mining in California

Extensive mining activities in California over the last two hundred years has left the state with significant mining-related environmental contamination problems, including toxic tailings piles, waste pits, abandoned processing areas, inhalation hazards, and continuous acid mine drainage contamination of surface water and groundwater resources. In addition to gold mining, California was mined for silver, iron, copper, arsenic, boron minerals, mercury, lead, sulfur (pyrite), benitoite, and asbestos (Figure 2). Figure 3 illustrates mining’s important current and historic role in the state’s economy.

Figure 2: Variety of mining commodities produced in California

<table>
<thead>
<tr>
<th>COMMODITIES PRODUCED IN CALIFORNIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>rock and abrasives</td>
</tr>
<tr>
<td>antimony</td>
</tr>
<tr>
<td>arsenic</td>
</tr>
<tr>
<td>asbestos</td>
</tr>
<tr>
<td>asphalt and bituminous rock</td>
</tr>
<tr>
<td>barite</td>
</tr>
<tr>
<td>bismuth</td>
</tr>
<tr>
<td>black sand</td>
</tr>
<tr>
<td>boron</td>
</tr>
<tr>
<td>bromine</td>
</tr>
<tr>
<td>cadmium</td>
</tr>
<tr>
<td>calcite</td>
</tr>
<tr>
<td>calcium chloride</td>
</tr>
<tr>
<td>chromite</td>
</tr>
<tr>
<td>clay</td>
</tr>
<tr>
<td>coal</td>
</tr>
<tr>
<td>cobalt</td>
</tr>
<tr>
<td>copper</td>
</tr>
<tr>
<td>diatomite</td>
</tr>
<tr>
<td>dolomite</td>
</tr>
<tr>
<td>feldspar</td>
</tr>
<tr>
<td>fluor spar</td>
</tr>
<tr>
<td>gem stones</td>
</tr>
<tr>
<td>gold</td>
</tr>
<tr>
<td>graphite</td>
</tr>
<tr>
<td>gypsum</td>
</tr>
<tr>
<td>iron</td>
</tr>
<tr>
<td>kyanite and andalusite</td>
</tr>
<tr>
<td>lead</td>
</tr>
<tr>
<td>limestone</td>
</tr>
<tr>
<td>lithium</td>
</tr>
<tr>
<td>magnesite</td>
</tr>
<tr>
<td>magnesium</td>
</tr>
<tr>
<td>manganese</td>
</tr>
<tr>
<td>mercury</td>
</tr>
<tr>
<td>mica</td>
</tr>
<tr>
<td>molybdenum</td>
</tr>
<tr>
<td>peat</td>
</tr>
<tr>
<td>purpuse and related rocks</td>
</tr>
<tr>
<td>pyrite</td>
</tr>
<tr>
<td>pyrophylite</td>
</tr>
<tr>
<td>quartz</td>
</tr>
<tr>
<td>quartzite</td>
</tr>
<tr>
<td>rare earth elements</td>
</tr>
<tr>
<td>salines</td>
</tr>
<tr>
<td>salt</td>
</tr>
<tr>
<td>sand and gravel</td>
</tr>
<tr>
<td>shale</td>
</tr>
<tr>
<td>silver</td>
</tr>
<tr>
<td>sodium carbonate</td>
</tr>
<tr>
<td>sodium sulfate</td>
</tr>
<tr>
<td>speciality sands</td>
</tr>
<tr>
<td>stone (crushed and dimension)</td>
</tr>
<tr>
<td>strontium minerals</td>
</tr>
<tr>
<td>sulfur</td>
</tr>
<tr>
<td>talc and soapstone</td>
</tr>
<tr>
<td>tin</td>
</tr>
<tr>
<td>titanium</td>
</tr>
<tr>
<td>tungsten</td>
</tr>
<tr>
<td>uranium</td>
</tr>
<tr>
<td>wollastonite</td>
</tr>
<tr>
<td>zeolite</td>
</tr>
<tr>
<td>zinc</td>
</tr>
<tr>
<td>zirconium and hafnium</td>
</tr>
</tbody>
</table>

Source: DTSC AML Handbook, Feb 1999
Mining in California is ongoing today, but not nearly at the scale of the Gold Rush. According to 2013 United States Geological Survey data, California ranks eighth in the nation for non-fuel mineral production, or 4.2% of the nation’s total output with a total market value of $3.3 billion. The state is second in the nation for production of construction sand, gravel, and Portland cement and is the sole producer of rare earth minerals and boron compounds. California is the sixth largest producer of gold out of ten gold-producing states. The California Office of Mine Reclamation estimates 700 active non-fuel mineral mines operating in the state in 2013. Non-
fuel mineral mines and processing facilities employ about 5300 people annually (Clinkenbeard & Smith 2015).

Approximately 67% of the abandoned mines in California are under federal custody and control—mostly under Bureau of Land Management (BLM) and United State Forest Service (USFS) authority (CA DOC OMR, 2015). Mines on privately owned lands also 31% of sites and can present unique regulatory challenges, since jurisdiction is limited. In terms of environmental risk, a relatively small percent (11%) of the 47,000 abandoned mines, 5170 sites, are estimated to present environmental hazards. These potentially hazardous sites form the pool in the prioritization study.

Figure 4: The majority of abandoned mines in California are under federal control and pose physical safety hazards

Source: California Office of Mine Reclamation Abandoned Mine Lands Program, 2013
Institutions Governing Abandoned Mine Lands Nationwide

The diverse group of land management entities responsible for AMLs further complicates prioritization efforts in the U.S. As illustrated in Table 2, a large number of abandoned mine lands throughout the United States are located on federal and privately-owned lands. This presents an overlapping and sometimes conflicting set of governing environmental regulations and jurisdictions applicable to these AML sites. The EPA Superfund program is tasked with managing large abandoned mine sites on private land or with mixed ownership. The Department of Agriculture agencies mainly address safety issues on their sites through hazardous materials and safety programs. The Department of Interior manages AMLs through a mixture of hazardous materials, watershed, and historic preservation programs. Federal agencies can opt for a Lead Agency CERCLA cleanup also under Executive Order 12580. After States and Tribes complete coal AML cleanups with Office of Surface Mining Reclamation and Enforcement grant funds, they might be able to address non-coal AMLs if there are funds left. Many of these programs are woefully underfunded and understaffed, and some only address issues of physical safety with regard to abandoned mines and do not consider potential long-term environmental and human health costs (BLM, 2015).

Often a combination of federal, tribal, state, and local statutes and regulations are applicable to AML sites. Prioritizing abandoned mine sites for cleanup has an added layer of difficulty when multiple entities control the budget, staffing, and determination of appropriate and relevant risk and cleanup criteria for sites. Additionally, many agencies have different core missions, which can influence prioritization approaches and potentially result in a dissimilar paths to address abandoned mine sites.

Despite the known environmental problems due to abandoned mine sites, there is no reliable estimate of hardrock mine sites on public lands in the western United States. The National Research Council Report (1999) states that BLM is responsible for managing 260 million acres of public lands, of which 90% is available for hardrock mining. Additionally, USFS is entrusted with 160 million acres of western lands, of which 80% are open to hardrock mining (Seymour,
Unknown numbers of mining sites on vast swaths of federally controlled land in the West presents an obvious obstacle to management and prioritization of sites in preparation for cleanup.

