

US EPA ARCHIVE DOCUMENT

# TECHNICAL RESOURCE DOCUMENT

## EXTRACTION AND BENEFICIATION OF ORES AND MINERALS

### VOLUME 2

# GOLD

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## **DISCLAIMER AND ACKNOWLEDGEMENTS**

This document was prepared by the U.S. Environmental Protection Agency (EPA). The mention of company or product names is not to be considered an endorsement by the U.S. Government or the EPA.

This Technical Resource Document consists of five sections. The first section is EPA's Profile of the gold industry; the remaining four sections are Site Visit Reports from site visits conducted by EPA. The Profile Section was distributed for review to the U.S. Department of the Interior's Bureau of Mines and Bureau of Land Management, the U.S. Department of Agriculture's Forest Service, the Western Governors Association, the Interstate Mining Compact Commission, the American Mining Congress, and Environmental Public Interest Groups. Summaries of the comments and EPA's responses are presented as an appendix to the Profile Section. The Site Visit Report Sections were reviewed by individual company, state, and Federal representatives who participated in the site visit. Comments and EPA responses are included as Appendices to the specific Site Visit Sections. EPA is grateful to all individuals who took the time to review sections of this Technical Resource Document.

The use of the terms "extraction," "beneficiation," and "mineral processing" in the Profile section of this document is not intended to classify any waste streams for the purposes of regulatory interpretation or application. Rather, these terms are used in the context of common industry terminology.

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## 1.0 MINING INDUSTRY PROFILE: GOLD

### 1.1 INTRODUCTION

This Industry Profile presents the results of U.S. Environmental Protection Agency (EPA) research into the domestic gold mining industry and is one of a series of profiles of major mining sectors. Additional profiles describe lead/zinc mining, copper mining, iron mining, and several industrial mineral sectors, as presented in the current literature. EPA has prepared these profiles to enhance and update its understanding of the mining industry and to support mining program development by the states. EPA believes the profiles represent current environmental management practice as described in the literature.

Each profile addresses extraction and beneficiation of ores. The scope of the Resource Conservation and Recovery Act (RCRA) as it applies to mining waste was amended in 1980 when Congress passed the Bevill Amendment, Section 3001(b)(3)(A). The Bevill Amendment states that "solid waste from the extraction, beneficiation, and processing of ores and minerals" is excluded from the definition of hazardous waste under Subtitle C of RCRA (40 CFR 261.4(b)(7)). The exemption was conditional upon EPA's completion of studies required by RCRA Section 8002(f) and (p) on the environmental and health consequences of the disposal and use of these wastes. EPA segregated extraction and beneficiation wastes from processing wastes. EPA submitted the initial results of these studies in the 1985 *Report to Congress: Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden From Uranium Mining, and Oil Shale* (U.S. EPA 1985). In July 1986, EPA made a regulatory determination that regulation of extraction and beneficiation wastes under Subtitle C was not appropriate (51 FR 24496; July 3, 1986). EPA concluded that Subtitle C controls were unnecessary and found that a wide variety of existing Federal and State programs already addressed many of the risks posed by extraction and beneficiation wastes. Instead of regulating extraction and beneficiation wastes as hazardous wastes under Subtitle C, EPA indicated that these wastes should be controlled under Subtitle D of RCRA.

EPA reported their initial findings on wastes from mineral processing from the studies required by the Bevill Amendment in the 1990 *Report to Congress: Special Wastes From Mineral Processing* (U.S. EPA 1990). This report covered 20 specific mineral processing wastes; none involved gold processing wastes. In June 1991, EPA issued a regulatory determination (56 FR 27300) stating that regulation of these 20 mineral processing wastes as hazardous wastes under RCRA Subtitle C is inappropriate or infeasible. Eighteen of the wastes are subject to applicable state requirements. The remaining two wastes (phosphogypsum and phosphoric acid process waste water) are currently being evaluated under the authority of the Toxic Substances Control Act (TSCA) to investigate pollution prevention alternatives. Any mineral processing wastes not specifically included in this list of 20 wastes no longer qualifies for the exclusion (54 FR 36592). Due to the timing of this decision and the limited numbers of industry wastes at issue, gold processing wastes are not addressed in this profile.

In addition to preparing profiles, EPA has undertaken a variety of activities to support state mine waste programs. These activities include visits to a number of mine sites; compilation of data from State regulatory agencies on waste characteristics, releases, and environmental effects; preparing summaries of mining-related sites on the Superfund National Priorities List (NPL); and an examination of specific waste management practices and technologies. Site visit reports are presented as later sections of this Technical Resource Document. EPA has also conducted studies of State mining-related regulatory programs and their implementation.

The purpose of this Profile is to provide additional information on the domestic gold mining industry. The report describes gold extraction and beneficiation operations with specific reference to the wastes associated with these operations. The Profile is based on literature reviews and on comments received on earlier drafts. This Profile complements, but was developed independently of, other EPA activities, including those described above.

This Profile briefly characterizes the geology of gold ores and the economics of the industry. Following this discussion is a review of gold extraction and beneficiation methods; this section provides the context for descriptions of wastes and materials managed by the industry, as well as a discussion of the potential environmental effects that may result from gold mining. The Profile concludes with a description of the current regulatory programs that apply to the gold mining industry as implemented by EPA, Federal land management agencies, and selected States.

## **1.2 ECONOMIC CHARACTERIZATION OF THE INDUSTRY**

In 1990, U.S. gold operations produced 9.5 million troy ounces of gold from ore, valued at \$3.6 billion. This represented an increase of 10 percent over the amount of gold produced domestically in 1989. Production levels in 1991 were 9.3 million ounces of gold; production for 1992 was estimated to be 10.3 million troy ounces (U.S. DOI, Bureau of Mines 1992). Prior to 1990, a significant portion of market demand was satisfied by importing refined products (U.S. DOI, Bureau of Mines 1990a). By contrast, the Gold Institute is projecting an \$8 billion surplus in domestic production between 1990 and 1994.

Historically, gold has been the principal medium of international monetary exchange, but its role has changed significantly in recent years. Between 1934 and 1972, the United States monetary system worked on a gold standard at a fixed rate of \$35 per ounce. After leaving the gold standard in 1975 and allowing private ownership of the metal, the U.S. gold market grew rapidly and the price of gold skyrocketed to a high of \$850 per ounce in January 1980. Since that time, the price of gold has dropped (U.S. DOI, Geological Survey 1973; U.S. DOI, Bureau of Mines 1985). Gold had an average selling price of \$438.31 per ounce in 1988 and is currently being traded at \$360 to \$400 per ounce.

New gold mines continue to open (24 in 1989), and existing mines are expanding their production capabilities. The United States is now the second largest gold producer in the world. In the 1993 *Mineral Commodity Summaries*, the Bureau estimates that the number of lode mines increased to 200 and that

approximately 200 small placer operations were in operation, most in Alaska. The numbers do not account for the thousands of "recreational" gold mines; these recreational mines are typically operated by two to three individuals who may only work on weekends or on a seasonal basis.

Historically, gold has been mined in virtually every State but has been concentrated in the following 15: Alaska, Arizona, California, Colorado, Idaho, Michigan, Montana, Nevada, New Mexico, North Carolina, Oregon, South Carolina, South Dakota, Utah, and Washington. State production figures available for 1991 include Nevada (61 percent of newly mined domestic gold or 5.7 million troy ounces), California (10 percent), Montana (6 percent), South Dakota (6 percent), Colorado (1 percent), Arizona (1 percent), Alaska (1 percent), and Idaho (1 percent). The 25 leading domestic gold-producing mines (1991), in order of output, are listed in Table 1-1

**Table 1-1. Twenty-Five Leading Gold-Producing Mines in the United States, 1991,  
in Order of Output**

Rank	Mine	County and State	Operator	Source of Gold
1 <sup>a</sup>	Nevada Mines Operations	Elko and Eureka, NV	Newmont Gold Co.	Gold Ore
2	Goldstrike	Eureka, NV	Barrick Mercur Gold Mines, Inc.	Gold Ore
2	Bingham Canyon	Salt Lake, UT	Kennecott-Utah Copper Corp.	Copper Ore
4	Jerritt Canyon (Enfield Bell)	Elko, NV	Freeport-McMoran Gold Co.	Gold Ore
5	Smoky Valley Common Operation	Nye, NV	Round Mountain Gold Corp.	Gold Ore
6	Homestake	Lawrence, SD	Homestake Mining Co.	Gold Ore
7	McCoy and Cove	Lander, NV	Echo Bay Mining Co.	Gold Ore
8	McLaughlin	Napa, CA	Homestake Mining Co.	Gold Ore
9	Chimney Creek	Humboldt, NV	Gold Fields Mining Co.	Gold Ore
10	Fortitude and Surprise	Lander, NV	Battle Mountain Gold Co.	Gold Ore
11	Bulldog	Hye, NV	Bond Gold, Bullfrog, Inc.	Gold Ore
12	Mesquite	Imperial, CA	Goldfields Mining Co.	Gold Ore
13	Getchell	Humboldt, NV	FMG, Inc.	Gold Ore
14	Sleeper	Humboldt, NV	Amex Gold, Inc.	Gold Ore
15	Cannon	Chelan, WA	Asamera Minerals (U.S.), Inc.	Gold Ore
16	Ridgeway	Fairfield, SC	Ridgeway Mining Co.	Gold Ore
17	Jamestown	Tuolumne, CA	Sonora Mining Corp.	Gold Ore
18	Paradise Peak	Nye, NV	FMC Gold Co.	Gold Ore
19	Rabbit Creek	Humboldt, NV	Rabbit Creek Mining, Inc.	Gold Ore
20	Barney's Canyon	Salt Lake City, UT	Kennecott Corp.	Gold Ore
21	Continental	Silver Bow, MT	Montana Resources	Copper Ore
22	Zortman-Landusky	Phillips, MT	Pegasus Gold, Inc.	Gold Ore
23	Golden Sunlight	Jefferson, MT	Golden Sunlight Mines, Inc.	Gold Ore
24	Wind Mountain	Washoe, NV	Amex Gold, Inc.	Gold Ore
25	Foley Ridge & Amie Creek	Lawrence, SD	Wharf Resources	Gold Ore

<sup>a</sup>Modified at the request of Newmont Gold Co. to read Nevada Mines Operations instead of Carlin Mines Complex.

(Source: U.S. DOI, Bureau of Mines 1992.)



. In 1991, these mines accounted for 68 percent of all domestically produced gold. According to the Bureau of Mines, approximately 10 percent of gold production is generated as a by-product of other mining (U.S. DOI, Bureau of Mines 1992, 1993).

According to the Bureau of Mines, gold industry employment has experienced a slight downturn since 1990. Employment at mines and mills was 16,000 in 1990 and was estimated to be 14,400 in 1992. No data were available on employment at processing facilities (U.S. DOI, Bureau of Mines 1993).

Another trend in the gold industry has been joint exploration and/or production ventures between two or more firms. An example of this trend is the recent agreement between Canyon Resources Corporation and Kennecott Exploration Company to jointly mine a large California gold reserve.

A general description of the typical domestic uses for gold products is shown in Table 1-2. From this table, it can be seen that common end uses include jewelry and the arts, dental, and industrial products. Although the majority of refined gold is used in jewelry manufacturing, gold is becoming increasingly important in other

**Table 1-2. U.S. Consumption of Gold <sup>a</sup>, by End Use Sector <sup>b</sup>**

End Use	1991 (kilograms)
Jewelry and the Arts:	
Karat Gold	78,875
Fine Gold for Electroplating	373
Gold-Filled and Other	3,819
Total	84,067
Dental	
	8,485
Industrial	
Karat Gold	1,068
Fine Gold for Electroplating	12,624
Gold-Filled and Other	8,110
Total <sup>c</sup>	21,802
Small Items for Investment <sup>d</sup>	
	--
Grand Total <sup>c</sup>	
	114,354

<sup>a</sup>Gold consumed in fabricated products only; does not include monetary bullion.

<sup>b</sup>Data may include estimates.

<sup>c</sup>Data may not add to totals shown because of independent rounding.

<sup>d</sup>Fabricated bars, medallions, coins, etc.

(Source: U.S. DOI, Bureau of Mines 1992.)

industries. Gold has superior electric and thermal conductive abilities, reflects infrared radiation and most of the visible spectrum, alloys easily with other metals, and resists corrosion and tarnishing. These characteristics make gold valuable in high-technology products such as computers, communications equipment, and spacecraft. In addition, gold has high malleability and ductility, making it extremely easy to work with. In the electronics industry, gold is used in printed circuit boards, connectors, keyboard contractors, miniaturized circuitry, and in some semiconductors (U.S. DOI, Bureau of Mines 1992).

### **1.3 ORE CHARACTERIZATION**

Gold occurs in a variety of geologic environments. Estimates of average abundance in the Earth's crust are on the order of 0.003 to 0.004 parts per million (ppm) (U.S. DOI, Geological Survey 1973). Deposits considered to be economically recoverable at current market prices may contain as little as 0.69 to 1.37 ppm [0.02 to 0.04 troy ounces of gold per ton of rock (oz/t)], depending on the mining method, total reserves, and the geologic setting of the deposit.

Geologic processes act to concentrate gold into minable ore deposits. All gold deposits, except placer deposits, are formed by hydrothermal processes. Hydrothermal systems form in numerous geologic environments, ranging from dynamic systems associated with magmatic intrusives to low-energy systems associated with deep fluid circulation heated by geothermal heat flow. Deposits formed from hydrothermal systems flowing at or near the surface (1,000 to 2,500 feet deep) are called epithermal deposits, while those formed deeper are called mesothermal deposits. Combinations of the various types of hydrothermal systems in various host rocks create variations in deposit morphology, grade ranges (variation in gold content), and wall rock alteration. Deposit morphology ranges in a continuum from veins several feet thick and hundreds to thousands of feet in vertical and lateral dimensions (formed by mineral precipitation in voids in the host rock) to disseminated mineralization (essentially micro veinlets) pervading through the host rock in irregular pods up to several hundred feet in dimension.

Placer deposits are formed when gold-bearing lode ores are exposed to chemical and physical weathering and subsequent erosion, resulting in transportation and deposition to form sedimentary deposits. The less-resistant minerals, such as pyrite, are quickly oxidized and leached from the host rock while gold and other resistant minerals (i.e., silica) persist. Generally, placers are found as sedimentary deposits associated with stream gravels or beach sand, although some aeolian (windblown sand) deposits exist. When transported in a stream, gold's high specific gravity causes it to be deposited in areas where the stream's velocity decreases, settling behind rocks and natural riffles. The particle size and composition of placer gold deposits usually depend on the distance from the source and the composition of the original lode deposit. Nugget size decreases downstream because of the hydraulic gradient. Native gold (60 percent - 90 percent gold) is generally alloyed with silver and, infrequently, with copper and other metals. These metals are more soluble than gold, and as they are removed, the gold is concentrated, and the percentage of gold in the nugget or particle is increased. For this reason, placer deposits farthest from the source tend to be more pure (Park and MacDiarmid 1975). Over time, placer gold deposits can be buried and lithified to form fossil placers. Placer gold deposits are discussed in more detail in a separate Technical Resource Document.

Grades range in all deposit types from subeconomic margins to high-grade cores. High grade varies with mining methods but usually refers to ores greater than 0.1 or 0.2 oz/t. Likewise, average deposit grades are economic distinctions. Deposits requiring high-cost mining and milling methods may require bulk averages of 0.25 oz/t or more, at 0.15 or higher cutoffs. Those deposits that are amenable to the lowest-cost mining and milling methods may average 0.03 to 0.04 oz/t with an ore-to-waste separation grade of 0.01 oz/t. Alteration of host rocks surrounding the gold mineralization affects mining and recovery methods and waste rock characteristics. Various types of alteration are silicification (replacement of host rock minerals with quartz), decalcification (acid leaching of carbonate minerals), argillization (replacement by clay minerals), carbonatization (addition of carbonate minerals), and calcsilicate skarnification (replacement of carbonate minerals by calcium-silicate minerals).

Gold deposits may be categorized based on similarities in geologic environment and genetic hydrothermal factors. Recent data show that the 25 largest gold producing mines may be grouped into four types: sediment-hosted disseminated gold (SHDG), volcanic-hosted epithermal deposits, porphyry copper-related deposits, and greenstone gold-quartz vein deposits (U.S. DOI, Bureau of Mines 1990c).

### **1.3.1 Types of Gold Ore Deposits**

#### **1.3.1.1 Sediment-Hosted Disseminated Gold**

These deposits are hosted by silty-sandy carbonate sediments. Epithermal hydrothermal systems alter and deposit gold in the sediments. Alteration decalcifies, argillizes, or silicifies the sediments. Gold mineralization is associated with the introduction of sulfide minerals and petroleum-based organic carbon. Sulfide contents typically range from trace to 5 percent. Gold is typically disseminated throughout the altered sediments. The largest mines of this type are the Goldstrike Mine and the Gold Quarry Mine of the Carlin Trend.

#### **1.3.1.2 Volcanic-Hosted Epithermal Deposits**

These deposits are found in intrusive/volcanic complexes and are formed by epithermal hydrothermal systems directly associated with cooling intrusive or volcanic rocks. Wall rock alteration may be minor to strong silicification and argillization. Sulfide contents range from 1 to 15 percent. There is a broad range of deposit morphologies from distinct, large veins to stockwork disseminations. Likewise, there are distinct and broad chemical/mineralogic variations. Typical subgroups are Au-Te vein deposits (Telluride, Colorado), base metal/carbonate vein deposits (Creede, Colorado), Au-Ag/ quartz-adularia vein deposits (Tonopay, Nevada), Au quartz-alunite vein deposits (Goldfield, Nevada), and Au-Ag Hot Springs deposits (McLaughlin, California).

#### **1.3.1.3 Porphyry Copper-Related Deposits**

Porphyry copper deposits are formed from hydrothermal systems developed and zoned around discrete intrusive granite stocks at depths of 2 to 2.5 km. The stocks may intrude both sediment or volcanic rocks and form deposits. Wall rock alteration is zoned around the stock and variable, depending on host rocks. Sulfide minerals, primarily pyrite, copper-sulfides, and molybdenum sulfides, are zoned in proportions of 1 to 15 percent around the stock. Many porphyry copper deposits contain low grades of (less than 0.01 oz/t) gold but produce significant gold as a byproduct of the large tonnages mined for the copper (Bingham Canyon, Utah).

Associated with porphyry hydrothermal systems hosted by sedimentary rocks are skarn deposits. Skarns are formed where the porphyry hydrothermal system interacts with limestone sediments, the result being complete calc-silicate skarn alteration of the limestone. Iron and base metal sulfide content often approaches 50 percent. Some skarns are sufficiently gold-enriched to be mined as primary gold deposits (Fortitude, Nevada).

#### 1.3.1.4 Greenstone Gold Quartz Vein Deposits

Very generally grouped, these deposits are distinct veins in Greenschist facies metamorphosed deep sea sediments. The veins are mesothermal deposits generally formed during metamorphism. Carbonate alteration invades the wall rocks around the veins. Sulfide contents are typically nil in the veins and wall rocks. Only two deposits in the United States fall into this category, but their gold production is significant. The Homestake Mine, South Dakota, is a deposit hosted in an Archean iron formation. Gold is associated with quartz veinlets distributed through distinct horizons in the iron formation. The Mother lode vein system in California is distinct gold-quartz veins in Mesozoic argillites (Jamestown, California). Erosion of these veins produced the rich placer deposits of California.

### 1.3.2 Mineral Content

The mineral content or assemblage of a deposit is the result of reactions between hydrothermal solutions and the wall rock, influenced by wall rock chemistry, solution chemistry, temperature, and pressure. Most gold ores contain some amount of sulfur-bearing minerals; carbonate deposits may also contain carbonaceous material. The weathering environment affecting the ore body following deposition is determined mainly by the location of the water table in relation to the deposit. Ores above the water table, in the vadose or unsaturated zone, will tend to be oxidized (referred to as "oxide ores"), while ores below the water table will usually be unoxidized (referred to as "sulfide ores").

Gold ores may contain varying amounts of arsenic, antimony, mercury, thallium, sulfur, base metal sulfides, other precious metals, and sulfosalts. The amount of these constituents depends on the nature of the deposit and the amount of weathering that has occurred. Subsequent alteration of the ore by oxidation influences both gold recovery and the byproducts of extracting the ore. Sulfide minerals oxidize to form either oxides or sulfosalt minerals. Leaching of sulfides or other minerals

**Table 1-3. Spectrographic Analyses of Samples of Various Types of Unoxidized Ores, Oxidized and Leached-Oxidized Ores, Carlin Gold Deposit, Lynn Window, Eureka Co., NV**

Element	Normal <sup>a</sup>	Normal <sup>a</sup>	Siliceous <sup>a</sup>	Pyritic <sup>a</sup>	Carbonaceous <sup>a</sup>	Arsenical <sup>a</sup>	Oxidized <sup>a</sup>	Leached-oxidized <sup>a</sup>
Si(%) <sup>b</sup>	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0
Al	5	7	0.5	2	3	5	5	5
Fe	2	2	0.5	3	1.5	2	2	2
Mg	5	10	0.15	5	10	7	5	0.5
Ca	7	>10.0	0.03	7	>10.0	10	10	0.2
Na	0.05	0.1	0.03	0.05	0.1	0.07	0.03	0.07
K	1.5	3	0	1.5	1.5	2	1.5	2
Ti	0.2	0.2	0.02	0.1	0.1	0.15	0.15	0.3
P	0	0	0	0	0	2	0	0
Mn (ppm) <sup>f</sup>	100	150	7	150	500	150	150	10
Ag	0	0	1	0	2	0	0	0.7
As <sup>d</sup>	154	800	385	180	480	11,000	1,450	790
Au <sup>e</sup>	9	12	23	6	5	69	10	50
B	150	70	7	20	100	30	70	70
Ba	200	200	500	100	500	500	150	300
Co	7	5	0	7	3	3	3	1.5
Cr	70	70	10	30	70	70	50	100
Cu	50	20	70	30	70	50	20	30
Ga	15	15	0	7	7	10	10	20
Hg <sup>d</sup>	25	40	55	25	20	200	35	100
La	50	0	0	50	0	50	70	50
Mo	15	7	5	15	50	10	5	5
Nb	0	7	0	0	0	0	0	10
Ni	50	20	3	70	100	20	20	15
Pb	15	0	0	10	15	0	15	30
Sb <sup>d,g</sup>	<40	150	40	<40	60	115	129	360
Sc	10	15	0	7	7	10	15	15
Sr	150	0	10	100	200	150	100	100
Tl	70	200	0	0	0	150	50	0
V	200	0	70	100	700	70	50	200
W <sup>g</sup>	<20	<20	<20	<20	30	20	<20	<20
Y	20	30	0	15	70	20	30	30
Yb	2	1.5	0	1	3	1.5	3	3
Zn <sup>d</sup>	51	114	6	7	100	<5	163	65
Zr	100	150	20	100	70	150	200	300

<sup>a</sup>Descriptions correspond to ores from specific locations.

<sup>b</sup>Elements Si through P given in weight percent.

<sup>c</sup>Elements Mn through Zr given in parts per million.

<sup>d</sup>X-ray fluorescence analysis.

<sup>e</sup>Atomic absorption analysis.

<sup>f</sup>Leico mercury vapor analysis.

<sup>g</sup>Calorimetric analysis.

(Source: Radtke 1980.)

may occur in association with oxidation. Sulfide ores retain their original composition. Zones of secondary enrichment may form at the oxidized/unoxidized interface. A list of elemental constituents in oxide and sulfide (unoxidized) ores in the Carlin Mine is presented in Table 1-3 (Radtke 1980).

The minerals found in gold ores, and elements associated with them, vary with the type of ore. Sulfide ores contain varying amounts of native gold and silica ( $\text{SiO}_2$ ), as well as sulfur-bearing minerals, including, but not limited to, sphalerite ( $\text{ZnS}$ ), chalcopyrite ( $\text{CuFeS}_2$ ), cinnabar ( $\text{HgS}$ ), galena ( $\text{PbS}$ ), pyrite ( $\text{Fe}_2\text{S}$ ), sylvinate ( $(\text{Au,Ag})\text{Te}_2$ ), realgar ( $\text{AsS}$ ), arsenopyrite ( $\text{FeAsS}$ ), ellisite ( $\text{TI}_3\text{AsS}_3$ ), and other thallium-arsenic antimony-mercury-bearing sulfides and sulfosalt minerals. Oxide ores may contain varying amounts of these minerals, as well as silica ( $\text{SiO}_2$ ), limonite ( $\text{FeO}\cdot\text{OH}\cdot\text{nH}_2\text{O}$ ), calcite ( $\text{CaCO}_3$ ), clay minerals, and iron oxides (Hurlbut and Klein 1977).

The mineral assemblage of the ore deposit is an important factor in selecting the beneficiation method. In general, the percent recovery of gold from sulfide ores using cyanidation is lower and more costly than for oxide ores. Recovery is reduced because the cyanide solution reacts with other constituents, such as sulfides in addition to gold, and complicates beneficiation. Increased costs are associated with the preparation of sulfide ores when they are oxidized in roasters or autoclaves (see the Beneficiation Section) (Weiss 1985). Milling, flotation, gravity concentration, and other beneficiation methods are customized to maximize recovery of precious metals from the ore deposit.

#### **1.4 GOLD EXTRACTION AND BENEFICIATION PRACTICES**

Gold operations consist of three major steps: extraction, beneficiation, and processing. Extraction is analogous to mining and is defined as removing ore material from a deposit. Four main techniques are used in the beneficiation of gold ore: cyanidation, flotation, amalgamation, and gravity concentration. The method used varies with mining operations and depends on the characteristics of the ore and economic considerations (U.S. DOI, Bureau of Mines 1984). Figure 1-1

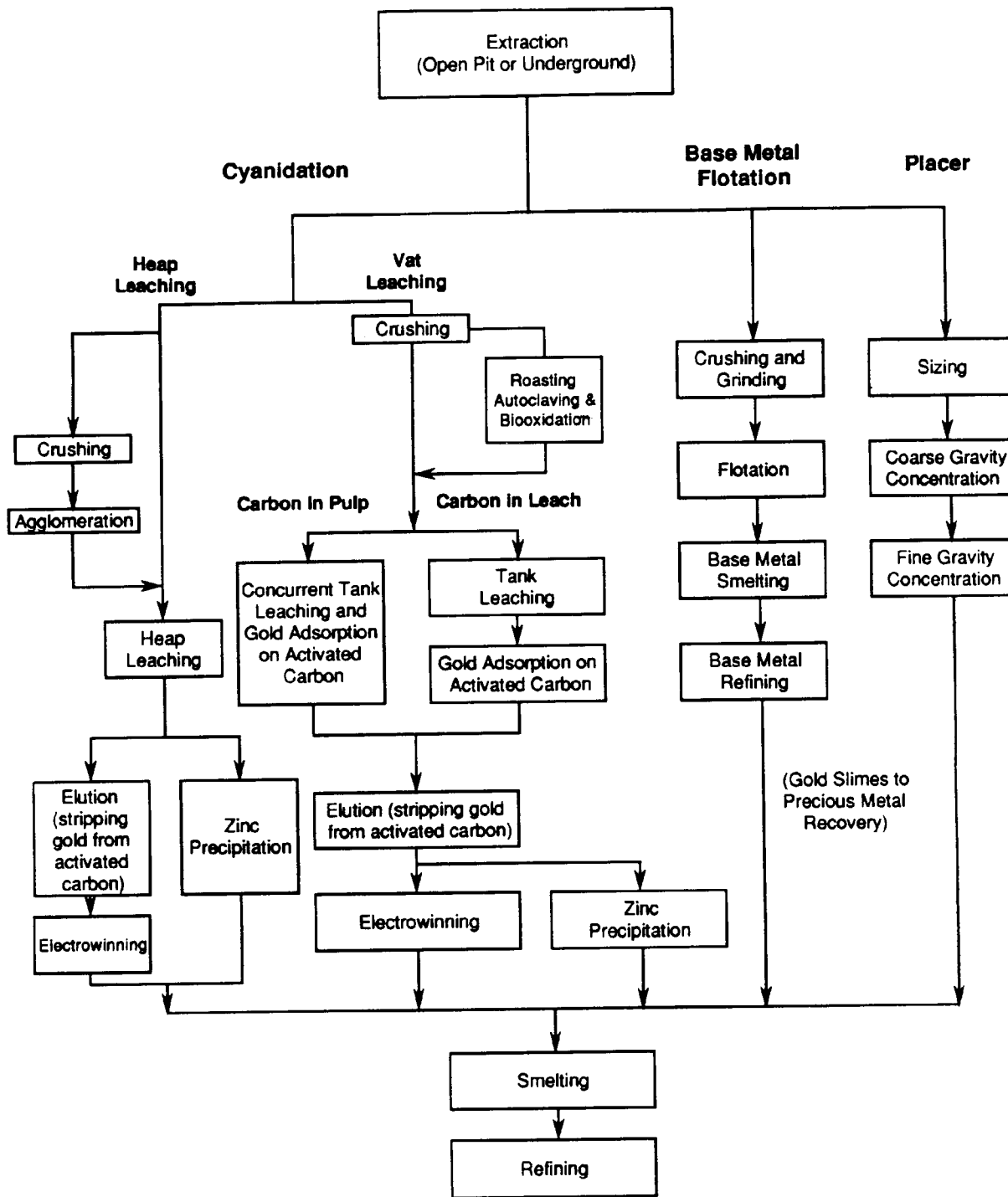


Figure 1-1. Gold Extraction and Beneficiation Overview

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is a diagram of the common methods used to beneficiate gold. Because lode ore gold mines generally use cyanidation techniques, the following sections focus on cyanidation. The discussion of amalgamation is brief, since this method is of historic significance and is not in use today. Gravity concentration methods are used in placer-type operations and are discussed in a separate Technical Resource Document. Base metal flotation operations are also discussed in other Technical Resource Documents (See the Copper and Lead-Zinc Technical Resource Documents). Beneficiation flow sheets for specific mine operations are presented in Appendix 1-A.

