5-2003

Water quality remediation at the abandoned Jones-Kincaid Mine site, Pyramid Mining District, Washoe County, Nevada

Si-Ok Choi
University of Nevada Las Vegas

WATER QUALITY REMEDIATON AT THE ABANDONED JONES-KINCAID MINE SITE, PYRAMID MINING DISTRICT, WASHOE COUNTY, NEVADA

by

SI-OK CHOI

A thesis submitted in partial fulfillment
of the requirements for

Bachelor of Science Degree
Department of Environmental Studies,
Greenspun College of Urban Affairs,
University of Nevada, Las Vegas

Content Advisor:
Cheryl McDonnell-Canan, Department of Geoscience Adjunct Faculty

Class Advisors:
Helen R. Neill, Chair and Assoc. Professor, Environmental Studies, ENV 499B
Krystyna Stave, Assoc. Professor, Environmental Studies, ENV 499A

CEB Format

University of Nevada, Las Vegas
May 2003

ACKNOWLEDGEMENTS

I would like to thank Cheryl McDonnell-Canan (UNLV, Department of Geoscience Adjunct Faculty), Dr. Krystyna Stave (UNLV, Department of Environmental Studies), and Dr. Helen R. Neill (UNLV, Department of Environmental Sciences) for their time and assistance in helping me to prepare this thesis.

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ABSTRACT

The purpose of this paper is to evaluate the cost and efficiency of four remediation methods, natural attenuation, permeable reactive barriers, pump and treat systems, and bioremediation, and to determine the best suitable method for preventing further environmental degradation from the abandoned Jones-Kincaid Mine (JKM), located within the Pyramid Mining District, Washoe County, Nevada.

Problems from abandoned mine sites may be divided into four types: water quality, public safety, economic concerns, and scenic interests. The foremost problem is the effect of pollution on water quality. Acid run-off and precipitation may be spread hundreds of miles and influence drinking water sources provided to homes and factories.

The remediation of the effects of acid mine drainage from the JKM site compares cost and efficiency of four different remediation methods. I examined these methods using the following criteria: treatable compounds, pH, suitable media, potential detrimental effects, and limitations.

My hypothesis is natural attenuation proved to be the most cost effective and efficient of the four remediation methods studied and works well in both soil and groundwater. Additionally, due to the acid mine drainage at the JKM site, natural attention may increase the pH levels by the remediation of metal compounds. Drawbacks to the natural attenuation method are continuous monitoring and maintenance are required because natural attenuation of contamination may also occur.

INTRODUCTION

The purpose of this paper is to evaluate the cost and efficiency of four remediation methods, natural attenuation, permeable reactive barriers, pump and treat systems, and bioremediation, and to determine the best suitable method for preventing further environmental degradation from the abandoned Jones-Kincaid Mine (JKM), located within the Pyramid Mining District, Washoe County, Nevada. The Nevada Bureau of Mines and Geology (NBMG) has stated the abandoned JKM site is a source of heavy metal and acid discharge contamination that degrades surface and groundwater quality in this area (NBMG, 1995).

Washoe County is located in the western corner of Nevada and encompasses 6,905 square miles. The Pyramid Mining District (District) is presented in Figure 1. The District is located in the Mullen Pass area, at the junction of the Pah Rah Range and Virginia Mountains, situated approximately 30 miles north of Reno (Bonham, 1969). The JKM contains at least two adits and mine shafts with well-documented acid run-off drainage. Dumps from other mining sites within the District, while usually dry, have the potential to generate acid run-off drainage during rain events. These drainages ultimately discharge into Pyramid Lake (NBMG, 1995).

Pyramid Lake in Nevada is one of the most beautiful desert lakes. It is a remnant of ancient Lake Lahontan, which ranged along the entire length of the Truckee River, and drained into Lake Tahoe and its tributaries. The Lake is located at approximately 4,000 feet above sea level. Species listed as threatened or endangered under the Endangered Species Act, such as cui-ui fish, have been documented in Pyramid Lake.