**Table 2: Estimated Number of Abandoned Mines throughout the U.S., by Land Holding Agency (Uniquely Accounted for by Each Agency)**

<table>
<thead>
<tr>
<th>Source</th>
<th>Estimated Number of Sites</th>
<th>Explanations/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Federal Agencies</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bureau of Land Management</td>
<td>100,000-500,000</td>
<td>On lands managed by BLM; based on targeted surveys conducted by BLM and states, and the Abandoned Mine Land Inventory which is not yet completed.</td>
</tr>
<tr>
<td>Forest Service</td>
<td>25,000-35,500</td>
<td>On lands within FS boundaries; based on aerial photos, fieldwork, and Dept. of Agriculture data.</td>
</tr>
<tr>
<td>National Park Service</td>
<td>2,500</td>
<td>Actual count in some states, not including Alaska and part of California</td>
</tr>
<tr>
<td>Fish and Wildlife</td>
<td>240</td>
<td>Based on department files and field office confirmation</td>
</tr>
<tr>
<td>Bureau of Mines (defunct agency) 1996</td>
<td>15,300 on Dept. of Interior lands; 12,500 on Dept. of Agriculture lands</td>
<td>Based on database of past mineral deposit activities</td>
</tr>
<tr>
<td>US Geological Survey</td>
<td>88,000 on Dept. of Interior lands</td>
<td>Based on data assembled from agencies and Western Governors' Association estimates</td>
</tr>
<tr>
<td><strong>Other Organizations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral Policy Center 1993, 2003</td>
<td>557,700</td>
<td>Based on 32 western states; compiled from state databases and records</td>
</tr>
<tr>
<td>Western Governors’ Association 1998, 2003</td>
<td>No total estimates given</td>
<td>Estimates for 13 of the 15 states involved, if added would total 263,000; some state numbers based on inventory; range from 150 in North Dakota to 100,000 in Arizona; wide variations in definition of mines.</td>
</tr>
</tbody>
</table>

Source: US EPA OSWER (Sept 2004)
Institutions Governing Abandoned Mine Lands in California

California is unique among the western states in that its surface mining regulatory program is local driven with state oversight (Figure 5). Since 1850, California is considered a “home-rule” state, since land use decisions are made at the local city or county level of government. Final conditional mining permits are issued by the local government, although the permits must still comply with applicable state and federal laws. A 2007 study by the California State Mining and Geology Board (SMGB) concluded that California’s local influence had a negative impact on the consistency of permitting, due to the variability and uncertainty of the permit process. Governmental efficiency is hampered by a complicated and varying set of permit rules throughout regions and the state; unpredictable processes set by local authorities can also complicate compliance efforts by the mining industry. The study also found that influential local permit applicants may have unfair advantages over their competitors (CA SMGB, 2007).

Figure 5: Comparison of Regulatory Mining Programs in the Western U.S.

Source: CA SMGB (2007)
III. LITERATURE REVIEW

Exclusions & Prioritization Criteria

In order to obtain a manageable study size for mine prioritization recommendations in California, I generalized and remove more environmentally benign types of mining sites from further consideration. Hazards due to abandoned mine sites are grouped into physical safety and environmental contamination categories; I only considered sites which pose environmental contamination concerns.

Many abandoned mine sites have erosion problems, stream washouts, and wind-blown dust issues, but sites can be further categorized to better focus on mines most likely to produce environmental contamination (DTSC AML Handbook, 1999). Abandoned mine sites are categorized by three general types of commodities: metallic (hardrock), non-metallic (construction aggregate), and coal (EPA CLU-IN, 2016). Gravel, sand, and other construction aggregate mine sites typically do not pose significant chemical contamination problems beyond their open pit footprint (DTSC AML Handbook, 1999), so I omitted non-metallic mining sites from this study. I also excluded coal mines from this study because coal is federally regulated as a separate industry, with its own permit and fee system in place to help manage reclamation costs. I excluded petroleum mineral production sites since they fall under specialized regulations and permitting. Approximately 5000 abandoned mine sites remain of the 47,000 in California given the exclusions of this study (Marsh, 2015).

Hardrock mines represent the greatest need for prioritization due to the frequency of associated chemical contamination concerns. Hardrock mines often disturb large quantities of material that must be handled to extract the commodity; the amount of mineral extracted per ton of ore disturbed is very small. The vast majority of ore and overburden disturbed becomes waste, often with residual metals contamination from the commodity mined as well as chemical contamination from processing and extraction operations. Some hardrock commodities are toxic themselves (mercury, lead) or require toxic reagents for processing (gold, silver). Modern mining techniques have made it feasible and more economical to extract minerals from lower quality ore, which can result in more waste. Historic mining operations typically left more of the
commodity in the waste rock and tailings due to mining technology limitations; historic mines for toxic commodities therefore tend to have more residual toxic metals present as well.

I selected five environmental criteria to apply to abandoned mine site types in California to determine what types of sites should be ranked higher in a prioritization scheme. The severity of environmental contamination is typically gauged by these same five criteria regardless of the source: risk to human health, risk to ecological receptors, relative size of the problem, cost to remediate, and persistence of contaminants. I compared these five criteria with relevant literature on contamination associated with hardrock mining, screening abandoned mine sites and/or contamination sites, and efforts to manage contamination from abandoned mine sites.

The prevalence of acid mine drainage, mercury, and arsenic contamination resulting from abandoned mines in the literature was well documented, as well as the extent of problems associated with these contaminant types to human and ecological receptors. Several studies by regulatory agencies were specifically dedicated to best practices in management of these three contamination issues from abandoned mines. California’s geology and the extent of gold and mercury mining throughout the state has resulted in widespread pyrite oxidation, acid drainage, elemental and methylated mercury, and arsenic mobilization problems. Studies related to abandoned mine sites in California conducted over the past twenty years have a bias for AMD, mercury, and arsenic issues, indicating that these types of mine sites should be prioritized over others due to the high degree of associated hazards.

**Most Significant Types of Environmentally Contaminated Abandoned Mine Sites**

The literature review on abandoned mine sites in California and in general revealed a prevalence of studies devoted to acid mine drainage, mercury, and arsenic issues. Available studies and guidance documents, even when limited to just California’s abandoned mines, were limited in scope intentionally or by necessity due to the expanse of the issue. California has abandoned mines from over sixty commodities, but rare metal mines were few in comparison to the expanse of gold and copper mining in the state (DTSC AML Handbook, 1999).
Multiple agencies and working groups have developed preliminary assessment and ranking guides for California mines with limited success. The DTSC AML Handbook was written by a core interagency group with vast AML expertise in California. The intent of the Handbook was to develop a preliminary assessment guide to better capture the extent of the problem in the state. Nevertheless, their final report DTSC stated “Developing a single guidance document to cover historic mining of more than sixty types of commodities proved to be a daunting, if not unrealistic task.” (1999). My study was limited to providing recommendations based on the literature study to help limit and guide the prioritization process. A focus on abandoned mines in California with AMD, mercury, and arsenic issues helps limit the approximately 5000 contaminated mine sites to a smaller subset, which can then be further analyzed for completed pathways and ranked accordingly.

**Acid Mine Drainage Contamination**

AMD from abandoned mine sites creates extensive environmental contamination problems throughout the U.S., especially in California with its heavy concentration of large-scale abandoned mines and prevailing pyrite deposits. The U.S. Forest Service conducted a study in 1993 that estimated 5000 to 10,000 miles of streams and rivers in National Forests throughout the U.S. are impacted by acid mine drainage (EPA Office of Water, 1997). Although there is no running total of AMD sites in California, it is acknowledged that numerous sites with AMD problems exist, and the amount of studies and research devoted to solving AMD problems in the state reflects that.

The EPA National Hardrock Mining Framework report identified acid mine drainage as a major environmental problem due to the formation of acidic runoff and associated mobilization of contaminants beyond the mined area. AMD is also referred to as acid rock drainage, particularly by the mining industry, since the process by which it forms is essentially natural. Mining activities exacerbate acid formation by increasing surface area of previously confined minerals and exposing large amounts of it to air and water. Both active and abandoned mine sites can generate AMD. Despite improvements in predictive AMD testing and modeling for modern
mining sites, there are still many uncertainties, and unpredicted AMD may occur after just a few years of operation (EPA Office of Water, 1997).

AMD primarily depends on the mineralogy of the mining area and the availability of water and oxygen. Sulfide minerals usually contain the valuable metallic ore deposits that are mined in California (CA DTSC, 1999). The oxidation of metallic sulfides is largely responsible for AMD generation—most especially pyrite (FeS2). Galena, sphalerite, and chalcopyrite also contribute to acid generation (EPA Office of Water, 1997). All four of these metallic sulfides are abundant throughout California, and mining activities enhance contact of these minerals with water and oxygen. According to the EPA Office of Water, relationships between particle size, surface area, and oxidation potential determine acid generating ability (1997). Particle size is a factor because it affects the amount of surface area exposed to weathering and oxidation; waste rock and tailings piles from mining activities sites greatly increase available surface area for these reactions. Due to recent technology enhancements, more waste rock and tailings are being produced during extraction, processing, and benefaction as companies now profitably mine lower grade ore bodies (Seymour, 2004).