In 1991, cyanidation and direct processing (smelting of precious metals recovered as a by-product from base metal mining) were used to generate 90 percent and 10 percent of all domestic recovered lode gold, respectively and 99 percent of all gold produced (Table 1-5, discussed later). Placer mining accounts for 1 percent of the total gold produced. Amalgamation was used to beneficiate less than 1 percent of all lode gold in 1986 (1986 was the last year for which complete data were reported concerning amalgamation) (U.S. DOI, Bureau of Mines 1990a).

#### **1.4.1 Extraction Methods**

Gold ore extraction may be conducted using either surface or underground techniques. Mining methods are selected based on maximum ore recovery, efficiency, economy, and the character of the ore body (including dip, size, shape, and strength) (Whiteway 1990).

Generally, gold mining is conducted using surface mining techniques in open-pit mines. This is primarily because of economic factors related to mining large-volume, low-grade ores and the improvement of cyanide leaching techniques. In 1988, the total of crude ore handled at surface lode mines was 160 million short tons (97.8 percent), while underground mines accounted for only 3.56 million short tons (2.2 percent) (U.S. DOI, Bureau of Mines 1991a). Table 1-4 summarizes the amount of crude ore, waste, and marketable product generated by surface, underground, and placer operations in 1988.



**Table 1-4. Crude Ore, Waste, and Marketable Product at Surface and Underground Gold Mines, 1988**

<b>Material/Ratio</b>	<b>Surface (Lode) Short Tons (000s)</b>	<b>Underground (Lode) Short Tons (000s)</b>	<b>Total Lode Short Tons (000s)</b>	<b>Placer Short Tons (000s)</b>
Material Handled	553,000	4,890	558,000	32,900
Crude Ore	160,000	3,560	163,560	15,000
Waste	394,000	1,340	395,000	17,900
Marketable Product Thousand Troy Ounces	5,250	241	5,490	153
Crude Ore to Marketable Product Ratio	21.3:1	15.7:1	21.1:1	91.5:1
Material Handled to Marketable Product Ratio	105.4:1	20.3:1	---	215.3:1

(Source: U.S. EPA, and compiled from U.S. DOI, Bureau of Mines 1990b.)

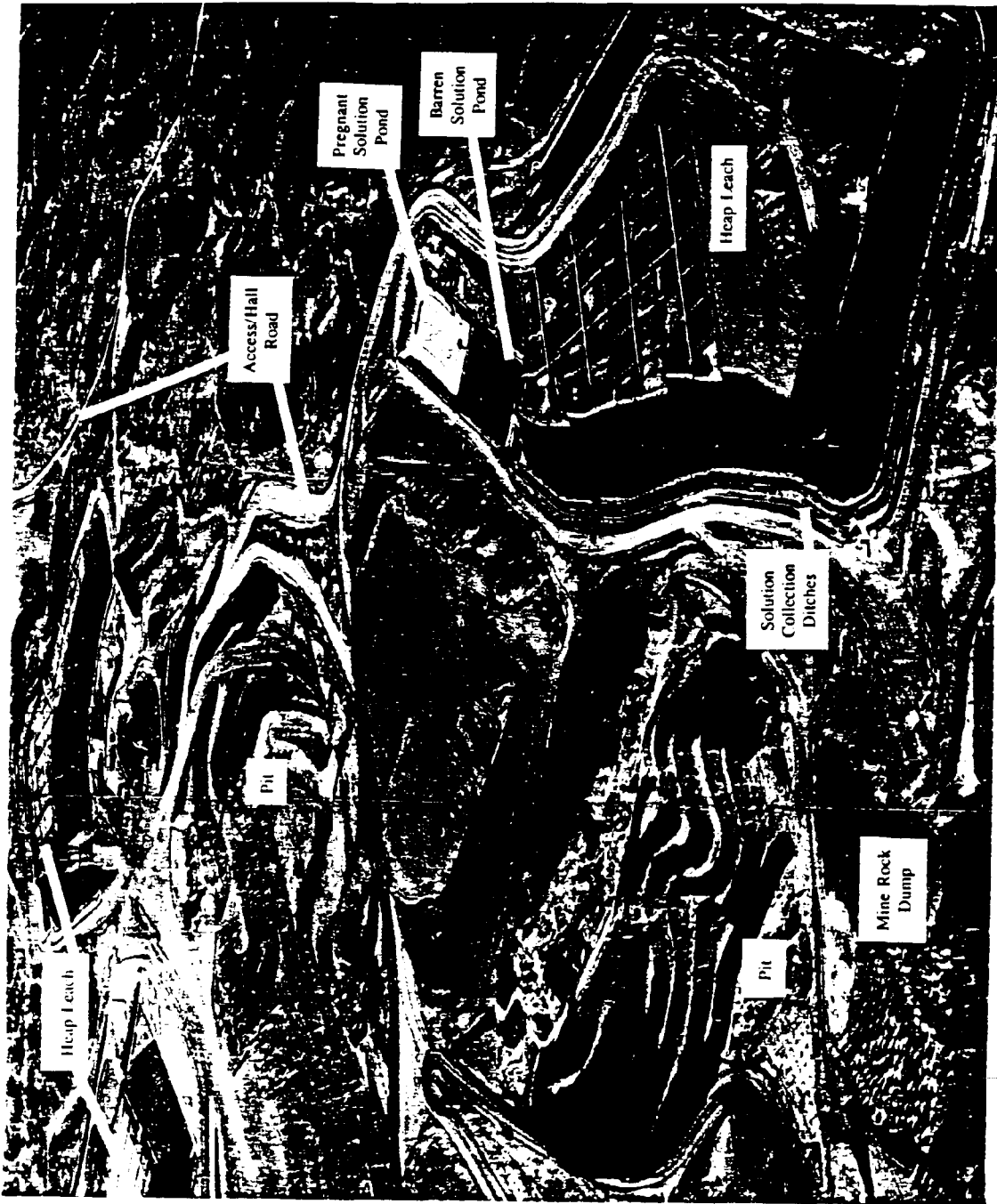
About 90 percent of the 201 active gold mines are lode-type and 10 percent are placer (U.S. DOI, Bureau of Mines 1990a). As noted previously, the top 25 gold-producing mines accounted for 68 percent of domestic production in 1991.

Surface mining methods associated with the extraction of gold include open-pit, placer, and dredge (industry often considers placer and dredge separately). Placer mining is used to mine and concentrate gold from alluvial sand and gravels. Underground mining operations use various mining methods, including caving, stoping, and room and pillar. Consolidated ore mining methods include surface and underground techniques for mining lode ore and are described below. These practices follow the basic mining cycle of drilling, blasting, and mucking.

#### 1.4.1.1 Surface Mining

The most predominant surface mining method used to extract gold ore is open-pit. Ore containing valuable minerals usually is surrounded by less valuable material. Overburden, the unconsolidated soil and consolidated rock material overlying or adjacent to the ore body, is first removed, and the crude ore is broken and transported to the mill or directly to a heap for beneficiation activities. Overburden and development rock (sometimes referred to as innerburden if interspersed with the ore body) may be continually removed during the life of the mine as the pit walls are cut back to permit deepening of the mine.

The depth to which an ore body is mined depends on the ore grade, nature of the overburden, and the stripping ratio. The stripping ratio is the amount of overburden that must be removed for each unit of crude ore mined. Stripping ratios vary with mine site and the ore being mined. Surface mining of gold is generally more economical than underground methods, especially in cases when the ore body being mined is large and the depth of overburden covering the deposit is limited. An illustration of a typical surface mine and heap leach operation is presented in Figure 1-2. The primary advantage of



surface mining is the ability to move large amounts of material at a relatively low cost, in comparison with underground operations. Open-pit and open-cut mining are considered to be the least expensive extraction techniques (U.S. EPA, Office of Water, Effluent Guidelines Division 1982).

#### 1.4.1.2 Underground Mining

In general, underground mining involves sinking a shaft or driving a drift near the ore body to be mined and extending horizontal passages (levels) from the main shaft at various depths to the ore. Mine development rock is removed, while sinking shafts, adits, drifts, and cross-cuts, to access and exploit the ore body. From deep mines, broken ore (or muck) is removed from the mine either through shaft conveyances or chutes and hoisted in skips (elevators). From shallow mines, ore may be removed by train or conveyor belt. Waste rock, mine development rock, or mill tailings may be returned to the mine to be used as fill for mined-out areas (U.S. EPA, Office of Water 1982).

#### 1.4.2 Beneficiation Methods

As discussed above, gold beneficiation operations include cyanidation, base-metal flotation, gravity concentration (for placer deposits), and amalgamation (which is generally no longer used). Base-metal flotation, gravity concentration, and amalgamation are described only briefly below. Because most lode ore gold mines use some form of cyanidation, these techniques are the main focus of this profile. In general, there are two basic types of cyanidation operations, tank leaching and heap leaching. In addition, tank leaching involves one of two distinct types of operations, Carbon-in-Pulp or Carbon-in-Leach. In Carbon-in-Pulp operations, the ore pulp is leached in an initial set of tanks with carbon adsorption occurring in a second set of tanks. In Carbon-in-Leach operations, leaching and carbon recovery of the gold values occur simultaneously in the same set of tanks. Table 1-5 presents a comparison of gold ore treated and gold product produced by beneficiation method.

Table 1-5. Comparison of Gold Ore Treated and Gold Product by Beneficiation Method, 1991

Beneficiation Method	Gold Ore Treated		Gold Product Produced	
	Percent	Metric Tons (000s)	Percent	Kilograms <sup>c</sup>
Cyanidation (All)	51	206,610	90	259,163
Heap Leaching	36	145,441	33	94,464
Tank Leaching	14	61,168	56	161,699
Amalgamation <sup>a</sup>	0.5	0.85	0	1,048
Smelting (Ore and Concentrates) <sup>b</sup>	49	201,370	10	28,296
Total Lode	100	409,018	100	286,998
Placer	100	5.5 million cubic meters	100 (1% of total gold)	2,888

<sup>a</sup>Values for amalgamation for 1986 production, the last year complete information has available.

<sup>b</sup>Smelting of base metal ores and concentrates, mainly copper and lead ores.

<sup>c</sup>1 kilogram is equivalent to 32.1507 troy ounces.

(Source: U.S. DOI, Bureau of Mines 1992.)

#### 1.4.2.1 By-Product Gold (Flotation)

Flotation is a technique in which particles of a single mineral or group of minerals are made to adhere, by the addition of reagents, preferentially to air bubbles (U.S. EPA, Office of Water 1982). This technique is chiefly used on base metal ore that is finely disseminated and generally contains small quantities of gold in association with the base metals. Gold is recovered as a byproduct of the base metal recovery. Although no production information is available specifically for flotation, U.S. Bureau of Mines personnel have suggested that production figures presented in Table 1-5 for smelting may approximate byproduct gold production by the base metal industry. In 1988, smelting recovered 0.67 million troy ounces of gold (11 percent of all domestic gold produced) (U.S. DOI, Bureau of Mines 1990a).

Ore is milled and sorted by size in preparation for flotation. The ore is then slurried with chemical reagents of four main groups: collectors (promoters), frothers, activators, and depressants. In a typical operation, the ore slurry and reagents are mixed in a conditional cell so the reagents coat the target mineral. The conditional slurry is pumped to a flotation cell, and air is injected. Air bubbles adhere to the reagents and carry the target mineral to the surface, away from the remaining gangue, for collection. In the flotation technique, the target mineral is not necessarily the precious metal or other value. Depending on the specific gravity and the reagents used, the values may be recovered from the top or bottom of the flotation cell.

#### 1.4.2.2 Gravity Concentration

Gravity concentration techniques used most at placer mines rely on gravitational forces to suspend and transport gangue away from the heavier valuable mineral. A separate report discussing this technique at placer mines is being prepared by EPA.

#### 1.4.2.3 Amalgamation

In amalgamation operations, metallic gold is wetted with mercury to form a solution of gold in mercury, referred to as an amalgam. This method of beneficiation is most effective on loose or free coarse gold particles with clean surfaces (U.S. EPA, Office of Water 1982). Because of its high surface tension, mercury does not penetrate into small crevices of ore particles as sodium cyanide does. Consequently, the ore must be milled finely enough to expose the gold material. In 1986, the last year for which complete statistics were provided, amalgamation operations produced 33,710 troy ounces of gold (0.5 percent of all gold produced domestically) (U.S. DOI, Bureau of Mines 1990a). Use of this method of gold beneficiation has been greatly restricted in recent times because of its high costs, inefficiency in large-scale operations, and scarcity of ores amenable to the technique.

Ore preparation consists of grinding, washing, and/or floating the ore. The ore is then fed into a ball mill along with mercury to form an amalgam. The amalgam is then passed over a series of copper plates where it collects. When fully loaded with amalgam, the plate is removed and the amalgam is scraped off. Upon heating the hardened amalgam in a retort furnace, the mercury is vaporized and the gold material remains. The mercury driven off by heating is captured, condensed, and reused. Alternatively, hot dilute nitric acid may be applied to the amalgam, dissolving the mercury and leaving the gold material. Amalgamation has traditionally been used in conjunction with other beneficiation methods such as cyanidation, flotation, and gravity concentration (Beard 1987).

Wastes generated as a result of amalgamation activities consist of gangue in the form of coarse- and fine-grained particles and a liquid mill water component in the form of a slurry. The constituents of the waste are similar to those found in the ore body (or gravel) plus any mercury lost during amalgamation. This material is sent to a tailings impoundment (U.S. DOI, Bureau of Mines 1984).

#### 1.4.2.4 Cyanidation

The predominant method used to beneficiate gold ore is cyanidation. This technique uses solutions of sodium or potassium cyanide as lixiviants (leaching agents) to extract precious metals from the ore. Cyanide heap leaching is a relatively inexpensive method of beneficiating low-grade gold ores while tank leaching is used for higher grade ore. In 1988, cyanidation operations (including both heap leaching and tank operations) treated 146.7 million short tons of gold ore and recovered 5.6 million troy ounces of gold (U.S. DOI, Bureau of Mines 1990a). This represented 90 percent of all lode gold produced from all beneficiation methods.

Although other lixivants are currently being tested, none are known to be used in commercial operations. Alternative lixivants include malononitrile, bromine, urea, and copper-catalyzed thiosulfate (U.S. DOI, Bureau of Mines 1985; U.S. DOI, Bureau of Mines, undated(a)). Bromine, for example, is being promoted as an alternative to cyanide by the Great Lakes Chemical Corporation. However, only pilot plant tests are known of at this time (Dadgar 1989; Winegar 1991).

Cyanidation techniques used in the gold industry today include heap or valley fill leaching followed by carbon adsorption (carbon-in-column adsorption), agitation leaching followed by carbon-in-pulp (CIP), or agitated carbon-in-leach (CIL). *In situ* leaching of gold is being researched by the Bureau of Mines, but is not used commercially at this time. Cyanidation is best suited to fine-grain gold in disseminated deposits. Heap or valley fill leaching is generally used to beneficiate ores containing less than 0.04 oz/t. CIP and CIL techniques, commonly referred to as tank or vat methods, are generally used to beneficiate ores containing more than 0.04 oz/t. These gold beneficiation cut-off values are dependent on many factors, including the price of gold and an operation's ability to recover the precious metal (van Zyl et al. 1988).

For this discussion, cyanidation-carbon adsorption is considered in four steps: leaching, loading, elution, and recovery (van Zyl et al. 1988) (see Figure 1-3

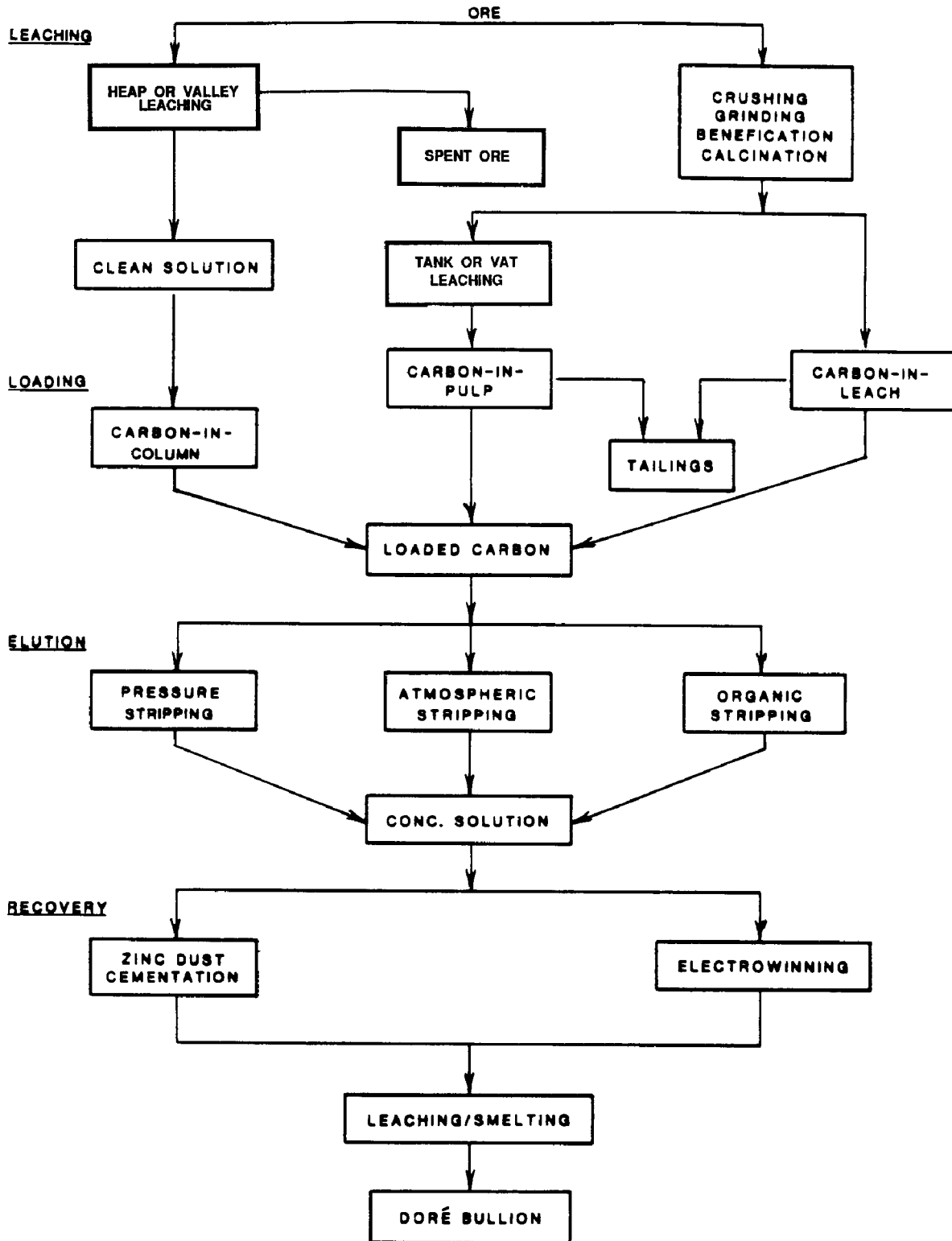


Figure 3-1. Flowsheet for Recovery of Gold Using Carbon Adsorption

(Source: Van Zyl, et al. 1988.)



). In leaching, the cyanide reacts with the ore to liberate gold material and form a cyanide-gold complex in an aqueous solution. Precious metal values in solution are loaded onto activated carbon by adsorption. When the loading is complete, the values are eluted, or desorbed from the carbon, and recovered by electrowinning or zinc precipitation, prior to smelting.

An alternative to cyanidation/carbon adsorption is cyanidation/zinc precipitation. The cyanidation-zinc precipitation technique is also presented in four steps: leaching, clarification, deaeration, and precipitation. The precipitate (a solid) is smelted directly. A full description of activated carbon adsorption and zinc precipitation follows the discussion of heap leaching. Other methods to separate the precious metal from the pregnant solution include solvent extraction and direct electrowinning; these methods are not common in the industry and are not discussed in this profile.

Depending on the type of ore (sulfide or oxide), the gold concentration in the ore, and other factors, the mine operator may prepare the ore by crushing, grinding and/or oxidation (roasting, autoclaving, or bio-oxidation) prior to cyanidation or flotation. In some cases, low grade ore is loaded directly onto heap leach pads with little or no preliminary ore preparation. This practice transports run-of-mine ore directly to the pad for leaching. In most other cases, the ore is crushed and/or ground, prior to leaching or flotation. Each of the steps involved in beneficiation is described in detail in the following sections.

#### Ore Preparation

##### *Crushing and Grinding*

Beneficiation begins with the milling of extracted ore in preparation for further activities to recover the gold values. Milling operations are designed to produce uniformly sized particles by crushing, grinding, and wet or dry classification. Economics play a large part in determining the degree of grinding or crushing performed to prepare the ore. Other factors include the gold concentration of the ore, the mineralogy and hardness of the ore, the mill's capacity, and the next planned step in the beneficiation of the ore. Run-of-mine ores with very low gold concentrations may be sent directly to a heap leach pile.

Milling begins when ore material from the mine is reduced in particle size by crushing and grinding. A primary crusher, such as a jaw type, is used to reduce ore into particles less than 150 millimeters (about 6 inches) in diameter. Generally, crushing continues using a cone crusher and an internal sizing screen until the ore is less than 19 mm (3/4 inch). Crushing in jaw and cone crushers is a dry process, with water spray applied only to control dust. From the cone crusher, ore is fed to the grinding circuit where milling continues in the presence of water. Water is added to form a slurry containing 35 to 50 percent solids. Grinding in ball or rod mills further reduces the ore particle size, as needed. In some cases, ore and water are fed directly into an autogenous mill (where grinding media are the hard ore itself); or, a semiautogenous mill (where the grinding media are the ore supplemented by large steel balls). Between each grinding unit operation, hydrocyclones are used to classify coarse and fine particles. Coarse particles are returned to the mill for further size reduction. Milled ore is in the form of a slurry, which is pumped to the next unit operation

(Weiss 1985; Stanford 1987). Fugitive dust generated during crushing and grinding activities is usually collected by air pollution control device blowdown streams and is generally recirculated into the beneficiation circuit. Most mills use water sprays to control dust from milling activities.

*Oxidation of Sulfides (Roasting, Autoclaving, and Bio-Oxidation)*

After milling, beneficiation of sulfide ores may include oxidation of sulfide minerals and carbonaceous material by roasting, autoclaving, bio-oxidation, or chlorination.<sup>1</sup> Roasting involves heating sulfide ores in air to convert them to oxide ores. In effect, roasting oxidizes the sulfur in the ore generating sulfur dioxide that can be captured and converted into sulfuric acid. Roasting temperatures are dependent on the mineralogy of the ore, but range as high as several hundred degrees Celsius. Roasting of ores that contain carbonaceous material oxidizes the carbon to prevent interference with leaching and reduced gold recovery efficiency. Autoclaving (pressure oxidation) is a relatively new technique that operates at lower temperatures than roasting. Autoclaving uses pressurized steam to start the reaction and oxygen to oxidize sulfur-bearing minerals. Heat released from the oxidation of sulfur sustains the reaction. The Getchell and Barrick Goldstrike Mines in Nevada, the McLaughlin Mine in California, and the Barrick Mercur Mine in Utah are currently using pressure oxidation (autoclave) technology, totally or in part, to beneficiate sulfide or carbonaceous gold ores.

Bio-oxidation of sulfide ores employs bacteria to oxidize the sulfur-bearing minerals. This technique is currently used on an experimental basis at the Congress Gold Property in Canada and at the Homestake Tonkin Springs property in Nevada. The bacteria used in this technique are naturally occurring and typically include *Thiobacillus ferrooxidans*, *Thiobacillus thiooxidans*, and *Leptospirillum ferrooxidans*. In this technique, the bacteria are placed in a vat with sulfide gold ore. The bacteria feed on the sulfide minerals and ferrous iron components of the gold ore. Research is currently being conducted on other bacteria that can grow at higher temperatures; high-temperature bacteria are thought to treat the ore at a much faster rate (U.S. DOI, Bureau of Mines 1990a). Although more time is required for bio-oxidation, it is considered to be less expensive than roasting or autoclaving (Hackel 1990).

*Agglomeration*

Ores with a high proportion of small particle size (minus 200 mesh) require preparation before leaching can be done effectively. Because percolation of the lixiviant may be retarded as a result of blocked passages by fine-grained particles, these types of ores are agglomerated to increase particle size. Agglomeration is the technique of aggregating individual particles into a larger mass, thus enhancing percolation of the lixiviant and extraction efficiency. This technique may increase the flow of cyanide solution through the heap by a factor of 6,000, decreasing the overall leaching time needed. Agglomeration is currently used in half of all

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<sup>1</sup> Chlorination is not commonly used to oxidize sulfide ores because of the high equipment maintenance costs caused by the corrosive nature of the oxidizing agent.

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heap leaching operations. The agglomeration technique typically involves (U.S. DOI, Bureau of Mines 1986) the following:

- Mixing the crushed ore with portland cement (a binding agent) and/or lime (to provide alkalinity)
- Wetting the ore evenly with cyanide solution to start leaching before the heap is built
- Mechanically tumbling the ore mixture so fine particles adhere to the larger particles.

