COSTS OF REMEDIATION AT MINE SITES

January 1997

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Washington, DC 20460

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1.0 INTRODUCTION

Costs associated with the remediation of modern mine sites are not well documented in the public record of published literature for several reasons, including the following:

- Remedial measures may be designed and implemented in response to compliance and enforcement actions, chemical spill events, state permit requirements, etc. However, while specific remedial actions taken must be reported regulatory agencies, costs typically are not.
- Some actions may involve limited, short-term actions (i.e., cleaning up minor spills); however, others may require more complex, long-term solutions that are often completed in multiple phases. Cumulative cost data are unlikely to be readily available for such long-term actions.
- Costs are often considered proprietary to the mine operator.

The objective of this project is to develop data on the costs of addressing typical environmental problems that arise at modern mines. EPA collected information for this report throughout 1995. The costs presented may be used by permit writers, regulatory agencies, enforcement personnel,and mine operators for mine planning (including financial assurance), as well as estimating the costs of future enforcement and/or remedial actions. These costs do not reflect permitting and legal expenses. Total remedial costs associated are dependent on location, nature and extent of the problem, type and duration of required remedial actions, and regulatory agencies involved.

1.1 Cost Factors

The costs associated with mine site remediation are highly variable (MEND, 1995) because of the site-specific nature of many environmental problems encountered at mine sites. Table 1-1 presents some of the factors that can influence costs associated with mine-site remediation. This list is not intended to be all-inclusive.

Table 1-1. Factors That Influence the Cost of Remediation at Mine Sites.

Category	Factors
Remediation Goals	Level of clean-up required/desired
Waste Characterization Sampling	Type and volume of material/waste Number and frequency of sampling events Methods selected/required
Water Quality	Degree of contamination (water and sediments) Quantity of metals loadings Lateral extent of plume/contamination Acid Rock Drainage (ARD) issues
Site Characteristics	Size of operation Site access (remote, etc.) Climate (temperature, precipitation, etc.) Geologic materials Elevation Topography (steep slopes, etc.)
Liners	Soil Clay Amended soil Synthetic Soil and subsurface properties
Site Hydrology	Precipitation Flow rate (groundwater and surface water) Water control (routing, diversions, etc.)
Water Treatment	Type of treatment (passive vs. active, chemical usage, etc.) Volume to be treated Management of treatment residuals Length of time required
Site Operations	Effect on production Time to achieve remediation goals Total ore and waste rock tonnage Extent of site impacts Earthwork requirements Labor Imported materials, if any
Regulatory Considerations	National Pollutant Discharge Elimination System (NPDES) and state surface water and groundwater quality requirements Resource Conservation and Recovery Act (RCRA) and state waste management rules State/Federal mine design, operating, and reclamation requirements Dam safety requirements Local regulations, including zoning

Table 1-1. Factors That Influence the Cost of Remediation at Mine Sites (cont.).

Category	Factors
Water Quality Monitoring	Number of analytes and analyses Laboratory analysis Size of area to be monitored Number of sampling stations Groundwater monitoring Surface water monitoring
Reclamation Requirements	Area to be revegetated Type and amount of cover materials Feasibility and duration Post-reclamation land use

Any one of these factors can significantly impact the final cost of remediation at a mine site. Actual incurred costs will vary considerably, and careful consideration of site-specific factors is necessary to achieve an accurate cost estimate.

1.2 Organization of Report

The remainder of this report presents available information on costs of remedial measures. Sections 2.0 and 3.0 provide general information from published materials on the ranges of costs associated with common environmental problems at mine sites. Section 2.0 addresses acid drainage, while Section 3.0 describes control of discharges from waste impoundments and piles. Ranges of cost data are provided because costs are highly variable and dependent on site-specific factors (see Table 1-1). Section 4.0 provides case studies of remedial measures undertaken at modern mining operations.

2.0 ACID ROCK DRAINAGE

In this report, the term *acid rock drainage* (ARD) refers to drainage from the natural oxidation of sulfide minerals contained in rock that is exposed to air and water, resulting in the production of sulfuric acid (Steffen, Robertson, and Kirsten, 1989). This phenomenon is often referred to as *acid mine drainage* (AMD). However, it is not necessarily confined to mining activities but can occur wherever sulfide-bearing rock is exposed to air and water. Some natural springs are acidic, usually in the vicinity of outcrops of sulfide-bearing rock. The principle components of the ARD process are reactive sulfide minerals, oxygen, and water (Steffen, Robertson, and Kirsten, 1989). The oxidation reactions, which are often accelerated by biological activity, yield low-pH water having the potential to dissolve and mobilize heavy metals that may be contained in the water, rock, or elsewhere. If water is available as a transport medium, the resultant drainage can contain products of the acid generation process, typically elevated levels of metals and sulfate. This drainage can have detrimental impacts on water quality.

Mining sometimes results in the exposure of mine wastes, tailings, or mine workings that contain sulfides in sufficient quantities to result in acid generation. However, not all operations that expose sulfide-bearing rock will result in ARD. Acid drainage will not occur if the sulfide minerals are sulfur deficient or if the rock contains sufficient alkaline material to buffer and neutralize the acid. In the latter case, the pH may be raised as a result of neutralizing reactions as the drainage passes through the waste. The quality and rate of release of ARD is governed by various chemical and biological reactions at the source of acid generation and along the drainage path.

More acidic waters can carry greater amounts of metals in ionic form than can more neutral waters. The oxidization of sulfide minerals (and other materials) begins when slightly acidic rain water comes into contact with sulfide-containing rock. The acidic rain water begins to react with the sulfide minerals, and the majority of the remaining sulfide minerals are oxidized and carried away by the sulfuric acid or ferric sulfate solutions that have been generated.

The degree to which sulfide minerals are dissolved is dependent on the amount of sulfur ion and total metals present. In many sulfide minerals, the amount of sulfur is insufficient for complete oxidation. In others, the sulfur ion is completely consumed during oxidation of the mineral. Minerals such as pyrite, chalcopyrite, and pyrrhotite contain excess sulfur and, therefore, generate excess sulfuric acid (H_2SO_4). High concentrations of sulfuric acid continue to oxidize other minerals until the acid is neutralized locally or until the low-pH waters generated travel away from the source. The sulfuric acid and ferric sulfate are usually derived locally but may, in some cases, come from an external source such as circulating groundwater. Pyrite is generally considered to produce the majority of free sulfuric acid.

The initial oxidation of pyrite is generally expressed by the following equation (Drever, 1988):

$$4FeS_2 + 14O_2 + 4H_2O = 4FeSO_4 + 4H_2SO_4 \qquad (2\text{-}1)$$

As shown in Equation 2-1, each mole of pyrite (FeS_2) generates one mole of free sulfuric acid (H_2SO_4). This reaction becomes self-generating in the presence of water and oxygen.

If ARD is not controlled, it can pose a threat to the environment due to the toxicity of heavy metals and other pollutants. Figure 2-1

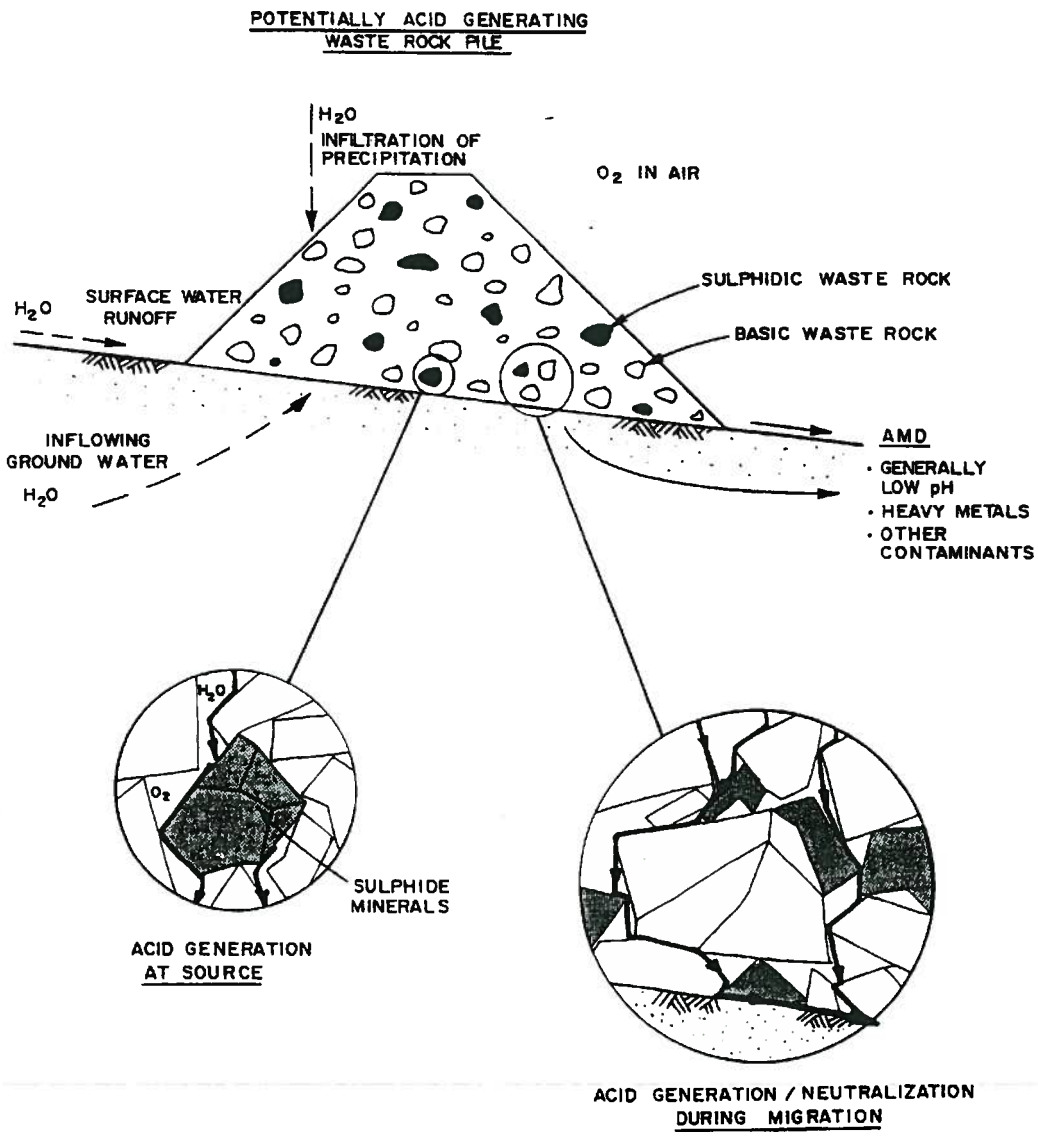

Figure 2-1. Schematic Showing Concept of Acid Generation and ARD Migration.

(Steffen, Robertson, and Kirsten, 1989) presents a conceptual schematic of acid generation and migration through a waste rock pile. The process involves the sulfide-containing and basic rock present in the pile, the potential sources of oxygen and water, and the acid generation/neutralization occurring where these elements are in contact. This figure illustrates water percolating through the dump, coming into contact with both acid-generating and -neutralizing materials, and emerging from the ore as ARD.

ARD may occur from natural sources, as well as in locations where sulfide-containing rock has been exposed during excavation and construction, mining, or other activities. Steffen, Robertson, and Kirsten (1989) list the following as sources of ARD from mining operations:

- Waste rock dumps from metal mines and spoil piles from coal mining,
- Drainage from underground workings,
- Surface runoff from open pit mine faces and pit workings, and
- Ore stockpiles and spent ore piles from heap leach operations.

For the purposes of this report, costs have been developed for remediating environmental problems resulting from waste rock piles and drainage from underground workings. These two scenarios are considered indicative of estimated remedial costs associated with ARD-caused environmental problems.

2.1 Waste Rock Piles

2.1.1 Typical Environmental Problems

Waste rock is generated by excavation and construction operations performed to access an ore body at a mine, especially at open pit mining operations. As sulfide-containing waste rock is exposed to precipitation and runoff, ARD may develop. Because most modern open pit mines generate significant quantities of waste rock, the potential for developing ARD is relatively high if the requisite

geochemical regime is present. The chemical and physical properties of the waste rock pile will significantly affect the chemical concentration of ARD and the rate of change of that concentration (Steffen, Robertson, and Kirsten, 1989). Different ARD concentrations and characteristics will result in variable costs of remedial actions for waste rock piles.

The potentially severe environmental problems resulting from waste rock piles and underground mines that generate ARD usually produce negative impacts on the quality of both surface water and groundwater in proximity to the mine. A change in the pH of downgradient surface waters may have detrimental effects on beneficial uses of those waters, such as domestic supply, agricultural supply, aquatic habitat, etc., primarily because of the dissolution of material and other impacts to the water chemistry discussed above.

2.1.2 Engineering Solutions

The goal of remediation at an ARD-producing site is reducing the migration of ARD to the environment. Water is the transport mechanism for contaminants, and, therefore, the solutions to ARD-caused problems usually focus on preventing the contact of water with the ARD source (Steffen, Robertson, and Kirsten, 1989), thus inhibiting the generation of acid and water outflows.

Suppression of acid generation is usually accomplished through one of four methods, including (1) exclusion of oxygen from the waste; (2) exclusion of water from the waste; (3) addition of chemicals that react with sulfuric acid generated and neutralize the water; and (4) promotion of the chemical reaction by adding oxygen and water to consume all available pyrite, leaving only the more insoluble sulfates behind and, thus, mitigating ARD generation.

Management of water contact with an ARD source is accomplished through four methods: (1) diversion of all surface water away from the source, (2) prevention of groundwater infiltration into the source; (3) prevention of precipitation infiltration into the source, and (4) controlled placement of acid-generating waste (Steffen, Robertson, and Kirsten, 1989).

Diversion of Surface Water: Diversion of surface water can be accomplished by constructing diversion ditches and berms or by selecting a site that will avoid high-flow runoff areas. Construction of diversion ditches and berms may be a short-term solution. However, long-term structures can be designed to minimize debris accumulation and control erosion. Diversion structures do require periodic inspection and maintenance even if they are designed for long-term use. In addition, flow volumes used for the design of diversion structures can be reduced by locating waste rock piles away from the bottoms of drainages and minimizing their surface areas. Costs incurred in constructing diversion structures to reduce potential surface water flow through the pile, as presented in Table 2-1, should be compared to the construction and operation costs incurred in selecting an alternative site. The costs presented in Table 2-1 include only direct costs incurred during remedial action.