Washoe County, Nevada

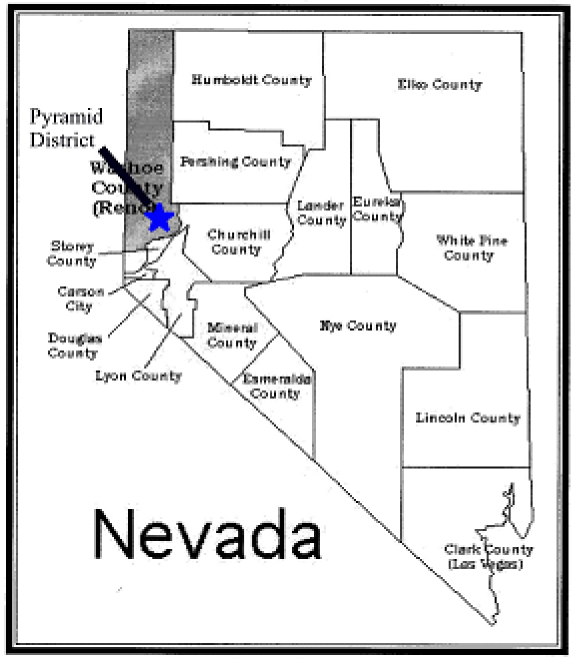

FIGURE 1: Location Map (NBMG, 1995)

Few concerns are more crucial to the well-being of Nevadans and future of the state than the water supply, as the state has very limited water resources. Healthy and diverse wildlife populations, as well as forests, are important to the quality of life in Nevada (SHPO, 2002).

The JKM (see Appendix A) is the one of the contaminated mine sites situated within the District. The JKM is located in Sections 22 and 23, Township 23 North, Range 21 East. The mine workings, consisting of a shaft approximately 500 feet deep, one adit over 1,000 feet in length, a second adit several hundred feet long, several shallow shafts, and several hundred feet of drifts, explore a prominent vein trending approximately North 45 degrees West. This vein is part of a system that can be traced on the surface for over two miles, comprised of brecciated, highly silicified, rhyolitic ash-flow tuff, and contains variable amounts of iron oxide, pyrite, enargite, and barite, with appreciable amounts of silver. The limited assay data available show a close correspondence between the copper content of the sulfide ores (copper in enargite) and the amount of silver present (Bonham and Papke, 1969).

The permanent water table, in the topographically low portions of the District, occurs at depths of 50 feet or less beneath the surface. Originally, the water table under the higher ridges in the District occurred at a depth of approximately 200 feet. Some of the JKM workings, such as the long tunnel, intersected the water table under these high ridges, and the resultant drainage lowered the water table to the level of the lowest mine workings. The result was to rapidly accelerate oxidation of iron in those portions of the vein, which was located below the previously existing water table in the JKM area. The water presently draining from the main tunnel of the JKM is quite acidic and contains both copper and iron sulfates (Bonham and Papke, 1969).

The JKM is important to study because environmental degradation could threaten human and animal safety. The deposits of greatest concern are quartz-alunite (high sulfides) deposits found in volcanic rocks, and porphyry copper and porphyry copper-molybdenum deposits located in plutonic rocks, both of which occur in the JKM area. Often found with these deposits is a potentially toxic element arsenic (NBMG, 1995). Arsenic is abundant at the JKM where an adit was driven to intersect the rhyolitic ash-flow tuff vein. According to the Agency for Toxic Substance and Disease Registry (ASTDR), arsenic is silvery-white, brittle, poisonous chemical element, widely distributed within the earth's crust. It is difficult to detect in water because it has no smell or color. Arsenic occurs naturally in soil and minerals, so it may enter water from wind-blown dust or run-off. Arsenic is also related to ore mined for metal, and may enter the water during mining activities. Human beings may take in small amounts of arsenic in the water they drink or ingested in foods, such as fish. An important concern with arsenic is that it increases the risk of lung cancer as medically evidenced in mining workers and residents living near arsenic chemical factories (ATSDR, 2001).

Additionally, the JKM drainage water plates copper (Cu) on steel framework of the mine and the wall rocks have little acid-buffering capacity. Hydrated iron sulfate occurs as a precipitate on pebbles in streambeds from 0 to 10 millimeters (mm) above water level (NBMG, 1995).

Heavy metals contained in rock or soil, moved and scattered by surface and groundwater, inhibit animal and plant growth. Contamination by heavy metals is significant because even small amounts are toxic to humans. Problems of contamination from heavy metals occur in abandoned mine sites because their drainage water often contains numerous types and densities of heavy metals (Jun and Oh, 2001).

Problems from abandoned mine sites may be divided into four types: water quality, public safety, economic concerns, and scenic interests. The foremost problem is effect of pollution on water quality. Acid run-off and precipitation may be spread hundreds of miles and influence drinking water sources provided to homes and factories (NBMG, 1995).