#### Heap Leaching

In the past 13 years, heap leaching has developed into an efficient way to beneficiate a variety of low-grade, oxidized gold ores. Compared to conventional cyanidation (i.e., tank agitation leaching), heap leaching has several advantages, including simplicity of design, lower capital and operating costs, and shorter startup times. Depending on the local topography, a heap or a valley fill method may be employed. Where level ground exists, a heap is constructed; in rough terrain, a valley may be dammed and filled. The design of these leaching facilities and their method of operation are site-specific and may even vary over time at the same site. Typically, heaps are constructed of lower-grade oxidized ores. Depending on the type of ore, it may be sent directly to the heap (run-of-mine ore), crushed, or agglomerated to maximize gold recovery. Recovery rates for heap and valley fill leaching range from 60 to 80 percent. Prior to constructing a heap, a pad and an impermeable liner are built to collect the leachate. A diagram of a typical heap leaching system is presented in Figure 1-4

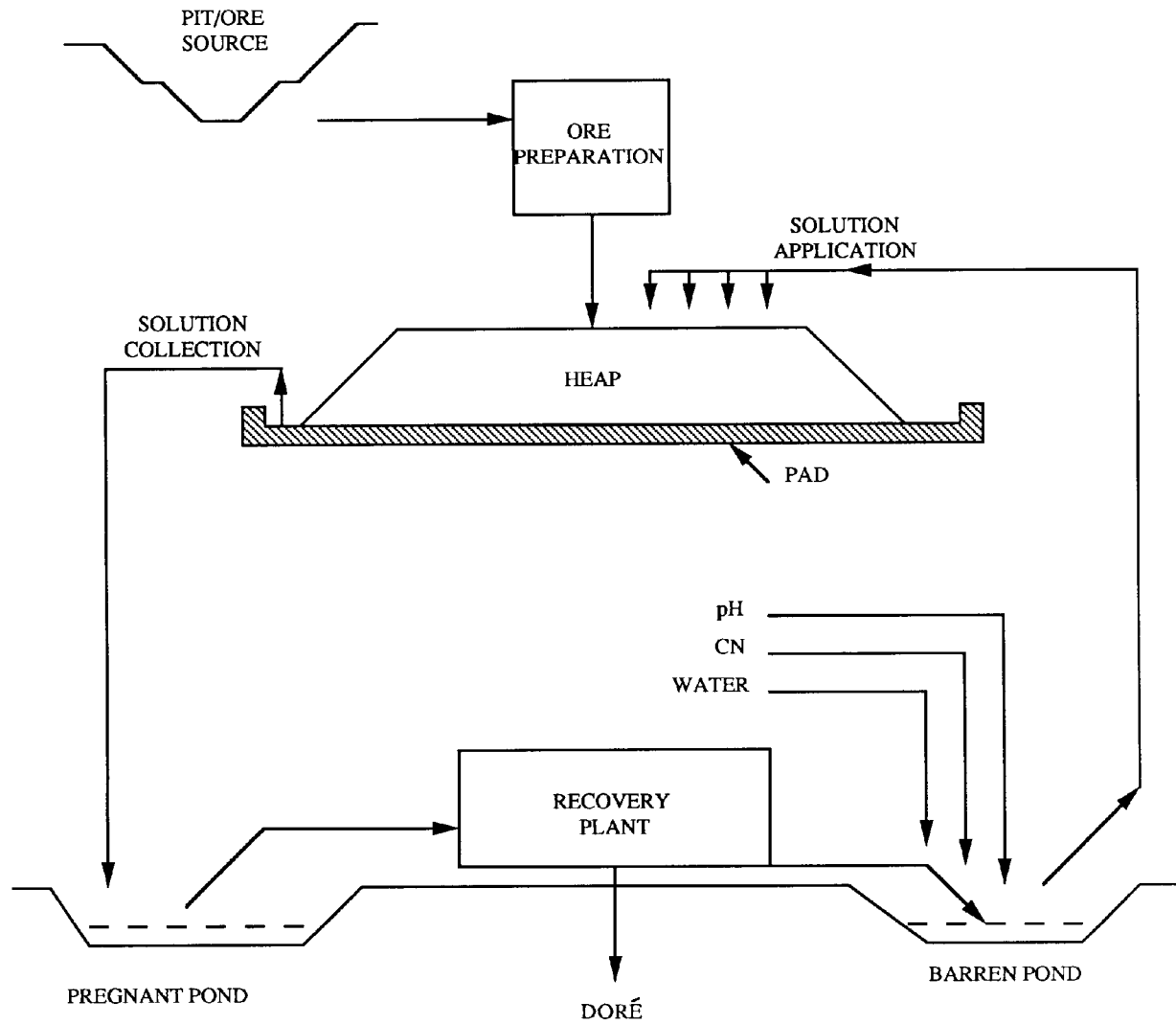


Figure 4-1. Typical Heap Leaching System

(Source: U.S. DOI, Bureau of Mines 1984.)

. This method is frequently applied to run-of-mine ore on which minimal or no crushing is performed.

Statistics generated by the Bureau of Mines group gold production from heap and dump leaching together. (Dump leaching is typically conducted on base metal ores from which byproduct gold may be recovered.) Currently, no gold heap or valley fill leaches are known to operate without a liner (Hackel 1990). The use of a liner in gold heap leaching operations may prevent the loss of gold values. In 1988, according to the Bureau of Mines, heap and dump leach operations treated 102.2 million metric tons of gold ore and recovered 2.3 million troy ounces of gold (U.S. DOI, Bureau of Mines 1990a). This represented 37 percent of all lode gold produced and 42 percent of all gold produced by cyanidation (see Table 1-5).

Heap leaching activities may involve some or all of the following steps (U.S. DOI, Bureau of Mines 1978, 1984):

- Preparation of a pad with an impervious liner on a 1° to 6° slope or greater for drainage, and extracting ore from the mine site (or alternatively gathering ore from waste piles)
- Crushing and/or agglomeration of the ore to between 1/2 and 1 inch in size if necessary and cost effective; some operations may leach run-of-mine ore (the agglomeration technique will be discussed later in this section)
- Placing the ore on the pad(s) using trucks, bulldozers, conveyor belts, or other equipment
- Applying cyanide solution using drip, spray, or pond irrigation (generally between 0.5 and 1.0 pounds of sodium cyanide per ton of solution)
- Collecting the solution via ditches, piping, ponds, and/or tanks.

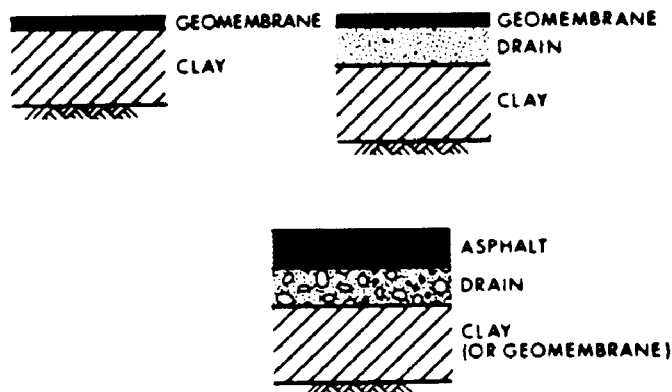
Two common types of pads used in gold heap leaching include permanent heap construction on a pad from which the leached ore is not removed; and on-off pads, which allow leached ore pile to be removed following the leach cycle. Permanent heaps are built in lifts composed of 5- to 30-foot layers of ore added to the top of the heap. On-off pads are used to a limited extent in the industry and are constructed to allow spent ore to be removed after the leaching cycle (Lopes and Johnston 1988).

Pad and liner construction methods and materials vary with the type of pad and site conditions. Construction materials may include compacted soil or clay, asphaltic concrete, and low-permeability synthetic membranes such as plastic or geomembrane (see Figure 1-5)

**SINGLE LINERS**



**DOUBLE LINERS**



**TRIPLE LINERS**

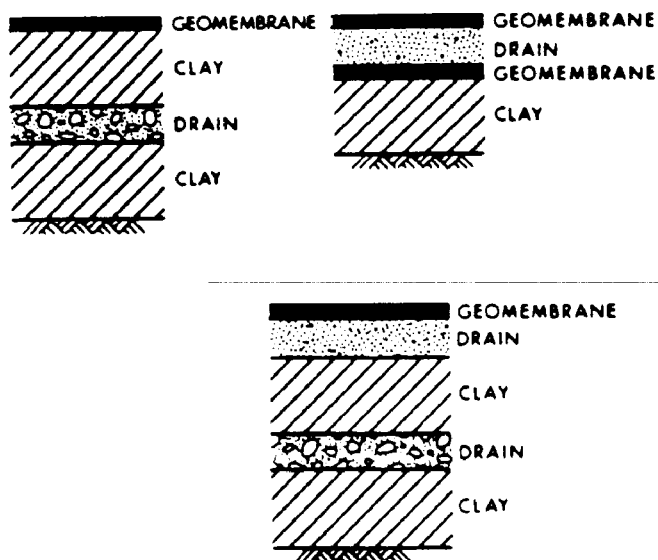


Figure 5-1. Typical On-Off and Life Pad Liner Construction Materials

(Source: Van Zyl, D.J.A., et al. 1988.)

) (van Zyl et al. 1988). Sand or crushed ore may also be used on top of the synthetic liner to aid in leachate collection and protect the pad. Older pads tend to be made of compacted clay. Newer pads are usually constructed of synthetic materials, typically installed over a compacted layer of native soil or imported clay. Some mines use synthetic liners composed of high-density polyethylene (HDPE) or very low-density polyethylene (VLDPE) in combination with compacted native materials. These liner systems are referred to as composite liners. On-off pads are generally constructed of asphaltic concrete to protect the liner from potential damage by heavy machinery used during unloading. The risk that a liner system will leak is most acute during mine operation when ore is added to the heap and fluids place pressure on it.

When all beneficiation ends and the heap or valley fill unit is reclaimed, the operator typically controls fluid movement to the liner by installing run-on/runoff controls and other measures.

A variation of heap leaching is valley fill leaching (Eurick 1991). This method is used at facilities with little or no flat land and utilizes liner systems similar to those used in heap leaches for solution containment. In valley fill leaching, the ore material is placed on top of a liner system located behind a dam on the valley floor. As in heap leaching, the ore is treated with lixiviant but is contained and collected internally at the lowest point in the ore on the liner system for further beneficiation, rather than in an external solution collection pond. Montana, Utah, and other States have approved valley fill operations.

In these leaching operations, cyanide complexes with gold and other metals as the liquid percolates through the ore. Because percolation efficiency may be a limiting factor in heap leaching methods, some operations treat higher-grade ore with cyanide solution during primary crushing. Fine-grained ore may be agglomerated to increase permeability; this is discussed in the next section. Leaching typically takes from weeks to several months, depending on the permeability and size of the pile. An "average/normal" leach cycle takes approximately 3 months (Lopes and Johnston 1988).

The reaction of the solution with the free gold is oxygen-dependent. Therefore, the solution is oxygenated prior to application or during spraying. The cyanide leachate percolates through the ore and is collected by pipes located under the pile or carried directly to ditches around the pile (U.S. DOI, Bureau of Mines 1986; Lopes and Johnston 1988). The solution is then collected in a pond or tank. The solution pond may be used as a holding pond, a surge pond, or a settling basin to remove solids contained in the cyanide solution. Some mine operations use an alternative series of ponds, including one for the barren solution, an intermediate solution pond, and a pregnant solution pond. The intermediate solution is passed through a new pile for further enrichment to form the final, or pregnant, solution (U.S. DOI, Bureau of Mines 1984).

These ponds may be single lined but are now more often double lined with plastic (HDPE), butylrubber, and/or bentonite clay to prevent seepage. To control wildlife access to cyanide solution, some mining operations have elected to construct tanks to collect and store leachate solutions (as an alternative to open ponds). For example, the Castle Mountain Project in Barnwell, California, will collect pregnant solution in three 250,000-gallon sealed tanks (U.S. DOI, Bureau of Land Management, Needles Resource Area 1990).

Those active operations using ponds to store cyanide solutions may fence or cover the solution ponds with screening or netting in an effort to prevent wildlife or waterfowl access, respectively.

Leaching occurs according to the following reactions, with most of the gold dissolving in reaction 2 (van Zyl et al. 1988):

- $4\text{Au} + 8\text{NaCN} + \text{O}_2 + 2\text{H}_2\text{O} \rightarrow 4\text{NaAu}(\text{CN})_2 + 4\text{NaOH}$  (Elsener's Equation and Adamson's 1st Equation)
- $2\text{Au} + 4\text{NaCN} + \text{O}_2 + 2\text{H}_2\text{O} \rightarrow 2\text{NaAu}(\text{CN})_2 + \text{H}_2\text{O}_2 + 2\text{NaOH}$  (Adamson's 2nd Equation)

Leaching is generally effective at a pH of 9.5 to 11, with the optimum being approximately 10.5. More acidic conditions may result in the loss of cyanide through hydrolysis, reaction with carbon dioxide, or reaction with hydrogen to form hydrogen cyanide (HCN). Alternatively, more basic conditions tend to slow the reaction process (U.S. DOI, Bureau of Mines 1984). Typically, the recovered cyanide solution contains between 1 and 3 ppm of gold material (U.S. DOI, Bureau of Mines 1986). Irrigation of the heap stops when the pregnant solution falls below 0.005 ounces of gold per ton of solution (Lopes and Johnston 1988). After the leaching cycle has been completed, the heap or valley fill unit can be rinsed with mine water or mill waste water to remove most of the remaining cyanide solution and gold-cyanide complex. Cyanide in the rinse water may be detoxified using several methods, such as the addition of hydrogen peroxide or sulfur dioxide.

Wastes remaining following the conclusion of heap and valley fill leaching operations include spent ore in the piles or spent ore disposed of elsewhere on site in the case of on-off heap leach pads. The spent ore will contain small quantities of spent cyanide solution, waste water from rinsing the ore, residual cyanide, and unrecovered gold-cyanide complex.

It is estimated that, in 1980, the gold industry generated 3 million metric tons of heap leach wastes. This rose to 11 million metric tons in 1982, because of increased use of leaching as a result of rising gold prices and increased gold production (U.S. EPA 1985). Based on 1988 Bureau of Mines estimates, 102.3 million metric tons of ore were treated by heap and dump leaching to produce 2.3 million troy ounces (72.7 metric tons) of gold. After leaching is complete, 102.3 million metric tons of spent ore were or will be generated (less the volume of gold removed). These wastes will be discussed in the Extraction and Beneficiation Wastes Section.

Recovery of gold from the pregnant solution generated by heap leaching is accomplished using carbon adsorption or direct precipitation with zinc dust (known as the Merrill-Crowe process). These techniques may be used separately or in a series with carbon adsorption followed by zinc precipitation. Both carbon adsorption and zinc precipitation separate the gold-cyanide complex from the noncomplexed cyanide and other remaining wastes, including water and spent ore. Unconventional techniques used to recover gold values include solvent extraction, direct electrowinning, and, more recently, ion exchange resin.



Sources examined for this report disagree as to the relative cost efficiency of each method. Because of the low cost of zinc, gold concentration by zinc precipitation may cost less than activated carbon adsorption/electrowinning (U.S. DOI, Bureau of Mines 1986). Activated carbon requires additional capital expenditures for a stripping plant, electrowinning, and a kiln to reactivate carbon for use in future beneficiation. On the other hand, carbon adsorption is both more efficient and less expensive, in terms of capital and operational costs, than zinc precipitation (U.S. DOI, Bureau of Mines 1978). Activated carbon techniques also are better able to process solutions with low metal concentrations and are thus most often used on solutions with a gold concentration below 0.05 oz/t of solution (U.S. DOI, Bureau of Mines 1978, 1984). Carbon-based and zinc precipitation methods are described in more detail below.

*Carbon Adsorption (Carbon-in-Column/Gold Recovery)*

In heap leaching carbon adsorption uses the Carbon-in-Column (CIC) technique. In the CIC technique, the pregnant solution collected from the leach pile is pumped from a collection pond or tank into a series of cascading columns containing activated carbon. The solution mixes with the carbon column in one of two methods: fixed-bed or fluid-bed.

The fluid-bed method involves pumping pregnant solution upward through the column at a rate sufficient to maintain the carbon bed in a fluid state moving gradually down through the column without allowing the carbon to be carried out of the system. Thus, loaded carbon can be removed from the bottom of the tank and fresh carbon added at the top. The fluid-bed method is the more common of the two methods used in operations adsorbing gold-cyanide values from unclarified leach solutions containing minor amounts of slimes. Because the fluid-bed method uses a countercurrent operating principal, it is often more efficient and economical than the fixed-bed method in adsorbing the gold-cyanide complex from solution (U.S. DOI, Bureau of Mines 1978, 1984).

In the fixed-bed method, the gold-laden cyanide solution is pumped downward through a series of columns. The columns generally have either flat or dished heads and contain a charcoal retention screen as well as a support grid on the bottom. Normally, the height-to-diameter ratio of the tanks is 2:1, although, in some instances, a larger ratio will increase the adsorption capacity of the system (see Figure 1-6

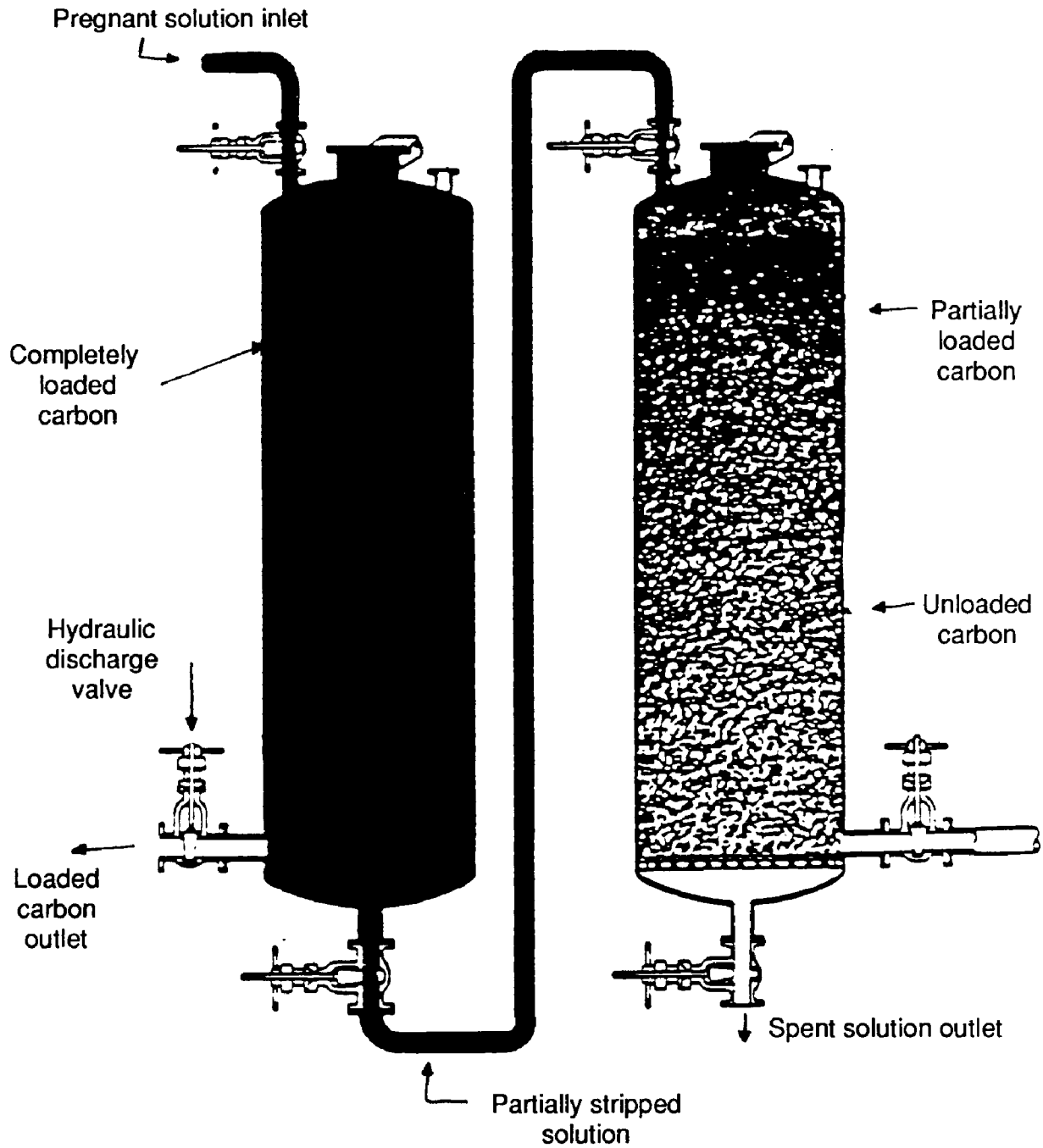


Figure 6-1. Typical Fixed-Bed Multiple Carbon-In-Column Operation

(Source: Society of Mining Engineers, Mineral Processing Handbook 1985.)

) (Weiss 1985).

In each vessel, the gold-cyanide complex is adsorbed onto activated carbon granules that preferentially adsorb the gold-cyanide complex from the remaining solution as the material flows from one column to the next.

The advantage of the fixed-bed method over the fluid-bed method is that it requires less carbon to process the same amount of solution (U.S. DOI, Bureau of Mines 1978, 1984). Typically,

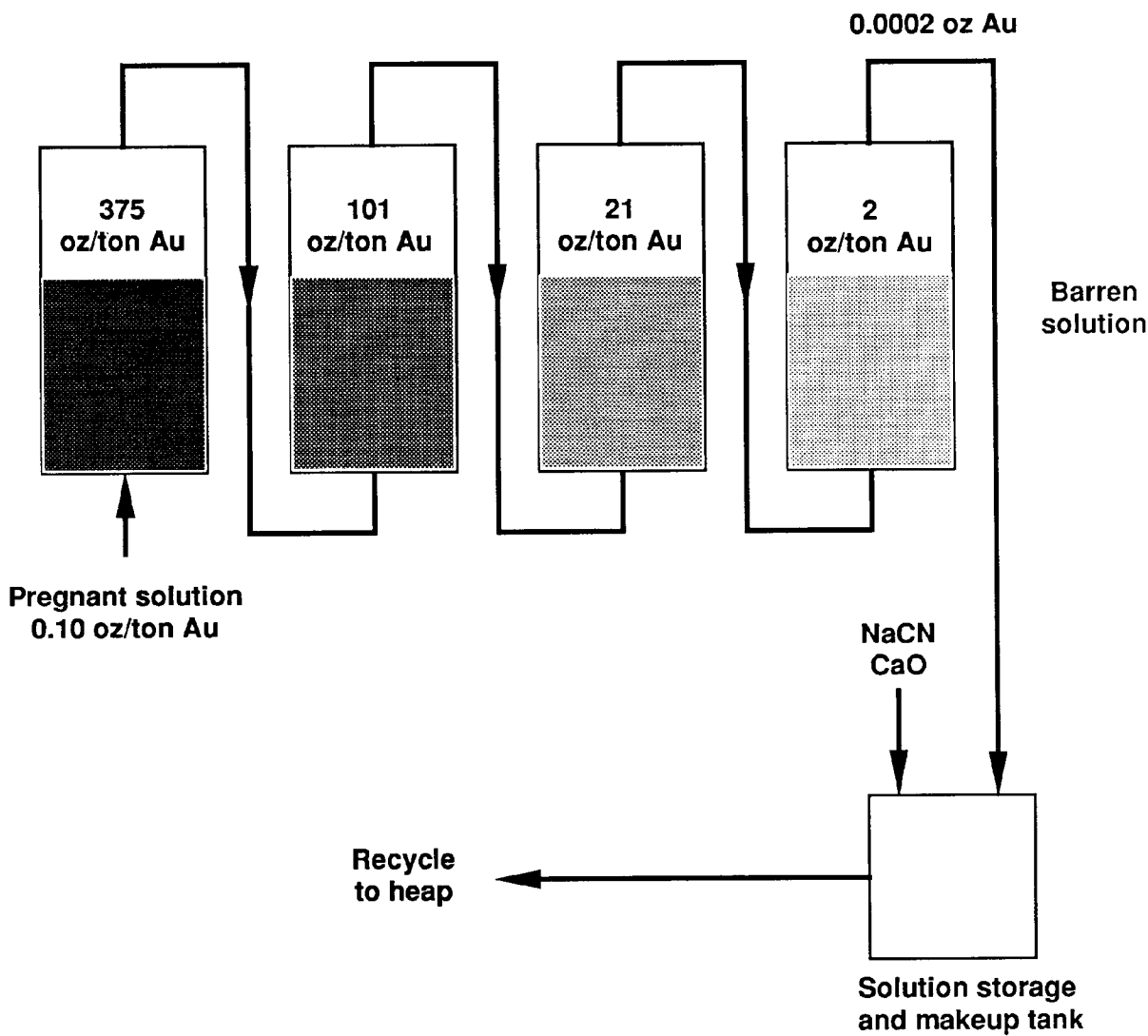


Figure 7-1. Hypothetical Distribution of Gold in a Continuous Carbon Adsorption Operation

(Source: U.S. DOI, Bureau of Mines 1978.)

the activated carbon collects gold from the cyanide leachate until it contains between 100 and 400 ounces of gold per ton of carbon depending on the individual operation (see Figure 1-7). Loading efficiency decreases with solutions containing less gold (U.S. DOI, Bureau of Mines 1978).

The precious metals are then stripped from the carbon by elution. The values can be desorbed from the carbon using a boiling caustic cyanide stripping solution (1.0 percent NaOH and 0.1 percent NaCN). Modifications of this method include the addition of alcohol to the stripping solution and/or stripping under elevated pressure or temperature (40°C to 150°C) (U.S. DOI, Bureau of Mines 1986). At the Barneys Canyon Mine, a stripping solution of hot sodium hydroxide is used. At this facility, that solution has been tested and shown to be as effective as stripping solutions containing caustic cyanide (LeHoux and Holden 1990).

After stripping, the carbon is reactivated on or off site and recirculated to the adsorption circuit (U.S. DOI, Bureau of Mines 1985). This activated carbon is washed with a dilute acid solution (pH of 1 or 2) to dissolve carbonate impurities and metal-cyanide complexes that adhere to the carbon along with the gold. This technique may be employed either immediately before or after the gold-cyanide complex is removed (Eurick 1991). Acid washing before the gold is removed enhances gold recovery. The Barrick Mercur Mine in Utah, the Barrick Goldstrike Mine in Nevada, and the Ridgeway Gold Mine in South Carolina are examples of facilities using acid prewash techniques, while the Golden Sunlight Mine in Montana and the Battle Mountain Mine in Nevada use acid postwash techniques (see the Mercur Mine flow sheet in Appendix 1-A).

Based on impurities to be removed from the carbon and metallurgical considerations, different acids and concentrations of those acids may be used. Usually, a hydrochloric acid solution is circulated through 3.6 metric tons (4 short tons) of carbon for approximately 16 to 20 hours. Nitric acid is also used in these types of operations, but is thought to be less efficient than hydrochloric acid (HCL) in removing impurities. The resulting spent acid wash solutions may be neutralized with a high-pH tailings slurry, dilute sodium hydroxide (NaOH) solution, or water rinse. When the wash solution reaches a stable pH of 10, it is sent to a tailings impoundment. Metallic elements may also be precipitated with sodium sulfide (Smolik et al. 1984; Zaburunov 1989).

The carbon is screened to remove fines and thermally reactivated in a rotary kiln at about 730°C for 20 minutes (Smolik et al. 1984). The reactivated carbon is subsequently rescreened and reintroduced into the recovery system. Generally, about 10 percent of the carbon is lost during the process because of particle abrasion. Recirculating the carbon material gradually decreases performance in subsequent adsorption and reactivation series. Carbon adsorption efficiency is closely monitored and fresh carbon is added to maintain efficiency at design levels (U.S. DOI, Bureau of Mines 1984, 1986).

The pregnant eluate solution containing gold may undergo electrowinning or zinc precipitation. Electrowinning (or electrodeposition) uses stainless or mild steel wool, or copper as a cathode to collect the gold product. The Golden Sunlight Mine in Montana uses 3.6 kilograms (kg) [8 pounds (lb.)] of steel wool

in eight cathodes within rectangular electrowinning cells. A 2.5-volt current is used to 250 amperes per cell during the operation (Smolik et al. 1984). After two cycles of electrodeposition, the steel wool must be removed and replaced. The depleted stripping solution may then be reheated and recycled to the carbon stripping system. The steel wool or electrowinning sludge, laden with gold value, is fluxed with sodium nitrate, fluorspar, silica, and/or sodium carbonate and melted in a crucible furnace for casting into bullion. For gold ores containing mercury, a retort step is required before gold smelting to recover metallic mercury (U.S. DOI, Bureau of Mines 1986; Smolik et al. 1984). Zinc precipitation is described below.

*Zinc Precipitation (Merrill-Crowe)/Gold Recovery*

Although carbon adsorption is the most common method of gold recovery in the United States, zinc precipitation is the most widely used method for gold ore containing large amounts of silver. Because of its simple and efficient operation, the Merrill-Crowe process is used at the 10 largest gold producing mines in the world, all of which are in South Africa. This technique is well suited to new mines where the ore has a high silver to gold ratio (from 5:1 to 20:1) (van Zyl et al. 1988).