Table 2-1. Summary of Estimated Costs of Engineered Solutions for Acid Rock Drainage for Waste Rock Piles (U.S. Dollars/Ton of Waste) (MEND, 1995)[a].

Remedial Technology	Lowest Observed Value	Highest Observed Value
Diversion Ditches and Berms	$1.00/yd^3 material moved[b]	$50.00/yd^3 material moved[b]
Collect and Treat	$0.02[c] $0.20[b]	$0.12[c] $0.49[b]
Collect and Treat with Soil Cover	$0.12[c] $0.26[b]	$0.42[c] $0.66[b]
Composite Soil Cover	$0.69[c] $0.83[b]	$0.87[c] $1.01[b]
Synthetic Liner (200-year life)	$8.00/yd^2 [b]	$40.00/yd^2 [b]

[a] The values shown include only direct costs and not legal or permitting expenses.
[b] Final unit costs in 1994 dollars.
[c] Capital unit costs in 1994 dollars.

Note: Actual costs may be more or less than those shown in the table based on site-specific circumstances.

Similary to waste rock piles, tailings piles may also be significant ARD sources. Costs associated with tailing ARD mitigation are presented in Table 2-2.

Table 2-2. Summary of Estimated Costs of Engineered Solutions for Acid Rock Drainage for Tailings (U.S. Dollars/Acre of Tailings Footprint).

Remedial Technology	upper estimates = capital costs lower estimates = final costs	
	Lowest Observed Value	**Highest Observed Value**
Collect and Treat	$131,000[a] $452,000[b]	$205,000[a] $503,000[b]
Collect and Treat with Soil Cover	$192,000[a] $423,000[b]	$385,000[a] $558,000[b]
Composite Soil Cover	$40,000 $48,000	$649,000[a] $877,000[b]
Synthetic Liner (200 year life)	$45,000 $51,000	$628,000[a] $854,000[b]

[a] Capital unit costs in 1994 dollars (MEND, 1995).
[b] Final unit costs in 1994 dollars (MEND, 1995).

Note: Actual costs may be more or less than those shown in the table based on site-specific circumstances.

Prevention of Groundwater Infiltration : Contact of groundwater with an ARD source may be prevented by intercepting or isolating groundwater before it enters the waste material, or by selecting a site to avoid areas where groundwater infiltration is limited. Because collection and interception methods are prone to failure in the long term, site selection is the best method of management. As an example, a gravity-controlled water system is much more trouble-free than a pumping system. The performance and cost of different groundwater interception and isolation methods vary over a wide range, depending on hydrogeologic and other site-specific parameters. The estimated costs of these engineering solutions are presented in Table 2-1.

Prevention of Precipitation Infiltration : The most practical method of controlling precipitation infiltration is by installing a low-permeability cover or liner, which is commonly constructed from soil and/or synthetic materials. These covers can be applied to near horizontal rock faces in open pits, underground mines, and waste rock piles. An important consideration in selecting the most appropriate cover material or combination of materials is the length of time during which control is required. The estimated costs of these engineering solutions are presented in Table 2-1.

Controlled Placement of Waste : Controlling ARD migration in waste rock piles can be aided by engineered placement methods such as cellular pile construction, compacting, mixing with low permeability material, etc. (Steffen, Robertson, and Kirsten, 1989). These methods of placing waste

rock to minimize infiltration should be considered in conjunction with other control methods, such as impermeable covers to further reduce infiltration.

2.2 Underground Mine Drainage

The environmental problems resulting from acid drainage from underground mines are similar to those from waste rock piles. However, the costs associated with remediation are different. The ARD from underground workings generally occurs as a point surface discharge, typically containing low-pH water. This point will usually be the lowest elevation entry into the mine.

Environmental problems from underground mines producing ARD cause negative impacts to the quality of both surface water and groundwater in proximity to the mine. The engineered solutions to these environmental problems are intended to manage contaminated waters and keep those waters from affecting rivers, streams, and groundwater uses.

Surface water may flow into underground mines through portals and ventilation shafts, as well as through fractures and fissures. Groundwater contamination is common at underground mines, and its interception, treatment, and control can be achieved by various methods that depend on the site's geology and hydrologic characteristics.

The cost for designing, installing, and maintaining water treatment systems is approximately proportional to the volume of water requiring treatment times the amount of material per unit volume of water. Moreover, the location of the site, the annual average precipitation amount, and the retention characteristics of the mine or ore pile can cause variations in flow rates. The design of the water treatment system must account for high- and low-flow fluctuations based on seasonal variations in precipitation. The operating cost of most water facilities is dependent on power consumption, reagent consumption, and personnel requirements. These costs must be calculated for each site. Daily direct costs can range from $100 to $1,500, depending on the complexity of the process and the flow volume treated. Once a water treatment facility is built, the volume of water treated does not significantly affect the cost.

2.2.1 Treatment Methods

Several methods of water treatment are currently being used or tested at mine sites, including lime precipitation, evaporation, biologic treatment using aerobic and anaerobic bacteria, wetland treatment systems, electrolyticwinning, and ion encapsulation in zeolites. The costs of these treatment methods are presented in Table 2-3.

Table 2-3. Cost To Treat Acid Rock Drainage (Dollars/Gallon/Minute Flow).

Remedial Technology	Range of Average Capital Cost	Range of Average Annual Operating Costs
Lime Precipitation	$2,900 to $6,400/gal/min [a]	$700 to $3,600/gal/min [a]
Evaporation	$2,000 to $6,000/gal/min	$200 to $2,200/gal/min
Passive Wetland	$2,900 to $18,500/gal/min [a]	$120 to $420/gal/min [a]

[a] From Gusek (1995).

Note: Actual costs may be more or less than those shown in the table based on site-specific circumstances.

The volume of water discharged from mines and waste piles located in dry climates is generally low, whereas discharge volumes tend to be higher in wetter climates. Low flows can typically be processed by evaporation methods or the use of wetlands. The costs associated with these processes are small, including the cost of an impoundment, miscellaneous plumbing, and importing peat for the beds and monitoring. A treatment system for a mine site demonstrating an average flow of less than 5 gallons per minute could be constructed for less than $10,000. Annual operating costs may average 10 percent of the initial construction cost. Large-scale process plants can have capital costs exceeding $20 million with annual operating costs exceeding $500,000 (Gusek, 1995).

For higher flow rates, the preferable system is lime precipitation. The standard lime process plant includes a receiving pond, lime storage bins, and mixing tanks where the lime is added and mixed with the influent. The influent then passes through a thickening tank where the precipitate is settled and dewatered. The pH of the overflow water is adjusted, if necessary, and the overflow water is discharged. Engineering for this type of plant includes the grading of a site, construction of ponds, purchase of tanks and process machinery, and fabrication. Fabrication of a weather-tight building to house the apparatus in colder climates is also necessary. The cost of this type of a facility may range from $50,000 to tens of millions of dollars (Gusek, 1995). Maintenance and operation of the facility may cost from several hundred to several thousand dollars per day, depending on the water flow volume and the amount of metals dissolved. Each plant must be specifically designed for the volume and characteristics of the waste water and the level of treatment required.

2.2.2 Collection of Acid Water

Acidic waters generated from mines can usually be diverted and collected at a single point where they are either gravity fed or pumped to a treatment plant. Waters generated from waste piles can be more difficult to direct to a single point. Associated costs include rehabilitation of the mine openings, surface grading and plumbing. Pump installation and operating costs are an additional cost, if they prove necessary. Operational costs must account for variable water flow rates and the pumping distance and elevation from the source(s) to the treatment plant.

Drainage from waste piles can be more difficult to collect. The factors affecting water collection depend on the location and size of the waste piles, the topography underlying the piles, and the permeability of the underlying strata. If the waters can be diverted to a single collection location by gravity, then the costs are similar to those for mine openings. If the installation of a collection system involves excavations, dikes and impoundments the cost is greatly increased. The cost of moving rock and dirt generally ranges between $5 to $50 per cubic yard. When the location, types, and quantities of borrow materials are known, a cost estimate can be developed.

If the waste is not overlying an impermeable membrane or if it does not have the proper characteristics to seal itself from the underlying strata, it is possible that acid water (or other waste water) will infiltrate through porous underlying strata. In this scenario, it may be necessary to drill a series of dewatering and collection wells into the strata to remove acid drainage. The configuration of the dewatering wells may be designed to encircle the area, to create a capture zone (cone of depression in the water table) associated with a single well, or in a line to form a curtain. Drilling costs, including materials, generally range from $10 to $50 per linear foot of borehole. These costs are dependent on the location of the site, the depth of the borehole and the amount of rig downtime beyond the control of the contractor.

Upon completion of drilling and testing of the dewatering wells, a pump collection system can be designed and installed along with the required plumbing. The cost of this system is dependent on the number of dewatering wells, the depth of the boreholes, the amount of water, and the elevation and distance the water has to be pumped. Pumps operating in acidic waters are usually designed to resist the affects of corrosion. If no electric power lines exist at the site, additional expenses are incurred to bring in power lines, install generators to maintain engine powered pumps.

3.0 SEEPAGE AND OVERFLOW FROM LEACH SYSTEMS AND TAILINGS IMPOUNDMENTS

Typical environmental problems occurring at the site of a tailings or leach system impoundment are a result of pollutant-laden process water overflowing or escaping through the dam; percolating downward into the groundwater; or moving through a breach in the retaining dam.

3.1 Overflow or Breach of an Impoundment Structure

The effects of a downstream release normally are a result of a higher than anticipated precipitation event or failure of an impoundment structure. The structural failure of an impoundment may be instantaneous. In this case, nothing can be done to stop the damage as it occurs. The solution to this situation normally requires rebuilding the dam and initiating a cleanup of the materials deposited downstream (or downgradient) from the site. If the breach or outflow is certain, but not immediate, measures can be taken to prevent the event. Such measures include increasing dam and liner height, directing flows to secondary structures, or implementing procedures to provide for a controlled release.

3.1.1 Dam Breach

The cost of the repair of an impoundment dam normally includes engineering design, location and procurement of materials, haulage of materials and installation. The haulage costs for the fill material are highly dependent on the distance that the material must be transported. The costs of material placement typically range from $5 to $50 per cubic yard with the engineering costs averaging 10 percent of the total cost of the project.

The cost of clean up of the tailings and miscellaneous debris that flow out of the impoundment, is based on the type and amount of tailings spilled, the standards set for clean up and the water flow volume in the stream (if a stream exists). For example, if a small spill occurred next to a large river, the river may disseminate all or most of the tailings, making tailings removal impossible. Another scenario might involve a small spill occurring in a drainage which contains no active stream. In this case, it may be possible to return the solids from this spill back to their original location, using earthmoving equipment. The cost of moving the material back in place can be as little as a few dollars per cubic yard. If the spill consists of only natural materials without any toxic constituents, it might be feasible to leave the material in place and reclaim it.

Another scenario might involve a large toxic spill occurring along a small active stream. This type of spill could generate the highest cleanup cost. It may be necessary to use earthmoving equipment, dredges and hand laborers to remove material from the stream and adjacent riparian areas.

The cost of this type of cleanup is so site specific that it can only be estimated following determinations made by the site engineers and regulatory agencies involved.

3.1.2 Overflow of an Impoundment

Releases of water from an impoundment can be anticipated if the overflow is expected to occur as a normal result of the mining operation. In the case of a sudden high flow precipitation event, the overflow could occur unexpectedly as in the dam breach described above. The remedial actions described above in Section 3.1.1 can be similarly applied to an overflow.

In a scenario where there is a gradual rise in the water level of the impoundment caused by greater than annual average precipitation or increase in discharge from the processing plant, a solution can be designed and implemented prior to the overflow. Some solutions might include increasing the height of the impoundment, building an additional impoundment, and installing/increasing the size of water treatment plant/controlled discharge (see Section 2.2.1).

3.2 Leakage from the Face or Toe of a Dam

Leakage from a dam can be stopped either by modifying the dam or by collecting, treating, and discharging the leakage. Modern tailings ponds generally contain enough fine grained material that they tend to plug themselves with the "slimes" generated from the milling process. If water leakage occurs, the most common solution in a wet climate is to construct a water treatment plant and then collect, treat, and discharge the water. In a dry climate, where a mine typically has water shortages, collected solution is often reclaimed and returned to the mill for re-use.

The waters contained in impoundments commonly found at modern cyanide and acid leach plants contain a lower percentage of suspended solids and as a result can be more susceptible to leakage than conventional process mills. In this case, it is very important to stop all leaks both for environmental and economic reasons. Repair of a leak may be as simple as replacing or repairing an impermeable liner. This could involve engineering of the repair, procurement of materials and installation by laborers. The cost of repairing a small leak may be as little as a few hundreds of dollars.

The costs of repairing a leak that occurs below a large leach pad/pond can be much higher. As an example, if a leak develops near the center of a hypothetical pad having horizontal dimensions of 200 by 200 feet and a height of 50 feet, the leak must first be isolated. The expense and time spent locating the leak are dependent upon the experience of the mine operator and the amount of monitoring and detection instrumentation already located near the pad. It may be necessary to drill a series of angle boreholes to ascertain the location of the leak. After locating the leak, the overlying material must be excavated to expose the leak. The excavation must be engineered to insure stable slopes for safety reasons. In this hypothetical scenario, approximately 15,000 cubic yards of material would have

to be removed to reach and expose the leak. The calculated cost for removing the material from the pad would be $75,000, if the cost for hauling material is $5 per cubic yard. The cost of repairing the leak would additionally involve engineering time, materials and labor. The total cost to repair this type of leak is estimated to be approximately $100,000.

4.0 MINE SITE CASE STUDIES

4.1 Overview

The initial objective of this project was to develop comprehensive data on remedial measures undertaken at selected modern mining operations throughout the United States, specifically focussing on cost data. Such detailed cost data, if available, would allow for site-by-site comparisons of the unit costs associated with addressing specific problems, and the factors that influence those costs. Unfortunately, there is generally no centralized source of information on modern mine site remedial costs, at the national level or in most States.