Acid mine drainage from abandoned mine sites may also infiltrate into groundwater or, during monsoons, run-off into streams. Water that has passed through mine tailings is highly acidic (pH 3-4), contains metal ions, and demonstrates high sulfate densities. At present, there is no clear solution for the disposal of acidic mine drainage. The traditional disposal method, if acid mine drainage is controlled at the drain point, is to use a natural purification method that increases the pH, such as pumping water through an anoxic lime stone bed. Other prevention methods include blocking the outflow mine tunnel or changing the groundwater path (Jooik and Yonsik, 1998).

Historically, groundwater contamination received little national attention because it was believed groundwater was fresh, clean, and free of contaminants because as groundwater passed slowly through soil, contaminants would stick to the soil particles or degrade by natural processes. The earth's soil and rock layers are now known to possess a limited capacity to filter out contaminants. Due to the fact that groundwater is underground, with limited access, it is difficult to study accurately (Burmaster, 1998).

According to the NBMG, the worst quality water has a low pH, which develops in deposits with little buffering capacity of wall rocks. The JKM has a pH level of 2.41, compared to the 6.5-8.5 pH standard drinking water levels. Table 1, located on the following page, is a water sample analysis from the JKM (NBMG, 1995).

The origin of low pH water levels in Washoe County is not known. The Nevada Division of Minerals tested three acidic water mine sites, which contained elevated metal concentrations, and posed significant problems from ground flow from adits into the streambed gravels. These sites were the JMK, the National District, and the Bloody Canyon Mine. Only the Bloody Canyon Mine has lower water quality with a lowered pH (NBMG, 1995).

The results of this contaminated groundwater study in Washoe County, Nevada, specifically within the JKM, will be shared with the Nevada Department of Conservation

TABLE 1: WATER SAMPLE ANALYSES FROM THE JONES-KINCAID MINE

Concentrations are given in milligrams per liter (NBMG, 1995)

	Jones-Kincaid Mine	Drinking-water standard
Ca	234	-
Mg	174	150
Na	47	-
K	6	-
Fe	1380	0.6
Mn	19	0.1
Cu	451	1.3
Pb	3.1	0.015
Zn	34	5
Cd	0.9	0.005
Cr	0.4	0.1
Co	6	-
As	16.0	0.05
Cl-	3.0	400
NO3-	<0.5	10
SO4-	4620	500
Alkalinity	<10	-
pH	2.41	6.5-8.5

and Natural Resources (NDCNR), the NBMG, and the Bureau of Land Management (BLM) which will benefit from the additional data on types and concentrations of harmful chemicals and heavy metals in groundwater that contaminate this mining area. Water-quality issues, such as acid-mine drainage, are the direct results of groundwater and surface water interacting with rocks exposed during mining activities. This analysis focuses on costs and efficiencies of remediation of the impacts on groundwater and surface water from ore processing and from other industrial activity at mining and milling sites.

APPROACH

The remediation of the effects of acid mine drainage from the JKM site compares cost and efficiency of four different methods: natural attenuation, permeable reactive barriers, pump and treat systems, and bioremediation. Other possible techniques, such as vegetation, compost, and clay-caps were considered, but vegetation and compost are not suitable due to low amounts of precipitation and a clay cap is a very expensive method.

Natural attenuation is a passive reduction in contaminant concentration, toxicity, mobility and/or volume as a result of physical, biological, and chemical processes that are naturally occurring (Deutsch, 2002). If natural attenuation were applied at the JKM site, it would generate processes, unaided by deliberate human intervention, which would reduce the concentration, toxicity, and mobility of heavy metals and harmful chemicals. Longer time frames, however, may be required to achieve contaminant reduction, compared to active remediation methods. Additionally, monitoring must be designed to verify that potentially toxic transformation products are not created at levels that are a threat to human health (GWRTAC, 1998).

A permeable reactive barrier (PRB) is an in-situ, below-ground, active remediation method that utilizes a treatment zone of reactive material that degrades or immobilizes contaminants as the groundwater flows through it. PRBs are installed as permanent, semi-permanent, or replaceable units across the flow path of a contaminated water plume. Natural gradients transport contaminants through strategically placed media, which degrade, absorb, precipitate, or otherwise remove groundwater contaminants. The choice of the reactive media for a PRB is based on the specific organic or inorganic contaminants to be remediated (U.S. EPA, 2001). If a PRB were installed downstream of the JKM site, the contaminated water plume would be forced it to flow it and, by doing so, the contaminants would be removed without soil excavation or groundwater pumping.