In zinc precipitation operations, the pregnant solution (or the pregnant eluate stripped from the activated carbon) is filtered using clarifying filters coated with diatomaceous earth to aid in the removal of suspended particles (see Figure 1-8

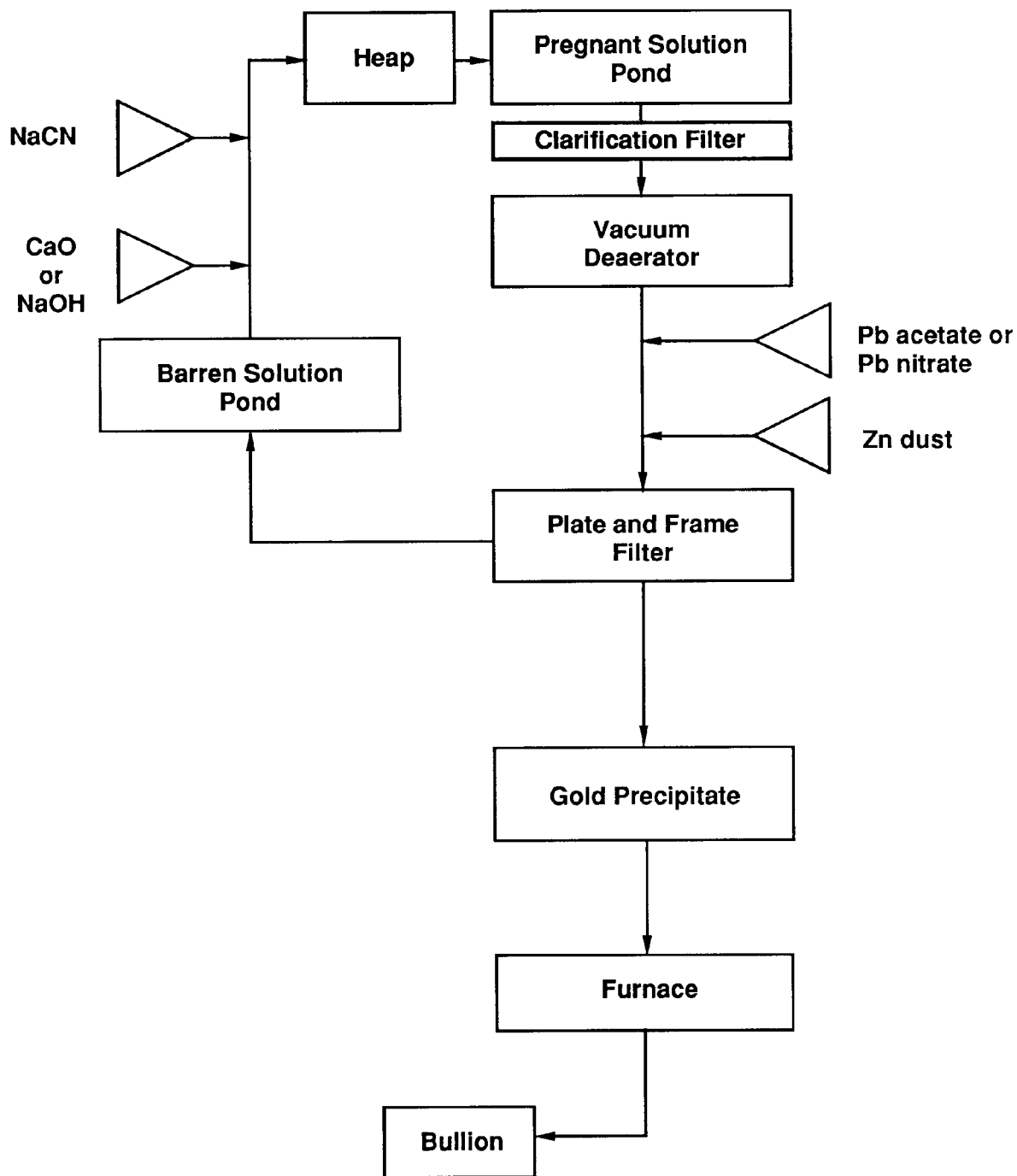
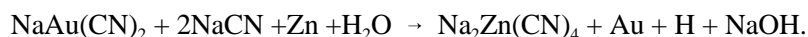


Figure 8-1. Merrill-Crowe Recovery System

(Source: Van Zyl, et al. 1988.)

) (Weiss 1985). Dissolved oxygen is then removed from the solution using vacuum tanks and pumps. This is necessary because the presence of oxygen in the solution inhibits recovery (U.S. DOI, Bureau of Mines 1984).

Metallic zinc dust then is combined with the deoxygenated pregnant solution. At some operations, a small amount of cyanide solution and lead nitrate or lead acetate is added. Lead increases galvanic activity and makes the reaction proceed at a faster rate. Zinc precipitation proceeds according to the reaction described below; the result is a gold precipitate (U.S. DOI, Bureau of Mines 1984).



The solution is forced through a filter that removes the gold metal product along with any other precipitates. Several types of filters may be used, including submerged bag, radial vacuum leaf, or plate-and-frame. The gold precipitate recovered by filtration is often of sufficiently high quality (45 to 85 percent gold) that it can be dried and smelted in a furnace to make doré (unrefined metals). In cases where further treatment is necessary, the precipitate may be muffle roasted or acid treated and calcined with borax and silica before smelting (Weiss 1985). Following filtration, the barren solution can be chemically treated (neutralized) or regenerated and returned to the leach circuit (Weiss 1985).

#### Tank Leaching

In tank leaching operations, primary leaching takes place in a series of tanks, frequently located in buildings rather than in outdoor heaps or dumps. Finely ground gold ore is slurried with the leaching solution in tanks. The resulting gold-cyanide complex is then adsorbed on activated carbon. Carbon-in-Pulp (CIP) conducts the leaching and recovery operations in two separate series of tanks, while Carbon-in-Leaching (CIL) conducts them in a single series. The pregnant carbon then undergoes elution, followed either by electrowinning or zinc precipitation, as described previously. The recovery efficiencies found at tank operations are significantly higher than those found at heap leach facilities. Tank methods recover from 92 to 98 percent of the gold contained in the ore.

Continuous countercurrent decantation (CCD) is a method of washing the solution containing metal values from the leached ore slurry to produce a clear pregnant solution. This procedure is used for ores with high silver values that preclude the use of activated carbon and that are very difficult to filter, thus precluding the use of filters. The resulting pregnant solution is generally treated by the zinc precipitation technique.

A new technology employed in South Africa uses ion exchange resin in place of carbon in the CIP technique. This technology—Resin-in-Pulp (RIP)—is expected to have lower capital costs and energy consumption than CIP operations, if they are operated effectively (Australia's Mining Monthly 1991). If the use of ion exchange resins is found to be compatible with a wide range of ores, the industry may shift to these resins wherever activated carbon is now used.



The number and size of tanks used in domestic CIP and CIL facilities vary. For example, the Ridgeway facility in South Carolina uses 10 tanks measuring 52 feet in diameter and 56 feet in height; the Mercur Mine uses 14 tanks, each of which are 30 feet in diameter and 32 feet in height; the Golden Sunlight Mine uses 10 tanks, each of which are 40 feet in diameter and 45 feet in height. Retention times vary as well, ranging from 18 to 48 hours, depending on the facility, equipment used, and ore characteristics (Smolik et al. 1984; Fast 1988; Zaburunov 1989). The amount of gold ore beneficiated by tank cyanidation methods increased since the mid 1980s.

Ore preparation (including grinding, lixiviant strength, and pulp density adjustment) and the time required to leach precious metal values varies depending on the type of ore. Oxide ores are typically beneficiated by grinding to 65 mesh and leaching with 0.05 percent sodium cyanide (for a pulp density of 50 percent solids) over a 4- to 24-hour period. Sulfide ores are typically beneficiated by grinding to 325 mesh and leaching with 0.1 percent sodium cyanide for a 10- to 72-hour period (for a pulp density of 40 percent solids) (Weiss 1985). *Carbon-in-Pulp*

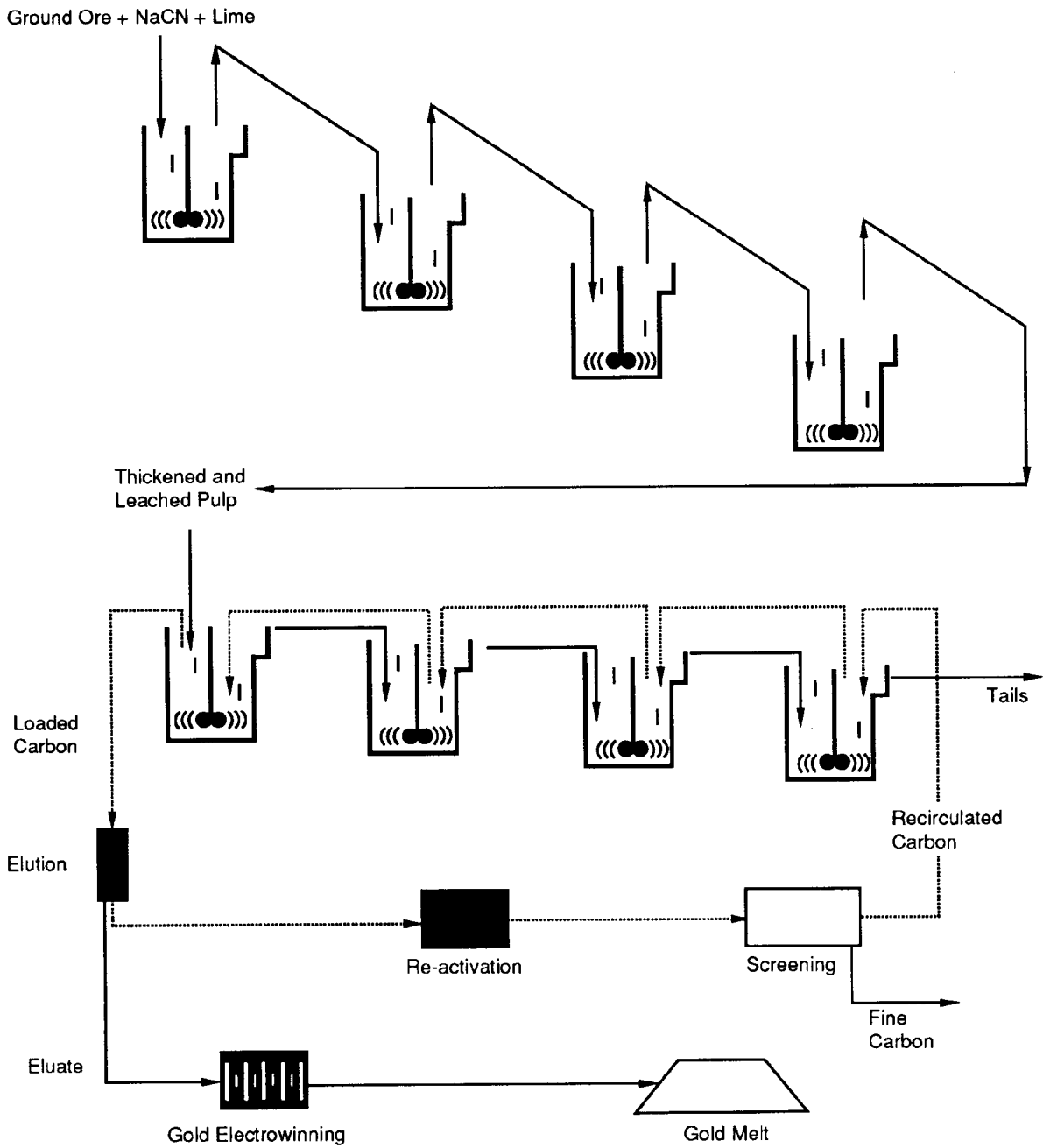


Figure 9-1. Typical Carbon-in-Pulp (CIP) Circuit

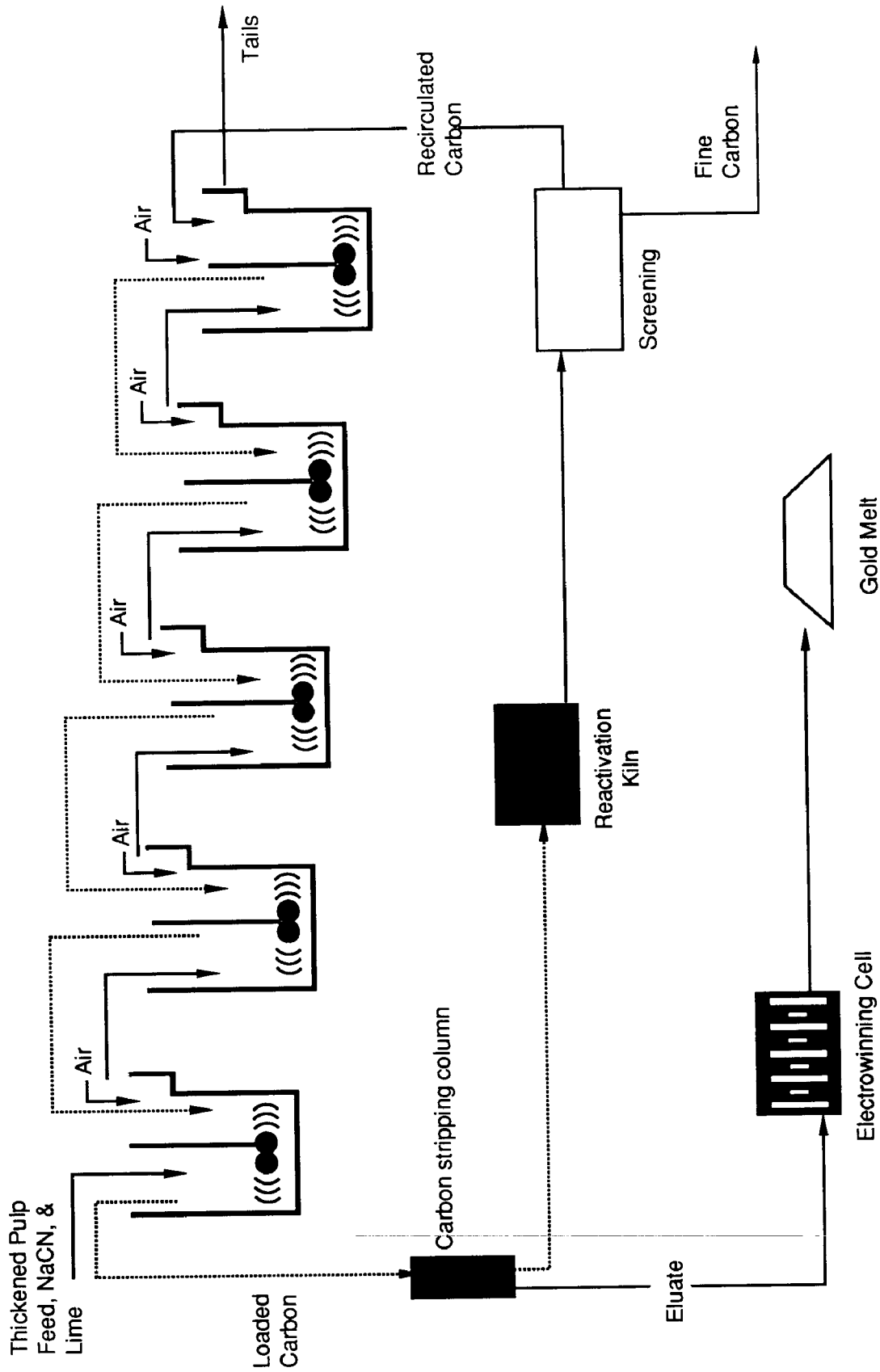
(Source: Calgon, Granular Carbon for Gold Recovery undated.)

In the CIP technique, a slurry of ore, process water, cyanide, and lime is pumped to the first series of tanks for agitation and leaching. Gold is leached from the ore in the leach tank train. The slurry containing leached ore and pregnant solution is pumped to the second series of tanks for recovery. A diagram of this technique is presented in Figure 1-9.

In the second series of CIP tanks, the slurry is introduced into a countercurrent flow with activated carbon. The slurry enters the first tank in the series containing carbon that is partially loaded with the gold-cyanide complex (see Figure 1-9) (Calgon Carbon Corporation, undated). In the suspended slurry, the activated carbon adsorbs gold material on the available exchange sites. As the carbon material becomes laden with precious metals, the carbon is pumped forward in the circuit toward the incoming solids and pregnant solution. Thus, in the last tank, the low-gold percentage solution is exposed to newly activated and relatively gold-free carbon that is capable of removing almost all of the remaining precious metals in the solution. Fully loaded carbon is removed at the feed end of the absorption tank train for elution, followed by electrowinning or zinc precipitation as described previously. (U.S. DOI, Bureau of Mines 1978, 1986; Stanford 1987).

#### *Carbon-in-Leach*

The CIL technique differs from CIP in that activated carbon is mixed with the ore pulp in a single series of agitated leach tanks. Leaching and recovery of values occur in the same series of tanks. A countercurrent flow is maintained between the ore and the leaching solution and activated carbon (see Figure 1-10



) (Calgon Carbon Corporation, undated). In the first tanks of the series, leaching of the fresh pulp is the primary activity. In later tanks, adsorption is dominant as fresh carbon is added to the system countercurrent to the pulp. Adsorption takes place as the gold-cyanide complex mixes with the carbon. As with Carbon-in-Pulp and heap leach operations, the pregnant carbon undergoes elution to remove values. The pregnant eluate then undergoes electrowinning or zinc precipitation prior to smelting.

Tank beneficiation methods produce a waste slurry of spent ore pulp or tailings. Spent ore is pumped as a slurry to a tailings impoundment (U.S. DOI, Bureau of Mines 1986; Calgon Carbon Corporation, undated; Stanford 1987). This solution may contain cyanide, spent ore, lost gold-cyanide complex, gold in solution, and any constituents in the water used in the operation to control shale. Small amounts of gold will continue to be leached in the tailings impoundment and some gold may be recovered as this solution is recirculated back to the mill.

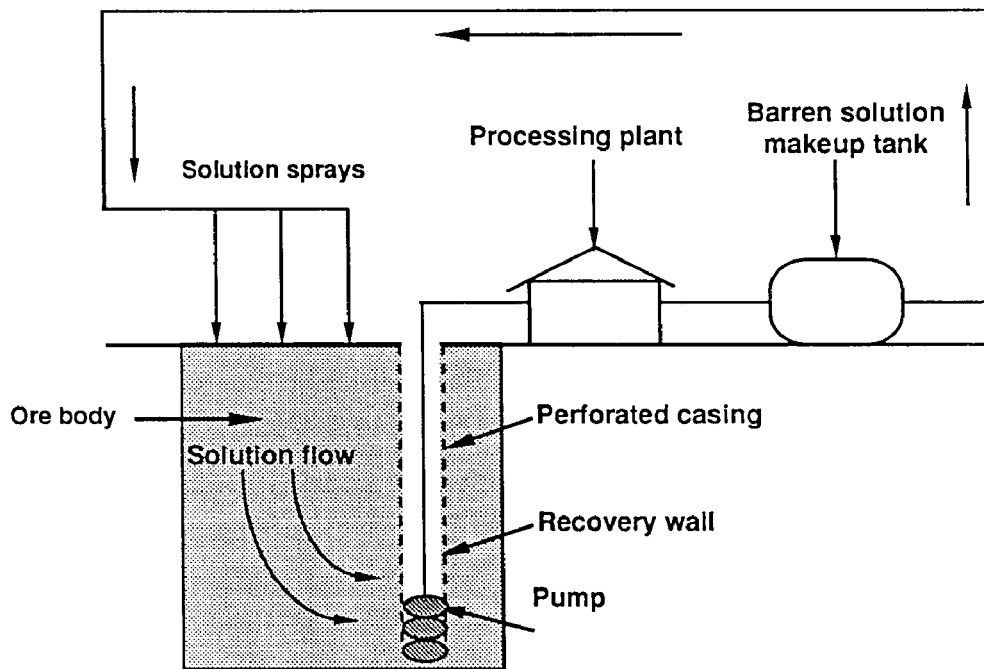
Barren leaching solution is either recycled directly back to the beneficiation circuit or sent to a tailings impoundment depending on the amount of solids in the solution. This solution may contain spent ore, residual cyanide solution, and minor amounts of gold.

#### *In situ Leaching*

*In situ* leaching, although common in the copper industry, is only an experimental procedure in the gold industry and is not used in commercial operations. It involves blasting an underground deposit in place to fracture the ore and make it permeable enough to leach. Subsequently, 20 to 25 percent of the broken ore is removed from the mine to provide "swell" space for leaching activities. In buried

ore bodies, cyanide solution is then injected through a well into the fractured ore zone (see Figure 1-11). At surface ore bodies, the solution can simply be sprayed over the deposit. Recovery wells are

Exposed Ore Body



Buried Ore Body

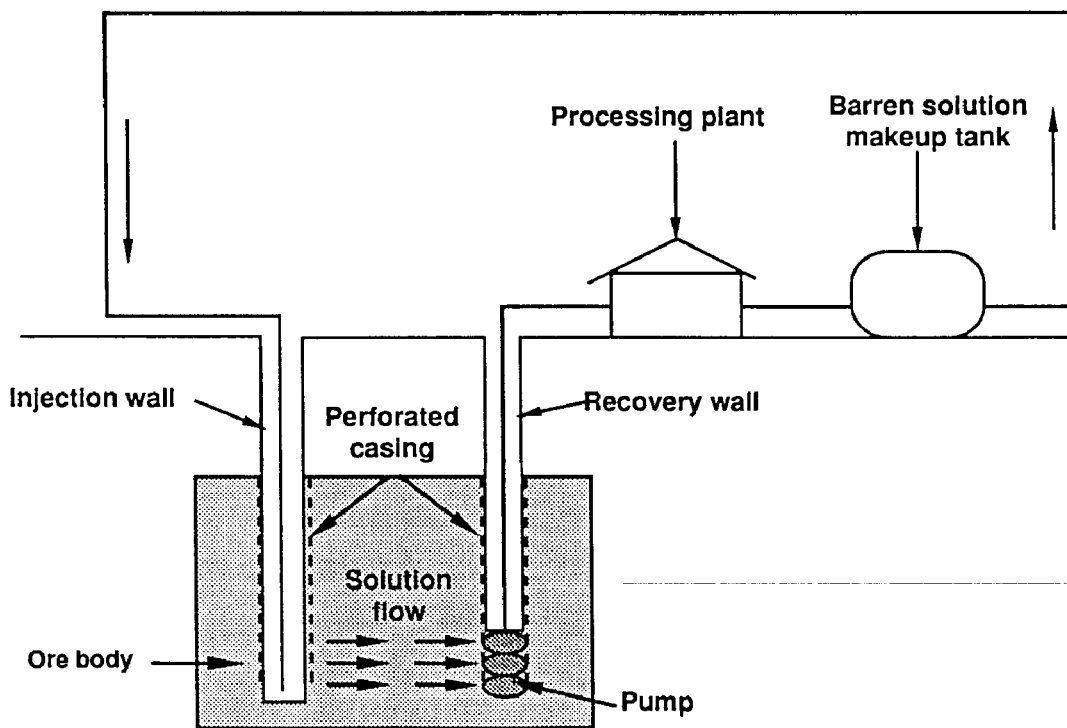


Figure 11-1. Typical In Situ Leaching Systems for Exposed and Buried Ore Bodies

(Source: U.S. DOI, Bureau of Mines 1984.)

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used to collect the gold-cyanide solution after it percolates through the ore. Ground and surface water concerns, similar to those found with dump leach sites, are commonly cited for *in situ* operations. *In situ* leaching has only been tested at the Ajax Mine near Victor, Colorado (U.S. DOI, Bureau of Mines 1984).

## **1.5 WASTES AND OTHER MATERIALS ASSOCIATED WITH GOLD EXTRACTION AND BENEFICIATION**

This section describes several of the wastes and materials that are generated and/or managed at gold extraction and beneficiation operations and the means by which they are managed. As is noted in the previous section, a variety of wastes and other materials are generated and managed by gold mining operations.

Some, such as waste rock and tailings, are generally considered to be wastes and are managed as such, typically in on-site management units. Even these materials, however, may be used for various purposes (either on- or off-site) in lieu of disposal. Some quantities of waste rock and tailings, for example, may be used as construction or foundation materials at times during a mine's life. Many other materials that are generated and/or used at mine sites may only occasionally or periodically be managed as wastes. These include mine water removed from underground workings or open pits, which usually is recirculated for on-site use (e.g., as mill/leaching makeup water) but at times can be discharged to surface waters. As another example, leaching solutions are typically regenerated and reused continuously for extended periods. On occasion, however, such as at seasonal or permanent closure, the solutions are disposed as wastes via land application or other means. Finally, some materials are not considered wastes at all until a particular time in their life cycles. These include spent ore at heap leaching operations: here, only when active leaching for precious metals recovery ends is the spent ore that comprises the heap considered a waste.

The issue of whether a particular material is a waste clearly depends on the specific circumstances surrounding its generation and management at the time. In addition, some materials that are wastes within the plain meaning of the word are not "solid wastes" as defined under RCRA and thus are not subject to regulation under RCRA. These include, for example, mine water or process wastewater that is discharged pursuant to an NPDES permit. It is emphasized that any questions as to whether a particular material is a waste at a given time should be directed to the appropriate EPA Regional office.

Facilities also store and use a variety of chemicals that are required by mine and mill operations. A list of chemicals used at gold mines, compiled from data collected by the National Institute for Occupational Safety



and Health, is provided in the table below (National Institute for Occupational Safety and Health, 1990). The first subsection below describes several of the more important wastes (as defined under RCRA or otherwise) and nonwastes alike, since either can have important implications for environmental performance of a facility. The next subsection describes the major types of waste units and mine structures that are of most environmental concern during and after the active life of an operation.

Chemicals Used at Gold Mines

Acetic Acid	Diisobutyl Ketone	Methyl Acetylene-	Silica, Sand
Acetone	Ethanol	Propadiene	Silica, Crystalline
Acetylene	Fluoride	Mixture	Silver
Ammonia	Graphite	Methyl Alcohol	Silver Nitrate
Argon	Hexane	Methyl Chloroform	Sodium Cyanide
Asbestos	Hydrogen Bromide	Mineral Oil	Sodium Hydroxide
Butyl Acetate	Hydrogen Chloride	Molybdenum	Stoddard Solvent
Calcium Carbonate	Hydrogen Peroxide	Nitric Acid	Sucrose
Calcium Oxide	Iron Oxide Fume	Nitrogen	Sulfuric Acid
Carbon Dioxide	Kerosene	Nitrous Oxide	Tin
Chlorine	Lead	Oxalic Acid	Vanadium Pentoxide
Coal	Lead Nitrate	Phosphoric Acid	Xylene
Copper	Litharge	Portland Cement	2-Butanone
Diatomaceous Earth	Mercuric Chloride	Potassium Cyanide	Diesel Fuel
Dichlorodifluoro- methane	Mercury	Propane	No. 1
		Pyridine	

1.5.1 Extraction and Beneficiation Wastes and Materials

The subsections below describe many of the wastes and materials generated and managed at gold sites. Notwithstanding the status of a particular waste or material, it should be noted that a number of factors that determine whether that waste or material poses any risk to human health or the environment. Perhaps the most important are the inherent nature of the material (which is generally determined by its origin and the processes by which it is generated), the manner in which the material is managed, and the environment in which it is managed and to which it could be released. As noted above, questions concerning the actual status of any particular material or waste should be directed to the appropriate EPA Region.

1.5.1.1 RCRA Defined Wastes

Waste Rock

According to the 1985 *Report to Congress: Wastes From the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale*, the greatest quantity of waste generated as a result of the mining and beneficiation of gold ore is in the form of overburden and mine development rock. Industry refers to these materials as waste rock. Generally, these materials are deposited in waste rock piles or dumps. It was estimated that the gold mining industry generated 25 million metric tons

of overburden and mine development rock in 1980 and 39 million metric tons in 1982 (U.S. EPA 1985). Surface mining operations generate more waste per unit of crude ore extracted than underground operations. At surface mines, 71 percent of all material handled is discarded as waste. At underground mines, 20 percent of all material handled is discarded. Using equivalent units, the ratio of material handled to marketable gold produced at lode operations is 682,000:1, the highest among metal ores (U.S. DOI, Bureau of Mines 1991a).