To collect site-specific cost information, EPA had it's contractor (SAIC) contact State offices responsible for regulating mining activities as well as reviewing published literature. State office visits were then conducted to obtain publicly available file materials documenting remedial activities. Such visits were undertaken in South Dakota, South Carolina, Nevada, Colorado, and Montana. Information on remedial activities in Arizona was obtained from the EPA Region IX Office in San Francisco. Overall, information was reviewed for many non-coal mining sites (more than 100 modern/post-1980 operations) where remedial actions have been taken to address actual or perceived threats to the environment. Cost data were not readily available, except for Arizona and South Dakota. This is largely because most States do not require submittal of these data. Where cost information was found in other States, it was primarily submitted on a voluntary basis. Similarly, while the literature provides extensive information on many significant environmental incidents, it also does not typically include cost information (presumably, at least in part, because such data are considered proprietary). As a result, the only comprehensive approach to cost data collection would be to contact the mining companies themselves. Such an effort was beyond the scope of this report.

Despite the above limitations, cost data were obtained for 24 modern (post-1980) mining operations throughout the western United States. These data are summarized in Table 4-1 and the accompanying case studies. The problems encountered at case study sites are representative both of environmental effects common to many mines (ARD issues, water management difficulties, etc.) as well as unique site-specific issues. One site, Noranda's Montanore Project represents a *proposed* mining operation where cost data were available for water collection and treatment options. This information was included because it is also applicable to water treatment costs associated with remedial activities at other sites. The varying level of detail in the case studies reflects the inconsistency of available data and ranges from a single dollar value for total remedial costs at a site, to breakdowns of each individual cost element (including site characterization, and design, construction, and maintenance of remedial alternatives). In most of the case studies, the level of detail regarding the site is not sufficient to estimate unit costs (per acre, gallon etc.). For example, many of the case studies do not present water flow data, the acreage affected or remediated, or the dimensions of tailings dams, heaps, waste rock piles, etc.

Table 4-1. Examples of Costs for Remedial Measures at Specific Sites.

Name and Location of Mine	Type of Problem	Remedial Action Taken	Cost Data (Dollars)
Microgold II Mine Florance, Idaho	Releases of mercury from plant contaminated soils and tailings pond. Did not significantly impact groundwater, although source of elevated levels in two wells is unknown (might have been background).	Excavation and encapsulation of soil using synthetic liner and cover.	$120,000 was put into escrow for clean-up.
Lucky Friday Mine Mullan, Idaho	100 gallons of copper sulfate solution overflowed a tank, drained into a sump and eventually into the Coeur d'Alene River.	Installed concrete curbing around tanks, installed paving in tank area and planted willows and other vegetation along river.	$47,700
Copper Cities Magma Copper Arizona	Unauthorized discharges/seepages from waste management and process solution units; NPDES non-compliance.	Construction of 100-year, 24-hour collection facilities and pumpbacks.	NPDES compliance costs/remedial measures: 1991 - $180,000 to $300,000 early 1993 - $544,173 O&M costs (an unspecified portion allocated to repairs/remedial activities): 1991 - $696,620 1992 - $155, 188
Pinto Valley Magma Copper Arizona	Unauthorized discharges/seepage from tailings and leach dumps, ponds, and solution ditches, including storm overflows and tailings and solution dam breeches.	Repair of tailings and solution dams; new and increased seepage collection activities.	Costs to respond to non-compliance 1992/93 order for problems: $636,537
Miami Operations Cyprus Miami Miami, Arizona	NPDES non-compliance, unauthorized discharge of wastewater to surface and groundwater.	Broad improvements in site-wide water management practices over a 10 year period. Discontinuation of unauthorized discharges including elimination of an unlined acid sump, groundwater pumping; construction of runon and runoff controls and additional enhanced containment systems, and waste rock excavation and capping.	Total capital costs for improved water management and NPDES compliance were slightly greater than $1 million.
Cyprus Sierrita Mine Sierrita, Arizona	Unauthorized discharge to surface water from process pond (ARD issues) and tailing water reclaim line.	To address pond seepage, constructed hydraulic barriers; replace PVC pipe with steel-encased pipe.	$101,030 for pond, $70,000 for pipe

Table 4-1. Examples of Costs for Remedial Measures at Specific Sites (cont.).

Name and Location of Mine	Type of Problem	Remedial Action Taken	Cost Data (Dollars)
Ray Complex ASARCO Arizona	Subsurface leakage of solutions from leach dumps, ponds, and processing facility - low pH and elevated copper; also water quality impacts from contaminated runoff.	Repair leaks in facilities and impoundments, dig drainage trenches to intercept leaks, drive a 13,000-foot long water diversion tunnel, build diversion dams and construct wetlands, provide long-term water treatment.	Net capital cost for NPDES compliances have exceeded $40 million with annual O&M cost for the treatment plant, ongoing surface water monitoring, and maintenance of containment structures exceeding $1.5 million in 1993.
Magma Copper Company Superior Division Arizona	Unauthorized discharges. Seepage of tailings and acidic mine water to surface water. Elevated metals levels - copper, cadmium, lead, and zinc.	Construction of seepage collection and pumpback systems, improved water reclaim in the mill (especially acidic water), and remediation of contaminated soils.	Capital costs of NPDES compliance activities to manage/control discharges reported in 1991 as about $280,000.
Thompson Creek Tonopah Mineral Resources Challis, Idaho	Acid generation from tailings and waste rock; unanticipated discharge from tailings pond.	No decision on approach to long-term remediation of tailings made to date. Short-term installation of tailings seepage pumpback. Options for long-term include pyrite removal in mill; buffering; water treatment, etc.	$7.5 million bond for water quality protection added for ARD remediation. Other total remediation cost estimates: $6 to $25 million.
Grey Eagle Mine Noranda Happy Camp, California	Tailings impoundment was source of water quality impacts (active 1982-86).	Water treatment plant used during active operations; tailings pond closed with geotextile cover and revegetated surface.	Treatment costs not available; but liner cost $131,000 per acre (unknown how many acres).
Franklin Consolidated Mine Idaho Springs, Colorado	Pyritic upper tailings pile eroding into Gilson Gulch, fine grained tailings in lower pile moved 100 feet by wind erosion.	For upper tailings pile, graded and compacted tailings; earthen berm and runon controls installed. For lower pile, cover source of blowing tailings with burlap and clean-up of windblown tailings; also berms installed in mill to contain spills.	State bond was increased by $16,000 to cover clean-up costs.
Gilt Edge Mine Lead, South Dakota	Acid water drainage and releases of cyanide into surface and groundwater; long-term from spent ore/pits and short-term from pad leaks.	For spent ore and pit seepage, installed collection and treatment ponds in drainages; treatment using reverse osmosis; spent ore eventually to be capped. For short-term pad leak, installed plug, repaired pad, and installed treatment for excess water.	Estimated at $3.7 million for long-term impacts; $350,000 for pad leak.
Paradise Peak Mine FMC Gold Nevada	Oil spill in the vicinity of the maintenance shop. Spill caused by failure of oil skimmer in shop clean-up water sump. Little potential for hydrocarbons to impact ground or surface water.	Sealing the point of discharge, installing berms around the contaminated area, performing soils removal, and ceasing water washdowns (use of dry reagent).	$103,801

Table 4-1. Examples of Costs for Remedial Measures at Specific Sites (cont.).

Name and Location of Mine	Type of Problem	Remedial Action Taken	Cost Data (Dollars)
Buckskin Operation Douglas Co., Nevada	Seepage containing cyanide in groundwater downstream from tailings impoundment.	Pump impoundment and install new lined pond; install tailings water reclaim system.	Approximately $200,000
Dee Gold Mining Newmont Gold Elko, Nevada	Water containing cyanide seepage from tailings dam; detected in nearby alluvial aquifer.	Installed groundwater recovery wells and vertical interceptor ditch; pumped recovered water to tailings impoundment.	Approximately $2 million
Jerritt Canyon Independence Mining Elko, Nevada	Seepage from tailings impoundment	Delineate seepage, install ground water recovery system and modify mill process to allow for recovered groundwater and tailings water re-use.	Approximately $2.1 million
Goldstrike Mines American Barrick Elko, Nevada	Break in waterline caused pond overflow resulting in release of 25,000 to 30,000 gallons seepage/runoff.	Decommissioned waterline and pump out of ponds.	$160,000 (Includes study of impacts)
Buckhorn Operation Cominco Resources Carlin, Nevada	Leaks from fuel lines and pipes; and diesel spill. Elevated total petroleum hydrocarbons in groundwater.	Collection of surface water runoff with oil-water separation, groundwater treatment by bioremedial solution and recovery/oil-water separation; soils excavation.	Over $290,000
Richmond Hill LAC Minerals Lead, South Dakota	Unanticipated acid drainage from spent ore (2.7 million tons).	Short-term: installation of runon/controls; construction of seepage collection and treatment system; and liming of rock. Long-term: return spent ore to pit and install impervious cap.	$8.5 million (additional bonding requirement)
Wharf Resources Lead, South Dakota	Nitrate in ground water downgradient of spent ore pile; may also be contribution from blasting residues.	Installation ion exchange system to treat spent ore removal for nitrate.	Approximately $2 million
Golden Sunlight Mine Whitehall, Montana	Cyanide leakage from tailings impoundment; environmental threats associated with ground movement in mill caused by massive weight of a waste rock pile.	Redesigned tailings impoundment, installed pumpback wells, provided alternative water wells and treatment of local domestic wells. **For ground movement impacts**, pumpback wells installed, waste rock moved to more stable area, and improved process solution containment systems installed.	$12 million has been spent as of March 1995 to address ground movement effects; an additional $1.8 million in costs expected in 1995. (No cost data for tailings seepage.)
Zortman-Landusky Mine Pegasus Mining Montana	Extensive ARD/AMD drainage to surface and groundwater from pits, cut ore, and waste rock; also cyanide releases from heaps and spent ore.	Installed pumpback systems and built a treatment plant; considering other, long-term/improved containment and treatment options.	$720,000 for current treatment plant; in 1993-94, $2.8 million spent on reclamation (unclear how much for environmental impacts); drafts of proposed compliance plans suggest significant additional costs to be incurred.
Montanaore Mine Noranda Kootenai National Forest, Montana	Proposed mine will have tailings pond with anticipated seepage of 450 gallons per minute	Proposing a seepage collection system with wetlands, evaporation or electrocoagulation treatment.	Projected cost of water management/treatment ranges from $2.5 million to $20.4 million.

Table 4-1. Examples of Costs for Remedial Measures at Specific Sites (cont.).

The cases studies describe a wide range of different levels of environmental concern as well as mine sizes. Overall, they generally support the previous chapters by showing that remedial costs are highly site-specific. Of additional note, the cost data for some sites only provides the expenditures to date. Future costs may be significant, especially where the long-term performance of a remedial alternative cannot be accurately predicted and/or perpetual care is likely to be required.

4.2 Case Studies

4.2.1 Case Study No. 1 - Elevated Nitrate in Groundwater at Leached Ore Piles

Site Name: Wharf Resources, Lead, South Dakota

Type of Mining: Cyanide Heap Leaching, on/off pad with spent ore neutralization

Nature of Environmental Effects: During the late 1980s, elevated levels of nitrate were observed in groundwater monitoring wells downgradient of Wharf's spent ore pile. Some nitrate loadings may also been the result of residuals from blasting operations.

Remedial Actions: Installation of the countercurrent ion exchange technology (CCIX) to reduce nitrate and nitrite levels in the spent ore/process solution. Ion exchange is a commonly used methodology for reduction, because the nitrate shows affinity for several types of resins. The CCIX system uses countercurrent flow through a packed bed resin with nitrogen removal and regeneration occurring simultaneously.

Costs of Remedial Activities: According to the South Dakota Department of the Environment and Natural Resources, the company's cost for installing the CCIX at the Wharf site was approximately $2 million. This does not include long-term operating costs, such as the costs associated with managing rinse solution.

References: SD DENR, 1995. SD DENR, 1991c.

4.2.2 Case Study No. 2 - ARD from Spent Ore Disposal/Waste Rock Pile

Site Name: Richmond Hill, LAC Minerals, Lead South Dakota

Type of Mining: The Richmond Hill mine is located in the Black Hills regions of South Dakota. Cyanide heap leaching operation with an on/off pad and spent ore neutralization. The facility is located at between 5,500 and 6,000 feet with approximately 28 inches of precipitation annually.

Nature of Environmental Effects: In 1992, the State of South Dakota observed acid mine drainage associated with spent ore disposal at the Richmond Hill mine in the Black Hills. An initial sample taken from the toe of the waste rock dump had a pH of 3.1 and subsequent additional sampling showed pH levels of 2.6 and 3.6 with elevated levels of sulfate, TDS, aluminum, copper, iron, and manganese acidic conditions and high concentrations of metals and sulfates. The original mine plan included processing a small quantity of sulfide rock and the State incorporated limited measures to address acid drainage in the mining permit. However, the actual generation of acid drainage was significantly greater than originally anticipated; necessitating more extensive short- and long-term mitigation measures. After additional testing, LAC Minerals determined that all of the waste rock generated during operations, 2.7 million tons, was acidic.

Remedial Actions: Remedial activities for acid drainage involved both short- and long-term actions. In the short term, the facility constructed treatment ponds at the toe of the dump and added caustic (some water is also diluted with uncontaminated storm water). Treated water can either be land applied or discharged via an NPDES permit. Other short-term measures included: removal of sulfide ore and placement on the pad, construction of runon controls, and addition of some neutralizing materials to the pile.

The long-term remedy for the site involves removal of acid generating waste rock and placement in the pit (presumed to also be acid generating). An impervious cap will then be installed.

Costs of Remedial Activities: According to the State, the cost of remedial measures at the site (primarily for long-term actions) is shown by the increase in the reclamation bonding requirements for Richmond Hill. After acid drainage was discovered, the surety bond for the site was increased by approximately $8.5 million. This includes the following subcosts.

Moving Waste Rock to the Pit	$2,521,000
Reclaiming Remaining Waste Dump	$150,000
Cover for Waste Rock in Pit	$653,000
Haul Sulfide ore from Pad	$65,000
Regrade and Revegetate Pad 3	$780,000
Regrade and Revegetate Pads 1	$126,000
3:1 Pad Base Addition	$4,221,000
APPROXIMATE TOTAL	$8,500,000

These amounts do not include the initial costs of delineating the extent of the problem and designing alternatives.