California’s unique geology contributes to AMD potential and severity of abandoned mines. Presence of volcanogenic massive sulfide (VMS) deposits collocated with metallic ore bodies has resulted in enormous amounts of AMD generation (CA DTSC, 1999). Once disturbed by mining activities, VMS deposits can fuel oxidation of sulfide minerals for decades. Most of California’s historic copper deposits were within VMS units; zinc, silver, gold, sulfur, and iron have been produced as byproducts in these areas as well. Presence of VMS at California’s mine sites greatly increases the severity and duration of AMD impacts.

The hydrology of California is a contributing factor to the extent and significance of AMD impacts in the state. California’s Mediterranean and desert climate zones are characterized by several months of dry summers followed by wetter winter seasons. Oxidation products build in AMD areas during dry cycles; as the length of the dry cycle increases the magnitude of a large contamination flush increases with the next precipitation event—which can cause fish kills from acid and heavy metals loadings (EPA Office of Water, 1997). Water in underground mines can slow acid generation from occurring as long as the material is below the water table, but the dry
seasons in California’s climate cause water tables to drop and acid generating material to be exposed to oxygen.

According to my environmental criteria, the type of abandoned mines with the highest priority level of environmental contamination in California are those with acid mine drainage concerns. AMD issues in California’s abandoned mines result in high level concerns for each of the five prioritization criteria: human health risks, ecological toxicity, severity of contamination, persistence in the environment, and cost to remediate.

AMD ranks high among abandoned mine site types due to toxicity concerns impacting human health and ecological receptors. AMD generation typically decreases the pH values of contact waters to 2.5, which is highly acidic. This high acid water causes metallic sulfide minerals to disassociate and release toxic metal cations, including lead, copper, silver, manganese, cadmium, iron, and zinc. Humans can be exposed to acid and heavy metals through direct contact of surface water or ingestion of drinking water. Copper and zinc cations released from AMD are especially damaging to ecosystem communities and poison water to the point where ecological dead zones are produced. Fish, birds, and other aquatic species can be exposed to these AMD contaminants by direct contact and ingestion of surface water and sediments.

AMD ranks high in the severity of contamination category as its impacts are often widespread from abandoned mine source areas due to hydrological connections and years of weathering, dispersion, and deposition. Waste rock, tailings, and overburden piles span hundreds of meters high and serve as a continual source of contamination due to weathering and washout from precipitation (Montero, Brimhall, Alpers, & Swayze, 2004). AMD exacerbates heavy metals contamination at abandoned mines as well, creating a multitude of serious environmental hazards downstream.

AMD also ranks high for environmental persistence, as it is very difficult to contain or stop acid generation once it starts. Pyrite is typically collocated with metallic ores in California and is also the most efficient acid producing mineral involved in AMD (Dold, 2014). Acid produced from pyrite also attacks more resistant sulfide metals, adding to acid and metal cation loadings. Iron rich sulfides such as marcasite, pyrrhotite, and chalcopyrite tend to retain high levels of base metals and heavy metals released upon oxidation, and all of these sulfide minerals are common
throughout California (CA DTSC, 1999). Because the source continues to produce contamination long after mining has ceased, no easily implemented remedial solutions to AMD exist (EPA Office of Water).

The continual production of contaminant for hundreds of years beyond the life of the mine and the enormous challenge of treating AMD contaminated areas scores highest on my criteria of expense to remediate. The most typical AMD remediation measure is avoidance or isolation of acid generating materials, such as diverting streams around tailings piles and capping mining wastes to protect them from precipitation infiltration. Because the acid generating portion of the mine is usually inaccessible, often only treatment of the contaminated runoff can be implemented while the contamination source continues inside the mine. Most mining areas are also remote, creating accessibility challenges for heavy equipment and difficulty getting power to sites. All of these factors lead AMD to generally be the most expensive abandoned mine problem to remediate in California.

Further evidence to rank abandoned mine sites with AMD in California highest among other types of sites lies in the amount of studies in California dedicated to AMD issues. In 1994, a technical committee of researchers and regulatory and landholding agencies sought to identify watershed pollution issues in California, and improve nonpoint source pollution control programs. The result of this study is the Abandoned Mines Technical Advisory Committee’s (TAC) Report on Abandoned Mines, submitted to the California State Water Resources Control Board. The committee recognized the scale and scope of the abandoned mine problem in California, and recommended criteria be developed to prioritize sites which required immediate attention, presented less risks, or did not need clean up at all. This study reinforced the need for a comprehensive prioritization system, but did not attempt to develop such as system. However, the committee agreed that metal loading from acid-generating abandoned mines was of utmost concern to degrading environmental quality of watersheds in California, and should be ranked highest. The TAC study acknowledged the overriding significance of acid mine drainage with the following quote: “After much discussion, however, our committee agreed that, because of the known high costs of abating pollution by acid generating mines, technical and bureaucratic impediments to effective cleanups, and time constraints, the focus of this report would be on degradation caused by acid-generating mines.” (1994, p. 8)
The severity and widespread environmental damage of AMD is well represented in active cleanup sites and studies on AMLs. AMD is identified as the predominant abandoned mine issue in Nevada and Colorado as well. The Iron Mountain Mine site in Shasta County, California operated for over one hundred years as a hardrock mine site, and is now an active National Priorities List site due to massive extents of AMD contamination. Nearby creeks to Iron Mountain are devoid of aquatic life due to continuous acid and heavy metals releases. A dilution system for AMD water is used to protect drinking water intakes for a population of 70,000 people within a few miles of the mine. Despite installation of a containment reservoir to keep mine-influenced water away from clean surface water, large storm events and overtopping of the reservoir has caused twenty major fish kills in the Sacramento River (EPA Iron Mountain Superfund website, 2015). In California, multiple abandoned mines with AMD issues poison biota and further threaten threatened and endangered fish species, such as the Winter Run Chinook Salmon. Iron Mountain is representative of one of the worst cases of AMD in California, and an example of why AMD sites should be a priority in a state ranking scheme.

**Mercury Contamination**

Mercury is ubiquitous at abandoned mine sites throughout California and is a contaminant of significant environmental concern. The majority of mercury production in the U.S. was extracted from California mines in the Coast Ranges (CA DTSC, 1999). Mercury was extensively mined along the Coast Ranges of California and then used throughout the Sierra Nevada Range in the amalgamation process to recover gold and silver. The New Idria Mercury Mine in San Benito County, California (pictured after the title page of this report) dominated U.S. mercury production from 1895 until 1930. Consequently, the New Idria Mercury Mine is now an active Superfund site for long-term remediation, and is considered to be one of the most contaminated sites in the State of California.

I selected mercury as the 2nd highest priority among abandoned mine sites in California due to its risks to human health, ecological toxicity, widespread contamination throughout the state, and persistence in the environment. Of primary concern is the fact that mercury bioaccumulates in the food chain, reduces water quality, and methylates in aquatic environments. The frequency
and extent of literature on mercury contamination from mining activities worldwide and in California is indicative of its significance and need to be prioritized among AMLs. As illustrated in Figure 6, 74 mercury impaired watersheds (black outlines) correlate well with historic mercury and gold mines locations along the Coast and Sierra Nevada Ranges, respectively.

Figure 6: Mercury and gold mine sites from the Mineral Resources Data System (MRDS) plotted in comparison to 303(d) listed watershed boundary reservoirs

Mercury ranks highest on my list of environmental criteria for hazards posed to ecological receptors. As illustrated in Figure 7, depositional mercury and mercury released directly to surface waters accumulate in alluvial sediment, where it combines with organic material to form methyl mercury. Methyl mercury bioaccumulates in fish, which are consumed by humans and animals and can lead to poisoning. In Figure 8, biomagnification is diagramed for methylmercury. Biomagnification is a huge toxicity concern for both human and ecological receptors. As illustrated in the figure, methylmercury concentrations are magnified with each increasing trophic level. The EPA reported that 44 states, two tribes, and one territory issued more than 3200 fish consumption advisories due to mercury in the year 2004; California issued the highest number of these fish advisories of all the western states (Suchanek et al., 2008).
Figure 7: Dissolved mercury enters surface waters from mining wastes, is converted to methylmercury (MeHg) primarily in reservoirs and lakes, and then bioaccumulated up the food chain into fish.

![Figure 7.1 Linkage Between Sources, Methylmercury, and Targets](source)

Source: CA RWQCB San Francisco Bay Region Guadalupe River Watershed Mercury TMDL Project Staff Report (Sept 2008)

Figure 8: Mercury methylates in aquatic environments and biomagnified up the food chain, presenting a significant ecological and human health toxin.