The quantity and composition of waste rock generated at mines vary greatly by site. This material can contain either oxides or sulfides, depending on the composition of the ore body. Constituents found in gold ores may include mercury, arsenic, bismuth, antimony, and thallium. These may occur as oxides, carbonates, and sulfides with varying degrees of solubility. Sulfur-bearing minerals, such as pyrite and pyrrhotite, can oxidize to form sulfuric acid (U.S. DOI, Bureau of Mines 1984). Factors that influence acid generation by sulfide wastes include (1) the amount and frequency of precipitation; (2) the design of the disposal unit; and (3) the acid generation and neutralization potential of the rock.

#### Spent Ore from Tank Leaching (Tailings)

Tank leaching, both CIP and CIL circuits, generate spent ore by leaching the gold values from finely ground ore. The spent ore exits the leach circuit as a slurry composed of gangue and process water bearing cyanide and cyanide-metal complexes. The characteristics of this waste vary greatly, depending on the ore, cyanide concentration, and the source of the water (fresh or recycled). The characteristics of the gangue are dependent on the ore source. The tailings may be treated to neutralize cyanide prior to disposal. The slurry is typically disposed of in a tailings impoundment with some of the free liquid component being recirculated to the tank leach as make-up water. In some cases, tailings may be used to backfill underground workings or used in on- or off-site construction.

#### Spent Ore From Heap Leaching

Heap or valley fill leaching generates spent ore when leaching operations cease, usually after the economically recoverable gold is removed from the ore. Spent ore may contain residual cyanide prior to initiation of detoxification procedures; some residual cyanide may remain complexed with other constituents. Spent ore would contain any trace metals present in the ore body. The spent ore in most heaps is left in place for detoxification and disposal. Ore leached on on-off heap leach pads is removed after leaching and detoxification and disposed of at an alternative site, such as waste rock or spent ore disposal sites.

Pads and liners used in heap leaching operations are considered to be wastes when intended for disposal, typically at closure of the facility. Depending on the types of liners used in any associated ponds or collection ditches, some cyanide, cyanide-metal complexes, and gold-cyanide solution may remain. Ponds and collection ditches may be reclaimed in place by backfilling with fill material; the pond or ditch liner material may be disposed of in place or removed for detoxification and disposal elsewhere.

### Cyanide Solution

During operation, most of the barren cyanide solution is recycled to leaching activities. However, the build-up of metal impurities may interfere with the dissolution and precipitation of gold and, therefore, require a portion of the solution volume to be bled off and disposed of (U.S. EPA, Office of Water 1982). Also, barren cyanide solution from both tank and heap leaching must be disposed of following mine closure (whether seasonal, extended, or permanent closure). In either case, solutions will contain free cyanide and metallo-cyanide complexes of copper, iron, nickel, and zinc, as well as other impurities, such as arsenic and antimony, that are mobilized during leaching. Solutions may be evaporated from ponds, discharged to tailings impoundments, or land-applied (after treatment to detoxify the cyanide).

### Zinc Precipitation Wastes

The wastes from zinc precipitation include a filter cake generated from initial filtering of the pregnant solution prior to the addition of zinc, and spent leaching solution that is not returned to the leaching process. The filter cake consists primarily of fine gangue material and may contain gold-cyanide complex, zinc, free cyanide, and lime. The filter may be washed with water, which is disposed of as part of the waste. The waste is typically sent to tailings impoundments or piles.

### Wastes From Carbon Regeneration

Carbon used in adsorption/desorption can be reactivated numerous times. The regeneration technique varies with mining operations, but generally involves an acid wash before or after extraction of the gold-cyanide complex, followed by reactivation in a kiln. Carbon particles not of optimum size are either lost to the tailings slurry, or to the greatest extent practicable, captured after reactivation. Carbon lost to the circuit is replaced with virgin, optimum-size carbon. Wastes from the reactivation circuits may include carbon fines and the acid wash solution. The carbon may contain small amounts of residual base metals and cyanide. The acid wash residues may contain metals, cyanide, and the acid (typically hydrochloric or nitric); according to Newmont Gold Company, the acid is usually neutralized in a totally enclosed system prior to release. Up to 10 percent of the carbon may be lost in any given carbon recovery/reactivation circuit from abrasion, ashing, or incidental losses. Most operations capture less-than-optimum-size carbon particles for recovery of additional gold values (either on-site or after being sent off-site). Recovery may involve either incineration and subsequent recovery of the gold that could not be desorbed chemically during the normal course of operations, or subjecting the material to an extended period of concentrated cyanide leach. Any liquids used to wash or transport carbon material are generally recirculated.

### Amalgamation Wastes

The slurry waste generated by amalgamation is composed of the mercury-bearing solution and gangue. The characteristics of waste water and gangue from amalgamation vary greatly depending on the ore. This waste may be pumped to a tailings pond. Modern placer operations in California have recovered mercury from the

sediments as a byproduct of historic gold mining. The source of the mercury is waste from historical amalgamation operations.

#### 1.5.1.2 Materials

##### Mine Water

Because mine water discharged to the environment can be a source of contamination, it is addressed in this section although it is not always a RCRA-defined waste. Mine water consists of water that collects in mine workings, both surface and underground, as a result of inflow from rain or surface water, and ground water seepage. As discussed previously, mine water may be used and recycled to the beneficiation circuit, pumped to tailings impoundments for storage prior to recycling or for disposal, or discharged to surface water under an NPDES permit.

During the life of the mine, if necessary, water is pumped to keep the mine dry and allow access to the ore body. This water may be pumped from sumps within the mine pit or from interceptor wells. Interceptor wells are used to withdraw ground water and create a cone of depression in the water table around the mine, thus dewatering the mine. Surface water contributions to the volume of mine water are generally controlled using engineering techniques to prevent water from flowing into the mine, typically by diverting it around pits or underground openings.

The quantity and chemical composition of mine water generated at mines vary by site. The chemistry of mine water is dependent on the geochemistry of the ore body and surrounding area. After the mine is closed and pumping stops, the potential exists for mines to fill with water. Water exposed to sulfur-bearing minerals in an oxidizing environment, such as open pits or underground workings, may become acidified. In contrast, according to Homestake Mining Company, flooding and subaqueous deposition of tailings has been used in some unique situations to prevent acidification in mines.

#### **1.5.2 Waste and Materials Management**

Wastes and materials that are generated as a result of extraction and beneficiation of gold ore are managed (treated, stored, or disposed of) in discrete units. For the purposes of this report, waste units are divided into three groups: (1) waste rock piles or dumps; (2) tailings ponds; and (3) spent ore piles once the leaching operation ceases in the case of heap leach operations. These units may be exposed to the environment, presenting the potential for contaminant transport. In addition, mine structures such as pits and underground workings are described in this section as they may expose constituents to the environment and increase the potential for transport.

### 1.5.2.1 RCRA Units

#### Waste Rock Piles

Overburden and mine development rock removed from the mine are stored or disposed of in on-site piles. These piles may also be referred to as mine rock dumps or waste rock dumps. Usually constructed without liners, these waste dumps are generally unsaturated. Such dumps can generate acid drainage if sulfide minerals, oxygen, and moisture are present in sufficient concentrations, without adequate neutralization potential or other controls in the dump itself. As appropriate, topsoil may be segregated from the overburden and mine development rock and stored for later use in reclamation and revegetation.

#### Tailings Impoundments

The disposal of spent ore from tank leaching operations (tailings) requires a permanent site with adequate capacity for the life of the mine. The method of tailings disposal is largely controlled by the water content of the tailings. Generally, three types of tailings may be identified based on their water content: wet (greater than 40 percent of the total weight is water), thickened (approximately 40 percent water), and dry (less than 30 percent water). Tailings impoundments are used to dispose of the following types of waste:

- Tailings,
- Mine water,
- Small amounts of activated carbon,
- Zinc precipitation wastes,
- Barren cyanide solution and cyanide metal complexes, and
- Liners and wastes from decommissioned solution ponds, tanks, and collection ditches.

Two general classifications of impounding structures may be used to describe a tailings impoundment: retention dams and raised embankments. The choice of impounding structure is influenced by the characteristics of the mill tailings, and area geology and topography. In a few cases, cyanidation tailings impoundments have been lined with synthetic or clay liners to inhibit seepage of tailings water.

The size of tailings impoundments varies between operations. For example, the Golden Sunlight Mine near Whitehall, Montana is planning an expansion; when completed, the total surface area of the facility's tailings impoundments will be 450 acres with a depth of 150 feet. The impoundment at the Ridgeway Mine in South Carolina currently measures 210 acres, but was to be expanded to 270 acres when a new pit comes into production. The Pegasus Gold Corporation in Washington, proposed to use staged construction to build their tailings impoundment embankment. Design capacity was 49 million tons of tailings (Montana Tunnels Mining, Inc. 1990; Zaburunov 1989).

### Spent Ore Piles

Spent ore in heaps that have previously been leached using cyanide (or other lixiviant), and the associated pads, may contain small amounts of residual cyanide solution and gold-cyanide complexes. Usually the heap remains in place as a form of spent ore disposal; treatment to neutralize the cyanide and/or other contaminants, as well as puncturing the liner to allow percolation, may be conducted prior to abandonment. The spent ore typically contains unleached metals and other minerals characteristic of the ore body that may present a potential for contaminant transport. During the design of the heap, it is important to consider that heaps are not only leaching units during active operations, but also become waste units as the heap is depleted of values.

Spent ore from on-off pads is detoxified, removed, and disposed of in waste rock dumps or spent ore disposal areas. As discussed in the Ore Characterization Section of this report, the mineralogy varies widely with the source of the gold ore (U.S. DOI, Bureau of Mines 1984). Spent leach piles are reported to vary from 2,000 to 1.5 million short tons in size (Versar, Inc. 1985). The Mesquite Mine in Imperial County, California, uses heaps 75 feet high (20 foot lifts) and covering 92 acres (Silva 1988).

#### 1.5.2.2 Non-RCRA Units

##### Mine Pits and Underground Workings

Pits and underground workings may be allowed to fill with water when a mine closes or stops operation, since there is no longer a need for dewatering. This accumulated water may acidify through contact with sulfide minerals in an oxidizing environment resulting in acid generation. The acid, in turn, may mobilize metals in the remaining rock. In some cases pits and underground workings are backfilled with waste rock or tailings. The potential for contaminant release is dependent on site-specific factors.

Abandoned underground mines and mine shafts may be unprotected, and the mine may, with time, subside, though this is mostly a problem with historical mines. Deficiencies in mine shaft protection may be caused by the use of unsuitable materials, such as inadequate shaft cappings, or by unexpected occurrences that break capping seals, such as water surges in flooded mines (U.S. DOI, Bureau of Mines 1983a).

## **1.6 ENVIRONMENTAL EFFECTS**

Mine pits and underground workings, overburden piles, waste rock dumps, tailings impoundments, and spent leach piles in the gold industry are potential sources of environmental contamination. While all are not waste management units, these are areas in which toxic contaminants are commonly found and have the potential to escape into the environment. Toxicants associated with these areas may include cyanide, cyanide-metal complexes, heavy metals, and acid rock drainage. These toxicants may degrade ground water, surface water, soil, and air quality during mine operation and after mine closure. A discussion of the potential environmental effects associated with gold mining is presented in the following sections. Specific examples from industry are included in this section, as appropriate.

This section on environmental effects does not purport to be a comprehensive examination of environmental effects that can occur or that actually occur at mining operations. Rather, it is a brief overview of some of the potential problems that can occur under certain conditions. EPA is aware that many of the potential problems can be, and generally are, substantially mitigated or prevented by proper engineering practices, environmental controls, and regulatory requirements.

### **1.6.1 Ground Water/Surface Water**

The primary concerns for ground and surface water at mine sites are chemical and physical contamination associated with mine operation. Acid formed by the oxidation of sulfide minerals may be a source of long-term problems at facilities that extract and beneficiate sulfide ores. In addition to wastes, reagents, such as sodium cyanide, used during beneficiation may also be released to ground and/or surface water. Mine rock dumps, disturbed areas, and haul roads may contribute sediment and increase the total solids load to surface water bodies. Potential environmental issues related to ground water are discussed in more detail below.

#### **1.6.1.1 Acid Generation**

Acid rock drainage refers to drainage that occurs as a result of the natural oxidation of sulfide minerals contained in rock that is exposed to air and water. This phenomenon is often referred to as acid mine drainage (AMD); however, it is not necessarily confined to mining activities and can occur wherever sulfide-bearing rock is exposed to air and water. Not all operations that expose sulfide-bearing rock will generate acid drainage. The potential for acid drainage to occur depends on the amount and frequency of precipitation, the acid generation and neutralization potential of the rock, presence of oxygen, and the design of the disposal unit (e.g., encapsulation).

Water percolating through mine workings or piles such as tailings or waste rock may leach sulfides from the ore and surrounding rock and result in the formation of acid drainage. This acid solution may be discharged to ground or surface water, depending on the hydrology of the site. The acid generation potential, as well as the potential for release of other constituents, is increased after the rock is exposed to the atmosphere (i.e., an oxidizing environment). The rate of acid generation is also influenced by the presence or absence of bacteria.

Bacteria, especially *Thiobacillus ferrooxidans*, are able to oxidize sulfur-bearing minerals. The effect of bacteria is pH-dependent; in some cases, lowering of pH over time produces a favorable environment for specific bacteria, leading to accelerated acid generation, once the pH reaches the appropriate level.

In rock dumps, overburden piles, and other mine materials piles that are typically unsaturated, acid drainage may start to form immediately. The acid generation potential, as well as the potential for release of other constituents, is increased in these units compared to the in-place ore body because the rock is finely ground or crushed, thus presenting greater particle surface area, and is in an oxidizing environment. Changes in pH directly affect the availability and transport of metals and other constituents. In addition, mine dewatering/flooding may result in similar impacts, as discussed in the following section.

Milled tailings are susceptible to leaching because of the increased surface area exposure of minerals not extracted during milling. Surface water discharges and seeps from tailings impoundments may contain elevated concentrations of metals leached from the tailings. Acid drainage from tailings impoundments may contribute to the leaching and mobility of metals.

#### 1.6.1.2 Mine Dewatering

Surface and underground mines may be dewatered to allow extraction of ore. Dewatering can be accomplished in two ways: (1) pumping from ground water interceptor wells to lower the water table and (2) pumping directly from the mine workings. At the end of a mine's active life, pumping typically is stopped and the pit or underground workings are allowed to fill with water. Over time, depending on final hydrologic equilibrium, filling may lead to uncontrolled releases of mine water. The mine water may be acidic and/or contaminated with metals, as well as suspended and dissolved solids.

#### 1.6.1.3 Release of Cyanide Solution From Active Heap Leach Units

Release of cyanide solutions from active leach piles or leachate collection ponds may occur during snowmelt, heavy storms, or failures in the pile or pond liners and associated solution transfer equipment. Although not waste-management related, at some operations, monitoring systems for cyanide releases may be installed to detect leaks below the pond and in receiving waters. Monitoring systems are required by some States; see the discussion in the Current Regulatory and Statutory Framework Section.

Release incidents were identified by Versar (Versar, Inc. 1985), with most releases being associated with leachate holding ponds. Doyle (1990) also reported five spill events that occurred during heap leaching activities in Idaho. Releases of cyanide were caused by heavy snowmelt and ice damage. Typically, the facility failed to design and monitor a leak detection system and neutralize cyanide solution prior to winter closure. Although most of these releases were to surface water, cyanide could also be released to ground water.



At the Summitville Site in Colorado failures in the liner have led to contamination of both surface and ground water. Discharge from French drains below the heap is contaminated with cyanide. Release of process water into Wightman Fork of the Alamosa River lead to fish kills in 1986.

At the Kendall Venture mine site in Lewiston, Montana, the ground water beneath the site has become contaminated with nitrate and cyanide in recent years. Nitrate concentrations in one well have risen from 0.016 milligrams per liter (mg/l) in 1988 to 13.6 mg/l in 1989, exceeding the State Drinking Water Quality Standard of 10 mg/l. Total cyanide concentrations inside the permit boundary of the facility have increased from 0.16 mg/l in 1988 to 0.26 mg/l in 1989. The State's "informal" water quality limit of 0.22 mg/l of free cyanide is set for waters outside the permit boundary. The permit allows the mine facility to maintain higher levels for the areas addressed by the permit.

In October 1990, following heavy rains, 10 to 12 million gallons of cyanide solution (100 ppm cyanide) and several tons of sediment spilled into Little Fork Creek and the Lynches River in South Carolina from the Brewer Gold Mine. During the same storm, debris blocked a collection channel and caused a 420,000-gallon spill containing 170 ppm cyanide. The spill resulted in the discoloration of Little Fork Creek and a fishkill for 49 miles down Lynches River (Doyle 1990; South Carolina Department of Health and Environmental Control 1990).

In addition to surface and ground water contamination, both cyanide solution collection ponds and water in the collection ditches at heap leach operations may contain cyanide and, therefore, may be potential sources of contamination for birds and other animals that come into contact with the pond. In response to this, some mine operations are opting to construct tanks for pregnant solutions and otherwise trying to cover existing ponds with fences, nets, or screens to control access to these water sources. Other tactics used to repel wildlife include recorded sounds of predator birds, air cannons, stuffed owls, scarecrows, and firing of hazing shells (Zaburunov 1989). EPA and industry manufacturers of sodium cyanide have entered into a voluntary testing Consent Order to address concerns identified by the U.S. Department of the Interior (DOI) Fish and Wildlife Service relating to wildlife exposure to cyanide.

#### 1.6.1.4 Release From Heap Leach Piles During and After Closure (Reclamation)

When heap leach operations are concluded, a variety of different constituents remains in the wastes. These include cyanide not removed during rinsing or neutralization, as well as heavy metals, and sulfides. After the operation has been closed or reclaimed, runoff from the spent ore may occur without proper design and construction considerations. This runoff may contain constituents associated with the ore, such as heavy metals, and total suspended solids. Depending on the method and completeness of detoxification, spent ore may also continue to have a high pH. Reclaimed piles may have passive controls to control run-on and runoff; the design capacity of these controls may be based on the 10-, 25-, or 100-year 24-hour maximum storm event or the probable maximum precipitation event, depending on the component. The specific requirements are usually determined by the State.

If sulfide ores are present, they may generate acidic leachate which may mobilize the metals that are present in the ore. The constituents associated with the leachate (metals and arsenic) can cause degradation of ground and surface water quality.

## **1.6.2 Soil**

Three types of environmental effects are commonly associated with soils: erosion, sedimentation, and contamination. Erosion and sedimentation may be caused by land disturbances and removal of vegetation related to mining activities (situations that are not unique to mining activities). Under these conditions, precipitation and snowmelt may lead to soil erosion. Soil contamination may result from solution spills associated with equipment (hydraulic oil), releases of leach solution because liner or other equipment failure, deposition of contaminated runoff from waste rock piles, or other circumstances. Included in this section is a review of methods to detoxify cyanide, because spent solutions are often land-applied as a disposal method.

### **1.6.2.1 Land Application of Spent Cyanide Solution**

Spent cyanide solution is generated as a waste during heap leach operations and closure. Prior to land application, these solutions may also be neutralized using calcium hypochlorite or ozone, or other methods (Porath 1981). Cyanide may be degraded or attenuated in soils by volatilization, chelation, precipitation, adsorption, biodegradation, and oxidation to cyanate. Long-term persistence of cyanide residues in mining waste are not completely understood (University of California at Berkeley 1988).

### **1.6.2.2 Detoxification of Cyanide**

The probable fate and transport of cyanide in mine wastes were reported as part of the Mining Waste Regulatory Determination (1986). The rinse solution used to remove residual cyanide and associated metal complexes from heaps usually consists of fresh or recirculated mine or process water. Rinsing continues until the effluent contains a predetermined cyanide concentration. Today, current technology and environmental concerns have led to the development of technologies that attempt to render cyanide benign in the environment. Many methods exist for complexing or decomposing cyanide prior to disposal. These are listed below (University of California at Berkeley 1988):

- Lagooning or natural degradation through photodecomposition, acidification by CO<sub>2</sub> and subsequent volatilization, oxidation by oxygen, dilution, adsorption on solids, biological action, precipitation with metals, and leakage into underlying porous sediments.
- Oxidation by various oxidants.
  - Chlorine gas
  - Sodium and calcium hypochlorites
  - Electro-oxidation and electrochlorination

- Ozone
- Hydrogen peroxide
- Sulfur dioxide and air.

In all cases, cyanide is oxidized initially to the cyanate,  $\text{CNO}^-$ . In some cases the cyanate ion is oxidized further to  $\text{NH}_4^+$  and  $\text{HCO}_3^-$ , and finally the ammonium ion may be oxidized to nitrogen gas.

- Acidification, with volatilization and subsequent adsorption of HCN for reuse.
- Adsorption of cyanide complexes on ion exchange resins or activated carbon.
- Ion and precipitation flotation through cyanide complexation with base metals and recovery with special collectors.
- Conversion of cyanide to less toxic thiocyanate ( $\text{CNS}^-$ ) or ferrocyanide ( $\text{Fe}(\text{CN})_6^{4-}$ ).
- Removal of ferrocyanide by oxidation or precipitation with heavy metals.
- Biological oxidation.

Each treatment method may generate a different waste with the chemical compounds used in cyanide removal as constituents. EPA is currently preparing a separate report on cyanide detoxification. Some of these (e.g., chlorine, ozone, hydrogen peroxide) are toxic to bacteria and other life forms but are unlikely to persist or can be cleaned up easily. Others (e.g., chloramine or chlorinated organic compounds) may persist for long periods in the natural environment.

Detoxification of cyanide using hydrogen peroxide is applicable to spent heaps, tailings, and solution ponds and tanks. The cyanide-bearing solution is sent to a series of hydrogen peroxide reaction tanks. (Ahsan et al. 1989.) Hydrogen peroxide and lime are added to the solution forming precipitate of metal hydroxides and oxidizing free and weakly complexed cyanide into cyanate ( $\text{OCN}^-$ ). Additional steps precipitate copper ferrocyanide, a reddish-brown solid that is stable at a pH of less than 9. Precipitates are separated from the solution and discharged to the tailings impoundment. The solution is then recycled until the desired cyanide concentration is attained in the effluent.

INCO has also developed a technique for detoxification of mine waste streams containing cyanide -- such as CIP and CIL pulps, barren solution, pond waters, and heap leach rinse solutions -- by removing cyanide and base metal complexes. The INCO process uses  $\text{SO}_2$  and air, which is dispersed in the effluent using a well-agitated vessel. Acid produced in the oxidation reaction is neutralized with lime at a controlled pH of between 8 and 10. The reaction requires soluble copper, which can be provided in the form of copper sulfate (Devuyst et al. 1990).

States have adopted specific standards for land application of spent cyanide solutions. For example, South Dakota has set the level for land application of solutions with cyanide at 0.2 mg/l, with additional requirements for concentrations of other heavy metals, sulfides, and other constituents, in conjunction with additional application and monitoring requirements.

EPA is unaware of detailed, long-term field evaluations of the efficiency of any of the cyanide detoxification methods.

### **1.6.3 Air**

#### **1.6.3.1 Fugitive Dust**

The primary sources of air contamination at mine sites are fugitive dust from mine pits and tailings impoundments. During the active life of the mine, water or chemicals may be applied to these impoundments to control dust and prevent entrainment. After mine closure, revegetation or other stabilizing methods may be used to control dust. Air provides exposure routes for constituents (inhalation, deposition, and subsequent soil or surface water contamination, etc.). The potential contaminants are heavy metals and other toxics.

### **1.6.4 Damage Cases**

Environmental damages resulting from mining gold and associated minerals have been documented. Under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (Superfund) and the CWA, EPA has documented contamination to ground water, surface water, air, and soil media.

#### **1.6.4.1 National Priorities List**

EPA has reviewed mining sites on the National Priorities List (NPL). Five sites on the Superfund NPL have problems related to gold extraction and beneficiation: Carson River, Nevada; Clear Creek/Central City, Colorado; Cimarron Mining Corporation, New Mexico; Silver Mountain Mine, Washington; and Whitewood Creek, South Dakota. Appendix 1-B provides a general site description and a summary of the environmental effects associated with each site.

#### **1.6.4.2 304(l) Sites**

Section 304(l) of the Water Quality Act of 1987 requires States to identify water bodies not meeting applicable water quality criteria, to identify point-source dischargers to these water bodies, and to develop and require implementation of individual control strategies (ICSs) for those point-source dischargers that contribute significantly to exceedance to the water quality criteria. Sunnyside Gold (Mayflower Mill) and Clear Creek/Central City are sites identified under 304(l) as point-source dischargers of contaminants related to gold mining activities. A summary of each site is provided in Appendix 1-C. Note that one of these sites, Clear Creek/Central City, is on the NPL and is discussed in Appendix 1-B as well.

## **1.7 CURRENT REGULATORY AND STATUTORY FRAMEWORK**

Gold mining activities are regulated through a complex set of Federal and State regulations. Statutes administered by EPA, such as the CWA (33 USC §1251 et seq.) and the Clean Air Act (CAA) (42 USC §7401 et seq.), apply to mining sites regardless of where they are located. Operations on Federal lands are subject to additional regulation by the Federal agency or agencies having jurisdiction over the lands, such as the Bureau of Land Management (BLM), the Forest Service (FS), the Fish and Wildlife Service (FWS), and the National Park Service (NPS). In addition, the Army Corps of Engineers has promulgated rules for construction and mining activities that have a potential impact on wetlands and navigable waters. Finally, operations must comply with a variety of State and local requirements, some of which may be more stringent than Federal requirements.

Federal air quality regulations do not specifically address gold mining, but they do regulate sources of certain types of air pollution. Federal water quality regulations, on the other hand, include effluent discharge standards for specific types of gold operations. Federal land management agencies have regulations that, in some cases, target particular types of extraction or beneficiation methods (e.g., placer mining turbidity issues). The BLM has a policy for management of mining operations using cyanide and other leaching techniques. State regulations similarly address operation types (e.g., cyanide heap leach operations), but less frequently target specific minerals.

This section summarizes the existing Federal regulations that may apply to gold mining operations. It also provides an overview of the operational permitting, water quality, air quality, waste management, reclamation, and wetlands protection regulations in two gold-producing States (Nevada and South Carolina). The regulatory requirements for heap leach operations in 15 gold-producing States are also summarized and presented in Table 1-6

Table 1-6. Heap Leach Regulatory Requirements for the 15 Gold-Producing States

State	Heap Leach Operations	Regulated	Effluent Standard <sup>a</sup>	Heap Liner	Residual Cyanide Destruction
Alaska	Yes	Yes <sup>b</sup>	Zero Discharge	Yes <sup>c</sup>	Yes <sup>c</sup>
Arizona	Yes	Yes	Zero	Yes	No
California	Yes	Yes	Zero	Yes	Yes
Colorado	Yes	Yes	Zero	Yes <sup>c</sup>	Yes <sup>c</sup>
Idaho	Yes	Yes	Zero	Yes	Yes
Michigan	No	Yes <sup>d</sup>	Zero	No	No
Montana	Yes	Yes <sup>e</sup>	Zero	Yes <sup>b</sup>	Yes
Nevada	Yes	Yes	Zero	Yes	Yes <sup>b</sup>
New Mexico	Yes	Yes	Zero	Yes <sup>b</sup>	Yes
North Carolina	No	Yes <sup>d</sup>	Zero	No	No
Oregon	Yes	Yes	Zero	Yes	Yes
South Carolina	Yes	Yes	Zero	Yes	Yes <sup>2</sup>
South Dakota	Yes	Yes	Zero	Yes	Yes
Utah	Yes	Yes <sup>f</sup>	Zero	Yes	Yes
Washington	No	Yes <sup>d</sup>	Zero	Yes	No

<sup>a</sup>All State discharge standards must meet Federal CWA requirement for zero discharge of process waste water from cyanidation operations (40 CFR, Part 440, Subpart J, undated). All States have a 0.22 mg/l ground water concentration limit for cyanide.