References: SD DENR, Undateda. Durkin, 1994.

4.2.3 Case Study No. 3 - Impoundment Overflow

Site Name: American Barrick Goldstrike Mines, Elko, Nevada

Type of Mining: American Barrick operates a cyanide heap leaching operation near Elko, Nevada. Waste rock/spent ore is managed in an on-site dump.

Nature of Environmental Effects: During summer 1993, American Barrick began to observe a sustained flow in the sedimentation pond that was not caused by surface runoff (instead it was likely seepage from the dump). The sedimentation pond is used to manage runoff from the waste rock pile. Runoff from the dump collects in the sedimentation pond. The gully in which the pond is located drains to Rodeo Creek, an ephemeral drainage. In late July 1994, between 25,000 and 30,000 gallons of water overflowed the pond (i.e., were discharged without a permit). The water flowed approximately 1,900 feet down Rodeo Creek from the point of intersection of the gully and the creek.

Regulatory Action: The State issued a Finding of Alleged Violation and Order (FOAV) for the release. (All of the information in this summary was included in the facility's written presentation for a Show Cause hearing related to the Order). In the Order, the State required that the operator delineate the extent of any impacts on soils and shallow groundwater. According to American Barrick's contractor, sulfate was the only parameter observed at elevated concentrations in ground water and soils (high sulfate levels were also found in the seepage).

Remedial Actions: American Barrick determined that a water line located above the pile was likely source of the discharge. This pipe was subsequently decommissioned. Further, Barrick pumped millions of gallons of water from the sedimentation pond to the tailings pond, to ensure no other discharges.

Costs of Remedial Activities: The total costs of remedial measures reported by American Barrick in 1994 were $160,000. This included $110,612 for pumping water from the sedimentation pond and $49,108 for preparing the delineation sampling plan. It should be noted that seepage from the waste rock pile was also observed in 1993. However, there was no discharge from the pond (and no violation). In 1993, American Barrick also had to pump nearly 2 million gallons of water from the pond, relocate an equipment washdown area, and modify stormwater management at the waste rock pile (the State files do not include any cost data from this incident).

Reference: Barrick, 1995.

4.2.4 Case Study No. 4 - Tailings Impoundment Seepage

Site Name: Jerritt Canyon Joint Venture, Independence Mining Company, Elko, Nevada

Type of Mining: Independence Mining Company operates the Jerritt Canyon Joint Venture in Elko, Nevada. Detoxified tailings from the vat leaching operation at the site are disposed in a tailings impoundment. Chlorination is used in the neutralization process. As of October 1991, more than 15,000,000 tons of ore had been processed in the vat leach operations. The tailings impoundment was initially constructed to provide for full containment (i.e., zero discharge).

Nature of Environmental Effects : The operator, Freeport McMoRan Gold (FMG) at the time, first suspected seepage from the impoundment in 1983. Nevada Division of Environmental Protection staff observed seepage from the tailings impoundment during an inspection in 1990. The seepage appears to flow from the eastern and southern sides of the tailings impoundment. The seepage caused elevated major ion concentrations, including chloride and TDS levels in the surficial aquifer. Cyanide has not been detected above the State's action level.

Remedial Actions: Since 1984, the operators of the mine have been investigating/delineating the seepage and undertaking remedial measures. Remedial measures have included installing a ground water recovery system. In addition, modifications were made to the milling process and associated piping to allow for direct reuse of tailings water from the impoundment, as well as re-use of recovered groundwater.

Costs of Remedial Activities : The most recent cost data available was presented in an October 18, 1991 letter from Independence to the State Bureau of Mining and Reclamation. Independence and the previous owners had spent nearly $2.1 million on delineating the seepage/contamination, installing a ground water recovery system, and making modifications to the milling process. Between 1984 and 1990, FMG spent $570,000 and Independence spent $1,500,000 during 1990-1991. Although the seepage remediation system was operational in October 1991, some additional future investments were expected by Independence to optimize system performance and maintain the collection system.

References: NDEP, 1990. Independence, 1991.

4.2.5 Case Study No. 5 - Cyanide Leakage from Tailings Impoundment

Site Name: Dee Gold Mining Company, Elko County, Nevada

Type of Mining: Newmont Gold Company now operates a cyanide heap leach operation near Elko that was formerly operated by Dee Gold. Some of the tailings from the leaching process are disposed of in tailings disposal facility No. 2. This unit is located in an ephemeral tributary of Boulder Creek. Boulder Creek, a perennial stream, flows approximately 1,000 feet downstream of the dam. The tailings dam was initially constructed to provide for full containment (i.e., zero discharge), with the clay core keyed into the underlying bedrock.

Nature of Environmental Effects : Monitoring data collected during the 1980s showed cyanide-laden seepage flowing from the tailings impoundment into the Boulder Creek alluvium. The highest measured cyanide concentration in the cyanide plume was 6 ppm. According to the operator's contractor, in November 1990, seepage was detected in the Boulder Creek alluvial aquifer. Seepage may have been enhanced originally by the initial location of a reclaim pond near the north abutment. The pond was moved shortly after seepage was detected.

Remedial Actions: To provide short-term seepage control, the facility installed three downgradient groundwater recovery wells. Collected water was pumped back to the impoundment. In 1991, the operators decided to design and install a vertical interceptor trench drain (VITD) to contain the seepage from the tailings impoundment. The VITD was planned to be operational in early 1992. The flows collected in the VITD system would presumably be returned to the impoundment.

Costs of Remedial Activities : As of late 1990 (the most recent cost data), the cost of designing and installing the VITD system as estimated to be approximately $1.25 million. This does not include the costs of delineating the seepage, installation and operation of the recovery wells, or ongoing VITD system operation and maintenance.

References: Dames & Moore, 1990. Rayrock, 1990. Hydro-Engineering, 1991.

4.2.6 Case Study No. 6 - Cyanide Leakage to Groundwater from Tailings Impoundment

Site Name: Buckskin Operation, Douglas County Nevada

Type of Mining: The Buckskin Operation is located 10 miles west of Yerington in Douglas County, Nevada. The facility was originally operated as a mine and mill by Pacific Silver Corporation. In 1987, Sonora Mining Corporation purchased the operation and began using the mill to vat leach ore from Sonora's Jamestown Mine in California (the mine became inactive). Carbon-in-pulp processing is used for gold recovery. Wet tailings from both Pacific Silver and Sonora's leaching operations were managed in an impoundment located on the edge of a large alluvial plain. Sonora modified Pacific Silver tailings disposal methods by greatly reducing the area of ponding/active disposal. Although the impoundment was generally constructed by Pacific Silver in accordance with State-approved designs, the operator apparently did not install a liner.

Nature of Environmental Effects : Groundwater contamination was initially observed at the site during 1987 when cyanide was detected in a water supply well downstream of the tailings impoundment. These findings influenced Sonora's proposed tailings management proposal. A zero discharge permit was issued for Sonora's operations in August 1990. Under the permit, the facility was required to install three groundwater monitoring wells downgradient from the tailings impoundment. Subsequent monitoring data collected during the 1980s showed cyanide-laden seepage flowing from the

impoundment into the underlying ground water. The elevated cyanide concentrations appeared to have been localized; a Geraghty & Miller report from 1991 showed no contamination in off-site wells.

Remedial Actions: During 1987, in response to the initial detection of cyanide contamination, Sonora conducted a site investigation to delineate the contamination caused by Pacific Silver, altering Sonora's plans for tailings management. In late 1990, after cyanide was detected in the permit compliance monitoring wells, the State issued an order to Sonora requiring them to stop the leaks from the Buckskin tailings impoundment. As a result, Sonora indicated that the company would "pump the existing impoundment dry" and install a new lined unit. The order specifically required that Sonora design and install a tailings water reclaim line. Remedial actions were undertaken in 1990-1991.

Costs of Remedial Activities: The 1987 investigation of groundwater contamination by Sonora's contractor cost approximately $52,000 with modifications to the tailings impoundment design expected to cost $50,000 - $100,000 (no final cost data available from 1987). No specific cost data were found on the remedial measures undertaken in 1990-1991. However, in a late 1991 newspaper article, a company official indicated that the costs of the remedial measures would be approximately $200,000.

References: Botts, 1990. Bateman, 1990. Wahler, 1987. Bergsohn, 1991.

4.2.7 Case Study No. 7 - Fuel Spill from Ancillary Facilities

Site Name: Buckhorn Operations, Cominco American Resources, Carlin, Nevada

Type of Mining: Cominco American Resources' Buckhorn Operation is a cyanide heap leach facility near Carlin, Nevada.

Nature of Environmental Effects: In late 1991 and 1992, Cominco observed several releases of hydrocarbons from ancillary operations. These included: (1) a gasoline release from underground piping, (2) a diesel fuel leak from underground piping, and (3) a surface spill of diesel oil. The contamination area associated with the gasoline leak was approximately 1 acre with groundwater concentrations of Total Petroleum Hydrocarbons of up to 37.9 ppm. The diesel leak from the pipe contaminated approximately .33 acre with ground water TPH concentrations of up to 1.32 ppm. The spill contaminated about .8 acre with trace amounts of TPH detected in groundwater. Finally, there are other localized areas of oil and diesel contamination at the plant site. Surface water contamination was limited to a confined marsh area with TPH concentrations of up to 1,360 mg/l. In November, 1992 the State issued a Finding of Alleged Violation and Order (FOVA) for sitewide hydrocarbon contamination. All of the information in this description is included in the facility's written response to the FOVA.

Remedial Actions: The selected remedial measures included collection and oil/water separation of surface flows, installation of groundwater recovery wells with oil/water separation and fuel recovery, injection of bioremediation solution through a new injection well and constructed trenches, and bioremediation of previously excavated soils.

Costs of Remedial Activities: A December 8, 1992 presentation by Cominco American Resources to the State of Nevada indicated that the cost of delineating the contamination and implementing selected remedial measures would exceed $290,000. This included site investigation and remediation activities, however, a complete breakdown of individual cost elements was not available.

References: Cominco, 1992.

4.2.8 Case Study No. 8 - Cyanide Leakage from a Heap/ARD Discharge from Spent Ore

Site Name: Brohm Mining Corporation, Gilt Edge Mine, Lead, South Dakota

Type of Mining: Brohm mining corporation operates a cyanide heap leach facility near Lead, South Dakota. Over 3,000,000 tons of neutralized spent ore has been disposed of Ruby Creek, which flows during wet periods. Ruby Creek flows into a perennial stream, Bear Creek.

Nature of Environmental Effects: Beginning in 1993, ARD has been observed in both Ruby Creek and Strawberry Creek with observed pH levels as low as 1.5-2.0. Historic tailings are the only wastes found in Strawberry Creek, however, studies completed by the operator have shown a hydraulic connection between Brohm's pit and Strawberry Creek.

In addition, from June 17 through 19, leakage occurred from one of Brohm's leach pads causing cyanide releases to ground and surface water. This violated Brohm's zero discharge permit.

Remedial Actions: U.S. EPA issued NPDES permits requiring Brohm to control the discharges in Ruby and Strawberry Creeks. As a result, Brohm installed a series of treatment ponds and a temporary holding pond in Ruby Creek. Water treatment is currently done by reverse osmosis. A lined collection pond for surface water and pumped ground water was also installed in Strawberry Creek. Further, over 165,000 tons of historic tailings in Strawberry Creek were cleaned-up. As of June 1995, Brohm was planning to install a second treatment system for all of the water in Ruby and Strawberry Creeks plus pit water (to be operated until the waste rock is reclaimed and capped). According to the operator, water quality has now been restored.

To address the 1991 pad leakage, Brohm was required by the State to submit reports documenting the extent of the contamination, and develop a remediation plan. The settlement between the State and Brohm included lowering solution levels in the surge pond, installing a bentonite plug in

the area of the leakage, permanently repairing the pad, and constructing a treatment system for excess water.

Costs of Remedial Activities : The short-term costs of acid drainage remedial measures are provided by the facility and long-term reclamation costs are provided by the State's bonding calculations. The facility's estimates for short-term measures (spent between 1993 and 1995) include:

Interim mitigation and treatment	$1,960,000
Historic tailings remediation	$451,000
Water treatment system	$741,000
ARD plan	$208,000
TOTAL	$3,360,000

This does not include the January 1994 reported cost ($400,000) for a reverse osmosis unit for water treatment (presumably their second, the first was purchased in 1993 for $350,000).

As described in the State's bond calculations, approximate long-term costs of remediation for ARD can be observed in several line items, including:

Ruby waste dump cap	$2,162,000
Limestone on Pit Benches	$78,000
Pit Cap	$650,000
Crusher area cap	$48,000
Leach pad cap	$472,000
QA of Cap Construction	$110,000
Pit water treatment	$195,000
Ruby dump capital items	$661,000*
TOTAL	$4,376,000

* Capital items include construction of ponds and water diversion ditches, sludge disposal, and water treatment during a planned four-year reclamation period.

The total reclamation bond for the site is now $8,517,000.

The costs of the remedial measures associated with leakage from the heap are available through the State's requirement of a performance bond for remediation. The total bond amount was $350,000.

References: SD DENR, 1991a. SD DENR, 1992b. SD DENR, 1993. Brohm, 1995. SD DENR, Undatedb.

4.2.9 - Case Study No. 9 - Tailings Erosion (Small Operation)

Site Name: Franklin Consolidated Mining Company, Inc., Clear Creek County, CO

Type of Mining: A small underground mine and cyanide vat leaching operation for gold production. The operator recently changed the gold recovery process from a Merrill-Crowe circuit to Carbon-in-Leach. Spent ore/tailings have been disposed of in two units, the upper and lower tailings impoundments. The upper tailings impoundment contained approximately 7,000 tons of tailings as of October 1993; the amount in the lower tailings unit was not specified. An additional 2,500 tons of pyrite concentrate were found in the mill area.

Nature of Environmental Effects: During a mine site inspection by the Colorado Division of Minerals and Geology on October 15, 1993, State inspectors found that pyritic tailings in the upper impoundment were continuing to erode into Gilson Gulch. The inspection report notes that Franklin was required to have submitted a corrective action plan for the eroding tailings by September 30, 1993; however, no plan had been received as of the date of the inspection. In addition, a drainage pipe was found at the base of the tailings to direct runoff/seepage into a lined pond. However, the pipe was apparently not functioning and ponding was observed. At the lower tailings impoundment, pyritic tailings had been dispersed by wind 100 feet outside of the unit. As a result of the observed impacts, the State of Colorado Mine Land Reclamation Board issued a Notice of Violation on March 1, 1994.