![Figure 7.8 Food Chain Biomagnification of Methylmercury](source)

Source: CA RWQCB San Francisco Bay Region Guadalupe River Watershed Mercury TMDL Project Staff Report (Sept 2008)

Mercury scores high on my criteria list due to its toxicity to human health as well. At high levels, mercury exposure may damage the brain, kidneys, and developing fetus (ATSDR, 2015). The larger and older fish that humans tend to eat also have the greatest quantities of mercury in
them due to their higher trophic level; in certain areas fish consumption is limited for sensitive populations due to concerns about mercury ingestion.

Mercury also was ranked high among my environmental criteria for its widespread extent and severity throughout AMLs in California. Mercury deposition is a result of vaporization and transport during ore processing, making source and impact areas difficult to define. Because mercury volatilizes easily, recovery operations were generally conducted on site at the mine by roasting cinnabar ore and recovering vapors of mercury. Mercury deposition from smelting operations were then wind-blown to impact large areas of land and water outside the immediate mining area. The mercury deposits of the Coast Ranges have small, irregular, and unpredictable ore bodies, which has resulted in a series of various mining strategies used at abandoned sites, resulting in large extent and varying forms of transported mercury contamination (CA DTSC, 1999). In the amalgamation process to recover gold, much of the elemental mercury used was released to the environment via soil, air, and surface water.

Mercury contamination from historic mining activities is the subject of multiple watershed studies by the California State Water Resources Control Board, which is indicative of its importance among contamination issues threatening surface water in California. Mercury is found in 714 of the 1467 NPL sites identified in the U.S., which is another indication of its severity as an environmental contaminant.

**Arsenic Contamination**

Arsenic is a common issue at abandoned mine sites in California, in part because it is naturally occurring in the state’s most productive metallic mining areas. In nature arsenic combines with oxygen, chlorine, and sulfur to form inorganic arsenic compounds. Arsenic forms organic arsenic compounds with carbon and hydrogen in plants and animals. Naturally occurring arsenic is often associated with gold and silver ore, and tailings piles from former gold, silver, and mercury mines. Pyrite can incorporate up to ten percent by weight arsenic in its chemical structure; arsenic has the ability to accelerate dissolution of pyrite and accelerate generation of AMD (Blanchard, Alfredsson, Brodholt, Wright, & Catlow, 2006).
Arsenic pyrite is prevalent along the Melones fault zone in the southern Mother Lode Gold District of California, home to the California Gold Rush. Many abandoned gold mines now exist in this area. Due to the presence of arsenian pyrite, mine tailings and weathered waste products along the Tuolumne River contain between 20 and 1300 parts per million (ppm) arsenic (Savage, Tingle, O’Day, Waychunas, & Bird, 2000). As these arsenic-rich sulfides weather, arsenic is released to the environment.

Demand for land and drinking and irrigation water in California is increasing as the population continues to grow. Development is now encroaching into vacant areas of land once used for mining. For example, homes in the Mesa de Oro subdivision of Sutter Creek in Amador County, California were constructed directly on top of mine tailings and soils heavily contaminated with arsenic from the former Central Eureka Mine. (Savage et al., 2000). Remediation was required after the homes were occupied to protect humans and animals from direct contact with high arsenic levels.

Arsenic is persistent in the environment and poses problems to drinking water since it is carcinogenic. When arsenic contaminated mine waste contacts river or lake waters, chemical reactions can lead to elevated levels of dissolved arsenic. Presence of arsenic in surface water and soils presents a serious direct contact and ingestion hazard to humans. In 2001 EPA revised the arsenic standard for drinking water to 10 parts per billion (ppb), down from 50 ppb. Multiple studies offer evidence on extent of arsenic pollution problems as a result of mining operations, which will be considered in the overall evaluation of contaminant priorities. Arsenic’s high toxicity to human health and ecological receptors is indicative of its seriousness as an abandoned mine pollutant.

Based on my prioritization criteria, abandoned mine sites with arsenic contamination rank 3rd among other types of contaminated sites. Arsenic outranked most other types of environmental contamination at mine sites because it is a severe and widespread problem in California, persistent in the environment, expensive to remediate, and poses a human health risk.

The severity of arsenic contamination on sites is evident by the amount of studies dedicated to assessing, treating, and protecting receptors from exposure to arsenic contamination. Sites listed on the EPA’s National Priority List are considered to be the most seriously contaminated.
hazardous waste areas identified for long term remediation. As illustrated in Figure 9, California has one of the highest frequencies of Superfund sites with arsenic contamination problems.

Figure 9: California has one of the highest frequency of sites on the National Priorities List with arsenic contamination (54-72 sites), which is indicative of the extent of arsenic issues

Source: ATSDR Toxicological Profile for Arsenic (2007)

The toxicity of arsenic to humans and concern for its ability to dissolve into drinking water rank arsenic-contaminated abandoned mine sites the 3\textsuperscript{rd} highest priority category in California. Arsenic ranks high among AML contaminants because human exposure to arsenic is a significant human health risk. Exposure to inorganic arsenic at high levels can cause death.
Short term human exposure to arsenic can cause skin discoloration and small warts. Arsenic ingestion from water supplies is known to cause skin cancer. Evidence from risk assessment studies indicate that arsenic ingestion is also linked to internal cancers, including liver, lung, kidney, and bladder cancer (Smith, 1992). Arsenic has been detected in human blood, urine, hair, nails and internal organs. It is believed children may have more risk of arsenic exposure, due to hand-to-mouth activities and greater exposure ratios of body weight to contaminant intake (ATSDR, 2007).

Arsenic ranks high among types of mine contamination due to its ecological toxicity. Certain freshwater and marine species of fish tend to bioaccumulate arsenic, although it is not biomagnified through the food chain like mercury (ATSDR, 2007).

I also ranked arsenic highly for its persistence in the environment. Arsenic contamination is difficult to treat and mobilizes in groundwater, which also adds to the expense of cleanup. Mining sites in California are often in rural areas where groundwater and surface water are used as drinking water. Keeping arsenic out of drinking water supplies is of utmost concern due to its toxicity.

Arsenic is identified as the primary contaminant of concern due to human health hazards in several studies of abandoned mine sites throughout the world. Xinjiang Province, China is one of the unhealthiest regions in the country, primarily due to arsenic contamination in groundwater from abandoned mine sites. Xinjiang Province correlates well to California due to the prevalence of abandoned gold and copper mines and naturally high background concentrations of arsenic found in soil. Mining areas in China and California tend to be in rural areas, where local people rely on groundwater for drinking water. Arsenic levels in Xinjiang groundwater are as high as 830 micrograms per liter, compared with a World Health Organization safe drinking water guideline of 10 micrograms per liter (Karn, 2015). Risks of arsenic exposure from contaminated groundwater could expose over 19 million Chinese people to this carcinogen (Rodriguez-Lado et al, 2013).

Arsenic was identified as the main critical contaminant in the Delita gold mine region of Cuba, due to surface and groundwater contamination and heavy metals in mine tailings and sediments. Arsenic and heavy metals were detected in the weathered material form old tailings used as fill.
Surface runoff transports very high levels of arsenic toward the sea, and nearby water wells exhibited elevated arsenic levels. Iron oxide components also play a role in the bioaccessibility of Arsenic in areas like California. (Toujaguez et al., 2013)

IV. AGENCY PROGRAMS TO ASSESS AND PRIORITIZE MINE SITES

Effective Institutional Management Programs

The state of California is in need of an institutional program to manage and regulate the backlog of abandoned mine sites. The magnitude of the abandoned mine lands problem in California is evident, as is the need to prioritize the inventory in order to make sound decisions on funding allocations to address the most seriously contaminated sites first. Multiple entities manage California’s AMLs with no umbrella or guidance agency to assist with the monumental task of prioritizing, assessing, and eventually cleaning up these sites. AMLs in California are managed by various Federal land management agencies (BLM, USFS, National Park Service, Fish and Wildlife Service), the EPA, multiple state regulators (DTSC, RWQCB, Department of Commerce), and private landowners. This scattered approach to managing AMLs makes it very difficult to fully characterize the extent of the AML problem in the State, and figure out where assessment and cleanup funds can provide the greatest benefits. Additionally, most of the entities listed do not have a specialized abandoned mine program, personnel on staff trained in AMLs, or adequate funding to work on mine prioritization efforts.