<sup>b</sup>Requirement applied on a site-by-site basis.

<sup>c</sup>Regulated through solid waste regulations.

<sup>d</sup>State does not have regulations specific to cyanide operations because it does not have such operations. If an application to conduct a cyanide operation were received, the State would regulate it under general mining regulations with specific requirements determined on a site-by-site basis.

<sup>e</sup>1989 State regulations no longer exempt cyanide operations under 5 acres in size.

<sup>f</sup>State heap leach regulations are being developed.

(Source: Compiled from State regulations.)

## **1.7.1 Environmental Protection Agency Regulations**

### 1.7.1.1 Resource Conservation and Recovery Act

The EPA implements the Resource Conservation and Recovery Act (RCRA) to protect human health and the environment from problems associated with solid and hazardous wastes. Mining wastes are included in the Act's definition of solid waste. In 1980, RCRA was amended to include what is known as the Bevill Amendment (§3001(b)(3)(A)). The Bevill Amendment provided a conditional exclusion from RCRA Subtitle C hazardous waste requirements for wastes from the extraction, beneficiation, and processing of ores and minerals.

The exemption was conditioned upon EPA's preparation of a report to Congress on the wastes and a subsequent regulatory determination as to whether regulation under Subtitle C was warranted. EPA met its statutory obligation with regard to extraction and beneficiation wastes with the 1985 *Report to Congress: Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos,*

*Overburden from Uranium Mining, and Oil Shale.* In the subsequent regulatory determination (51 FR 24496; July 3, 1986), EPA indicated that extraction and beneficiation wastes (including gold mining and milling wastes) should not be regulated as hazardous but should be regulated under a Subtitle D program specific to mining waste.

### 1.7.1.2 Clean Water Act

Under section 402 of the CWA (33 USC §1342), all point-source discharges to waters of the United States must be permitted under the NPDES with the exception of some storm water discharges covered by the 1987 amendments to the CWA. A point source is defined as any discrete conveyance, natural or man-made, including pipes, ditches, and channels. NPDES permits are issued by EPA or delegated States.

Effluent limits imposed on an NPDES permittee are either technology-based or water-quality-based. The national technology-based effluent guideline limitations have been established for discharges from most active gold mines under the Ore Mining and Dressing Point-Source Category 40 CFR Part 44 (40 CFR, Part 440, Subpart J, undated). These regulations address point source discharges from all types of gold extraction techniques, including open-pit, underground, froth-flotation, heap, *in situ*, and tank cyanide leaching. Discharges from regulated operations must meet best available technology/best practicable technology (BAT/BPT) standards for cadmium, copper, lead, mercury, zinc, total suspended solids (TSS), and pH. The specific effluent standards for these contaminants are summarized in Tables 1-7a and 1-7b

**Table 1-7a. BPT<sup>1</sup> and BAT<sup>2</sup> Standards for the Ore Mining and Dressing Point-Source Category:  
Copper, Lead, Zinc, Gold, Silver, and Molybdenum Ore Subcategory  
Concentration of Pollutants Discharged in Mine Drainage (milligrams per liter)**

Pollutant	BPT Maximum for 1 Day	BPT Average of Daily Values for 30 Consecutive Days	BAT Maximum for 1 Day	BAT Average of Daily Values for 30 Consecutive Days
Cadmium	N/A	N/A	0.10	0.05
Copper	0.30	0.15	0.30	0.15
Lead	0.6	0.3	0.6	0.3
Mercury	0.002	0.001	0.002	0.001
Zinc	1.5	0.75	1.5	0.75
Total Suspended Solids	30	20	N/A	N/A
pH	6.0 - 9.0	6.0 - 9.0	N/A	N/A

1 BPT - Best Practicable Technology

2 BAT - Best Available Technology

**Table 1-7b. BPT and BAT Standards for the Ore Mining and Dressing Point Source Category:  
Copper, Lead, Zinc, Gold, Silver and Molybdenum Ore Subcategory  
Concentration of Pollutants Discharged From Mills That Use the Froth-Flotation  
Process Alone or in Conjunction With Other Processes for Beneficiation  
(milligrams per liter)**

Pollutant	BPT Maximum for 1 Day	BPT Average of Daily Values for 30 Consecutive Days	BAT Maximum for 1 Day	BAT Average of Daily Values for 30 Consecutive Days
Cadmium	0.10	0.05	0.10	0.05
Copper	0.30	0.15	0.30	0.15
Lead	0.6	0.3	0.6	0.3
Mercury	0.002	0.001	0.002	0.001
Zinc	1.0	0.5	1.0	0.5
Total Suspended Solids	30	20	N/A	N/A
pH	6.0 - 9.0	6.0 - 9.0	N/A	N/A

(Source: 40 CFR Part 440 Subpart J.)



. States with heap leach operations typically impose a zero-discharge requirement for process waste water from cyanide leaching operations. Permit writers can establish additional technology-based limitations at a specific mine based on best professional judgment (BPJ).

The permit writer must ensure that the NPDES permit will protect the water quality of the receiving water. Table 1-8 identifies the Federal water quality criteria established by EPA under the CWA, and the current drinking water standards, Maximum Contaminant Level (MCL), established by EPA under the Safe Drinking Water Act (SDWA). The CWA also requires each state to develop water quality standards to protect the designated uses of receiving waters. NPDES permit writers must also determine whether technology-based effluent limitations are adequate to ensure that applicable water quality standards are met. Where technology-based limits are not sufficiently stringent, water-quality-based effluent limitations must be developed. As a result, an NPDES permit may include technology-based effluent limitations for some pollutants and water-quality-based effluent limitations for other pollutants.

**Table 1-8. Federal Water Quality Criteria and Drinking Water MCL <sup>a</sup> (mg/l)**

Constituent	Fresh Acute <sup>b</sup>	Fresh Chronic <sup>b</sup>	Marine Acute <sup>b</sup>	Marine Chronic <sup>b</sup>	Maximum Contaminant Level (MCL)
Antimony	9,000	1,600	(--)	(--)	0.01 or 0.005 (option) <sup>c</sup>
Arsenic	190	360	36	69	0.05
Cyanide	22	5.2	1.0	1.0	0.2
Mercury	2.4	0.012	2.1	0.025	0.002
Thallium	1,400	40	2,130	(--)	0.002 or 0.001 (option) <sup>c</sup>

<sup>a</sup>There are no standards for the other metals and minerals (e.g., bismuth, tellurium, pyrite, and pyrrhotite) discussed in the section on environmental effects.

<sup>b</sup>Standards are relative to water hardness. Standards shown are for hardness 100.

<sup>c</sup>(option) Where options are presented, the final limit will depend upon the selection of a Practical Quantitation Limit (PQL), the limit of detection at which analysis of samples can produce consistent results in normal laboratory conditions.

(Source: U.S. EPA 1991.)

Contaminated storm water runoff from some mining operations has been documented as causing water quality degradation. In the past, storm water discharges received limited emphasis under the NPDES program. However, EPA promulgated regulations (55 FR 47990; November 16, 1990) that specifically address point source discharges of storm water from industrial facilities, including active

and inactive/abandoned mine sites. These regulations require NPDES permits for all point source discharges of contaminated storm water from mine sites. Storm water requirements will be applied to mine sites either individually (i.e., through individual NPDES permits) or in larger groups (i.e., through general NPDES permits applicable to similar operations).

Some discharges from mine sites do not meet the traditional definition of a "point-source discharge." Specifically, runoff from tailings piles, overburden and mine development rock piles, and other mine areas often is not controlled through a discrete conveyance. As a result, these types of discharges have frequently been considered nonpoint-source discharges. Under the Section 319 of the CWA, States have been required to prepare nonpoint-source assessment reports and to develop programs to address nonpoint sources on a watershed-by-watershed basis. Each State must report to EPA annually on program implementation and resulting water quality improvements.

#### 1.7.1.3 Clean Air Act

Under the CAA (42 USC § 4209, Section 109), EPA established national primary and secondary ambient air quality standards for six "criteria" pollutants. These are known as the National Ambient Air Quality Standards (NAAQSs). The NAAQSs set maximum concentration limits for lead, nitrogen oxides, sulfur dioxide, carbon monoxide, suspended particulate matter of less than 10 microns in diameter, and ozone. To attain the air quality goals set by the CAA, States and local authorities were given the responsibility of bringing their regions into compliance with NAAQSs. In addition, States may promulgate more stringent ambient air quality standards. EPA also has promulgated air quality regulations that specifically address smelting operations. Since this report does not evaluate mineral processing, no further discussion of those rules are found in this report.

New Source Performance Standards, authorized under CAA §111, also have been promulgated for metallic mineral-processing plants (40 CFR §60(LL)). A processing plant is defined as "any combination of equipment that produces metallic mineral concentrates from ore; metallic mineral processing commences with the mining of the ore." However, all underground processing facilities are exempt from the NSPSs. Also, NSPS particulate emission concentration standards only apply to stack emissions. NSPSs require operations to contain stack-emitted particulate matter in excess of 0.005 grams per dscm. In addition, stack emissions must not exhibit greater than 7 percent opacity, unless the stack emissions are discharged from an affected facility using a wet scrubbing emission control device. However, on or after 60 days following the achievement of the maximum production rate (but no later than 180 days after initial startup), operations must limit all process fugitive emissions (meaning fugitive dust created during operation though not released through a stack) to 10 percent opacity.

Prevention of Significant Deterioration (PSD) provisions of the CAA are intended to ensure that NAAQS are not exceeded. Under this program, new sources are subject to extensive study requirements if they will emit (after controls are applied) specified quantities of certain pollutants. Few mining sites are subject to PSD requirements since they typically are not predicted to emit sufficient quantities.

State ambient air standards promulgated to meet or exceed Federal NAAQSs are generally maintained through permit programs that limit the release of airborne pollutants from industrial and land disturbing activities. Fugitive dust emissions from mining activities may be regulated through these permit programs (usually by requiring dust suppression management activities).

Currently, only the six criteria pollutants are regulated by NAAQS. Several other pollutants are regulated under National Emission Standards for Hazardous Air Pollutants (NESHAPs). NESHAPs address health concerns that are considered too localized to be included under the scope of NAAQSs.

Under the 1990 Amendments to the CAA, Congress required EPA to establish technology-based standards for a variety of hazardous air pollutants, including cyanide compounds. In November of 1993, EPA published a list of source categories and a schedule for setting standards for the selected sources. Furthermore, if a source emits more than 10 tons per year of a single hazardous air pollutant or more than 25 tons per year of a combination of hazardous air pollutants, the source is considered a "major source." Major sources are required to use the maximum available control technology (i.e., BAT) to control the release of the pollutants (CAA Section 112).

## **1.7.2 Department of Interior**

### **1.7.2.1 Bureau of Land Management**

Most gold mining operations on Federal lands are conducted on mining claims located pursuant to the General Mining Laws. Under the 1872 Mining Law, a person has a statutory right to go upon the open (unappropriated and unreserved) public lands of the United States for the purpose of prospecting for, exploring, developing, and extracting minerals. Once a person has made a valuable mineral discovery and has properly located the claim pursuant to the mining laws, the person has broad possessory rights to develop the minerals upon which the claim was based.

Because of the broad nature of the claimant's possessory rights, the Federal agencies having management responsibilities over the lands upon which the claim is located cannot, in most cases, wholly restrict mining operations. Nonetheless, the surface managing agency can subject the mining operations to reasonable regulation to prevent "unnecessary and undue degradation" of Federal lands.

All mining claims located on lands managed by the BLM are subject to BLM regulation to prevent "unnecessary and undue degradation" of the Federal lands and resources involved. The BLM's authority to regulate mining claim operations under this regulation derives from the Federal Land Policy and Management Act of 1976 (FLPMA), the statute which sets out the BLM's general land management and planning authority. Exploration sites are subject to the less-than-5-acre exemption or must submit a plan of operation if greater than 5 acres.

The BLM's general surface management regulations governing mining claim operations, which include gold mining operations, are found at 43 CFR Part 3809. These regulations cover general design, operating and reclamation standards, monitoring requirements, bonding requirements, environmental review requirements, and remedies for noncompliance. They establish three general use categories for mining operations, each eliciting different levels of oversight by the BLM. These categories are (1) casual use operations (i.e., those that normally result in only negligible disturbances of Federal lands and resources and that require no prior notice to or approval from the BLM), (2) notice-level operations (i.e., those that involve disturbances of 5 acres or less for which the operator must notify the BLM prior to commencing surface disturbing activities), and (3) plan-level operations (i.e., disturbances of greater than 5 acres, and operations in some specified areas, for which the operator must obtain BLM approval of a plan of operations prior to commencing activity).

All operations, including casual use and operations under either a notice or a plan of operations, must be conducted to prevent unnecessary or undue degradation of the Federal lands. All operations must also be reclaimed and must comply with all applicable State and Federal laws, including air and water quality standards such as those established under the CAA and the CWA.

All mining operations are subject to monitoring by the BLM to ensure that they do not cause unnecessary or undue degradation, and that all operators are responsible for fully reclaiming the area of their claim.

The current BLM policy for bonding was established by an internal Instruction Memorandum (IM) issued on August 14, 1990 (U.S. DOI, Bureau of Land Management 1990a). Under this IM, the BLM will not require bonds for most casual use or notice-level operations. However, a 100 percent reclamation bond will be required from all operators who have established records of noncompliance. Additionally, the IM requires the posting of a 100 percent reclamation bond for all operations that use cyanide or other leachates and discharge cyanide-bearing tailings or fluids to impoundments or tailings ponds. The 100 percent bonding requirement applies only to those portions of the operation encumbered by cyanide facilities.

All plan-level operations, regardless of operation type (e.g., strip, open-pit, dredge, and placer) will be required to post a bond. Bond amounts are to be set at the discretion of the BLM (up to \$2,000 per acre, except as noted above), depending on the nature of the operation, the record of compliance, and whether it is covered by a satisfactory State bond.

By another internal IM issued on August 6, 1990 (U.S. DOI, Bureau of Land Management 1990a), the BLM established uniform standards for surface management of mining operations that use cyanide and other chemical leaching methods for mineral extraction on public lands. This IM directs BLM Area and District offices to inspect all cyanide operations at least four times a year. All facilities employing cyanide leaching techniques must be fenced and must ensure protection of the public, wildlife (including migratory birds), and livestock. All operations must use the Best Practicable Technology (BPT) and must meet at least the following standards:

- Facilities must be designed to contain the maximum operating water balance in addition to the water from 100-year, 24-hour storm event. Containment ponds must be included in all containment systems.
- Tanks containing lethal solutions must be bermed to contain the maximum tank contents in the event of catastrophic tank failure.
- Facilities must be constructed so that solution containment is maximized.
- Leakage detection and recovery systems must be designed for heap and solution containment structures. Monitoring of ground and surface water through closure and final reclamation is required.
- Cyanide solution and heaps must be neutralized or detoxified.
- Surface disturbances must be minimized.
- Engineering designs, maps, and cross sections of the leaching facilities must be submitted as part of operating plans. Ground water and soil mechanics information is required for review of the designs.

These minimum standards must be met by all operations under mining claims on BLM land that use cyanide leaching techniques, unless an equally effective standard is set and enforced under State law. The authorized officer may waive certain of these minimum standards for existing operations in limited circumstances and only when the operations are not resulting in unnecessary or undue degradation or causing other unacceptable results (such as unauthorized discharges or avian mortalities). The BLM will supplement these minimum criteria through the development of State and/or district or resource area plans, as appropriate.

Mining claims located in BLM wilderness study areas are generally subject to stricter regulation than other mining claims. The regulations covering mining in wilderness study areas are found at 43 CFR Part 3802. The IM discussed above for cyanide management applies to relevant operations in wilderness study areas in addition to the 43 CFR Part 3809 regulations.

The BLM has the authority to issue leases for gold on certain acquired (as opposed to public domain) lands. Although this is rarely done, such leases would be covered by the general regulations applicable to hardrock leasing found at 43 CFR Part 3500.

#### 1.7.2.2 National Park Service and Fish and Wildlife Service

Generally, location of new mining claims is prohibited in most areas managed by the NPS and the FWS. Regulations at 36 CFR Part 9 govern activities on land managed by the NPS under patented and unpatented mining claims already in existence prior to the time the lands were included with units of the NPS. On the other hand, the regulations at 50 CFR Part 29 govern mining activities under mineral rights on lands managed by the FWS that were vested prior to the acquisition of the land by the United States. As of 1989, mining

activities were being conducted in 14 refuges under the jurisdiction of the FWS, 8 of which were in Alaska (Kilcullen 1990).

### **1.7.3 Department of Agriculture; Forest Service**

Although the BLM has general management authority for the mineral resources on FS lands, the BLM regulations governing activities under mining claims do not apply to units of the FS. Instead, surface uses associated with operations under mining claims on FS lands are governed by the FS regulations in 36 CFR Part 228, Subpart A. The FS regulations generally mandate that operations under mining claims be conducted to minimize adverse environmental impacts on FS surface resources.

The FS regulations are similar to the BLM regulations and provide for FS consultation with appropriate agencies of the U.S. DOI in reviewing technical aspects of proposed plans of operation. However, the FS regulations differ in that the general use categories do not specify acreage, as opposed to the BLM's, where the use category is based on the acreage disturbed. The FS regulations require that persons proposing to initiate any operations that might disturb surface resources must file a notice of intent to operate with the district ranger with jurisdiction over the area to be affected. If the district ranger determines that the operations will be likely to cause significant disturbance of surface resources, the operator must submit a proposed plan of operations. Neither a notice of intent to operate nor a proposed plan of operations are required for the locating or marking of mining claims; mineral prospecting or sampling that will not cause significant surface disturbance; operations that do not involve the use of mechanized equipment or the cutting of trees; or uses that will be confined to existing roads.

The proposed plan of operations must include a thorough description of the proposed site, the nature of the proposed operations, and measures for meeting environmental protection requirements. Operations must comply with applicable environmental laws and must, where feasible, minimize adverse environmental effects on FS resources. The FS will conduct an environmental assessment of the proposed plan of operations and, if necessary, prepare a National Environmental Policy Act (NEPA) environmental impact statement.

The regulations specify standards for reclamation and provide that the district ranger may require a reclamation bond to cover the cost of reclamation. Where State bonding regulations exist, the FS has established memorandums of understanding with the States to prevent double bonding. In these cases, the bond amount must meet the more stringent standard, whether it is that of the State or the FS. Regulations specific to mining operations on FS Wilderness Areas are found at 36 CFR Part 293.

### **1.7.4 Army Corps of Engineers**

Gold mining operations that fall within the jurisdiction of Army Corps of Engineers include placer mines, which have a great potential to physically restructure wetlands or "navigable waters." Until 1986, most placer mining activities were regulated by the Corps, under Section 404 of the CWA, through permits for the discharge of dredged materials. In 1986, the Corps and EPA entered into an agreement (updated in 1990) on

the definition of "fill material" for 404 permitting. The agreement provided that jurisdiction of placer mining discharges would be determined on a case-by-case basis. Since then, the Corps has been responsible only for dredge and fill activities accessory to mining operations. These activities include construction of sediment ponds and roads, filling of dredge pits, etc., and are regulated nationwide through permits issued by the Corps.

## **1.7.5 STATE REGULATIONS**

### **1.7.5.1 Nevada**

Nevada has regulatory requirements controlling gold mining activities. Some of the regulations are a result of Federal program delegation (e.g., NPDES), while others were developed under Nevada statutes (e.g., reclamation).

In Nevada, 80 to 90 percent of mining operations are located on BLM or FS land. According to a State official, Nevada considers the Federal Government's role as a land owner to be no different from the role of any other land owner (Taff 1991). Although Federal agencies like the BLM and FS have the authority to manage the resources on their land, the State does not believe they have the authority to supersede State regulations designed to protect the environment as a whole. Nevada considers its regulation of mining, including operational permitting and reclamation requirements, to be part of its efforts to protect general environmental quality, especially water quality. Therefore, operations located on Federal lands must comply not only with the BLM or FS operating and reclamation requirements, but also with State operating and reclamation permitting requirements and general air and water quality regulations.

More specifically, an operation on Federal land must obtain both an operating permit from the State and "notice" or "plan of operations" approval from the appropriate Federal agency (see the BLM and FS discussion above for specifics regarding when "notice" and "plan of operations" are required). Similarly, operations located on Federal land must obtain State "reclamation permits" (separate from operating permits), and must also comply with BLM/FS reclamation requirements. However, specific attention has been given to facilitate compliance with both State regulations and the BLM and FS regulations. For instance, State permits incorporate most of the BLM and FS requirements. For this reason, and because State permit requirements are more comprehensive than those promulgated by the BLM and FS, a State permit is considered by the BLM and FS to be adequate proof that all their own requirements have been met (Taff 1991). However, the appropriate Federal agency performs comprehensive analysis, the results of which are incorporated into the permit. The specific State regulations governing gold mining operations are discussed below.

#### **Reclamation**

Although the State's operating permits contain some reclamation requirements (such as the stabilization of tailings and closure planning), reclamation permits address, in greater detail, the specific closure procedures

the operator agrees to undertake. Specific requirements are applied on a case-by-case basis but generally include revegetation and containment of all wastes to prevent runoff and erosion. Both operating permits and reclamation permits require facilities to submit closure plans for process component sources (defined as any distinct portion of a facility that is a point source) at least 2 years before the anticipated closure of the source (Nevada Administrative Code 1989).

Reclamation regulations that became effective on October 1, 1990, require all existing exploration projects and mining operations to obtain a reclamation permit no later than whichever is earlier: October 1, 1993, or abandonment of the project. All new exploration projects and mining operations must obtain a permit prior to beginning operations. Each reclamation plan must identify a proposed postmining land use for the area that will be disturbed by operations and must describe the manner in which the disturbed area will be reclaimed to a condition that will support the proposed postmining land use.

In addition, each reclamation permit must be supported by a reclamation surety. The regulations identify several forms of surety that are acceptable. The amount of the reclamation surety is determined by estimating the actual cost to the Government agency of implementing the proposed reclamation plan.

Nevada regulations now require all surface mines to purchase reclamation bonds. Existing mines, however, had until 1993 to purchase bonds. Under a memorandum of understanding between the State, the FS, and the BLM, mining operations in the State on Federal land may have either the State, the BLM, or the FS designated as the holder of the reclamation surety. This prevents double bonding on Federal lands. However, when operations have the BLM or FS as the surety holder, the State retains the right to evaluate the surety amount for adequacy and may require additional surety if it is found to be insufficient to ensure reclamation. The State calculates the bond amount based upon the potential estimated cost to the agency of reclaiming the site if the operator fails to complete reclamation and based on the operator's record of compliance (Taff 1991).

#### Water Quality

Nevada regulates the discharge of pollutants, including suspended solids, from mining activities under a federally approved NPDES program. The State program requires pollution control permits for heap leach operations and mill dischargers (Miereau 1991). Pollution control permits prohibit the discharge of process fluids or liquid waste streams from these facilities during operation and closure activities. To obtain a pollution control permit, a facility must incorporate Best Management Practices (BMPs), including double-lined ponds or clay-lined tailings impoundments, into its design. Also, the placement of waste rock and tailings must be such that the potential for leaching is minimized. The State did approve a "319" Nonpoint-Source Pollution Management Program. It has drafted BMPs, but no regulations.

In addition, Nevada allocates water rights by establishing preferred uses of water within designated ground water basins. Mining is considered a preferred use for certain ground water basins. However, to access water reserves, mining operations must obtain a special appropriation permit to withdraw a certain amount of



ground water or surface water from a particular basin. The State limits total withdrawals from any given basin to the annual recharge or "perennial yield" of the basin (Jessup 1988).

As of September 1, 1989, all existing mining facilities were given 3 years from that date to obtain operating permits (Nevada Administrative Code 1989). After July 1, 1990, all new onsite construction or modification projects were required to obtain permits. Permit applications require a plan of operations, hydrogeologic studies, assessment of impact to surface and ground water, methods for the control of storm water, notification of disposal sites for spent ore, etc. However, pilot facilities, small-scale operations (less than 10,000 tons of ore chemically processed per year or no more than 30,000 tons total per mine lifetime), and placer operations that rely exclusively on physical separation methods may file an abbreviated permit application. Permits also require stabilization of tailings and spent ore. Tailings and impoundment materials must be sampled and characterized once the impoundment is no longer active. In addition, mining operations are required to leave tailings impoundments in a state that is not hazardous to wildlife. Spent ore from cyanide leaching methods must be rinsed until weak acid dissociable (WAD) cyanide levels in the effluent rinse water are less than 0.2 mg/l, the pH of the effluent rinse water is between 6 and 9, and any runoff from spent ores piles would not degrade the waters of the State.

As part of the Water Pollution Control Permit, mines report quarterly on results of meteoric water mobility testing and waste rock analysis to determine the acid-generating potential of waste rock. The meteoric mobility test is an extraction procedure. The extracted solution is analyzed for nitrate, phosphorous, chloride, fluoride, total dissolved solids, alkalinity, sulfate, and metals. Waste rock analysis is intended to determine the net acid generation potential of the material placed in the waste rock dump during a quarter. Samples are collected daily during the quarter and classified based on their net carbonate value as sulfate: highly basic, basic, slightly basic, neutral, slightly acidic, acidic, and highly acidic. The quarterly composite sample to be analyzed is prepared on a tonnage weighted average for each classification and aggregated prior to analysis.

#### Air Quality

Nevada's ambient air quality standards meet, but do not exceed, Federal requirements, with the exception of the ambient standards for the Lake Tahoe area. For this area, the State has promulgated standards for ozone and carbon monoxide that are tougher than those required by EPA (Jessup 1988). Air quality permits must be obtained for the construction and operation of any new sources. An evaluation must be submitted by the applicant prior to the issuance of a registration certificate for a new or modified point source. This evaluation must include an estimate of air quality after construction of the proposed facility to ensure that ambient air quality will be maintained. In addition, Nevada's air quality regulations contain emission limits for specific mining companies, including several precious metal mining operations. Under Nevada Administrative Code (445.430-445.846), Point-Source Particulate Permits are required. These permits cover fugitive dust from construction and operation activities.

### 1.7.5.2 South Carolina

South Carolina has regulatory programs, including permitting and bonding, that control gold mining activities. Some programs are delegated by the Federal government while others are under the authority of South Carolina statutes.

#### Operating Permits

Under the South Carolina Mining Act (Section 48-20 of the State Code), the Division of Mining and Reclamation of the Land Resources Commission (LRC) is charged with ensuring that lands and waters involved in mining are protected and restored to the "greatest practical degree." LRC's responsibilities include issuing mining and reclamation permits, reviewing and approving reclamation plans, collecting reclamation bonds, and inspecting facilities to ensure compliance. LRC coordinates its activities with and supplements the regulatory activities of the Department of Health and Environmental Control (DHEC). As amended in 1990, the Act states clearly that reclamation requirements for a mine facility are part of closure. Annual reclamation reports are required by LRC and are also required through construction permits issued by DHEC. The South Carolina Mining Act, as amended in 1990, gives the LRC authority to assess civil penalties for noncompliance with the approved reclamation plan or schedule of reclamation. Penalties up to \$1,000 per day per violation are authorized.

Operating permits are required for all surface mining activities with excavations exceeding 1 acre in area (South Carolina Code of Regulations 1980). Permits require submittal of site location and hydrogeologic information, facility construction plans, and containment system plans (e.g., settlement ponds and terraces). Reclamation plans are also required with any operating permit application. Reclamation is not required where infeasible for particular areas, provided steps are taken to minimize the extent of the disturbance.

#### Reclamation

Reclamation bond amounts are set at the discretion of the DHEC. To obtain bond release, mining sites must be revegetated, slopes must be graded, and a useful purpose established for any water impoundments.

#### Water Quality

South Carolina's Bureau of Water Pollution Control (WPC) within DHEC is charged with protecting surface and ground waters of the State. The Bureau's authority stems from the Clean Water Act (CWA) and the South Carolina Pollution Control Act (PCA). Applicable regulations include: SC Regulation 61-9 (NPDES Permits), SC Regulation 61-68 (Preparation and Submission of Engineering Reports), SC Regulation 61-68, -69 (Water Classification and Standards), and SC Regulation 61-71 (Well Standards and Regulations).