Remedial Actions: The corrective action plan for the impacts involved grading and erosion control for the upper pile. The upper pile tailings were to be compacted in a single pile and an earthen berm constructed to confine these materials. The diversion ditch above the pile was to be "improved" and deepened. For the lower pile, the plan including wind erosion control by covering with burlap netting and clean-up of the windblown tailings. In addition to tailings related-activities, the facility was required to install curbing in the mill building to contain cyanide spills.

Cost of Remedial Activities: The costs of remediation are reflected in post-inspection revisions to the operator's bond. No specific line item costs for remedial measures are available. However, as noted in Franklin consultant's February 23, 1994 letter describing the proposed actions, a bond increase of $16,000 was generally necessary to cover the remedial actions.

References: York-Feirn, 1993. Poulter, 1994.

4.2.10 Case Study No.10 - ARD and Cyanide Discharges; Metals Loading; Liner Failure

Site Name: Summitville Mine, Summitville, CO

Type of Mining: This Superfund site was a gold mine in the San Juan Mountains of southern Colorado. Ore was mined from an open pit and beneficiated on a single cyanide heap leach pile. The facility operated during the mid-1980s. Waste rock from the pit was disposed of in on-site piles. The site is located in an area of historic underground mining operations.

Nature of Environmental Effects : From the beginning of operations in the mid-1980s, it became clear that the initial plan of operations included an inadequate determination of water management requirements. Subsequent treatment technologies for unanticipated discharges proved inadequate. Further, acid drainage and associated metals loadings from waste rock piles as well as historic drainage tunnels were discovered. Finally, the potential for acid generation was underestimated during mine planning. When operator declared bankruptcy in December 1992, the fluid levels in the heap were within 5 feet of the emergency spillway (and would have overflowed without treatment). In addition, avalanches damaged the liner during initial construction necessitating the construction of a seepage collection and pumpback system.

Remedial Measures: Long-term remedial/site reclamation measures remain to be determined for the site. EPA/State of Colorado have been operating the wastewater treatment system since the operator went bankrupt. The current focus is on opportunities for bioremediation to address both cyanide detoxification and acid generation.

Costs of Remedial Activities : This site presents extraordinary clean-up requirements in a highly sensitive environment. Because no final remedy has been selected or schedule for site clean-up completion established, it is impossible to provide detailed cost estimates. However, the long-term costs of clean-up measures are now projected to approach $100 million.

References: Pendleton, 1995. Plumlee, 1995. Jones, 1993.

4.2.10 Case Study No. 10 - Pre-mine Planning, Proposed Water Treatment Options

Site Name: Noranda, Montanore Mine, Kootenai National Forest, Montana

Type of Mining: Proposed copper and gold underground mining operations with a conventional flotation mill. Tailings will be managed in an impoundment.

Nature of Environmental Effects : The tailings impoundment is anticipated to have seepage of up to 1,798 liters per minute; requiring discharge to the Kootenai River Basin. In addition, excess mine water will be land applied and managed in percolation ponds. Seepage from the percolation ponds can also impact surface water. To meet applicable State water quality standards, Noranda must provide for water collection and discharge treatment.

Mitigation Measures : The plan of operations includes plans for a drainage system and options for water treatment. Constructed wetlands are the least costly suggested treatment technology, however, their effectiveness are not certain. Active treatment technologies proposed include evaporation and electrocoagulation.

Costs of Remedial Activities : The estimated cost of constructing the drainage collection system is $1.5 million. Wetlands treatment would cost between $1 and 2 million, while evaporation and electrocoagulation would cost $18.9 and $6.9 million, respectively.

Reference: Marshall, 1990.

4.2.11 Case Study No. 11 - Water Quality Impacts from Tailings Impoundment

Site Name: Noranda, Grey Eagle Mine, Happy Camp, California

Type of Mining: 500-ton-per-day open pit gold mine with vat leach operation. Spent ore disposed in tailings impoundment. Operations began in 1982 with closure in 1986.

Nature of Environmental Effects : The tailings impoundment was a source of water quality impacts necessitating construction and operation of a water treatment plant.

Remedial Measures: The water treatment plant was used during active operations. For closure, an impermeable cover consisting of a geotextile cover with a clay liner and surface revegetation was required. To date, the cover has proven effective in preventing infiltration through the tailings.

Costs of Remedial Activities : The construction costs of the cover averaged $131,000 per acre of tailings (the specific area to be covered was unavailable).

4.2.12 Case Study No. 12 - ARD and Cyanide Discharges from Large Heap Leach Operation

Site Name: Zortman-Landusky Mine, Pegasus Mining, Montana

Type of Mining: Extensive surface mining operations with heap leaches and processing circuits. Active operations began in the late 1970s - early 1980s. Pegasus is currently planning an expansion of leaching operations. The facility is located in an historic mining district with several drainages impacted by old adit discharges and/or historic mining.

Nature of Environmental Effects : Acid drainage as well as cyanide releases have impacted surface and ground water in two separate watersheds. While some impacts have been increased by releases from historic adit and wastes, Zortman's impacts are evidence by extensive water quality data.

Remedial Measures: Zortman initially installed containment and pumpback systems in each drainage and have developed a wastewater treatment facility. However, the existing facilities have proven inadequate to capture all surface and subsurface drainage; they specifically cannot contain maximum flows. Through an ongoing enforcement action, a broad water quality compliance plan is being developed.

Costs of Remedial Activities: No specific cost data are available from the files and the long-term cost will ultimately depend on the selected remedy. However, a 1994 newspaper article in the Helena Independence Record cited the mine manager as indicating that the company spent $720,000 constructing the current water treatment facility. Further, he indicated that over $2.8 million was spent on "reclamation" in 1993-1994 (uncertain how much of this was directed to remediation). Finally, the size of the site, complexity of the impacts, and types of remedies under consideration suggest that millions of additional dollars will likely be required for continued monitoring, design, construction, and maintenance of remedial measures/treatment systems.

References: Independence Record, 1994. Hydrometrics, 1994. Hydrometrics, 1995.

4.2.13 Case Study No. 13 - Cyanide Seepage from Milling Operations

Site Name: Golden Sunlight Mine, Placer Dome, Inc., Whitehall, Montana

Type of Mining: An open pit gold mine with cyanide heap leaching that has been active since 1983. The facility is currently in the process of permitting an expansion. Operations at the site began in December 1992. However, the facility was shut down between June 1994 and February 1995 due ground movement and resulting mill damage.

Nature of Environmental Effects: Environmental impacts, from "minor" spills to long-term effects on the surrounding environment, have been prevalent at Golden Sunlight since the beginning of operations. The most significant impacts have been associated with ongoing cyanide-contaminated seepage from the tailings impoundment, sloughing/cracking of waste rock dumps, and the threats of acid drainage. The most recent environmental/safety incident involved "ground movement" in the plant area (and related ground water impacts) caused by the massive weight of waste rock in piles at the site (this is the only incident with available cost data).

Remedial Measures: To address cyanide-contaminated seepage, Golden Sunlight redesigned the presumably lined tailings impoundment, installed pump-back wells, and provided alternative water supply wells and water treatment for downgradient domestic water supplies. Pumpback/dewatering wells have been installed in the plant area to address the ground movement-related impacts (as well as changing waste rock management practices). Further, the operator moved 15 million tons of waste rock to a more stable on-site location. Finally, Placer Dome installed a containment system for 12 tanks that hold weak cyanide solution, a concrete corridor to protect water lines, and a stronger tank for tailings water reclaim storage.

Costs of Remedial Measures: As noted above, there are no remedial cost data for any of the environmental impacts other than those related to ground movement. To address ground movement, the operator had spent about $12 million as of March 1995 with an additional $1.8 million expected to be spent by end of the summer.

References: Pay Dirt, 1995a. Pay Dirt, 1995b.

4.2.14 - Case Study 14 ARD from Tailings Impoundment

Site Name: Thompson Creek Mine, Tonopah Mineral Resources, Inc., Challis, Idaho

Type of Mining: The Thompson Creek mine is located in Custer County, approximately 35 miles southwest of Challis. The site consists of an open pit molybdenum mine. Mine ore is beneficiated by crushing, grinding, and conventional flotation. Tailings are managed in an impoundment, while waste rock is disposed in two angle of repose piles. Mining began in the mid-1980s. The mine is located near the Salmon River and its tributaries.

Nature of Environmental Effects: Beginning in the late 1980s, the operator began to observe acid generation from a tailings impoundment. The impoundment was initially intended to be a zero discharge unit. However, seepage was encountered from the beginning of operations necessitating the construction and operation of a pumpback system. In addition, some types of waste rock were found to have acid generation potential, although no impacts were observed in downstream drainages.

Remedial Measures: Cyprus initially estimated that water quality standards could be met by diluting impoundment seepage with natural runoff. No water treatment beyond sediment control was expected to be required. To address the acid drainage, the operator has investigated a wide range of different potential remedial measures for the tailings impoundment. Such measures have included conventional treatment systems, application of buffering solution to the tailings, and installation of pyrite recovery/flotation system in the mill. To address waste rock, the facility uses selective placement of potentially acid generating materials (including capping/buffering with other non-reactive rock types). No final selection of a long-term alternative has been made to date.

Costs of Remedial Measures: The long-term costs of remedial measures are difficult to determine because the final remedy has not been selected. Some evidence of the magnitude of such costs is provided by the bond required by the State Department of Water Resources for the tailings impoundment (to address potential water quality impacts that were not expected during mine planning). As of 1991, the value of this bond was over $7.5 million (no more recent data are available).

Reference: Steffen Robertson & Kirsten, 1982. Steffen Robertson & Kirsten, 1991a.

4.2.15 Case Study No. 15 - ARD and Metals Contaminated Seepage of Process Solutions

Site Name: Magma Copper Company, Pinto Valley Division, Copper Cities Unit, Arizona

Type of Mining: Reprocessing of Miami tailings for copper recovery.

Nature of Environmental Effects : NPDES permit no. AZ0020419 (1986) authorized discharge of seepage and runoff from the inactive dumps and shop area to Pinal Creek from discharge point 002, from inactive dumps to Pinal Creek via discharge point 003, and from inactive dumps and undisturbed landscape to Pinal Creek from discharge point 004, in accordance with effluent limitations, monitoring requirements, and other conditions. In April 1991, an EPA inspector observed unauthorized discharges of effluent below the No. 5A seepage control dam, and at the base of the No. 004 collection dam. Magma's sampling data from the 5A area indicated that the water was low pH, with elevated concentrations of copper, zinc, and manganese. A water sample collected above the No. 004 collection dam contained arsenic, barium, copper, manganese, nickel, lead, and zinc.

Magma noted in response to a June 21, 1991 Findings of Violation and Order (FOV) that the "outfall location" near the No. 004 collection dam was actually the downstream end of the open channel spillway of the dam, and attributed it to a nearby spring. Magma also reported in the 1991 response that the stain below the 5A dam was about 2,000 feet long and six to eight inches wide, with a lower limit approximately two-thirds of a mile above the confluence of the unnamed wash where it was located with Pinal Creek. Magma felt that there was insufficient information that could be used to estimate the amount of solution that had entered the drainage. Magma found no evidence of environmental damage as a result of the staining.

In September 1991, a pipe separated at a pump by the No. 002 containment area and acid (pH=3.5) effluent containing copper, lead, and zinc was discharged to Pinal Creek for about 30 minutes. (FOV)

Further seepage from the No. 5A seepage control dam was reported in January 1992, and EPA issued a FOV on January 24, 1992.

Remedial Measures : In order to receive its NPDES permit, Cities Service Company (owner until 1986) constructed 100-year, 24-hour storm collection facilities in 1981-1982, to capture leaching solutions from old mine dumps and contaminated stormwater, and prevent them from being discharged. In 1991, Magma proposed to cease discharges of copper solution from the No. 5A seepage control dam, by one of three measures: attempting to redrill and pressure grout the 5A dam; installing caisson and pumps above the 5A dam; or constructing a new dam. Magma also proposed to move the 004 discharge point to a location upstream of the entrance of the rerouted spring, remove No. 11 tailings starter dam, and upgrade upstream collection facilities.

Remedial measures taken were reported in a 1/22/93 letter to EPA:

Tinhorn Wash/Outfall 002: Corrective actions taken at Tinhorn Wash included rerouting the discharge pipeline from the pumping system to prevent a discharge in the event of a future failure of the pipeline, and relocating the pumping system.

No. 1 Basin/Outfall 004: To best address EPA's concerns, Magma elected to relocate the discharge point outfall location approximately 10 feet downgradient of its existing position, and submitted an NPDES permit renewal application accordingly, in June 1992.

No. 5/5A Basin/Outfall 003: Based on hydrogeologic information, Magma chose to construct a large containment facility (Zook Dam) to collect the seepage identified by EPA from this area. Other potentially less costly alternatives, including treating and releasing, may have been acceptable. However, time constraints precluded Magma from completely investigating, or permitting and constructing, a treatment system.

Costs of Remedial Activities : In 1991, Magma stated that its expected NPDES compliance costs were as follows:

No. 5A Seepage Collection Dam: $30,000, $100,000, or $150,000
Move 004 discharge point, remove No. 11 dam, and upgrade facilities: $150,000

In early 1993, Magma reported the following costs of NPDES compliance (Table 4, 2/5/93 letter):

Item	Cost	Date
Tinhorn Wash/Outfall 002	$ 3,579	1/92
No. 1 Basin/Outfall 004	$ 1,500	estimated 2/5/93
No. 5/5A Basin/Outfall 003	$539,093	1-12/92 (final cost slightly higher)
TOTAL	$544,173	

O&M costs were described in 2/5/93 letter and provided for November 1986 to 1991, then updated in a 2/23/93 letter. Costs are estimated because Miami Unit maintenance personnel repair Copper Cities water control facilities during inspections and in conjunction with work done on non-NPDES facilities located at the Copper Cities. Magma's estimates for O&M, capital, and other costs of NPDES related facilities were as follows:

1986	1987	1988	1989	1990	1991	1992
$15,505*	$103,618	$80,661	$52,714	$65,874	$155,188	$696,620

* November 5-December 31, 1986

References: Magma, 1991a. USEPA, 1992.