In 1994, the California Technical Advisory Committee (TAC) for Abandoned Mines report clearly identified that California has no specific, comprehensive program at any governmental level to clean up abandoned and inactive non-coal mines. The report noted that a variety of federal, state, and local programs have conducted cleanups on a few sites, and federal land management agencies sometimes address safety hazards. Recommendations were provided by TAC to close this regulatory gap, as well as address the following issues, which were identified as serious impediments to a functional, comprehensive abandoned non-coal mine lands reclamation program: fragmentation of efforts and expertise among various regulatory programs, inaction due to lack of funding or due to liability concerns, poorly defined or
unrealistic cleanup goals, lack of assessment data detailing the regional extent of the problems, the need for improved cleanup technology (CA TAC, 1994).

Despite the state having more abandoned mine lands than any other, California has no full-time employees dedicated to non-coal solid minerals regulatory program or an abandoned mine land program administration, and no separate budget for either. California is one of seven western states that do not track annual statistics on the number of acres under mining permits, number of acres disturbed by mining, or the number of acres reclaimed (CA SMGB, 2007). These statistics also represent obstacles to the state developing an effective AML priority list and managing it effectively, as well as ensuring that more mine sites do not end up on the orphaned mine inventory.

An effective institutional program is required at the state level to ensure that California can account for its AMLs by prioritizing mines. Despite the multiple entities managing lands with AMLs, an umbrella program at the state level can develop a list of prioritized mine sites and best determine where federal and state funds should be directed to protect the people and ecosystems most vulnerable to contamination. An effective program must have clear assigned program responsibilities, a focused goal to prioritize, assess, and clean up abandoned mine sites, trained and dedicated staff, adequate funds to manage the program, and authority to ensure regulations are applied consistently and understood by the public. Unfortunately, no such program with all of these facets exists in California. The Abandoned Mine Lands Unit within the Department of Conservation’s Office of Mine Reclamation currently lists seven staff members on its web site and has a very small operating budget. The current staffing and budget are insufficient to prioritize and manage approximately 5000 contaminated abandoned mine sites in California.

**EPA Site Assessment and Superfund Programs**

The Superfund Site Assessment Program within EPA Region 9, which includes California, often has the first look at abandoned mine sites since they are considered “orphaned.” Orphaned mine sites have some level of contamination present but lack a responsible party to initiate and pay for assessment and cleanup activities. Superfund acts as a safety net of sorts to ensure that these
abandoned mine sites get addressed, and if possible, that parties responsible for the contamination are held accountable.

The Superfund Site Assessment process screens sites and determines whether an emergency cleanup is necessary, the site should be listed on the National Priorities List (NPL) for long term remedial action, or a state or tribal cleanup program would be most appropriate to address the contamination. The process begins when a site is discovered or reported with a potential or confirmed release of hazardous substances. EPA and its state and tribal partners evaluate preliminary site data according to the Hazard Ranking System (HRS) in order to assign it to an appropriate cleanup program. Only sites that are too complex, contentious, or expensive for states to handle are listed on the NPL (EPA Superfund, 2015). Currently, eight California abandoned mine sites are listed on the NPL and sixteen California abandoned mine sites are being addressed under the EPA Superfund removal program.

Although it is not designed as such, the Superfund program tends to be a “catch all” for abandoned mine sites that have no financially viable responsible party to perform cleanup, or are in the jurisdiction of a private or government entity without the expertise or available funding to address the cleanup properly. Generally, Superfund is reserved for abandoned mine sites with the largest, most complex cases, or where other regulatory programs were not successful in meeting environmental protection goals (EPA, 1997).

However, Superfund processes and requirements are not effective in cleaning up abandoned mine cleanups in certain cases. For example, under Superfund an entire contamination source area must be identified and controlled to meet site closure requirements, yet that is rarely achievable in large, complex, and naturally regenerating contamination sites which result from abandoned mining activities. Superfund should continue to be used as a safety net for AMLs with no other options, but the need for an effective institutional management program specifically geared toward prioritizing, assessing, and cleaning up contaminated AMLs is evident.
Federal, Interagency, and State Programs

Land management agencies such as the Bureau of Land Management (BLM) and the National Park Service (NPS) own significant acreage of land in California, much of it riddled with abandoned mines. These agencies manage their own abandoned mine lands programs, but are mostly focused on physical safety hazards posed by mining features. For the most part, BLM and NPS do not have the technical or financial ability to run complex abandoned mine prioritization, assessment, or cleanup operations within their agency, nor the capacity to pursue responsible parties in an effort to spur cleanup actions.

The federal Resource Conservation and Recovery Act (RCRA) program involvement in mining prioritization efforts is minimal since most mining wastes are excluded from hazardous waste regulations. Congress amended RCRA in October 1980 with the Bevill amendment, which excluded most mining waste from being regulated as hazardous waste under Subtitle C (EPA, 1997). RCRA programs in 48 out of 50 states are delegated to the State, including in California, but they typically do not have a role in abandoned mine lands management or prioritization.

Several organizations within California state government work on AML assessment, cleanup, and operations and maintenance of a cleanup remedy. The Department of Toxic Substances Control (DTSC) conducts Preliminary Endangerment Assessments (PEAs) on AMLs, which is similar to EPA’s site screening process to determine if it should be included on the National Priorities List. DTSC specializes in sites with soil contamination and active source areas. Due to the size, complexity, and cost involved in many contaminated abandoned mine areas, DTSC may also provide monitoring and operations and maintenance for sites as they wait for NPL listing or funding and cleanup. DTSC has a specific Abandoned Mine Lands Preliminary Assessment Handbook (Feb 1999) used to evaluate the particular environmental issues posed by AMLs.

California State and Regional Water Quality Control Boards (SRWQCB) also play a role in abandoned mine issues, because AMLs are closely tied to surface water and groundwater environmental impacts. The SRWQCB has the authority to issue Investigative Orders and Cleanup and Abatement Orders to responsible parties to promote action at groundwater source
sites. However, if responsible parties are not identified and the scope of the site is large, often these sites will be monitored and await action by EPA.

The California Department of Conservation houses the Abandoned Mine Lands Unit. Abandoned legacy mines in California are the focus of the AMLU program, which is within the Office of Mine Reclamation. The AMLU is involved in the ongoing collaborative efforts of a team of state and federal environmental contamination experts to develop a prioritization tool for abandoned mine sites in California.

V. EVALUATION OF EXISTING ASSESSMENT AND PRIORITIZATION SCHEMATICS

Effective Prioritization Schemes

Past attempts to assemble estimates of the number of abandoned mine sites throughout California as well as the extent of environmental contamination, cost to remediate, and means of prioritization were largely unsuccessful. It is difficult to meaningfully combine and compare accounting efforts between federal landholding agencies due to different means of classification of mining sites by each agency. Some agencies define an abandoned mine site by related mining features within an area, whereas other agencies define each mining feature as an individual site (U.S. GAO, 1996). Thus far, accurately quantifying the cost to remediate and reclaim abandoned mine sites is unattainable since the extent of known and potential environmental contamination due to abandoned mine sites is largely uncharacterized and unknown.

Appendix I compares nine different prioritization schemes for abandoned mine sites in order to evaluate their applicability and relative effectiveness to rank California’s abandoned mine sites. Because each prioritization scheme was developed independently according to the agency’s needs, the decision tool used in each scheme is noted for context. Through my literature review I have determined that AMD, mercury, and arsenic contamination are the most significant issues impacting California AMLs. Therefore each of the nine prioritization schemes has been examined for how it evaluated these three issues. Each scheme was noted as Qualitative or Quantitative depending on how it ranked sites within the study area. Limits and exceptions to
each scheme are also noted in the chart. Additional explanation on prioritization schemes follows this section.

**Feinstein Abandoned Mine Lands Prioritization List, March 2007**

The Feinstein Abandoned Mine Lands Prioritization List was assembled in response to a request by Senator Feinstein in 2007. An excerpt from the report submitted to Senator Feinstein is included below as Figure 10. As one of the drivers behind the request was financial liability of backlogged abandoned mine sites, the cost of remediation was selected as the primary ranking factor. Because Superfund sites tend to be the largest, most complex, and most contaminated sites, Superfund sites ranked high in this study overall. Limitations of this study include the many abandoned mine sites for which estimated costs and extent of contamination are largely unknown. The Superfund sites listed are likely accurate in assumptions made, however, there may be other sites in California that were not considered that could rank even higher.