The Bureau's authority over mining facilities extends as long as there are potential impacts to surrounding waters, from construction through post-closure. The Bureau's program is implemented through permitting systems, violation of which can result in the issuance of consent orders or administrative orders as well as

civil and criminal actions. The Bureau issues NPDES permits for surface water discharges, as well as construction permits for facility components, which include ground-water monitoring requirements.

South Carolina has an EPA-approved NPDES program and regulates effluent discharges accordingly. The State discharge limits are the same as the Federal guidelines. In addition to classifying surface waters according to expected use, the State has ground water classifications that are intended to maintain ground water quality. The State classifies all ground water as "Groundwater B" (GB), meaning that it must be suitable for use as drinking water without pretreatment. State drinking water MCLs are the same as Federal MCLs. Two other classifications, one more stringent [Groundwater A (GA)] and one less stringent [Groundwater C (GC)], can be applied only upon petition by a private interest (Jessup 1988). However, the State official contacted knew of no instances where GA or GC classifications had been granted (Kennedy 1991). Mining operations are required to install monitoring wells to ensure that ground water quality standards are maintained.

To further protect water quality, DHEC issues construction permits for industrial waste water treatment systems, which include mining process waste water ponds and rinse systems for cyanide leaching operations. Construction permits also enforce DHEC's policy (no actual rules exist) of requiring operators to place impermeable liners or asphalt pads under tailings impoundments and leaching areas (Kennedy 1991).

#### Air Quality

South Carolina opacity requirements, which limit fugitive dust emissions from all sources including mining operations, are more stringent than Federal opacity requirements. DHEC's Bureau of Air Quality Control issues and enforces Air Emissions Permits under the South Carolina Pollution Control Act and State Regulation 61-62.1. Facilities are issued five-year operating permits and construction permits that establish emission limits for various units. In addition to these limits, the permit makes operators subject to applicable New Source Performance Standards for Metallic Mineral Processing (40 CFR Part 60, Subpart LL). The permit may also require that dust from haul roads and turnaround areas be controlled by water sprays and water trucks and that stockpiles or waste rock piles be sprayed with water when wind erosion creates excessive emissions. The Bureau of Air Quality Control is authorized to seek civil and/or criminal penalties when permit requirements are violated by a facility. Formal facility inspections are conducted by DHEC on an annual basis.

#### Solid Waste

Under State law, mining wastes are currently excluded from regulation as solid waste. However, legislation that was under development, the Solid Waste Management Act, would broaden the State's definition of "industrial solid waste" to include materials that have been chemically altered, including wastes from cyanidation operations (Joy 1990). Operators would be required to obtain solid waste permits (separate from operating permits) for the disposal of such chemically altered mining wastes. Solid waste permits

mandate controls for runoff water and require spreading and revegetation of the waste to prevent erosion (South Carolina Code of Regulations 1980).

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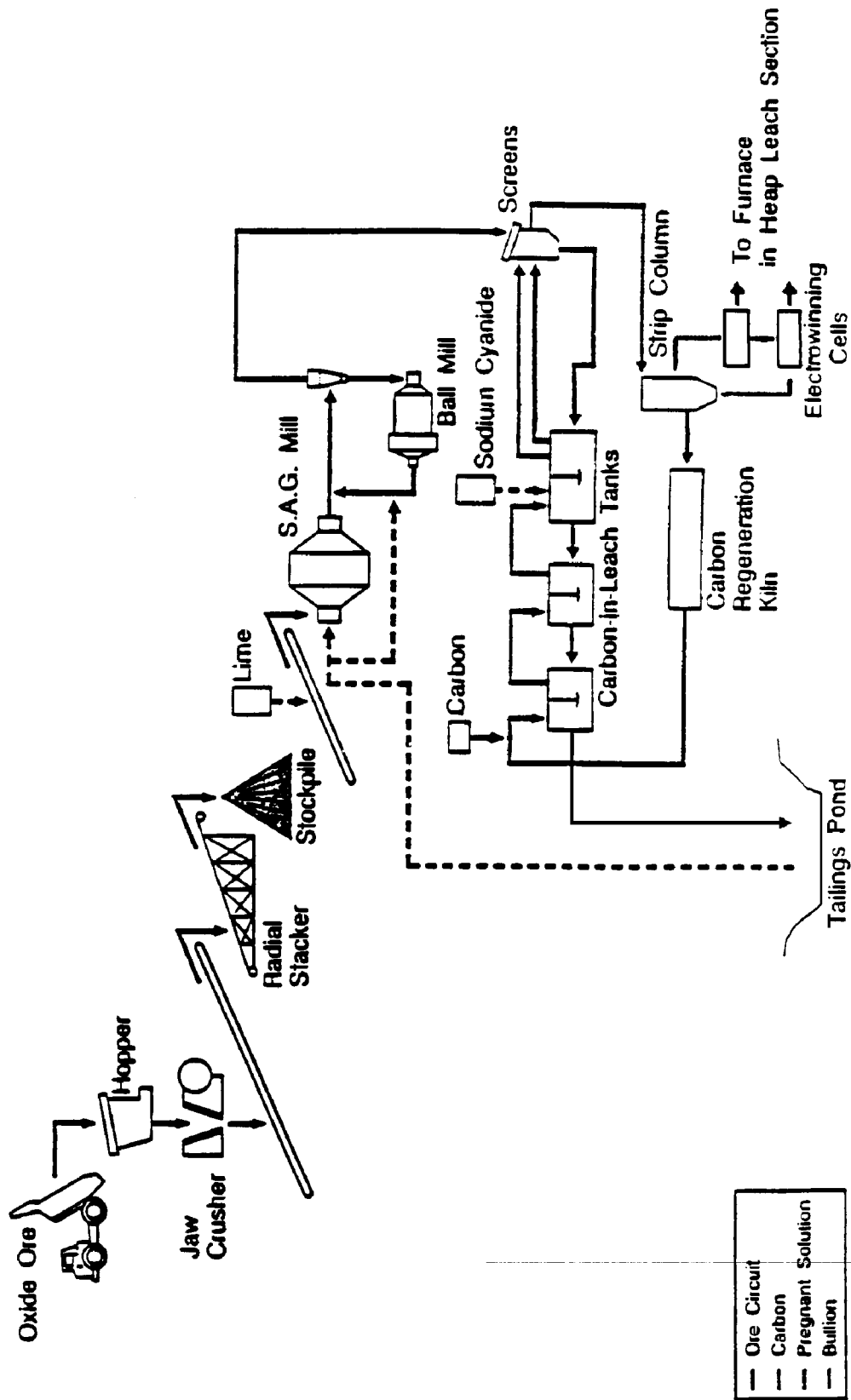
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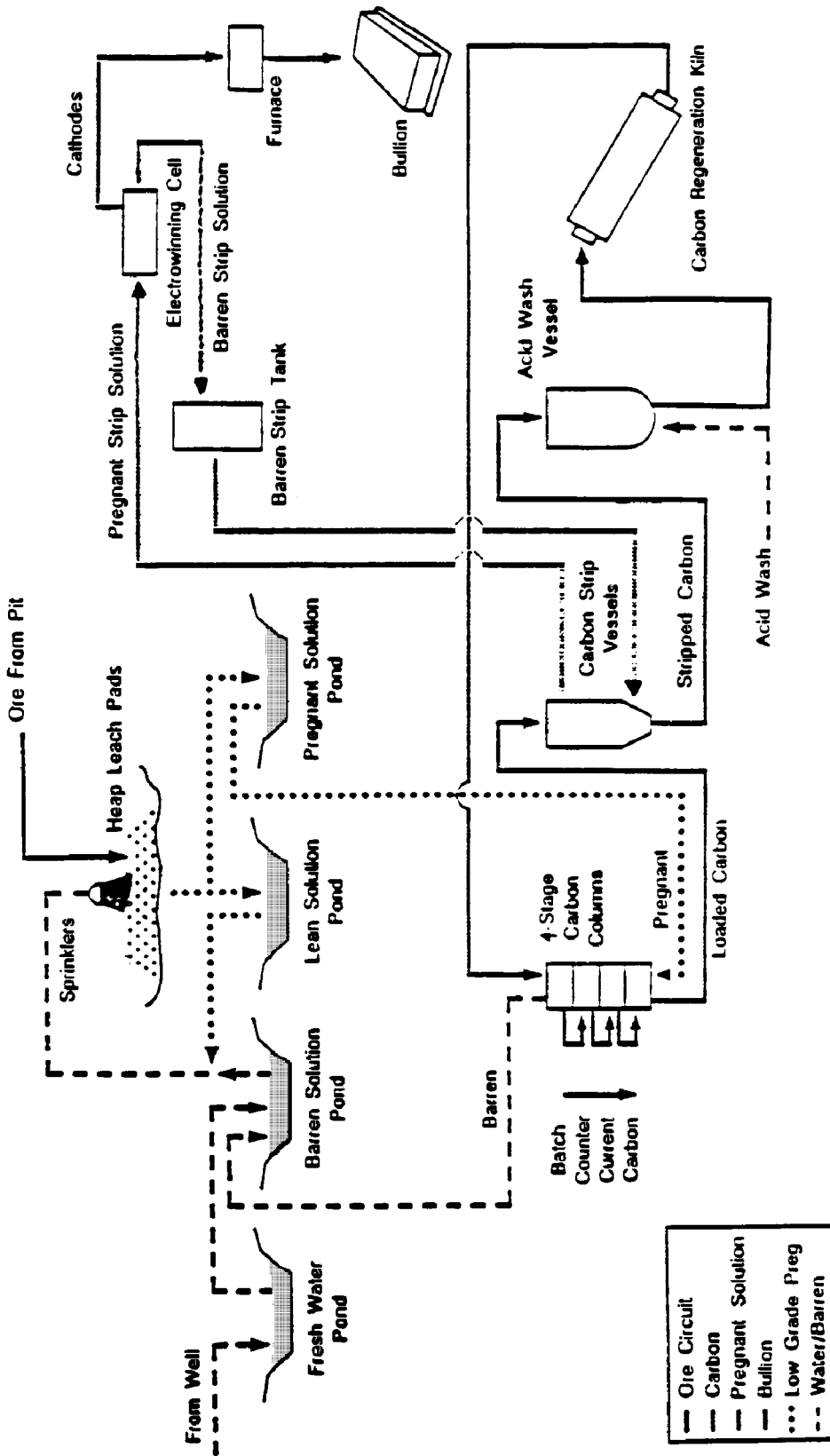
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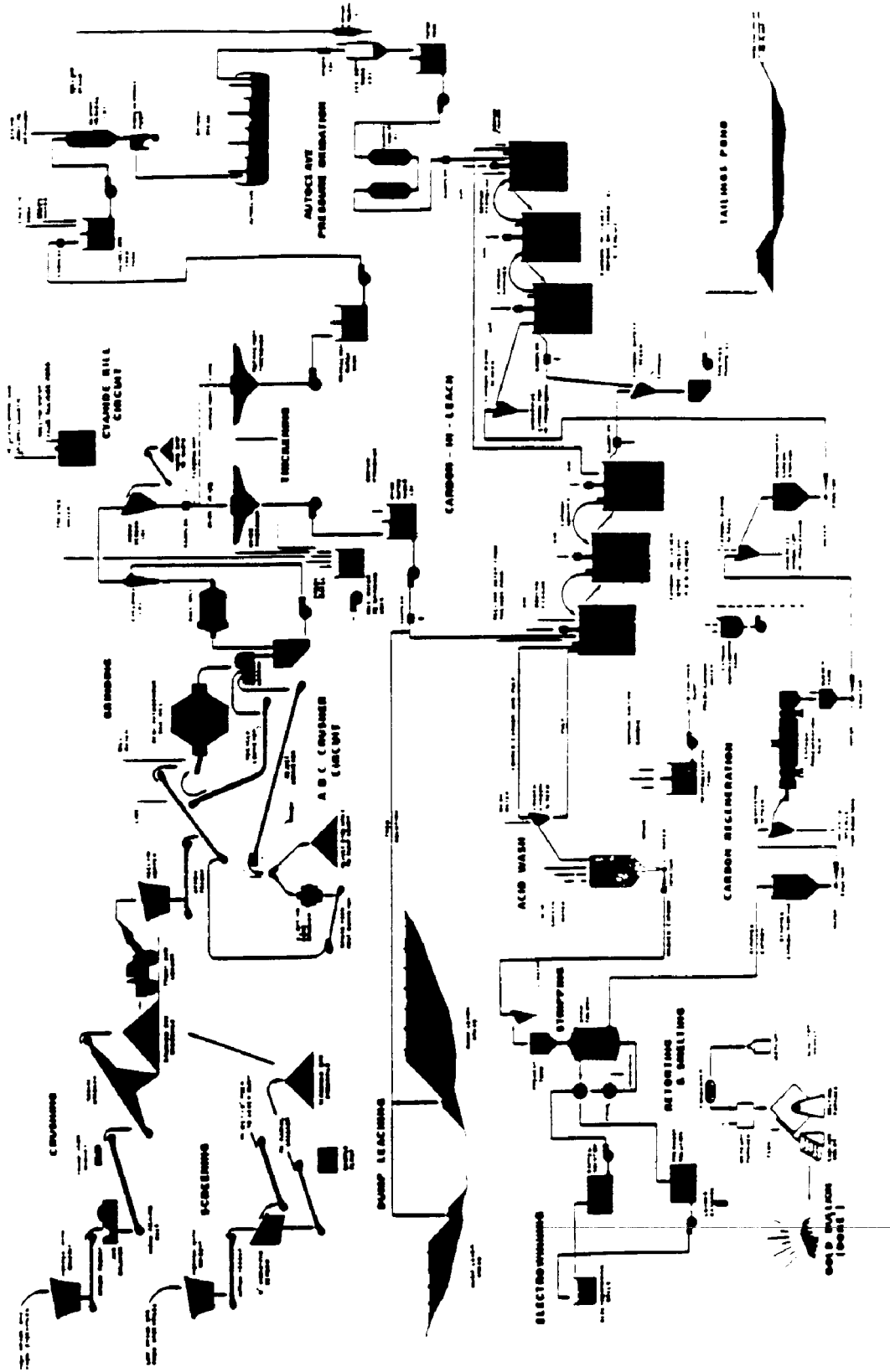
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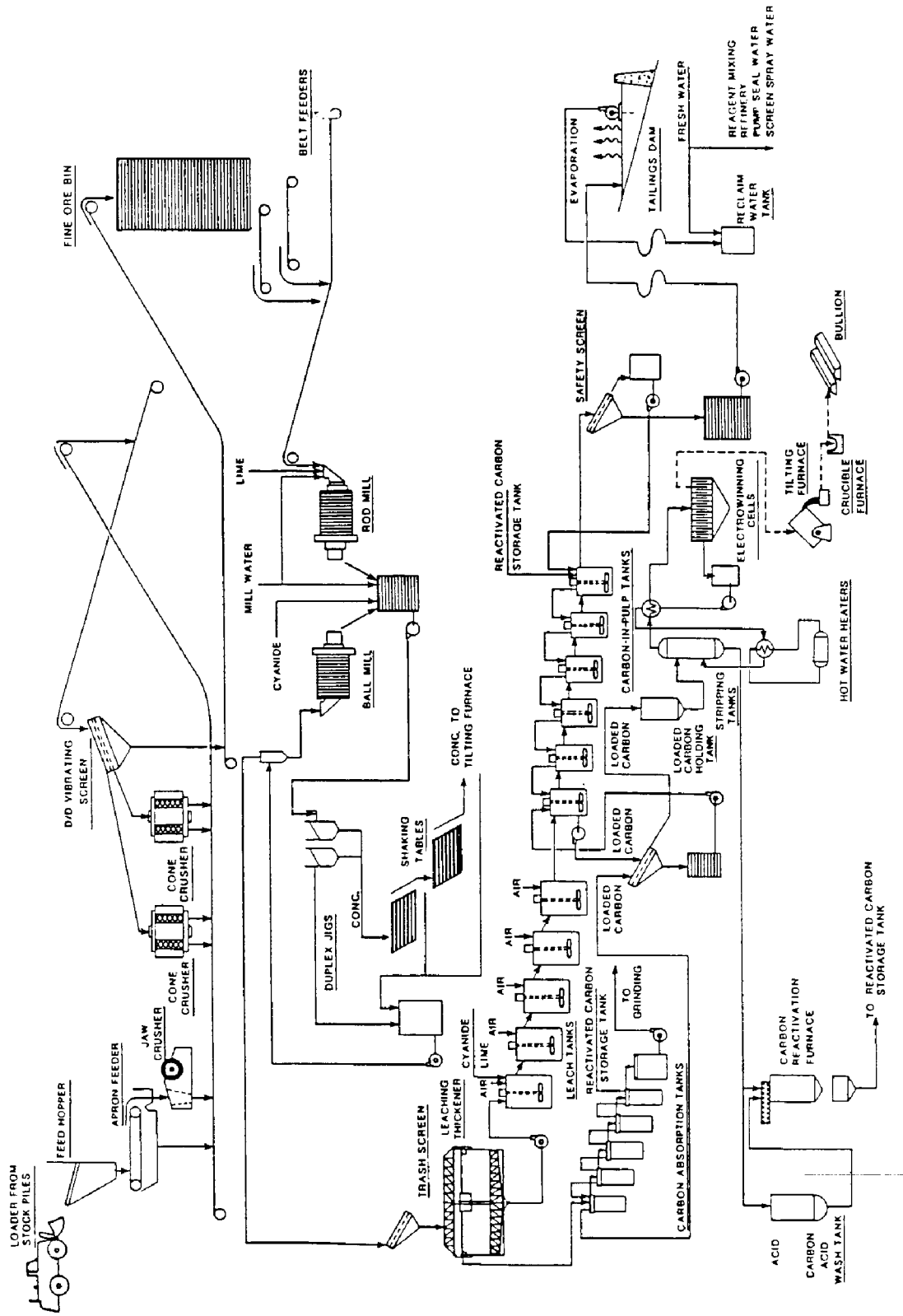


**APPENDIX 1-A FLOW SHEETS OF SPECIFIC MINE OPERATIONS**









**APPENDIX 1-B**

**NPL SITE SUMMARIES RELATED TO GOLD EXTRACTION AND BENEFICIATION**

**(from Mining Sites on the National Priorities List, Site Summary Reports,  
Volumes I-V, Environmental Protection Agency, June 21, 1991)**

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## **CARSON RIVER SITE, LYON AND CHURCHILL COUNTIES, NEVADA**

### **Operating History**

The Carson River Superfund Site is a 50-mile stretch of the Carson River in the Nevada counties of Lyon and Churchill. The site begins in Brunswick Canyon between Carson City and Dayton and extends downstream through the Lahontan Reservoir. This portion of the Carson River has been contaminated by mercury from the historical operations of approximately 100 gold and silver ore-processing mills. These mills lost an estimated 12 million to 18 million pounds of mercury to either mill tailings or direct discharges to the Carson River during their active lives in the late 1800's. Now, the tailings piles left behind discharge an estimated 8 million pounds of mercury annually to the river system. The Carson River site was proposed for the NPL in October 1989 and listed in August 1990.

Mercury is the contaminant of concern. The Carson River basin is a large recreational and commercial fishery resource. The basin is comprised of five hydrographic areas that include Carson Valley, Eagle Valley, Dayton Valley, Churchill Valley, and the Carson Desert, totalling about 3,365 square miles. The east and west forks of the Carson River arise in the Eastern Sierra, flow through an intricate irrigation system within the Carson Valley and then coalesce to form the mainstream of the Carson River. The river continues north through the Carson Valley, skirting the east side of Eagle Valley, then turns northeast to pass through Brunswick Canyon. Continuing east through Dayton Valley, the river flows into Churchill Valley, site of the Lahontan Reservoir, the main water storage reservoir of the Newlands Irrigation Project. Below Lahontan Dam, a complex system of canals and drains facilitate irrigation within the Carson Desert. The river and irrigation return flow ultimately flow northeast to the Stillwater National Wildlife Refuge and the Carson Sink, or south to Carson Lake.

An estimated 700,000 people annually use the river system for recreation, fishing, and irrigation. Approximately 1,200 acres of food and forage crops are irrigated by water from the 50-mile stretch of the Carson River in the NPL site. The river is not used for drinking water. The Dayton Valley Estates Water Company services 139 homes with water from an underground aquifer. The wells are 1.25 miles from mercury-contaminated tailings piles. In the Dayton Valley area, at least 226 households served by private wells are within 3 miles of either the Carson River or a mercury-contaminated tailings pile. At least 30 of these homes are within 2,000 feet of either the Carson River or a contaminated tailings pile.

The Carson River Site consists of sediments in the river and tailings piles associated with historical milling operations along the river. Mercury-contaminated tailings piles have been found 5 miles up Brunswick Canyon, 3 miles up Six Mile Canyon, and within the Carson Plains. Areas near the Comstock Load, where extensive mining occurred, such as in Gold Canyon, may also be major potential sources of mercury-contaminated mine tailings piles. Annual rains transport mercury from the tailings piles to the Carson River.

The Nevada Department of Environmental Protection (NDEP) sampled one tailings pile located near Six Mile Canyon in May 1986. The tailings pile was estimated to be approximately 100 feet long, 15 feet wide, with an average of 4 feet high, with mercury contamination of 493 ppm. The volume of contaminated material is estimated to be 222 cubic yards. For Hazard Ranking System (HRS) purposes, only one tailings pile was sampled to define the waste quantity for the Carson River Superfund Site. According to the NDEP, this tailings pile is one of hundreds of mercury-contaminated tailings piles known to exist in Brunswick and Six Mile Canyons. Because of the large number of known contaminated piles, and because of the large amount of mercury lost during the milling process, the waste quantity estimated from the one sampled tailings pile is expected to vastly underrepresent the total waste quantity at the site.

A Remedial Investigation and Feasibility Study (RI/FS) for the Carson River site was initiated in September 1990. EPA's immediate priority was to analyze the options for the stabilization and containment of the tailings piles. In addition, EPA is searching historical mining claims and land ownership titles for Potential Responsible Parties.

Because of the historical nature of the mining operations which resulted in the mercury contamination, there is little information available on the operating history of the site. During the late 1880's, ore mined from the Comstock Lode near Virginia City was transported to any of 75 mills, where it was crushed and mixed with mercury to amalgamate the gold and silver. Because water power was available, 12 mill sites in the Brunswick Canyon area of Carson River dominated. It is not known when operations at the mills ceased; however, the peak discharge reportedly occurred in the 30-year period from 1865 to 1895. The mills have since been demolished.

Liquid mercury was imported and used in the amalgamation of gold and silver in the ratio of 1:10, mercury:ore. The average loss of mercury was 0.68 kg for each ton of ore milled. EPA estimates that during the operation of these mills an estimated 14 million to 15 million pounds of mercury were lost, of which only 0.5 percent was later recovered. Currently, an estimated 8 million pounds of mercury-contaminated sediments are discharged annually from the tailings piles.

From 1906 to 1914, quicksilver was recovered from tailings at Douglas Mill in Six Mile Canyon. The unknown operators of the quicksilver mine recovered approximately 75,000 pounds of mercury using cyanide and flotation. Later, the Alhambra Mine Company also attempted to recover mercury from contaminated waste piles. Alhambra used a cyanide leaching process to recover gold, silver, and mercury. Alhambra's reprocessing operation lasted from December 1984 to July 1986; it is unknown how much gold, silver, and mercury it recovered.

The Lahontan Reservoir has trapped Carson River sediments since it was constructed in 1915, acting as a sink for mercury-contaminated sediments. It has not been determined if areas below the dam will be included in the RI/FS. It is possible that the results from an ecological assessment of the area below the dam will request the inclusion of this area in the Carson River Superfund Site. The Carson River and the Lahontan Reservoir are owned by the State of Nevada. The ownership of land adjacent to the river is unknown but may be determined through a review of mining claims.

### **Environmental Damages and Risks**

Neither the preliminary assessment nor the HRS worksheets discuss any known human effects associated with mercury, the contaminant of concern. Possible exposure pathways are soil, air, ground and surface water, and the food chain.

The greatest toxicological concern is methyl mercury, which is obtained from the consumption of fish. The major source of methyl mercury in the environment is via microbiological conversion of inorganic mercury by methanogenic bacteria in sediments of aquatic ecosystems. Organic mercury is 90 percent absorbed through the gastrointestinal tract and easily crosses the skin barrier. Once absorbed, organic mercury is mobile in the body, readily crossing into the brain as well as into a fetus. Organic mercury is slowly broken down and excreted through feces. The halflife of organic mercury is 65 days.

During summer 1981, fish were collected to determine the mercury concentration in fish tissues. Results indicated that significant mercury accumulation is occurring within fishes of the Lahontan Reservoir. Mercury concentrations in muscle tissue ranged from 0.11 mg/kg in young-of-the-year white bass to 9.52 mg/kg in striped bass. Of the 53 muscle tissues analyzed, 36 (68 percent) exceeded the 1 mg/kg "action



level" considered safe by the Food and Drug Administration. Mercury concentrations in heart tissues ranged from 0.17 mg/kg in carp to 5.58 mg/kg in striped bass. Liver tissues had mercury concentrations ranging from 0.21 mg/kg in brown bullhead to 23.65 mg/kg in striped bass. These levels are considerably higher than the 0.20 mg/kg considered as background for fish. In general, mercury concentration within species increased with fish weight.

In 1986 the Nevada Department of Wildlife and Consumer Health Protection Services issued a fish consumption advisory. The Department recommended that no more than one meal of fish (8 ounces) caught in the Lahontan Reservoir or outfall waters below the reservoir should be eaten each week because of possible toxicity from mercury. Specifically children or women of childbearing age should not consume any fish from these waters. The health advisory was expanded and reissued in 1987 to indicate that no more than one meal of fish per month should be eaten, and walleye more than 21 inches long should not be eaten.

Approximately 1,200 acres of food and forage crops are irrigated by the Carson River between Dayton and the Lahontan Reservoir. However, no studies indicate or describe the presence of mercury in food or forage crops.

Although water drained from the Lahontan Reservoir through canals is used mainly for irrigation, some canal water also drains into the Stillwater Marsh. Most of the water entering the marsh is reportedly irrigation return flows. The Stillwater Wildlife Management Area is a major breeding ground and stopover for hundreds of thousands of birds migrating on the Pacific Flyway. Fish and bird kills in the Carson Sink have been attributed to increased salinization of the water and possibly increased susceptibility of the wildlife to disease because of elevated levels of potentially toxic elements such as arsenic and selenium. Mercury was not detected at the Stillwater Marsh Reservoir outlet during NDEP sampling in 1983 and 1984.

## **CLEAR CREEK/CENTRAL CITY SITE; CLEAR CREEK AND GILPIN COUNTIES, COLORADO**

### **Operating History**

The Clear Creek/Central City historical hardrock mining site is one of the most mined areas in Colorado. Data indicate that up to 25 mines and 6 milling operations are operating in Gilpin and Clear Creek Counties. The area also includes more than 800 abandoned mine workings and tunnels. Mining activity in the Central City/Black Hawk area began in 1859 with placer gold mining. Exploration tunnels were built from 1860 to 1937. Mining operations have included gold, silver, copper, lead, and zinc. Although mining operations have varied recently because of fluctuating market prices, historically 85 percent of the mining has been for gold, 10 percent for silver, and 5 percent for copper, lead, molybdenum, and zinc.

The Argo Tunnel, the most extensive and probably the most complicated of the five tunnel/mine systems at the site, is an abandoned mine drainage and ore haulage tunnel. The Argo Tunnel is 4.16 miles long and is connected to eight major mining zones. There are a total of 36 laterals that branch from the Argo Tunnel, 10 of which connect to mine systems. It is estimated that there are 91 surface openings and 21,400 feet of vein strike associated with the Argo Tunnel system. In 1982, it was documented that the owner was using the tailings near the tunnel portal as decorative landscaping and was selling tailings samples to local distributors. The Argo mill site is also a local tourist attraction as it is listed in the National Register of Historic Places.