The pump and treat system involves extracting contaminated groundwater through recovery wells or trenches and treating the groundwater by ex-situ, aboveground, processes, such as air stripping, carbon adsorption, biological reactors, or chemical precipitation (U.S. EPA, 2001). A pump and treat system for addressing groundwater contamination is a combination of an extraction technology, such as pumping, and a subsequent treatment technology. This discussion focuses on the pumping portion of this combination. Treatment technologies, which vary by contaminant, may consist of any of the other remediation technologies discussed above. If a pump and treat system is used for remediation at the JKM site, this method has easy to control processes, may use practices adapted from drinking water cleaning, has commercially available equipment, and moderate investment costs (GWRTAC, 1998). Long operation times needed for pump and treat remediation, however, present a major disadvantage. Additionally, if applied improperly, this method may spread contaminants, via the subsurface geology, and further pollute the groundwater at the JKM site.

Bioremediation refers to the use of micro biota to degrade hazardous organic and inorganic materials to innocuous materials. Certain bacteria and fungi are able to utilize, as sources of carbon and energy, some natural organic compounds, and convert these and other naturally occurring compounds to byproducts that are less complex and harmful than the parent material. At metal contaminated sites, such as mining and mineral processing sites, the addition of biological nutrients has been demonstrated to stimulate natural microorganisms to operate a natural process for biological attenuation and stabilization of heavy metals. If bioremediation were applied at the JKM site, it would have the advantages of removing organic and metal contaminants at a relatively inexpensive cost. Bioremediation, however, requires a long period of time and the technology is not guaranteed for the removal of inorganic contaminants (GWRTAC, 1998).

In order to evaluate the four alternative remediation methods for the JKM site, it was necessary to obtain more data on costs and efficiencies of natural attenuation, permeable reactive barriers, pump and treat systems, and bioremediation. The cost of cleaning up abandoned mine sites far exceeds state and federal government resources. There is, therefore, a need to identify efficient remediation approaches that reduce mine site contamination at minimal costs.

METHOD

In order to determine the best remediation technique there must be a comparative research of the four different methods. There are too many variables in design to give a complete range of costs and efficiencies for each method. A comprehensive summary of the four remediation methods included the following five influencing factors: treatable compounds, pH, suitable media, potential detrimental effects, and limitations. The general influencing factors of technologies, treatable compounds, at the JKM site is presented because the major contaminants are metals. Table 2, located on page 11, compares 20 features of the four different remediation methods and their applicability to treat the contaminant problems at the JKM site (GWRTAC, 1999; U.S. EPA, 2000).

In order to accomplish these comparisons, a thorough literature review was conducted considering the major component costs of the four remediation methods. State and federal agencies were also contacted to measure the cost and efficiency of each of the four methods variables.

Cost data for the four remediation methods were obtained from “Cost Analyses for Selected Groundwater Cleanup Projects” (NSCEP, 2001) and “Groundwater Remediation Technologies Overview Reports for In-situ Bioremediation and Chemical Treatments” (GWRTAC, 1998, 1999). Data was also collected for influencing factors and potential detrimental effects of the four remediation methods from “Lecture Notes on Environmental Geochemistry of Metals: Investigation and Remediation” (Deutsch, 2002) and “Abandoned Mine Site Characterizations and Cleanup Handbook” (U.S. EPA, 2000). Costs estimates were summarized as low, medium, high, and very high. The general efficiency data is also presented in the same form of comparison to the other remediation methods. This determined whether the costs of a particular method of remediation exceeded the efficiencies obtained from the use of that particular remediation technology.

Table 3 compares the costs and efficiencies of natural attenuation, permeable reactive barriers, pump and treat systems, and bioremediation for a period of one year.

RESULTS

Technologies and influencing factors are listed below in Table 2.