Superfund sites are those listed on the National Priorities List due to a Hazard Ranking System score above 28.5; Superfund sites are estimated to have high remediation costs. For this prioritization effort, 117 abandoned mine sites were assigned to three Tiers based on past (actual) and estimated capital cost of cleanup:

- Tier 1 ($10M - $100M or more);
- Tier 2 ($1M - $10M); and
- Tier 3 ($100K - $1M)

Historically, AMD is the most expensive remediation issue, so AMD sites topped the Feinstein list more than any other sites. All Tier 1 sites have AMD, arsenic, and/or mercury contamination issues, and nearly all Tier 2 and Tier 3 sites do as well. Most Tier 1 sites had human health receptor issues. Less than half of the Tier 2 sites had high human health exposure priorities noted. The top four (most expensive to remediate) sites had AMD issues as the primary problem. More than half of the Tier 2 sites had AMD issues.
Figure 10: Feinstein Map Excerpt & Key

Source: CA DOC OMR AML (2007)
CA DOC AMLU – California’s Abandoned Mines: A Report on the Magnitude & Scope of the Issue in the State, June 2000

This study screened 47,000 abandoned sites in California. Physical safety was included among the ranking criteria, and the focus was on preselected watersheds in California. This study is useful for ranking the preselected watersheds, however since the criteria for selecting these watersheds was not discussed, its application is limited. Acid mine drainage was the prominent contamination issue among ranked sites, due to its detrimental impacts to water quality. Results from this analysis are not indicative of a baseline for California watersheds since it is unknown why these sites were selected among others, which rules out associated mine sites from other watersheds not evaluated.

CAMLAG Partnership: California Abandoned Mine Lands Agency Group

The CAMLAG interagency work group consists of State & Regional Water Quality Control Boards, the CA DTSC, CA DOC, EPA Region 9, and Public Land Management Agencies. The purpose of CAMLAG is to support more efficient and effective implementation of programs and tools to address California’s abandoned mine sites, and to develop criteria for selecting and addressing abandoned mine sites for remediation (Marsh, 2015). The work product from the CAMLAG effort is called MINESHAFT. MINESHAFT is a complex ranking formula derived from weighted environmental criteria that will be applied to each of the abandoned mine sites in California to obtain a ranking score. This formula is still under development but highlights are discussed below.

The CAMLAG formula relies on a source-transport-receptor data input model to proportionally weight prioritization criteria. CAMLAG uses geographic information system data from previous abandoned mine land studies to help determine transport and receptor information, and applies source information criteria based on commodity mined and geological characteristics. CAMLAG only addresses the release of hazardous substances at abandoned mine sites; physical safety issues are not evaluated. The following weighted criteria are factored into the source-transport-receptor model:
CAMLAG has made progress in developing prioritization criteria for sites in absence of site assessment data. This is an extremely valuable asset in a prioritization tool because it allows the site to be prioritized without conducting a preliminary site assessment or comprehensive soil and groundwater site assessment. By examining the source in detail and applying weighted factors to the commodity and known geologic factors, such as massive sulfide deposits, CAMLAG is able to more accurately account for the significance of environmental contamination at a site.

The source portion of the formula basis becomes problematic when the commodity mined is not toxic, yet the abandoned mine site likely exhibits toxic contamination from reagents used or reactions that have occurred since mining ceased. Since abandoned gold mining sites are dominant in California, and gold is a non-toxic commodity without an assigned Soil Screening Level (SSL), it was necessary to devise an alternative way to account for contamination at abandoned gold mining sites. Mercury was used ubiquitously in processing at gold mining sites, and naturally occurring sulfide and arsenic deposits commingled with the gold deposits were common. The formula to rank sites, which is still under development, will account for non-toxic...
commodities by assigning a relative number based on a combination of other likely toxic factors. As depicted in Figure 12, an SSL will be assigned for gold mines based on whether it was a processing plant site, if it is upstream of an impacted water body, the SSL of the secondary commodity, or it will be assigned the default value of the mercury SSL if unknown.

Figure 12: CAMLAG Accounting for Toxicity at Abandoned Gold Mine Sites

Source: Hillenbrand (2015)

When the CAMLAG formula is finalized, the interagency group will attempt to validate the formula by applying it to current lists of prioritized mine sites, several of which are captured in Appendix 1 of this study. The method will also be adjusted using knowledge of listed mines and the relationship between known problems.
This comparative study of regulatory surface mining programs was conducted by the California State Mining and Geology Board for the following thirteen western states: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming. The study compared California’s SMARA of 1975 with regulatory surface mining programs in the other western states and evaluated the mining policies and program of the U.S. BLM, since so much federal land with mining activity fall under their jurisdiction.

The SMGB study determined the most significant problems posed by non-coal minerals mining in California through research, interviews, and surveys. Acid mine drainage was ranked as the top most problematic issue in California, followed by reclamation, traffic, reclamation bonds, and land use/zoning, respectively. Other noted significant problems in California included water quality, safety, groundwater withdrawal, ground de-watering, and erosion/sedimentation.

Information gleaned from the other western states on their top concerns is also compelling, despite the geological, political, and regulatory differences between them. Both California and South Dakota named acid mine drainage as their number one problem. Montana and North Dakota selected reclamation as their number one issue of concern, while Nevada and Utah selected reclamation bonding as their primary issue. Land use/zoning concerns were ranked as the most significant problem in Colorado and Wyoming. The most frequently identified significant non-coal mineral mining problems of the other twelve western states, according to the study include water quality, reclamation, reclamation bonding, and land use/zoning. Of note is the fact that acid mine drainage was not a suggested category in this question; interviewees specified AMD under “other.” (CA SMGB, 2007)
Hazard Ranking System (HRS), November 1992

The Hazard Ranking System (HRS) is used in the EPA’s site scoring system to determine if a given site poses enough environmental risk to conduct a removal action or be placed on the NPL for remedial action. HRS scores are determined by evaluation of the following four pathways:

1. Groundwater migration;
2. Surface water migration (including drinking water, human food chain, and environmental);
3. Soil exposure (resident population and nearby population); and
4. Air migration.

(EPA OSWER, 1992)

Although HRS does prioritize sites, a Preliminary Assessment (PA) and Site Inspection (SI) are both required to gather enough data to enable completion of the HRS scoring system. Given the large inventory of abandoned mine sites, it is not feasible to conduct nearly 5000 PA/SIs in California in order to enable the HRS scoring process to commence. The field work alone that would be required for the SI portion is infeasible for EPA to complete. HRS is not well adapted to abandoned mine sites due to burdensome data collections required to use the tool, and difficulty obtaining representative samples that could reasonably predict contamination issues at an AML.

USGS Mineral Resources Data System (MRDS); large complex collection of reports describing metallic and nonmetallic mineral resources

This study was one of the first attempts to get a listing of abandoned mine sites that should be evaluated for environmental and health and safety concerns. Abandoned mines were classified by size (small-medium-large) and commodity; large size and more toxic commodities tend to pose more of an environmental concern according to the MRDS ranking.

USGS Volcanogenic Massive Sulfide Deposits (VMSD) lists, 1986 – info on VMS deposits around the world with grad and tonnage models

The VMSD list was an early prioritization of abandoned mine sites that were collocated on one of the world’s known volcanogenic massive sulfide deposits. Mine sites listed were likely candidates for extensive AMD contamination given the large sulfide deposits and extensive
disturbances to the subsurface by mining activities. Twenty-six mines in California are listed on the VMSD list due to California’s geology.

**Comparison of existing prioritization efforts**

Of the prioritization schemes examined in this study, the CAMLAG group’s MINESHAFT prioritization scheme has the most potential to accurately and fully capture prioritization of abandoned mine sites in California. The CAMLAG weighted prioritization formula is based on a very detailed analysis of source-transport-receptor analysis for contamination sites. This quantitative effort shows the most promise for giving a more accurate picture of the orphaned mine sites in the state, and which ones should be funded for assessment and cleanup as soon as monies become available. Because the formula is not yet developed, a detailed review of CAMLAG’s accuracy cannot yet be performed.