4.2.16 Case Study No. 16 - Tailing Impoundment and Leach Operation

Site Name: Magma Copper Company, Pinto Valley Division, Pinto Valley Operations, Arizona

Type of Mining: Open pit, concentrator, and dumpleaching/SX-EW.

Nature of Environmental Effects : NPDES permit no. AZ0020401 (1984) authorized discharge of stormwater overflow from discharge points 002, 003, and 004, and tailings seepage from discharge point 005 to Pinto Creek. On January 16, 1991, an EPA inspector observed an unauthorized discharge of effluent surfacing about 50 yards below Gold Gulch 2 reservoir, which contained water and copper dump leach solution that overflowed from Gold Gulch 1 dam.

On June 22, 1990, and January 16, 1991, an EPA inspector observed effluent surfacing below the toe of tailings dam no. 3 and flowing toward Pinto Creek. On January 16, the seepage was flowing at about one gallon per minute. A sample of the seepage contained 0.42 mg/L of total copper.

On August 18, 1989 and January 4, 1991, the face of tailings dam no. 3 failed, and tailings entered Pinto Creek. An estimated 96,000 gallons of a mixture of tailings and water was discharged in 1989, and an estimated 150 to 250 tons of tailings were discharged to Pinto Creek and its tributaries in January 1991.

On January 16, 1991, an EPA inspector observed an unauthorized discharge of a mixture of storm runoff water and industrial water, which consisted of shop runoff water, pump gland water, and other industrial wastewater, surfacing below the Miller Springs catchments dam and flowing at about six gallons per minute towards Pinto Creek. A sample collected during the inspection contained 0.0023 mg/L of total copper.

On August 11, 1991, September 5, 1991, and September 23, 1991, the Miller Springs ditch became plugged, causing the ditch to overflow to a tributary of Pinto Creek and Pinto Creek. An estimated 3000 gallons of effluent containing suspended solids and copper were discharged on August 11, an estimated 24,000 gallons were discharged on September 5, and an estimated 39,000 gallons were discharged on September 23.

EPA issued a Finding of Violation on November 27, 1991 (IX-FY92-02), and Magma submitted a response and preliminary engineering plan on January 29, 1992. Magma notified EPA on July 15, 1992 that all upgrade projects outlined in the plan and the follow-up quarterly reports had been completed.

Exceptionally heavy rainfall in January 1993, added to unusually high precipitation in December 1992, caused area wide flooding and subsequent damage to water control facilities at Pinto Valley Operation (PVO). Massive rainfall exceeded design capabilities of water management facilities and resulted in extensive damage. Gila County was declared a state and federal flood disaster area in January 1993. Pinto Valley Operation facilities were upgraded in 1992 to handle stormwater runoff from a 100-year, 24-hour storm event, but continuing heavy storm event conditions caused an upset condition starting on January 8, 1993. The PVO area received 86% of its average annual rainfall in

seven weeks in December 1992 and January 1993. The PVO mill was shut down for eight days in January in order to commit all pumping resources to overflow prevention. Millions of gallons of water were deliberately pumped into the PVO open pit.

In August 1992 and early January 1993, overflow process leachate solution containing sulfuric acid, beryllium, cadmium, copper, nickel, and zinc was diverted from Gold Gulch I to prevent a breach in the dam, with overflow contained in Gold Gulch II. In January, approximately 30% of the 20.9 million gallons released was being recovered, compared to 98% in August. On January 19-20, 1993, Gold Gulch II overflowed into Pinto Creek, releasing approximately 27.7 million gallons of stormwater and PLS. In February, heavy precipitation again required a bypass of Gold Gulch I to prevent a breach in the dam, with overflow contained in Gold Gulch II and approximately 658,000 gallons released and 30% recovered.

In January and February 1993, heavy precipitation contributed to an overtopping of the No. 1 Tailings Dam berm, resulting in an erosional event on the face of the dam. Approximately 54.1 million gallons of storm water and process water, and 90,000 cubic yards of tailings were released.

In July 1994, EPA and Arizona Department of Environmental Quality (ADEQ) announced that Magma Copper Company would pay $625,000 for Clean Water Act violations at Pinto Valley, Superior, and Copper Cities. Under the agreement, Magma also undertook a supplemental environmental project that required the cleanup of pollution in the Pinal Creek drainage area from the abandoned Old Dominion Mine near Globe, Arizona, and paid $50,000 to initially fund three additional projects to benefit affected watersheds.

Remedial Actions: Magma planned to upgrade the seepage collection facilities in place prior to the March 1991 sloughing of the face of tailings dam no. 3, and reconstruct or construct new ancillary facilities, including access roads, powerlines, and transformers and pipelines.

In early 1993, Magma reported the following NPDES compliance activities:

Upper Catchment/Miller Springs: A hydrologic assessment was performed to establish site specific conditions. A toe drain collection system was then designed and installed at Upper Catchment to eliminate seepage to the Miller Springs area. An internal berm was raised and sediment that had accumulated in the catchment was removed.

No. 1 Seepage Collection System/Outfall 002: To address the moist area below the outfall culvert, Magma installed an elbow riser on the intake side of the outfall culvert, so as to ensure that an acceptable amount of stormwater storage capacity was in place to comply with the existing NPDES permit. A permanent pump and cassion collection structure were also installed to recycle stormwater to process operation.

Gold Gulch: A review of hydrogeologic data collected from the area led Magma to decide that the establishment of a new outfall location would address the issues raised by EPA, and submitted a revised NPDES permit application. Costs incurred related to Gold Gulch were described as miscellaneous upgrades to facilities.

Cottonwood Canyon: Magma could not identify the source of the intermittent seeps identified by EPA. Magma therefore decided to relocate the existing permitted outfall downgradient of the seeps, and submitted a revised NPDES permit application.

Miscellaneous: Magma incurred costs to lease equipment and for miscellaneous parts and labor.

No. 3 Tailings Dam Expenditures: Magma hired contractors to perform repairs on the face of the No. 3 Tailings Dam at the time of the slough. These costs were considered costs of NPDES compliance. Costs were incurred for earthwork, surveying, miscellaneous equipment rental, a pump study, and pump purchase.

Prior to and after the March 1991 sloughing, Magma incurred additional costs to constantly maintain and, where necessary, repair the tailings dam face, which Magma considered a cost to operate and maintain the tailings dam itself, rather than a cost for NPDES compliance. Contractors retained to perform other tailings dam work are charged to O&M of the tailings dam. Filling in erosional areas on the benches and assuring proper drainage were also considered O&M activities.

Costs to repair the seepage collection facilities that were in place prior to the sloughing were considered compliance costs. Following the sloughing, Magma designed and constructed new facilities engineered to a more rigorous design standard than required for compliance with the existing NPDES permit. Estimated costs for upgrades from the facilities in place prior to the sloughing, to these more rigorous design standards, were subtracted from the actual costs for the new facilities.

Extensive remedial activities were performed by Magma following the heavy rainfall period in December 1992 and early 1993.

Costs of Remedial Activities : Magma submitted a Summary of Expenditures to Comply with Administrative Orders IX-FY91-27 (Superior), IX-FY92-02 (Pinto Valley), and IX-FY92-08 (Copper Cities) on January 22, 1993 (not located), and supplemental information on February 5, 1993. Magma's stated costs for the Pinto Valley Operations were as follows:

Item	Cost	Date
Upper Catchment/Miller Springs:	$ 57,868	10-11/91, 3/92, 6/92
No. 1 Seepage Collection System:	$ 5,451	2-3/92
Gold Gulch:	$ 4,733	5/92
Cottonwood Canyon:	$ 1,000	estimated

Misc. equipment, materials, parts, labor:		$ 61,1511-6/91
Subtotal	$130,204	(2/5/93 response)
No 3 Tailings Dam Expenditures:	$406,333	(2-7/91)
	$100,000	estimated prior in-place seepage collection facilities to meet NPDES compliance.
Subtotal	$506,333	
TOTAL	$636,537	

Magma reported that O&M costs at PVO are generally charged against an operating unit such as the concentrator, and that NPDES costs are not captured separately. O&M costs for the tailings dam and industrial water supply facilities are not included. In 1993, Magma's estimates for O&M, capital, and other costs were as follows (2/23/93 response):

1987	1988	1989	1990	1991	1992
$298,548	$352,366	$359,557	$310,685	$2,076,505	$741,663

A Magma representative stated on October 1, 1993 that the cost of the cleanup of "the spill" at Pinto Creek was about $250,000 at that point, but that the total cost would not be known for about one month. Total cost information was not located in EPA's files.

References: USEPA, 1991c. Magma, 1992b. Magma, 1993b. Magma, 1993d. USEPA, 1993. USEPA, 1994b.

4.2.17 Case Study No. 17 - Discharge from Tailings Dam and Process Pond

Site Name: Magma Copper Company, Superior Division, Arizona

Type of Mining: Underground copper mine and milling facilities.

Nature of Environmental Effects: On March 8, 1989, an EPA inspector observed a discharge from the toe of Tailings Dam No. 6 into an unnamed dry wash tributary to Queen Creek. Magma ceased this discharge after April 10, 1989. A sample of the discharge contained copper and zinc.

On August 15, 1990, during a storm event, the berms on the east and west sides of Smelter Pond No. 1 were breached, resulting in an unauthorized discharge of over one million gallons of mine drainage water to an unnamed tributary of Queen Creek. The discharge contained cadmium, lead, copper, and zinc, and had a low pH (3.4).

From April 18 through April 26, 1991, Magma discharged mine drainage or tailings water containing copper and zinc from an unauthorized discharge point known as Clear Water Ditch.

In a letter dated May 28, 1991, EPA required that Magma, Superior Division, provide information related to the recent discharges described above, including planned remedial activities and costs of actions to cease these discharges. EPA issued a Finding of Violation and Order requiring compliance with NPDES permit requirements on August 28, 1991 (IX-FY91-27).

Remedial Actions: Early in 1993, Magma listed the following activities performed by contractors:

Install secondary sump below seep pump.
Construction for seepage control.
Install two 450 ft. siphon lines.
Equipment rental.
Install 3 culverts.
Install lime lines sp #1.
Install culvert NW corner.
Culverts, build-up berm, dig out ends.
Install culverts at depot.
Install alternate power sources for seep pumps.

In June 1991, Magma described the following proposed activities:

- Construct diversion dike at northeast side of Smelter Pond No. 1, to divert runoff from Clear Water Ditch into Smelter Pond No. 1 for subsequent treatment.
- Increase storage capacity of Smelter Pond No. 1 by installing a pumpback system, raising Smelter Pond No. 1 crest, dredging contained solid materials, and/or dredging contained solid materials.
- Sample, analyze, and possibly excavate contaminated soils from Clear Water Ditch and open drainage channel.
- Enlarge and improve the secondary sump collecting initial seepage from the Smelter Pond area.
- Investigate alternate methods of handling pyrite operations drainage (cyclone overflow water), such as installation of a pump and associated piping to pump cyclone overflow water directly to the Mill #2 Settling Pond or Tailings Dam #5 for water reuse within the mill operations.
- Investigate alternate methods of handling sandfill cyclone overflow water, such as installation of a pump and associated piping to pump the cyclone overflow water to the Mill Pond for reuse as process water within the mill.

Costs of Remedial Activities : In June 1991, Magma estimated that its NPDES compliance costs would be as follows:

- Dike design, soils drilling/investigation, runoff investigatory work: $61,900 (dike construction costs currently unknown).
- Pumpback system: $120,000; design and runoff characterization work for dam raise: $12,100; actual dam raise construction costs unknown.
- Contaminated soils, preliminary estimate: $58,300
- Construction of second sump: $3,000; enlargement of this sump: $5,000.
- Anticipated pump/piping costs for pyrite operations drainage: $15,000.
- Anticipated pump/piping costs for sandfill cyclone overflow: $5,000.

TOTAL estimated costs: $280,300.

Early in 1993, Magma reported the following NPDES compliance costs:

Contractors:	$ 10,615
Magma equipment:	$ 55,127
Pumps:	$ 2,954
Pipes:	$ 10,739
Misc. equipment:	$ 3,375
TOTAL:	$ 87,811

O&M/capital/other costs (2/23/93):

1989	1990	1991	1992
$63,226	$113,995	$120,041	$154,476

References: USEPA, 1988. Cyprus, 1989. Cyprus, 1991a. Cyprus, 1991b. Cyprus, 1992.

4.2.18 Case Study No. 18 - Contaminated Groundwater Uncontrolled Process/Mine Water Discharges

Site Name: Cyprus Miami Mining Corporation, Cyprus Miami Operations, Arizona

Type of Mining: Open pit copper mining with flotation mill and SX/EW.

Regulatory Actions: EPA first issued Finding of Violation and Order No. IX-FY86-78 to Inspiration Consolidated Copper Company (ICCCo.) on July 28, 1986. EPA then issued modified orders in October 1986 and February 1987. In July 1988, Cyprus Miami Mining Corp. (Cyprus) purchased the assets of the Inspiration operations from ICCCo. EPA drafted a revised FOV dated December 1, 1988 based on a meeting in October 1988 with Cyprus. In August 1989, EPA and Cyprus

again met, and Cyprus redrafted FOV IX-FY86-78. Cyprus submitted the revised FOV to EPA on December 18, 1989, including language that Cyprus was not responsible for the CWA violations of ICCCo., despite remedial actions taken. Cyprus stated that it did not concede the accuracy of any statement or finding of fact in the FOV. The following violations come from the December 1989 version submitted by Cyprus.