TABLE 2: SUMMARIES OF TECHNOLOGIES AND INFLUENCING FACTORS

Technology / Influencing factor	Natural attenuation (GWRTA, 1998)	Permeable reactive barriers (U.S. EPA, 2000)	Pump & Treat Systems (U.S. EPA, 2000)	Bioremediation (GWRTA, 1998)
Treatable compounds	Arsenic, VOCs, SVOCs, Fuel, hydrocarbon, and metals	Arsenic,sulphate, nitrate, phosphate, methanes, ethanes, propanes, and metals	VOCs, and metals	Nitrate,sulphates, nitrogen and oxygen substituted compounds, alcohols, and complex organic compounds
pH	Mid-high	Low-high	Mid-high	Mid-high
Suitable Media	Groundwater and soil	Groundwater	Groundwater	Soil
Potential Detrimental effects	May be used in conjunction with, or a follow-up to, other remedial measures	Toxic degradation intermediated can also be generated	Depends on site conditions and contaminant characteristics .	Lower costs that most active remedial alternatives and minimal disturbance to the site operations
Limitations	Institutional controls may be required, and the site may not be available for reuse until contaminant levels are reduced.	The contaminants immobilized by adsorption and precipitation, however, could be remobilized products of organic condition changes.	Effectiveness of remediation varies with the nature of the contaminant and is affected greatly by subsurface geology.	Process is more difficult to apply to clayey and other low permeability soils.

The natural attenuation remediation method listed in Table 2 treats arsenic, volatile organic compounds (VOCs), solid volatile organic compounds (SVOCs), fuel hydrocarbons, and metal compounds in groundwater and soil. Potential detrimental effects include that it may be required to use additional active remedial measures to reduce contaminant levels. Additionally, institutional controls may be required, and the site may not be available for reuse until contaminant levels are reduced (GWRTAC, 1998).

The second remediation method presented in Table 2 is the use of permeable reactive barriers that treat a wide variety of arsenic, sulfate, nitrate, phosphate, methanes, ethanes, propanes, and metal compounds in groundwater. Potential detrimental effects that are toxic degradation intermediates may also be generated by this process. Limitations include that chemical treatment walls, as a passive treatment technology, have the least affect on the ecosystem. The contaminants immobilized by adsorption and precipitation could, however, be remobilized as organic conditions change (U.S. EPA, 2000).

A third method presented in Table 2 is pump and treat systems that deal with VOCs, and metal compounds in groundwater. Potential detrimental effects depend on site conditions and contaminant characteristics and limitations include that the remediation effectiveness varies with the nature of the contaminant and is greatly affected by the subsurface geology (U.S. EPA, 2000).

The final remediation method shown in Table 2 is bioremediation. Nitrates, sulfates, nitrogen and oxygen substituted compounds, alcohols, and simple and moderately complex organic compounds may be treated in soils. Bioremediation has lower costs than most active remedial alternatives and minimal disturbance on site operations. The bioremediation process is limited, however, in applications to clayey and other low permeability soils.

In Table 3, below, the four remediation methods are summarized according to costs and efficiencies.

TABLE 3: SUMMARY OF REMEDIATION COSTS AND EFFICIENCIES (GWRTAC 1999, EPA 2000)

METHODS	Natural attenuation (GWRTAC, 1999)	Permeable reactive barriers (U.S. EPA, 2001)	Pump and treat systems (U.S. EPA, 2001	Bioremediation (GWRTAC, 1999)
COST ($)	Low	Low-high	Medium-very high	Med-high
EFFICIENCY (1yr)	Mid-high	Low-high	Mid-high	Mid-high

Costs: Low=<$5,000
Low-medium=$5,000-50,000
Medium-high=$50,000-150,000
High=>$50,000
Very high=>1,000,000

Efficiencies: Low= increase pH < 3
Medium= increase pH < 4
High= increase pH < 5

With the natural attenuation method, the cost was low (<$5000), but the efficiency was medium (increase < 4). Using the permeable reactive barrier method, cost was medium-high ($50,000-150,000), and the efficiency was low-high (increase 3< pH <5). Pump and treat systems cost was medium- very high ($50,000-1000000), and the efficiency was medium-high (increase 4 <pH <5). In bioremediation method, both cost and efficiency were medium-high.

DISCUSSION

Due to the lack of quantitative information available on the potential impacts of mining on surface and groundwater quality, the goal of this study was modified to examine the two best remediation methods, of the four methods investigated, regarding cost and efficiency remediation over a five-year period at the JKM site. Both natural attenuation and bioremediation have medium to high remediation efficiencies, but the cost of natural attenuation is much lower, less than 25,000 dollars over five-year period, while bioremediation costs range between 25,000 and 750,000 dollars for the same duration.

My hypothesis is natural attenuation proved to be the most cost effective and efficient of the four remediation methods studied and works well in both soil and groundwater. Additionally, due to the acid mine drainage at the JKM site, natural attention may increase the pH levels by the remediation of metal compounds. Drawbacks to the natural attenuation method are continuous monitoring and maintenance are required because natural attenuation of contamination may also occur.