According to a study published in *Environmental Management*, the prioritization and risk assessment process has undergone a preference shift from a qualitative to a more quantitative direction over the past five decades (Zhang, Kluck, & Achari, 2009). This arises from the need for a scientifically defensible system to prioritize sites and allow management entities to practically address sites in order of importance. The increase in available technology to more accurately assess contamination contributes to the push for quantitative data backing decisions. Better understanding of the relationships between contaminants, their effects on humans and the environment, and symptomatic transport and exposure scenarios allow for more representative quantitative comparisons between sites to establish priorities (Zhang et al., 2009). CAMLAG will meet the need of a more robust, repeatable process to quantitatively rank abandoned mine sites in California according to relative contamination hazards.

**VI. DISCUSSION AND CONCLUSIONS**

**Environmental Impacts**

Hardrock mining processes of obtaining minerals, generating waste materials, and milling, smelting, and processing extractives to obtain metallic commodities creates an inherent
environmental impact. Hardrock mining involves physically extracting natural resources from the earth and processing them down to a usable form. Extractive industries disturb the natural environment and create or exacerbate natural processes that can lead to contamination of groundwater, surface water, soil, and air.

Long after mining activities cease, waste and disturbances created at abandoned mine sites can continually produce chemical contamination. Abandoned mine features left in place such as adits, shafts, condensers, tailings, waste rock, and processing debris can also pose ongoing environmental contamination problems. Figure 13 illustrates historic mercury mine workings at New Idria Mercury Mine, which is now a Superfund site.

Figure 13: Old Mercury Mine Workings and Cracked Mercury Vapor Pipe at the abandoned New Idria Mercury Mine, San Benito Co, CA

(Keller, 2015)

Prior to 1970, hardrock mining required limited awareness or requirements to minimize environmental damages caused by mineral extraction. Mines typically located tailings ponds, ore dumps, and waste rock repositories at the lowest convenient point in the mining area. As water follows gravity, the lowest point where these waste materials were stored was typically in or adjacent to a streambed or wetland. Milling reagents, processing chemicals, and other liquid wastes generated at mines and mine processing areas commonly entered these water bodies and were transported beyond the immediate mining area. Likewise, particulate emissions from smelting operations, chemical extraction, and open-air piles of waste rock and tailings were transported by wind into surrounding soils and surface water (Seymour, 2004).
Abandoned mine sites contaminating freshwater resources in California is one of the most critical environmental contamination issues, due to the semi-arid climate and prolonged drought. Mining-influenced water can contain acids, heavy metals, nutrient loads, radiation, and sediment that can adversely impact human or ecological receptors. Surface water impacts from abandoned mine sites are of greater concern than groundwater impacts, since surface water tends to move at a much faster velocity than groundwater, and can more quickly spread contamination. Since groundwater moves slower, it has more limited impacts on aquifers. Additionally, groundwater lacks available oxygen, so the oxidation process of contaminants is less likely to occur. However, groundwater is also difficult to access for remediation, so keeping mining wastes away from groundwater is still important (EPA Office of Water, 1997).

**Geological and Hydrological Challenges**

The geologic processes and glacial deposition that slowly took place over the lifetime of planet earth gradually formed the soil and groundwater. Comparatively speaking, extractive mining takes place in a blink of geologic time, but creates massive disturbances. Extractive mining breaks up the subsurface and creates more surface areas than if left undisturbed. Although some components of acid mine drainage are natural—hence the industry’s preferred term “acid rock drainage”—mining drastically alters the natural configuration of subsurface geological layers. This alteration fractures geological formations and creates exposure pathways where previously segregated minerals, air, groundwater, and surface water interact chemically. Physical and chemical characteristics of local soils largely influence appropriate approaches for predictive analysis of environmental contamination and remediation strategies.

California’s complex geology complicates efforts to prioritize abandoned mine sites by adding further unknowns. Active fault lines throughout California present additional challenges by altering predictable soil layers and groundwater flow paths along slip planes. California’s dynamic seismic characteristics make the already difficult job of predicting geology and hydrogeology more difficult by introducing breaks in the system.

Because most of the abandoned mines in California were created and worked many years ago, many unknowns exist that impact groundwater quality. Most abandoned mines are lacking
construction details, have undisclosed underground tunnels, adits, and shafts, unknown waste disposal areas, and processing areas that could serve as contact points for runoff water to pick up contaminants. Unknown underground mine works make it difficult to predict where groundwater is flowing and what contaminants it may be coming in contact with along the way.

Key Points of Departure for Prioritizing Abandoned Mine Sites

This report makes several key points and recommendations to better manage the abandoned mine lands in California, and progress in the prevention of further environmental degradation due to abandoned mine sites.

- Abandoned hardrock mining sites are the most potentially environmentally damaging and should be prioritized higher over other types of abandoned mine sites.
- Acid mine drainage is the most significant issue at abandoned hardrock mining sites; acidifying water bodies and mobilizing heavy metals is toxic to human and ecological receptors, and its regenerative properties make it a difficult and expensive problem to tackle.
- Abandoned mine sites with mercury contamination ranks second, due to its ability to bioaccumulate in the food chain, reduce water quality, and methylate in aquatic environments.
- Abandoned mine sites with arsenic contamination ranks third, due to its carcinogenic properties, persistence in the environment, and threat to drinking water sources.
- The CAMLAG mine prioritization effort, which currently is still under interagency development, is the most promising prioritization scheme to date for abandoned mine lands. CAMLAG will develop a standard, weighted formula for source-transport-receptor data, which can then be applied to each mine site to obtain an overall prioritization score.
- In order to fund the next phases of mine prioritization, assessment and cleanup, California and federal laws need to be revised to provide a funding source to address the thousands of abandoned mine sites in California and other states, as well as prevent
additional mine sites from being “orphaned.” by mandating more stringent requirements for overhauled with regard to hardrock mining

Qualitative Analysis from Combined Study Areas

Overwhelmingly, literature and case study research points to abandoned mine sites with acid mine drainage, mercury, and arsenic contamination, respectively, as the most significant environmental issues. This was determined by application of five environmental criteria to the literature study: human health risk, ecological toxicity, relative severity, persistence of contaminants, and cost to remediate.

Presence of AMD, mercury, or arsenic contamination problems at abandoned mine sites should immediately place these sites toward the top of the priority list. Examining available contaminant transport mechanisms and completed pathways to human and ecological receptors can then prioritize these sites further to develop an approachable plan to address the worst sites first. Since the amount of sites in need of assessment, characterization, and cleanup far exceed the funds and remediation technology available, applying this screening criteria to the total sites is key to being able to readily utilize funds to address sites as they become available, and continually petition Congress for additional funds or provision of a new funding mechanism to address this enormous environmental threat.

Because abandoned mine pollution cannot be directly linked to a point source or current land use, and the parties responsible for the contamination are no longer around or financially solvent, regulatory threats ring hollow. As the Abandoned Mines Technical Advisory Committee (TAC) put it in their 1994 report on abandoned mines, “…abandoned mine pollution control is basically a series of individual, site-specific reclamation projects, not a program directed at finding better ways to conduct an activity.” The TAC concluded that formation of a diverse stakeholder group consisting of regulators, landholding agencies, researchers, industry, environmental advocacy groups, and communities was essential to advance toward better solutions.

EPA’s National Hardrock Mining Framework (Sept 1997) noted deficiencies in the hardrock mining regulatory program that needed stronger enforcement in order prevent additional mine sites from becoming abandoned. This Framework made early recommendations to strengthen
the hardrock regulatory program by limiting loopholes, streamlining permitting, and requiring a more robust evaluation of environmentally preferred alternatives during the National Environmental Policy Act Environmental Impact Statement process for approval of proposed mine sites. This study also recognized the need for a more comprehensive hardrock mining program within EPA to correct shortcomings of existing mining sites that were designed “discharge free,” but then required permits for waste disposal after ongoing operations. Most notably, recommendations for achieving improved environmental protection specifically called for development of scientifically based predictive tools to improve upon acid mine drainage and metals mobility predictions.

**Gaps in Data, Studies, and Predictive Analysis**

In order to prioritize the large number of abandoned mine sites in California, assumptions must be made on the types of sites that would most likely pose the greatest contamination threats. This study applied five criteria to the available literature and derived AMD, mercury, and arsenic contaminated mines as the type that should be prioritized first. Further analysis of specific characteristics of AMD, mercury, and arsenic contaminated mines is needed in order to determine the extent of the source contamination, extent to which contaminants are transported, and evaluation of completed pathways to receptors. Following a more thorough review of the abandoned mine inventory for these factors, AML rankings can better be adjusted to more meaningfully reflect the most hazardous sites.