Nature of Environmental Effects : Based on a 1980-1983 groundwater study for the Globe/Miami area and EPA's inspections, EPA found that subsurface flows of mine wastewater from Webster Lake, Ellison Pond, and the acid sump (unlined) "created a severe contamination plume in the alluvial system formed by the former Webster Gulch channel," and subsurface flows from these sources had advanced and continued to advance downgradient through the Holocene alluvium underlying Bloody Tanks Wash and Miami Wash. A "significant portion" of the mine wastewater present in this aquifer, which is "hydrologically linked" with overlying tributaries of Pinal Creek including Miami Wash and Bloody Tanks Wash, used to surface along portions of Miami Wash and in the Bixbe Road Seepage Cut just west of Miami Wash, which discharges into Miami Wash. Aerial photographs of Inspiration Consolidated Copper Company's operations in September 1980, and an EPA inspection in June 1985, showed that mine wastewater was discharged from the Bixbe Road Seepage Cut into Miami Wash, and surfaced at various points along portions of Miami Wash, where it continued downstream to Pinal Creek. In inspections in 1986, EPA observed that mine wastewater continued to discharge into Miami Wash, which was flowing at flood stage into Pinal Creek, from two sources: the Bixbe Road Seepage Cut and a culvert in New Webster Gulch near the No. 5 Decant Structure.

In February 1991, EPA issued a new FOV to Cyprus (IX-FY91-06), and then issued an amended FOV on July 10, 1991. On July 18, 1991, Cyprus submitted costs of past steps taken to achieve NPDES compliance, and a report by a contractor describing additional NPDES compliance activities pursuant to the 1991 order and estimating costs for these activities. Cyprus estimated that it might be able to reduce these estimated contractor costs by performing some of the planned work itself.

Remedial Actions:

1986 FOV issued.

ICCCo. complied with a number of EPA's requirements in the original and first two modified orders. Among other measures taken, ICCCo. permanently drained and ceased discharging mine wastewater to Webster Lake and Ellison Pond, and eliminated the unlined acid sump.

Between July 1988 and December 1989, Cyprus attempted to remediate the contamination plume by removing and disposing of mine wastewater in the aquifer that could contribute to a discharge at the Bixbe Cut, maintaining tailing interceptor wells, installing two new monitor wells below Hicks Crossing, increasing the pumping capacity at Kiser Basin to 1200 gpm, increasing burch pumping to 1000 gpm, and performing aquifer modeling work to develop remedial plan.

1991 FOV

Past steps taken by Cyprus as of July 1991:

- NPDES 001: Sediment was removed from the NPDES 001 containment structure to reestablish stormwater runoff storage capacity.

- NPDES 003: Improvement included raising the containment structure berm for increased storage capacity and new culvert installation.

- NPDES 004: Completed construction of earthen containments and dikes for control of stormwater runoff, with a July 1991 storage capacity of 3.5 million gallons.

- NPDES 005: Improvements included construction of a large (2.3 million gallons) stormwater containment structure, leach dump terracing, ditching, and berming along the 005 drainage area. Pre-existing water tanks and mine water truck quick fill were installed so that mine dewatering water could be used for dust control.

- NPDES 007: Three earthen containment structures (12 million gallon stormwater storage capacity) were reconstructed along the 007 drainage area using existing sand, silt, and fill material.

- NPDES 005/006 Compliance Plan (July 1991):

The compliance plan intended to eliminate flow at the NPDES 006 compliance point and contain a 10-year return period storm at the 005 compliance point. The 006 compliance point was located on a shallow channel incised into the bedrock about 500 feet downstream from a haul road constructed with wasterock placed in the drainage. Exceedences of the copper standard tend to be associated with higher discharges (greater than 30 gpm), which were happening approximately 30% of the time. Discharge at 006 was thought to be sustained by a shallow reservoir of subterranean water that was recharged during storm events and gradually drained through the fractured granite bedrock underlying the basin between storm events. Surface drainage above 006 suggested that stormwater runoff from a considerable portion of the drainage basin discharges from "Feehan's Flume" into a closed basin created by waste rock placement. The stormwater impounded in the basin below Feehan's Flume (runoff from 92 acres) was thought to rapidly seep into and through the fractured bedrock that is present below a relatively thin layer of sediment, leaching copper from the fractured bedrock when the groundwater table rises after a storm event.

The existing detention basin at the 005 compliance point contained a 1.4-year storm event. The compliance plan for this drainage proposed enlarging the existing detention basin, constructing another detention basin downstream, and pumping the captured stormwater to the North Barney Pit. The near-

term expansion of the Bluebird Pit was expected to reduce the drainage area to the 005 compliance point, but this was not factored into the modeling effort.

NPDES 005 would receive spillway flow from the proposed detention basin north of the haul road during storm evens greater than a 11.6 year frequency. The proposed basin would receive storm runoff pumped from the detention basin in the 005 watershed. The compliance plan was designed to eliminate discharge at NPDES 005 in 50 out of 58 years, based on SCS rainfall-runoff relationships and historical precipitation records. The average amount of water delivered to North Barney Pit would be about 16.9 million gallons per year.

Phase one would prepare the system upstream to accept the pumped storm runoff, with the water ultimately going to the North Barney Pit. Approximately 6400 linear feet of eight-inch diameter plastic pipe would be installed to connect the proposed Live Oak Containment structure #2 to North Barney Pit. The Live Oak Containment structure #2 would be constructed with a clay core, filter material, and riprap or mine waste. An estimated 21,700 cubic yards of clay and filter material would be required. A pump station would be installed at Live Oak Containment Structure#2 capable of pumping at least 1000 gpm into the North Barney pipeline. A 300-foot, 670 cubic yard trench would then be constructed to divert the Upper Feehan's Flume drainage to Live Oak Containment structure #2.

Phase two would complete three containments (Basins #1, #2, and #3) in the northern section of the Feehan's Flume watershed. The earthen dike material would come from waste rock. Clay cores would not be installed because these basins would be pumping stations not intended to store water over the long term, and because leakage should be captured in basins #4 and #6, downstream. Based on rainfall-runoff modeling, the proposed earthen dikes were designed to be high enough to contain flows from 100-year storm events regardless of pumping rate to North Barney Pit. A pipeline from the proposed basin #4, north of the haul road, would be constructed (pump and pipeline - 700 gpm) (to where?). A 5550-foot pipeline from #4 to #1 and a 2500-foot pipeline from #1 to North Barney Pipeline near Live Oak Containment Structure #2 would be constructed, with pump and pipeline in basin #1 capable of transporting 900 gpm. Phase two earthwork would eradicate the diversion ditch built in Phase 1.

Phase three activities would include excavation of 40,000 cubic yards from the north half of the haul road, and 30,000 cubic yards from the eastern toe of the waste dump in order to place 4000 cubic yards of clay and 10,000 cubic yards of filter material against the south half of the haul road (six feet of clay between 14 feet of filler). The haul road would serve as a gravity containment structure with an impermeable upstream face. The containment structure (basin #4) would serve as a pumping station and stormwater runoff retention basin. The proposed 29 acre feet (AF) detention basin would have a pumping system of 700 gpm and would receive water from Feehan's Flume, a small concrete containment structure at the NPDES 006 compliance point (pumped across haul road), and NPDES 005 facilities. In case of overflow, a cut of approximately 70 cubic yards into the native hill east of the

containment structure would serve as a spillway to the haul road and the two detention basins discussed in phase six.

Phase four entailed construction of a 350-foot earthen ditch to divert flow in Feehan's Flume to basin #4.

Phase five entailed construction of a 100-cubic-yard concrete containment structure (basin #7) to collect excess flow from basin #4, with 350 gpm pumped through 650 feet of eight-inch pipe over the haul road, and prevent discharge at the NPDES 006 compliance point.

Phase six included enlarging detention basin #5 by a factor of 2.5, to contain 17.7 AF, by excavating 17,200 cubic yards of earth, and installation of pump and 2000 feet of pipeline to transport 200 gpm to basin #4 (phase three). A smaller detention basin #6 (6.7 AF) would be constructed with a clay core at the road crossing downstream and would serve as the last containment before flow discharges to Bloody Tanks Wash, pumping at 200 gpm to detention basin #5 via 1800 feet of eight inch pipeline. Basins #5 and #6 would have double barrel 36-inch corrugated metal pipe emergency outlets.

Cost estimates were included in the compliance plan for the following items:

Phase 1
- Pipeline from Live Oak Containment #2 to North Barney Pit
- Pump and Control Panel
- Live Oak Containment #2: place clay and filter
- Excavate diversion trench to divert upper Feehan's flume drainage area to Live Oak #2

Phase 2
- Basin #1, #2, #3 earthwork/waste haulage
- Pump and control panel
- Pipeline from basin #4 to basin #1
- Pipeline from basin #1 to connect to North Barney Pipeline

Phase 3 (basin #4)
- Haul road excavation
- Waste dump excavation
- Excavate key
- Excavate spillway
- Place clay and filter
- Pump and control panel

Phase 4
- Excavate trench to divert Feehan's Flume to basin #4

Phase 5 (basin #7)

- Clearing and grubbing
- Excavate key
- Reinforced concrete, rock fill, 6" stainless steel pipe
- Pump and control panel

Phase 6 (basins #5 and #6)

- Enlarge existing basin #5
- Improve outlet - #5
- Pipeline from basin #5 to basin #4
- Excavate - #6
- Clay fill - #6
- Outlet - #6
- Pipeline from #6 to #5
- Pump and control panel

Costs of Remedial Activities : Past steps taken by Cyprus as of July 1991:

NPDES point no.	Cost
001	$ 365
003	$ 781
004	$10,755
005	$26,267 (internal earthwork)
	$32,067 (quick fill installation-contractor)
007	$10,221
TOTAL	$80,456

NPDES 005/006 compliance plan (July 1991):

Phase 1	$ 122,770
Phase 2	$ 150,159
Phase 3	$ 229,800
Phase 4	$ 2,400
Phase 5	$ 104,468
Phase 6	$ 144,470
Subtotal	$ 755,000
Mobilization (2.5%)	$ 19,000
Subtotal	$ 774,000
Engineering/Administration (15%)	$ 116,000
Contingencies (15%)	$ 116,000
TOTAL	$1,006,000

Detailed containment structure and facility designs, electrical power, pump and piping design specifications, and equipment selection were not included in the above cost estimate for points 005 and 006.

References: ASARCO, 1994a. USEPA, 1994a. ASARCO, 1994b. Fennemore, 1994. ASARCO, 1994c.

4.2.19 Case Study No. 19 - ARD from Tailings Dam and Leaching Operations

Site Name: ASARCO, Inc., Ray Complex, Arizona

Type of Mining: Copper mine - open pit, leach dumps, milling and SX-EW

Nature of Environmental Effects : On July 1, 1991, EPA issues an administrative order against ASARCO. The case was referred to DOJ in September 1991, and DOJ issued a demand letter in October 1992. Settlement negotiations were initiated in November 1992. As of September 1991, ASARCO was charged with 16 unauthorized discharges of process water, improper operation and maintenance, water quality standards exceedences, failure to monitor, and failure to report. Between September 1991 and June 1994, ASARCO had 18 unauthorized discharges and 154 days of water quality standards violations stemming from subsurface flows from ASARCO's leach dumps to Mineral Creek, in addition to NPDES permit violations. ASARCO was asked to address effects including discharges containing pollutants to Mineral Creek, seepage from pregnant leach solution collection dams and the electrowinning facility, and runoff from a proposed leach dump and waste rock dump.

In its June 1994 compliance plan, ASARCO described areas at the Ray Mine that ASARCO had identified as having the potential for adversely impacting water quality; steps that ASARCO had taken or was planning to take to investigate or address these potential impacts; where possible, an estimation of the time frame for completion; and where possible, an estimate of costs. ASARCO updated this information in a sixty-day progress letter dated August 29, 1994.

Subsurface concerns.

Subarea A - North of pit and tunnel inlet. Subsurface conduit of acidic (pH=4) solution to a point downgradient of the 4D RDA (sulfide leach dump).

Subarea C - South of pit and tunnel outlet. Leaks in the liner of the Big Dome Pond were detected by an electromagnetic induction survey. Pumpback wells located between the Big Dome Pond and Mineral Creek encountered "relatively low pH" water, possibly the result of liner leaks.

ASARCO's electromagnetic induction survey also showed an anomaly in the area downgradient of the Stacker Dam, indicating that the dam might not have been keyed into the bedrock. Seepage was

detected at one gallon per minute beneath the Lower Slimes Dam, and "low pH" water has been detected in monitoring wells downgradient of the dam. Electrolyte was seeping from the electrowinning building as a result of leaks in the electrowinning cells and the floor of the tank house. Monitor wells encountered "low" pH, high copper water.

ASARCO also reported possible seepage under the dam at the electrowinning impoundment, which might be captured by the pumpback wells west of the building; possible seepage into Mineral Creek through an unconformity in the Mineral Creek channel, possibly resulting in a ring of turquoise stained rock observed in the creek; and approximately 4000 feet of recently exposed cemented mineralized gravels in the bed of Mineral Creek, which might leach metals back into the creek.

Stormwater runoff.

ASARCO reported that in Subarea A, above the tunnel inlet between Big Box Canyon Dam and the area where runoff flows into the pit, runoff from overburden dumps enters Mineral Creek. EPA commented that ASARCO should also address runoff from the new planned 4G dump leach area, which was exceeding water quality standards.

In Subarea B, the major portion of the mine area, all runoff is or can be directed to the pit.

In Subarea C, the area below the tunnel outlet and below the pit, which drains toward Mineral Creek, ASARCO also describes stormwater runoff measures, and measures to prevent water from Dalton's Pond from reaching Mineral Creek or groundwater.

Remedial Actions:

Subarea A.

Subsurface. ASARCO installed an exploratory trench to further delineate the subsurface conduit, planned to install a drain and sump in this trench with pumpback capacity, and planned to conduct groundwater monitoring to confirm that the installed control is operating correctly. In the process of installing the trench, two turn of the century, man-made adits were uncovered, with low pH (3.9) water containing 65.3 mg/L dissolved copper flowing out of one adit at a rate of 0.73 gpm.A suspected third adit had not been located. ASARCO filled the trench below the adit with coarse rock surrounding 25 feet of 32" slotted HDPE vertical collection pipe, and planned to install a pump by November 1, 1994. ASARCO planned to use the collection pipe to monitor groundwater quality, and had not yet determined how many additional pumpback wells, if any, would be required, nor what the associated costs would be.

Stormwater. ASARCO planned to construct two diversion ditches, one on the east side and one on the west side of the rock deposition areas (RDAs), to divert an estimated 50% of stormwater from

reaching the 4 and 5 series RDAs. These ditches would be lengthy and would pass through rough terrain.