In 1943, four miners were killed because of a blowout in the Argo Tunnel caused by mining activities. In 1980, a second blowout occurred that was attributed to "natural" causes (i.e., the collapse of "roof falls" used for damming water). As a result of the 1980 blowout, Clear Creek was "grossly contaminated" and showed

"serious violation of metal standards" the next day. (Note that extensive information was not available for the other tunnel/mine systems as it was for the Argo Tunnel.)

The Clear Creek/Central City site was nominated for the NPL in 1982 and added to the NPL in 1983. A removal action was conducted by EPA's Emergency Response Branch at the Gregory Incline in March 1987 to protect human health and the environment from hazards associated with the collapse of a retaining crib wall. EPA removed the wall, decreased the slope of the tailings pile to stabilize it, and then constructed a gabion-basket retaining wall.

### **Environmental Damages and Risks**

The Phase II remedial investigation provided an assessment of the risks to human health associated with the Clear Creek site. Overall, risks to human health are not expected from ingestion of surface water when used as drinking water, ingestion of surface water while swimming, or ingestion of fish, based on the exposure scenarios evaluated in this assessment. Potential risks are associated with ingestion of ground water, incidental ingestion of tailings, and inhalation of airborne dust. Arsenic contributes most significantly to risks from ground water and tailings. All of the chemicals evaluated for the inhalation pathway pose risks to human health. Lead exposures from ingestion of soil, dust, and ground water pose potential risks to children.

It was determined during the site investigation that Clear Creek, between the Argo Tunnel and Golden, Colorado, "cannot support fish due to the contamination caused by mining activity." Contaminants of concern for aquatic life are aluminum, arsenic, cadmium, chromium, copper, fluoride, lead, manganese, nickel, silver, zinc, and low pH. During the Phase I remedial investigation, concentrations of these chemicals in Clear Creek, North Clear Creek, and in the wetland below National Tunnel were compared to Federal Ambient Water Quality Criteria (AWQC) or to the Lowest-Observed-Effect Level (LOEL). Criteria for aluminum, cadmium, copper, lead, manganese, silver, and zinc were exceeded in Clear Creek and North Clear Creek. In North Clear Creek, criteria for pH were also exceeded. In the wetland, criteria were exceeded for aluminum, cadmium, copper, manganese, silver, zinc, and pH.

The Phase II remedial investigation focused on the potential risks to trout and macroinvertebrates at the site. It was found that trout could be acutely affected in the mainstem of Clear Creek, North Clear Creek, and West Clear Creek, along with numerous tributaries of the streams. In addition, virtually all of the tunnel discharges are expected to be acutely toxic to fish.

In the mainstem of Clear Creek and several of its tributaries, trout are at moderate to high risk of adverse chronic (reproductive) effects. In North Clear Creek, there is a clear risk of adverse reproductive effects. Potential risks of adverse reproductive effects are high in West Clear Creek from Woods Creek to the confluence of Clear Creek. Chemicals in Lions Creek and Woods Creek are likely to cause chronic effects.

Zinc sediments could cause adverse reproductive effects in all stream segments that were evaluated. Arsenic, cadmium, copper, and lead in sediment pose chronic risks at some locations.

## **CIMARRON MINING CORPORATION SITE, CARRIZOZO, NEW MEXICO**

### **Operating History**

The Cimarron Mining Corporation Superfund Site is 10.6 acres of privately owned land approximately 1/4 of a mile east of Carrizozo, New Mexico, and approximately 100 miles south-southeast of Albuquerque. It was originally constructed to recover iron from ores. The facility was sold in 1979 and subsequently revamped to

mill precious metals ore. The precious metal recovery facility consisted of a conventional agitation cyanidation mill that resulted in the discharge of contaminated liquids and stockpiling of contaminated tailings and waste trench sediment at the site. The mill operated without a State discharge permit. The mill was closed in July 1982 and the owners of the facility filed for bankruptcy in July 1983.

Cyanide is the primary contaminant of concern; however, several metals were also identified as contaminants of concern. Approximately 1,500 people live within 2 miles of the site. The Carrizozo municipal wells are located within 2 miles of the site and were estimated in 1985 to serve a population of 1,636. Contaminated media of greatest concern at the site are shallow ground water and surface soils. The site was added to the NPL on October 4, 1989.

While conducting the remedial investigation at the Cimarron site, the existence of another abandoned mill became known. The other location, known as Sierra Blanca, is 1 mile south of the Cimarron site. The two mills were owned by the same parent company (Sierra Blanca Mining and Milling Corporation) and, for a short period, operated concurrently. File information indicates a possible spill at Cimarron prompted the relocation of milling operations to Sierra Blanca. Investigation of the Sierra Blanca mill is being performed as a second operable unit.

The RI/FS was conducted between May 1989 and May 1990. In the Record of Decision (ROD) (September 1990), EPA announced the selected remedy for the site. The selected remedy will pump contaminated ground water from the shallow aquifer and convey it to the Carrizozo publicly owned treatment works (POTW) for treatment, thereby eliminating the potential for migration of contaminated shallow ground water to the deeper water supply aquifer. In addition, source control measures would be implemented.

The mill facility was used to mill iron ores and recover iron using a magnetic separator during the late 1960's and 1970's. Cyanide was not used in the original process and tailings from the mill were transported off site and used as fill material in the Carrizozo area.

In 1979, Southwest Minerals Corporation bought the mill site and apparently began using a cyanide process to extract precious metals from ores transported to the mill. Detailed information on the metals extraction process operating between 1979 and 1981 was not available to EPA during their remedial investigation. Cyanide was detected in an onsite discharge pit sediment sample collected by the New Mexico Environmental Improvement Division (NMEID) in 1980, which indicates that cyanide extraction was likely in operation at that time.

Southwest Minerals expanded the operation in 1981 even though they were operating without the required discharge permit. The mill ceased operation in July 1982 following the June 23, 1982, receipt of an NMEID notice of violations for discharging into a nonpermitted discharge pit. The State did not pursue legal actions against Southwest Minerals and the company filed for bankruptcy in July 1983.

The EPA interviewed former mill employees and examined the onsite equipment during the remedial investigation in order to summarize the precious metals recovery operations employed at the site after 1981.

Ore was transported to and stockpiled on the site before it was transferred to a jaw crusher for size reduction. After the ore was crushed, it was transferred to the mill building where it was placed in a large hopper. Hydrated lime was added to prevent production of hydrogen cyanide gas and to optimize the cyanidation reactions. The hopper fed a ball mill and rake classifier where cyanide solution was added to the ore.

Sodium cyanide and potassium cyanide (stored onsite in 220-pound drums) mixed with water composed the cyanide solution. In addition, two metal stripping chemicals (AMPREP and Enstrip 70), containing 15

percent potassium cyanide, less than 1 percent lead oxide, and nitro-aromatic compounds were apparently added to the cyanide solution to promote additional leaching of precious metals.

The cyanide solution was mixed in two large vats, gravity fed to a large holding tank, and subsequently pumped from this tank to the rake classifier, creating a cyanide-solution/crushed-ore slurry. From the rake classifier, the slurry was pumped to a heated, agitated vat. Heating the slurry promoted the reaction of cyanide with precious metals. The slurry was pumped to a second agitated vat and then to each of four thickeners. Pregnant (precious metal-containing) cyanide solution was skimmed from the top of each thickener and routed (countercurrent to the direction of slurry flow) back to the second agitated vat. Pregnant solution contained in the agitated vats was gravity fed to a large metal holding tank near the lab building.

Pumped from the holding tank, pregnant solution was fed through small pressure filters to an electrowinning cell in the lab building. Precious metals were deposited onto aluminum plates, which were heated in an outside kiln to separate the aluminum from the doré (unrefined metals).

The barren cyanide solution contained free cyanide and metal-cyanide complexes of copper, iron, nickel, cobalt, zinc, and other impurities. Most of the barren solution was pumped to two cement block-lined trenches near the main operations building for recycling into the mill circuit, but a portion was discharged to the unlined discharge pit to avoid build-up of metal impurities that would subsequently interfere with the dissolution and precipitation of gold in the cyanidation process. Backwash waste solution from the pressure filters was disposed of in the discharge pit. Chlorine was added to the waste solution to oxidize the cyanide. Analyses of samples from the pit indicate that this treatment was not effective. The ineffectiveness of the chlorine treatment was possibly because of poor application methods and/or the existence of a significant quantity of complex cyanide forms not affected by chlorine. The cement block trenches and the unlined discharge pit are the two main sources of cyanide migrating into the ground water at the site.

Solids from the last thickener in the series were pumped through a solid separator and were conveyed and discharged to a truck for transport to the tailings piles. The remaining fluid fraction (and small-size solids) were apparently gravity fed to the two cement block trenches for recycling into the cyanidation process. As sediment built up in the trenches, it was removed and stockpiled onsite.

### **Environmental Damages and Risks**

Site contamination was revealed in the analyses of soil samples collected during a 1980 NMEID field inspection. This initial sampling revealed the presence of cyanide and elevated metals in shallow ground water, soil, and mill tailings. Additional investigations, including the RI/FS, delineated the extent of cyanide and metals contamination at the Cimarron site.

The June 1990 Remedial Investigation Report presents an endangerment assessment of the potential human health risks associated with the existing conditions at the site. Land surrounding the site is used for agricultural, commercial, recreational, and residential purposes. An estimated total population of 1,500 lives within a 2-mile radius of the site. The main mill facility is fenced to prevent access, including the tailings disposal area.

The total population served by ground water from the aquifer of concern within 3 miles of the site was estimated in November 1985 to be 1,636. This includes 1,500 people served by the town of Carrizozo municipal water system. The municipal supply wells are located within a 2-mile radius of the site. The closest drinking water well is located about 0.8 miles from the site. An onsite well was used for industrial purposes. The risk assessment identified cyanide and several metals as contaminants of concern.

The risk assessment determined that, under a current exposure (for an offsite resident) scenario, it is unlikely that human receptors will experience adverse noncarcinogenic health effects. The highest excess cancer risk for exposure resulting from site visits or inhalation of fugitive dust in Carrizozo is  $4.7 \times 10^{-8}$ .

The risk assessment determined that, under a future exposure (for an onsite resident) scenario, there may be concern for potential noncarcinogenic health effects in children or adults ingesting contaminated ground water. The highest excess cancer risk is  $8.7 \times 10^{-6}$  resulting from incidental ingestion of soils.

## **SILVER MOUNTAIN MINE, LOOMIS, WASHINGTON**

### **Operating History**

Underground mining for silver, gold, and copper began at the site in 1902. EPA's remedial investigation states that the mine was active in 1936, 1943, 1945, and 1956, and that by 1956 the mine had approximately 2,000 feet of underground mine workings and a few thousand tons of mine dump. A mill was built in 1952 but may have never been used. No other records of production were known to exist. From late 1980 to late summer 1981, Precious Metals Extraction (PME), Ltd., constructed and operated the leaching operation described above. This operation was abandoned in 1981 with no site closure or cleanup of contaminated material.

Detailed records on the process used by PME and the construction of the leach heap and leachate collection pond were not available to EPA during their remedial investigation. However, field observations and data collected by the Bureau of Mines during their investigation in 1989 provide basic data on the leaching process and unit construction:

"PME cleared an area of approximately 180 feet by 140 feet, adjacent to existing mine dumps. A leach pad base of sandy soil up to 3 feet thick and graded with a 2.5 percent slope to the southwest was prepared. At the southern end of the leach pad a rectangular trench 7 feet by 75 feet and averaging 4 feet in depth was dug as a leachate collection pond. The soil base and pond were then covered with a green 20-mil thick plastic liner. Another layer of sandy soil, from 0 to 6 inches thick was then placed over the plastic liner. Approximately 5,300 tons of material from the mine dump were loaded onto the pad. The prepared heap was approximately 100 feet long, 105 feet wide, and 14 feet high." As stated above, several tons of caustic soda and lime, and approximately 8,000 pounds of sodium cyanide were combined with water and applied to the leach heap.

Processing of the leachate to remove the precious metals may have been accomplished through direct electroplating or by using activated carbon, but information on the processing is not conclusive. Drums containing activated carbon were found onsite. The operation was abandoned in late summer 1981 without neutralizing the solution in the leachate pond or materials in the leach heap. Empty cyanide drums and large containers of activated carbon also remained onsite.

### **Environmental Damages and Risks**

Initial interest in the site began in 1981, when the owner of the surface rights informed the Okanogan County Health Department of the heap leaching operation (U.S. EPA, Region X 1990a; Bowhay 1983). Originally, the Washington Department of Ecology responded to the threat caused by the cyanide in the leachate collection basin. Upon further investigation, EPA found additional potential sources of contaminants (the leach heap, mine dump, mine drainage, and bedrock) and additional contaminants of concern (arsenic and antimony, as well as cyanide).

The Remedial Investigation Report, completed in January 1990, presents a human health risk assessment for the site. The risk assessment identifies arsenic, antimony, and cyanide as the contaminants of concern. Population near the site is sparse, with fewer than 20 people within a 3-mile radius served by drinking water wells. The land in closest proximity to the site is used for cattle grazing. The closest domestic water well is approximately 3 miles south of the site. Currently, the closest livestock watering well is 2 miles from the site. Other concerns include use of the site by local teenagers who may potentially become exposed to the contaminants.

Arsenic, antimony, and cyanide are the major contaminants in water. Based on future exposure scenarios, exposure to arsenic in water could result in an increase in cancer risk of  $2 \times 10^{-4}$ . There is also risk of noncarcinogenic effects from arsenic, cyanide, and other chemicals.

The major contaminant in soil is arsenic. Based on future exposure scenarios, exposure to soil could result in an increased cancer risk of  $2 \times 10^{-3}$ , as well as noncarcinogenic effects.

## **WHITEWOOD CREEK SITE, LAWRENCE, MEADE, AND BUTTE COUNTIES, SOUTH DAKOTA**

### **Operating History**

Homestake Mining Co. initially began gold mining near Lead, South Dakota, in the late 1870's. Approximately 110 million tons of ore were produced during the operating history of the site. Mining operations extended to a depth of more than 8,000 feet below the land surface. The first milling operations used crude methods to crush the ore and recovered gold by gravity or by amalgamation with mercury. Mercury amalgamation was used primarily until 1971 when cyanide began to be used exclusively. It is estimated that between 1/8 and 1/2 ounce of mercury per ton of ore crushed was lost, with 50 percent of this being discharged in the waste stream.

Tailings and untreated waste water were continuously discharged into Whitewood creek during the 100-year operating history of the site, excluding a 5-year period during World War II when the mine was closed. Tailings were discharged directly into the creek or its tributaries from a number of mine operators until approximately 1920, after which Homestake was the only source of tailings discharge. The discharge of tailings was a common practice of the time. In 1963, up to 3,000 tons of tailings and 12,500 tons of water were being discharged per day into Whitewood Creek.

In the 1920's, ball and rod mills were brought into use at the mine. The ball and rod mills created finer-grained tailings, or "slimes." After 1935, sand-sized tailings were typically used to backfill mined areas, and the "slimes," as well as some coarse-grained sands, were discharged into Whitewood Creek. This practice continued until 1977. In 1977, Homestake constructed a tailings impoundment in the upper reaches of the watershed at Grizzly Gulch, located in the upper reaches of the Whitewood Creek watershed, to treat residual slimes and process waters. In December 1984, a waste water treatment system was put into operation to treat water from the tailings impoundment and the mine. The plant uses rotating biological contractors to remove cyanide and ammonia, iron precipitation and sorption to remove metals, and sand filtration to remove suspended solids from mine water. The solids are returned to the tailings pond and the water is discharged into Gold Run Creek, which runs into Whitewood Creek between the towns of Lead and Deadwood. This treatment was then supplemented to meet the newly imposed NPDES and State stream standards when Homestake began the research and development of a new waste water treatment plant using a bio-treatment process. This discharge is monitored to meet requirements of the CWA.

From the 1870's to the end of the century, a substantial portion of the discharged tailings were distributed in and on the alluvial materials of the floodplain because Whitewood Creek was a small meandering stream with insufficient capacity to transport the large quantity of tailings. Over time, the discharged tailings and some alluvial material filled the meanders of the creek, which straightened its channel and increased its gradient. This, in turn, caused Whitewood Creek to downcut its channel to the resistant shale bedrock, which today forms the channel bottom for most of the length of the 18-mile stretch of the site. As a result of the changes in the sediment-carrying capacity of Whitewood Creek, little deposition of tailings on the alluvial materials is believed to have occurred beyond the turn of the century.

### **Environmental Damages and Risks**

Systematic studies of the Whitewood Creek area by the South Dakota Department of Health, which began in 1960, quantified the solids and cyanide loading to the creek and recommended further studies. In 1965, a study by the South Dakota Department of Game, Fish, and Parks determined that aquatic bottom organisms were not present in Whitewood Creek downstream from the waste discharges. Several additional studies, which focused on the possible serious environmental hazard created by mercury contamination, led to the discontinuance of mercury use in gold recovery operations in December 1970.

A study published in 1978 found arsenic concentrations ranging from 2.5 to 1,530  $\mu\text{g/l}$  in ground water from areas with large tailings deposits. As a result of these studies, it was concluded that the Whitewood Creek area would remain highly contaminated until the discharge of tailings was discontinued. This resulted in the construction of Homestake's Grizzly Gulch Tailings Disposal Project, which became fully operational on December 1, 1977 and produced a dramatic improvement in the physical appearance and quality of the creek waters.

The potential lifetime excess carcinogenic risks from exposure to arsenic through ingestion of soils and ground water within the site for both the representative and maximum exposed site resident were determined to be unacceptable. For the representative and maximum exposed site resident, ground water risks were determined to be  $1.9 \times 10^{-4}$  and  $4.4 \times 10^{-3}$ , and soil risks were determined to be  $2.4 \times 10^{-4}$  and  $2.6 \times 10^{-3}$ , respectively, all of which are greater than the acceptable Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) level of  $1 \times 10^{-4}$ . Potential risks to recreational visitors were determined to be acceptable. The potential risk to the representative site resident from the consumption of ground water is acceptable when evaluated with respect to the National Primary Drinking Water Standard. The greatest potential risk to the representative site resident comes from surface soils on residential properties that have elevated arsenic levels rather than tailings deposit area soils or irrigated cropland soils. Elevated arsenic levels on residential properties are the result of past deposition or the use of tailings as road gravel.

Elevated arsenic concentrations in the downgradient alluvial ground waters present a possible future unacceptable potential risk. The current potential risk of these ground waters was not considered because they are not used as a water supply and a state regulation prohibits the installation of water supply wells within the 100-year floodplain of Whitewood Creek, within which these ground waters are situated.

Potential noncarcinogenic health effects associated with exposure to arsenic, cadmium, chromium, copper, lead, manganese, mercury, and nickel through the ingestion of soils and ground water within the site were determined to be unacceptable for the maximum exposed site resident. Effects for all other groups were determined to be within acceptable levels. The unacceptable level for the maximum exposed site resident assumed residency on the tailings deposit areas, the concomitant high rates of incidental ingestion of the soils in these areas, and the consumption of downgradient alluvial ground waters, scenarios not currently encountered by site residents but that could be encountered in the future.

**APPENDIX 1-C**

**304(I) SITES RELATED TO GOLD MINING ACTIVITIES**



### **Sunnyside Gold (Mayflower Mill)**

The Mayflower Mill is an active operation that processes ore from the Sunnyside Mine, which produces gold and silver plus sulfides of lead, zinc, and copper. The waste water discharge from the mill has been identified as a point source that contributes significantly to contamination (e.g., high metals concentrations, primarily zinc, and whole effluent toxicity) in Cement Creek and the Animas River into which the creek flows. The development of a control strategy for this facility to ensure compliance with applicable water quality standards is complicated with numerous other point- and nonpoint-source mining discharges, which have an impact on receiving waters.

### **Clear Creek/Central City**

Including Clear Creek on the 304(l) list was intended to address all of the surface water discharges, primarily from mining operations, which have led to identification of Clear Creek as an NPL site (ranked No. 174 in 1983). EPA has conducted extensive sampling and analysis to characterize the contamination (high metals concentration and toxicity to aquatic life both in Creek water and sediments) and identify contributing discharges. Contaminants of concern include aluminum, arsenic, cadmium, chromium, copper, fluoride, lead, manganese, nickel, silver, zinc, and pH. The greatest toxic effects have been found to occur during seasonal high-flow periods and storms. Active and inactive mine sites in numerous mining sectors with point- and nonpoint-source discharge are the responsible parties.

US EPA ARCHIVE DOCUMENT

**APPENDIX 1-D  
COMMENTS AND RESPONSES**

## Appendix 1-D: Comments on the Draft Industry Profile and EPA Responses

A draft of the *Industry Profile: Gold* was provided for review and comment to the following: U.S. DOI, Bureau of Mines, the Western Governors' Association, the Interstate Mining Compact Commission, the American Mining Congress (AMC) and various Environmental Interest Groups for their review and comment. Approximately 450 comments were submitted to EPA by the following six reviewers: the Bureau of Mines, American Barrick Resources Corporation, Hecla Mining Company, Homestake Mining Company, Newmont Gold Company, and The Precious Metal Producers. The comments included technical and editorial changes, as well as comments on the scope of the Profile and how it relates to authorities provided under RCRA Subtitle D.

Because several general concerns were raised by a number of commenters, EPA has grouped the comments into two categories. The first includes seven general concerns that were raised by all commenters. These are addressed in the first section below. The second category of comments includes technical comments on this Profile, which were raised by specific reviewers, rather than the group as a whole. These are addressed in the second section below. All other comments, including minor technical and marginal notes, have been incorporated into the revised Profile; EPA believes they have served to improve the document's accuracy and clarity. EPA would like to thank all the agencies, companies, and individuals for their time and effort spent reviewing and preparing comments on the Profile.

### General Issues Pertaining to All Profiles

1. Comment: Several commenters objected to the use of hypothetical phrases like "may cause" or "may occur." Their use was characterized as misleading and inappropriate in describing environmental impacts in an Industry Profile of this type.

Response: It is felt that the descriptions of conditions and impacts that may occur regarding potential effects is appropriate in many cases, since the intent of the relevant sections of the profiles is to describe potential impacts that may occur as a result of extracting and beneficiating ores and minerals. As noted in the responses to related comments below, EPA has extensively revised the sections of the profiles addressing environmental effects. They are now more focussed and direct; they describe, in general terms, a number of specific types of impacts that can occur under particular conditions or in particular environments.

2. Comment: A related issue raised by commenters was that EPA did not balance the profile by describing environmental protection practices currently followed by the mining industry. Instead, the commenters were critical that EPA selected the worst sites to describe, which represent only a small number of mines and even a few clandestine operations.

Response: It is felt that the Profile (and related site reports) represents current environmental management practices as described in the current literature.

3. Comment: Commenters on each of the profiles were concerned that the sites described in the discussion of environmental effects were under some other regulatory authority (e.g., CERCLA).

Response: As noted above, the relevant sections of the profiles have been revised extensively. However it is felt that, with proper qualification, sites under other regulatory authorities, including CERCLA, are relevant to any examination of actual or potential environmental effects.

4. Comment: Commenters were concerned that the Profile considered materials other than those considered "wastes" under RCRA.

Response: Since the profile is intended to identify the potential environmental effects of mining, it was considered appropriate to discuss both wastes and materials that have similar potential to pose risks to human health and the environment.

5. Comment: Many commenters recommended that the mitigating effects of site-specific factors on potential environmental effects be discussed.

Response: As noted above, the relevant sections of the profiles have been revised including the addition of language that emphasizes the site-specific nature of potential environmental effects.

6. Comment: Many commenters recommended that the effectiveness of State regulatory actions in preventing adverse environmental effects be integrated into any discussion of potential effects.

Response: The Profile has been amended to reflect the fact that State requirements can substantially reduce or eliminate many adverse environmental effects.

7. Comment: A number of comments were received on the table in each draft profile that cited NIOSH data on the quantities of certain chemicals found on mine property and that included worker exposure limits. Commenters questioned the data's accuracy and relevance.

Response: The table has been replaced with a simple list of chemicals typically found on sites.

#### **Technical Issues Pertaining to the Gold Profile**

8. Comment: The Profile ignores state-led regulatory programs.

Response: Due to the number of States with programs regulating the mining industry, and the wide variation in those programs, it was decided to address the regulatory programs implemented by two States, Nevada and South Carolina. Nevada was chosen because of the vast majority of current gold mining occurs in that State. South Carolina was selected to reflect mining regulation in a wet climate. A discussion of these is presented in both the draft Profile and this revised document.

10. Comment: The Profile is a 1991 release. The massive expansion of the industry since that time is masked by the use of 1988 data to characterize the industry.

Response: The most recent publicly available information at the time of the Profile's preparation (late 1990) was used in the draft profile. The draft has been revised to include updated information (as of April 1992) from the Bureau of Mines.

11. Comment: The Profile does not quantify the magnitude of known or potential contamination.

Response: As noted in the first section above, the primary purpose of the profile is not to catalog or rank environmental effects. The Profile has been revised to clarify its intent.

12. Comment: The use of the word extraction is unclear. Extraction, in the metallurgical sense, refers to a method used to remove the values from the ore; in the Profile it is analogous to mining.

Response: As described in the profile, in 1980 Congress conditionally exempted from RCRA Subtitle C, wastes from the "extraction, beneficiation, and processing of ores and minerals". In this case, the term extraction is analogous to mining.

13. Comment: Too much time is spent on mining and beneficiation techniques that relate to an insignificant portion of the industry. Examples include open cut and block caving methods; flotation, gravity concentration, and *in situ* leaching. This results in speculation about impacts from techniques that are of minimal importance.

Response: Relevant portions of the profile have been revised substantially in response to this comment. The description of mining methods has been deleted. Text describing by-product gold from base metal operations (flotation) and gravity concentration has been edited significantly. The *in situ* discussion simply references a pilot-scale study, and thus remains largely unchanged in the revised profile.

14. Comment: The profile ignores regulations protecting against acid drainage.

Response: The Profile has been revised and clarified regarding the discussion of acid drainage. Nevada's regulations governing acid drainage are discussed in the section concerning that State's Water Pollution Control Permits.

15. Comment: Sulfide ores are rarely, if ever, used in heap leaching operations.

Response: The description of heap leach operations has been extensively revised based on reviewers comments. The text concerning the use of sulfide ores has been modified accordingly.

**APPENDIX 1-E  
ACRONYM LIST**

## ACRONYM LIST

AMD	acid mine drainage
AWQC	Ambient Water Quality Criteria
BAT/BPJ	best available technology/best professional judgment
BLM	Bureau of Land Management
BMP	best management practice
BPJ	best professional judgment
CAA	Clean Air Act
CCD	continuous countercurrent decantation
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CIC	carbon-in-column
CIL	carbon-in-leach
CIP	carbon-in-pulp
CWA	Clean Water Act
DHEC	Department of Health and Environmental Control
dscm	dry standard cubic meter
FLPMA	Federal Land Policy and Management Act
FS	Forest Service
FWS	Fish and Wildlife Service
GA	Groundwater A
GB	Groundwater B
GC	Groundwater C
HDPE	high-density polyethylene
HRS	Hazard Ranking System
ICSS	individual control strategies
IM	Instruction Memorandum
kg	kilogram
lb.	pound
LOEL	Lowest-Observed Effect Level
MCL	Maximum Contaminant Level
mg/l	milligrams per liter
MSHA	Mine Safety and Health Administration
NAAQS	National Ambient Air Quality Standards
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NIOSH	National Institute for Occupational Safety and Health
NMEID	New Mexico Environmental Improvement Division
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NPS	National Park Service
NSPS	New Source Performance Standard
NTIS	National Technical Information Service
oz/t	troy ounces per ton
PME	Precision Metals Extraction. Ltd.
ppm	parts per million
PSD	prevention of significant deterioration

**ACRONYM LIST (continued)**

RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation and Feasibility Study
RIP	Resin-in-Pulp
ROD	Record of Decision
SHDG	sediment-hosted disseminated gold
SIP	State Implementation Plan
TSCA	Toxic Substance Control Act
TSS	total suspended solids
USC	U.S. Code
U.S. DOI	U.S. Department of the Interior
U.S. EPA	U.S. Environmental Protection Agency
U.S. GS	United States Geological Survey
VLDPE	very low-density polyethylene
WAD	weak acid dissociable