Predicting contamination at mine sites that have not undergone a complete site assessment is a difficult endeavor. Even modern mining methods incorporate detailed geological studies to predict environmental contamination (such as acid mine drainage) prior to beginning operations, but replicating natural chemical interactions and hydraulic behavior in a lab and with modeling software still leaves various unknowns and uncertainties. “Chemical interactions within ecosystems can be extremely complex. Identifying the full range of potential interaction of numerous chemicals with a multitude of biological species is not practical. The AML Handbook identifies “symptoms” of environmental damage. However, environmental degradation can occur and not be visible.” (CA DTSC, 1999)
It is not possible to also assess abandoned mine lands in California in this study, but developing recommendations for a prioritization approach is the first step in the process. Prioritizing abandoned mine sites, performing site assessments and re-adjusting rankings, and then cleaning up the highest rank sites as funds become available are the next steps in the process of better managing California’s AMLs.

VII. RECOMMENDATIONS

Opportunities for Further Research and Action

Conducting interviews with experienced mine remediation professionals is recommended in order to supplement these findings with valuable experiential insight and lessons learned. Also, additional drilldown is needed to further rank acid mine drainage, mercury, and arsenic sites according to exposure criteria to human and ecological receptors. Preliminary site assessment data will be needed for each site in order to accomplish this.

Proposed Federal Laws to Fund Abandoned Mine Land Prioritization, Assessment, and Cleanup Programs & Prevent Additional Mine Sites from Becoming Orphaned

Two proposed federal laws related to hardrock mining have been proposed in the legislature, but neither has been brought to the floor for a vote. To some extent, each of these proposed laws attempt to make headway in addressing the large backlog of abandoned mine sites.

The first proposed federal law, H.R. 963 is the Hardrock Mining Reform & Reclamation Act of 2015-2016. This bill proposes a means of funding orphaned mine site management and cleanup through royalty fees on new mining sites. A funding mechanism is badly needed in order to address the large backlog of abandoned mine sites in California and the nation. However, H.R. 963 is opposed by the mining industry and conservative western politicians that prefer local governance over federal laws.

This bill would apply to any mining claim, millsite claim, or tunnel site currently covered under the general mining laws. The intent of H.R. 963 is to update the 1872 General Mining Law with
a modern version, including royalty fees and reclamation requirements. Locatable minerals would be subject to a royalty of 8% of the gross income from mining; federal lands subject to an operations permit would be limited to a 4% royalty fee. Royalty fees do not apply to annual gross income from mineral production less than $100,000. Mining claim maintenance fees also apply in certain cases.

The Hardrock Mining Law restricts mining claims on wilderness areas and areas of critical environmental concern. State, local, or tribal governments can petition the Secretary of the Interior to withdraw areas of special value from the general mining laws as well. If mining is proposed on federal land, the Secretary of the Interior must ensure that activities do not degrade public lands and resources.

The Hardrock Mining Reform & Reclamation Act will also require financial assurance as a part of the exploration permit process, although details of such assurances are not known. Restoration of mined lands so that prior or other beneficial uses are supported is required. The Hardrock Minerals Fund would be established, which consists of the Hardrock Reclamation Account and the Hardrock Community Impact Assistance Account, which will be funded by a seven cent per ton of displaced material fee for mining operators. This account would then be utilized to reclaim and restore land and water resources adversely affected by past hardrock mining activities.

Passage of H.R. 963 is one way to potentially help manage the large backlog of abandoned mine sites in need of prioritization, assessment, and cleanup by providing a funding mechanism to conduct these activities, as well as stronger regulations to prevent additional sites from becoming orphaned.

S.B. 1443 is supported by some industry and regulators as a way to promote cleanup of contaminated mine sites by private entities without taxing the mining industry. However, exclusions of Clean Water Act liability remains a controversial component for some.
The second proposed federal law is S.B.1443, the Good Samaritan Cleanup of Abandoned Hardrock Mines Act of 2013. Good Samaritan provisions have been considered since 1997 when EPA wrote the National Hardrock Mining Framework, but none have yet passed into law. This act encourages remediation of inactive and abandoned mine sites by entities that had no role in the creation of the environmental pollution. These “Good Samaritans” are not legally responsible for the remediation, but are allowed to proceed with cleanup on a voluntary basis. The proposed amendment to the Federal Water Pollution Control Act (Clean Water Act) is the controversial part of this proposed bill. Passage of S.B. 1443 would authorize a permitting authority with an approved Good Samaritan program to issue discharge permits. Essentially, this shields the Good Samaritan from liability under the Clean Water Act. Certain parties are opposed to this exemption as it could result in a spill or discharge, without any means to require additional clean up or repair of the attempted fix that caused the spill.

Related literature on abandoned mine site prioritization also acknowledges the loopholes in the current regulatory system that are allowing additional modern mines to become orphaned sites, and existing exemptions that make it more difficult to hold responsible parties accountable for environmental contamination due to mining activities. The following excerpt from John Seymour’s article entitled “Hardrock mining and the environment: issues of federal enforcement and liability” comments on this point:

EPA studies confirm, however, that active hardrock mines continue to present significant risks to the environment. In examining the sites listed on the NPL, EPA found that more than half had been active at some point during the previous decade, causing the agency to conclude that "at least some of the problems [at the mining sites] are attributable to modern practices.' Similarly, EPA's review of the number and kinds of environmental violations at active facilities confirmed that mining sites frequently present significant environmental threats. Nearly 20% of the mining sites inspected by EPA and state regulators during the period 1990-1995, for example, were subject to enforcement actions for releases of pollutants to the environment, or for non-compliance with Clean Air Act or Resource Conservation and Recovery Act (RCRA) requirements." The large percentage of RCRA violations at mining sites is particularly noteworthy because, under the Bevill Amendment of 1980, many mining wastes are exempt from the strict
regulation of hazardous waste treatment, storage, and disposal facilities under RCRA Subtitle C. Periodically, EPA has considered the effect of the Bevill exemption on the nature and kinds of risks arising at mining sites. In one recent study, for example, the agency concluded that Bevill-exempt waste "poses a broad range of environmental risk." (Seymour, 2004, 822)

The need for hardrock mining legislation reform is well documented in literature. A Regents of the University of California article commented on how lack of comprehensive mining laws rely too heavily on CERCLA for cleanup, versus legislat ing more protection for western watersheds due to mining activity:

Hardrock mining has caused significant harm to the environment, particularly in the West. Mining laws enacted in the 19th Century sought to encourage mineral production and the transfer of mineral lands to private interests and were largely unconcerned with environmental protection. Federal regulation of hardrock mining, although increasingly effective in recent decades in mitigating the environmental effects of mining, remains heavily influenced by these laws and unable to fully prevent degradation of western watersheds. Federal land managers often have resorted to their authorities under CERCLA to recover response costs or compel cleanup at contaminated mining sites nation-wide….CERCLA litigation, however, is expensive, retrospective, and fruitless at many "orphaned" sites where viable corporate entities no longer can be found. Statutory and regulatory reforms to the regulation of hardrock mining are necessary to more effectively protect public health and the environment. (Seymour, 2004, 795)

In order to fund the next phases of mine prioritization, assessment and cleanup, California and federal laws need to be revised to provide a funding source to address the thousands of abandoned mine sites in California and other states, as well as prevent additional mine sites from being “orphaned” by mandating more stringent requirements for hardrock mining. If the Superfund program is an indication of how often parties do not fulfill their environmental responsibility to cleanup damage they caused, it seems unlikely that a large enough response would be garnered from a Good Samaritan-type regulation alone to make strides at reducing the abandoned mine lands inventory in California. The majority of sites lie on permanent federal
land, so voluntary parties would be investing their own resources to support the public good. Although helpful, likely additional regulations would be needed as well to address a much greater amount of site cleanup. Passage of the Hardrock Mining Reform and Reclamation Act of 2015-2016 or a similar bill that establishes a fee on mining activities to fund previously orphaned mining sites is essential to begin to chip away at the long inventory of orphaned mine sites. Likewise, it is crucial to tighten up regulations regarding financial assurance, reclamation, and ongoing monitoring and environmental cleanup at active mining sites.
VIII. REFERENCES