ASARCO found that construction of maximum saturation event (exceeding 100-year flood) containment was not feasible in this area due to topographic and space constraints. Portions of existing RDAs would have to be removed. ASARCO therefore argued that the only means of insulating Mineral Creek from runoff from overburden dumps that was technically feasible, and potentially economically feasible, would be to extend the existing tunnel to a point above the overburden dumps. Runoff would either be pumped back for reuse or treatment, or drain to the pit area. The tunnel would have to extend through 13,000 feet of bedrock, underneath the far eastern end of Subarea A, and a small diversion dam would be constructed to divert Mineral Creek into the tunnel extension. To help offset the cost of the tunnel, ASARCO proposed to cover more than 60 acres of manmade wetlands below the tunnel with expanded RDAs. The wetlands were created in the construction of the Little Box Dam and the Big Box Dam. These measures were required under EPA's recently established stormwater control program for industrial stormwater discharges, and ASARCO argued that they exceeded the conditions of its existing permit.

In response to a request from EPA that ASARCO consider interim stormwater containment measures during construction of the tunnel, ASARCO provided cost information for construction of containment ponds in Subarea A, but argued that the high cost ($4.4 million) of these ponds made it overly burdensome for EPA to require interim containment measures in this case.

Subarea B.

Stormwater. As a short term solution, ASARCO constructed dikes and rollovers in all disturbed areas where runoff can be directed into the pit, to ensure that runoff would reach the pit. However, due to the increased volume of water in the pit, and the need to reduce water levels to prevent interference with present operations, ASARCO planned to build a water treatment plant, and was considering a location above the Elder Gulch tailing pond. Effluent from a new treatment plant would be discharged in accordance with a revised NPDES permit, or pumped to Elder Gulch Tailings Pond, where it would mix with other water and be recycled back into operations, depending on the current water balance. ASARCO constructed a pilot water treatment plant to assess the feasibility of this project. ASARCO emphasized the need to identify an alternative to pit storage of stormwater, so that the Pearl Handle Pit could be deepened and new benches opened, in order for mining to continue beyond 1996.

Subarea C.

Subsurface. ASARCO repaired leaks in the liner of Big Dome Pond. A pumpback well downgradient from the pond was pumping back low pH water until mid-July, when the pump probes

had to be lowered because the water level in the well had fallen; as of August 1994, the well was pumping 3.6 hours per day.

Downgradient of Stacker Dam, ASARCO installed monitoring wells, which would serve as pumpback wells, one screened in bedrock and one screened in alluvium. If the pumpback system proved to be insufficient to control flow, ASARCO planned to install a 150-foot cutoff wall in the drainage. ASARCO also installed monitoring wells, which would serve as pumpback wells, downgradient of the Lower Slimes Dam, and planned to install a cutoff wall in that drainage, if necessary.

At the electrowinning building, ASARCO installed two surface collection sumps with pumpback capacity, at the north and south ends of the building. These sumps were initially concrete, but were subsequently lined with HDPE due to degradation in the concrete. ASARCO also installed six pumpback wells, three shallow and three deep, around the tank house, to pump any recovered fluids to Big Dome Pond; and three shallow wells in the basement of the electrowinning building to dewater the subgrade. In June 1994, ASARCO was in the process of replacing the electrowinning cells, originally concrete with PVC liners, with new cells constructed of polymer concrete (vinyl ester resin). Cells were being lined with HDPE liner until they were replaced. ASARCO initiated a maintenance program to eliminate piping drips and leaks below the cells; grouted and caulked cracks in the floor; and rebuilt parts of the floor, including installation of fully welded HDPE liners in select areas of the floor. Depending on the success of the HDPE floor liner, ASARCO was considering rebuilding the floor and coating it with polymer concrete. However, the HDPE liner proved effective in preventing solution from migrating through the floor, and by August 1994 ASARCO planned to install liner wherever necessary.

Stormwater. To control runoff in this area, ASARCO was constructing a combination of dikes, dams, ditches, holding ponds, and pumpback systems. ASARCO planned to install new controls in areas providing less than 10-year, 24-hour containment: the area immediately south of the diversion tunnel outlet (north of Susie D Dam), the western slope of the Sag Dump, the an area north of the electrowinning building. ASARCO planned to increase monitoring to include discharges and accept discharge limitations for four outfalls receiving stormwater that has contacted disturbed ares.

In addition, water collecting in Dalton's Pond (runoff from the mill and mine offices area) was pumped to Big Dome Pond, where it was treated, put in a process water circuit, or returned to the pit. ASARCO installed a 2000 gpm pump in the pond to increase dedicated pumping capacity, and modifications were made to reduce the drainage area to the pond. ASARCO planned to fully line the pond to prevent subsurface discharge to groundwater. The pollution control dam below the pond was being raised seven feet.

Costs of Remedial Activities : As of August 1994, ASARCO's contractor costs for work required for the Aquifer Protection Permit (APP) for the State of Arizona totaled $2.8 million. Additional APP studies were expected to cost $577,000.

NPDES compliance costs reported by ASARCO in June and August 1994 were as follows:

Subarea A.

Install trench	$ 6,000
Pump, sump, pipeline and electrical equipment	$10,000
Additional pumpback wells, if needed	not estimated
Diversion ditches	$2 million
Stormwater ponds	$4,368,000
Extend tunnel	$20 to $25 million

Subarea B.

Dikes/rollovers	not estimated
Build new water treatment plant	$10 million
Develop alternative to pit storage of sw	not estimated

Subarea C.

Repair liner leaks, Big Dome Pond	$16,500
Four pumpback wells	$28,840
Pumpback system equipment, Stacker Dam	$ 8,000
150-foot cutoff wall, Stacker Dam	$87,000
Pumpback system equipment, Lower Slimes Dam	$ 8,000
130-foot cutoff wall, Lower Slimes Dam	$76,000
Pumpback well installation, Lower Slimes Dam	$ 5,472
Electrowinning building	
Sumps	$ 50,000
Six pumpback wells	$ 90,000
Three shallow wells	$ 20,000
Install sumps, pumpback pumps, wells	$165,460
Replacement of all cells	$1.1 million
Drip/leak elimination program	$ 40,000
Grout/caulk floor	$ 2,000
HDPE liner experimental project	$ 65,000
HDPE liner in all appropriate areas	$300,000 to $400,000
Complete floor rebuild/polymer concrete	$1.8 million

Dalton's Pond work to date (August 1994)	$ 38,194
Line Dalton's Pond	$225,000
2,000 gpm pump	$ 14,138 (incremental cost of increasing pump capacity was $9,000)
Water treatment plan	$3 million to $10 million

Improvements related to past violations in Subarea C (August 1994): $1,289,441.

O&M costs related to the operation of the water treatment plant, personnel costs to monitor Mineral Creek and maintain dams and diversion ditches were $527,725 in 1992 and $1,594,418 in 1993. O&M costs for the Big Dome Pond pumpback wells are estimated to be $14,144.

References: ASARCO, 1994a. USEPA, 1994a. ASARCO, 1994b. Fennemore, 1994. ASARCO, 1994c.

4.2.20 Case Study No. 20 - Fuel Spill at Maintenance Facility

Site Name: Paradise Peak Mine, FMC Gold Corporation, Nevada

Type of Mining: Open pit gold mine with cyanide heap leaching and milling operations

Environmental Effects: In August 1992, an inspection was performed by the Nevada Department of Environmental Protection. The inspection team found an area of oil spill discharge in the vicinity of the mine maintenance shop. The facility subsequently found that the source of the spill was a leak from an underground shop clean-up vault. The vault included a oil skimmer that provided for separation and recovery of oil from shop drain water. Water was then released to a drainage ditch. The leak was caused when a mechanical control failure allowed the oil in the vault to flow into the drainage ditch. FMG admitted being aware of the problem since Summer 1992 and intended to develop a remedial action plan, however, due to apparent inadvertent oversight little work had been done to address the problem prior to the inspection. The facility indicated that site investigations showed that there was little potential for hydrocarbons to reach underlying ground water (prior to undertaking the remedial actions described below). The operator was issued a Notice of Violation for the release. All of the information described below was obtained from the facility's written presentation at a State Show Cause Hearing.

Remedial Measures: Immediately after the inspection, in cooperation with the State, the facility developed a plan to address the spill. This included: (1) sealing the discharge point from the vault, (2) restricting access to contaminated area, (3) sampling to determine the nature of the release, (4) installing berms around the contaminated area to prevent oil migration, and (5) ceasing water washdowns and using a dry reagent for spill clean-up. Subsequently, after soil sampling, the operator

conducted a soils removal actions. Approximately 831 tons of contaminated soil was sent off-site for disposal. Further, the facility proposed to dispose of washwater in the tailings impoundment (it is unknown if this was approved by the State).

Costs of Remedial Activities : The facility's Show Cause submittal provides cost data for remedial measures they include (in 1991-1992 dollars):

Site investigation contractor	9,053
Internal FMG labor and equipment	12,894
Analyses	15,926
Waste disposal contractor	41,563
Trucking contractor	14,971
Other	9,441
TOTAL	103,801

In addition, FMC Gold budgeted approximately $10,500 for modifications to allow discharge of washwater to the tailings impoundment (unclear if this was spent).

References: FMC Gold Company, 1992.

4.2.21 Case Study No. 21 - Copper Sulfate Spill

Site Name: Lucky Friday Mine, Hecla Mining Company, Mullan, Idaho

Type of Mining: The Lucky Friday Mine began operation in 1987 producing gold, silver, lead, and zinc. The facility consists of an underground mine and 1,000 ton per day flotation mill. Flotation tailings are managed in an on-site impoundment. The mine is located along the South Fork of the Coeur d'Alene River, one mile east of Mullan, Idaho.

Nature of Environmental Effects : On September 6, 1988, 100 gallons of copper sulfate were accidentally dumped into the Coeur d'Alene River. An employee was mixing copper sulfate solution in a vat, which overflowed into a sump. The sump drained to the tailings impoundment where the solution was eventually discharged to the river. The incident was not reported to the State until September 12, 1988, when State inspectors observed dozens of dead fish and variety of dead aquatic insects. According to the available references, the impacts of the release (i.e., harm to aquatic organisms) extended 1.3 miles downstream from the facility. The State determined that it would be at least seven years before the fishery was restored.

Remedial Measures: Hecla undertook several remedial measures in response to the copper sulfate spill. Concrete curbing was placed around the copper sulfate mixing tanks. The curbing was designed to retain the volume of the largest vat. In addition, the east side of the mixing area was paved

to minimize potential pollutant migration. Further, Hecla planted numerous willow trees and other vegetation along the river bank where aquatic life was impacted. Finally, the operator initiated a semi-annual environment auditing program.

Costs of Remedial Activities : No detailed cost information is available related to remediating the copper sulfate spill. However, in responding to draft Consent Order, the facility noted that over $47,700 had been spent on remedial measures

References: IDER, 1988. IDER, 1990. Hecla, 1990.

4.2.22 Case Study No. 22 - Mercury Soil Contamination Remediation

Site Name: Microgold II Mine, Powell and Micro Gold II Partnership, Florance, Idaho.

Type of Mining: In 1983, the Microgold II partnership began operation of an open pit mine with ore being crushed and passed over shake tables where mercury was added. The site only operated during summer 1983 with 120 tons of ore being beneficiated. The resulting amalgam was then heated, allowing the mercury to vaporize and gold to be collected. Mercury was captured for reuse. Tailings from the shaker tables were managed in an unlined tailings pond. The facility was located approximately 1,400 feet from the west fork of Meadow Creek, which flows into the Wind River, a tributary of the Salmon River.

Nature of Environmental Effects : Releases of mercury contaminated the soils around the shaker table mixing area and the sediments in tailings pond. When the State issued a Notice of Violation and Order in November 1983, mercury levels in the soils were as high as 1,163 ppm. Subsequent sampling in 1985 found mercury levels of 100-250 ppm in the tailings sediments and 50-380 ppm in the mixing area soils. Tailings water had mercury only slightly above background. The State required the operator to sample groundwater. Groundwater data generally showed levels consistent with background, although the source of elevated levels in two wells could not be distinguished between mining and a naturally contaminated spring.

Remedial Measures: Under an Administrative Order issued by the Idaho Department of Health and Welfare (IDHW) in February 1985, the operator was required to conduct a site investigation and develop a clean-up plan. Three options clean-up options were identified. The option selected by IDHW involved excavation of contaminated soil and on-site encapsulation (using a synthetic liner and cover). The clean-up began in Spring 1986 and was completed in October 1986.

Costs of Remedial Activities : No line-item remedial cost information was found in the State files. However, on August 29, 1986, the State and the facility agreed to a Consent Decree that required Microgold to place $120,000 in escrow to pay for the clean-up.

References: IDHW, 1983. IDHW, 1984. CH2M Hill, 1985. U.S. District Court, 1986.

4.2.23 Case Study No. 23 - Unauthorized Discharge of Leach Solution to Surface Water

Site Name: Cyprus Sierrita Mine, Sierrita, Arizona

Type of Mining: Large open pit copper mine with flotation mill and dump leaching/SX-EW operations.

Nature of Environmental Effects: In 1992-1993, Cyprus Sierrita had unauthorized discharges of process solution to Demetrie Wash - an ephemeral stream that flows through the site. Long-term discharges were caused by subsurface migration/seepage from an unlined process pond to the wash. The bond contains barren solution, other process waters, and storm water runoff. The pond water has generally low pH and elevated concentrations of copper and zinc. Additional short-term impacts on Demetrie Wash occurred when a 2.7 million gallons was released after a tailings pipeline broke. The water was approximately 67% dilute tailings water reclaim and 33% ground water recovered from wells located downgradient of the tailings impoundment. The water had less than .01 ppm copper.

Remedial Measures: To address the long-term seepage issues, the operator performed a conductivity study to delineate the source of the seepage. The operator subsequently constructed hydraulic barriers. For the tailings line break, the operator replace the existing PVC pipe with steel-encased piping.

Costs of Remedial Measures: As reported to EPA Region IX, the total cost of addressing subsurface seepage (as of 1994) was $101,030. The cost of replacing the pipeline (also as of 1994) was $70,000. Of specific note, similar to the other Arizona sites discussed above, Sierrita has also undertaken facility-wide remedial measures to address unauthorized discharges of process water to surface and ground water (no cost data were readily available for facility-wide actions but known to be in the millions). This case study was included as an example of costs associated with a single, unit-specific remedial action.

Reference: EPA 1994.

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