The implementation of natural remediation is not simply a “do nothing” approach. Natural remediation requires a thorough site assessment to determine whether it will be effective when compared to more aggressive strategies, and, if implemented, requires active monitoring and reevaluation during the life of the clean-up project (GWRTAC, 1998). Additionally, natural attenuation must meet the clean-up goals within a time frame comparable to the other three remediation methods. With the lowest cost of the four remediation methods, natural attenuation allows resources to be devoted to a higher priority site. However, use of natural attenuation may impact property transfer because longer time frame is necessary to reach remedial goals.

CONCLUSION

From this study I learned about the possible effectiveness of mitigation of acid mine drainage at the JKM site. Of the four methods studied (natural attenuation, permeable reactive barriers, pump and treat systems, and bioremediation), natural attenuation proved to be the most cost effective and efficient method for remediation of acid mine drainage at the JKM site. Environmental degradation, caused by the JKM acid mine drainage, may be substantially decreased by using the natural attenuation remediation method. The results of this study will assist in the mitigation of acid mine drainage from other abandoned mine sites located within the District.

For future study, I would like to investigate continuing monitoring of natural attenuation at the JKM site. I would like to do more research on the chemical reactions associated with pyrite for a better understanding of mine water chemistry and the relationship between reaction rates and pH. Additionally, I would like to examine a combination of the natural attenuation and bioremediation methods to see if this would lead to a more efficient, yet cost effective approach, for acid mine remediation.

REFERENCES

CBE Style

[ATSDR] Agency for Toxic Substances and Disease Registry [Internet]. Atlanta(GA); Center For Disease Control; [updated 2001 June 22; cited 2002 Sep 13]. Available from http://www.atsdr.cdc.gov/toxprofiles/phs2.html

Bonham, HF, and Papke, KG. Geology and Mineral Deposit of Washoe and Storey Countries, Nevada. Mackay School of Mines; 1969. 140 p.

Burmaster, E. Groundwater contamination in the United States, Environment [Internet]. 1988 [cited 2002 Sep];20(7):3, 25. Available from http://web7.epnet.com/citation.asp

Deutsch, B. Environmental Geochemistry of Metals: Investigation and Remediation: Las Vegas: Natural Groundwater Association; 2002. 400 p.

[GWRTAC] Groundwater Remediation Technologies Analysis Center [Internet]. Cuwenberghe LV, Roote DS: Technology Overview Report; 1998 October [cited 2003 Jan 10]. In-situ Bioremediation. Available from http://www.gwrtac.org/html/topics/bioslurp.htm

[GWRTAC] Groundwater Remediation Technologies Analysis Center [Internet]. Yin Y, Allen HE: Technology Evaluation Report; 1999 July [cited 2003 Jan 5]. In-Situ Chemical Treatment. Available from http://www.gwrtac.org/html/topics/bioslurp.htm

Jooik H. and Yonsik S. Theories and Applications of Chemistry. Observed Acid Mine Drainage of Closed Coal Mine and Treatment Methods. Korea: Coal Industry Promotion Board; 1994. 202 p.

Jun K. and Oh S. Chemical Fixation of Heavy Metal in Contaminated Soil from Abandoned Mine Land. Institution of Engineering Works 2001 Jan: 67-80

[NBMG] Nevada Bureau of Mines and Geology of Open-File Report 95-4 for the Western Governors' Association. Water Quality at Inactive and Abandoned Mines in Nevada. Nevada Bureau of Mines and Geology [Internet]. 1995 [cited 2002 Sep 25]. Available from http://www.nv.blm.gov/AMV/IAMLETreport.htm

[NSCEP] National Service Center for Environmental Publications. Abandoned Mine Site Characterization And Cleanup Handbook:2001:NSCEP.

[SHPO] State Historic Preservation Office. Pyramid Lake; Nevada Historical Marker 18 [Internet] 2002 [cited 2002 Oct 29]. Available from http://dmla.clan.lib.nv.us/docs/shpo/markers/mark18.htm

[U.S. EPA] Environmental Protection Agency. [Internet]. Abandoned Mine Site Characterization and Cleanup Handbook: 2000 August [cited 2002, Nov.17]. Available from http://www.epa.gov/superfund/resourcesRemedy/pdf/amscch.pdf

[U.S. EPA] Environmental Protection Agency. [Internet]. Cost Analyses for Selected Groundwater Cleanup Projects: Pump and Treat Systems and Permeable Reactive Barriers: 2001 February [cited 2002, Nov.17]. Available from http://www.clu-in.org/download/remed/542R00013.pdf