History of Mining and Milling Practices and Production in San Juan County, Colorado, 1871–1991

By William R. Jones

Chapter C of

Integrated Investigations of Environmental Effects of Historical Mining in the Animas River Watershed, San Juan County, Colorado

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Abstract

The history of mining and milling practices and production in San Juan County, Colorado, can be divided into four time periods based on the changes in milling technology. These periods are defined as (1) the Smelting Era 1871–1889, (2) the Gravity Milling Era 1890–1913, (3) the Early Flotation Era 1914–1935, and (4) the Modern Flotation Era 1936–1991. During these periods mining production was influenced by national and world events such as war, metals prices, government policies, and mining and milling technology. During the Smelting Era, mines were small, milling was rarely done, and most ore was shipped as crude ore directly to the smelters. Selective mining left mineralized rock on surface dumps, and underground as stope backfill. Production in this period was an estimated 93,527 short tons. During the Gravity Milling Era, higher capacity mining technologies were developed, and milling of low-grade ores became common. New technologies, including aerial tramways, air-powered drills, electrical devices, and an integrated narrow gauge railroad system helped increase productivity. Mine production in the period increased to 4.3 million short tons, of which more than 96 percent was waste; that 96 percent was discharged directly into the Animas River and tributaries as mill tailings. During the Early Flotation Era, continued mining technology improvements allowed bulk mining of low-grade ore, which was milled rather than discarded on dumps. Tunnels and workings increased in extent. Production in this era totaled 4.2 million short tons. Mill tailings continued to be discharged into rivers and streams. In the Modern Flotation Era, milling efficiencies improved and production tonnages increased further, but owing to changes in the attitudes of the public and the courts, mill tailings were impounded in tailings ponds, rather than discharged to the Animas River. Long haulage tunnels became practical and drained ground water in the vicinity of the mine workings. Mining in the county increased as a result of World War II and Korean War government incentives, but it decreased after 1953, as costs increased and metals prices failed to keep pace. Increased environmental regulation of mining impacted the industry as reclamation costs reduced profitability. High gold prices and ore grades helped the Sunnyside mine remain in production until 1991 when mining ended in the county after 121 years. Production for the modern flotation era totaled 9.5 million short tons.

Total ore production for 1871–1991 is estimated at 18.1 million short tons, of which an estimated 8.6 million short tons of mill tailings was discharged into the Animas River and tributaries.

[1]Silverton, Colo.

Introduction

Silverton and San Juan County have a history of mining production that spans more than 120 years, from initial discoveries in 1871 to the end of major production in 1991. During this time the industry evolved and grew, owing to a complex mix of technology and economics influenced in the broadest sense by America's need for metals. The mining industry has always been a leader in technological innovation and the industry around Silverton was no exception. Four distinct periods of mining and milling practices can be identified: 1871–1889; 1890–1913; 1914–1935; and 1936–1991. Total production for the mines in San Juan County is listed in table 1.[2] These four periods are best defined by the ore processing and milling methods in use during the period. Mining techniques changed somewhat more gradually, but they maintained a clear connection to the demands placed on the mines by the rapid innovations of mineral processing technology. Mines in the study area are shown in figure 1, and the mills and smelters in figure 2. (See Church, Mast and others, this volume, Chapter E5.) Data on the type of mill, capacity, and processes used and dates of construction or expansion are in table 2. Tramways (table 3 and fig. 2) were constructed to provide efficient transport of the ore to larger and more efficient mills, and narrow gauge railroads (table 4 and fig. 2) facilitated in moving the ore concentrate to smelters outside the upper Animas River, Mineral Creek, and Cement Creek basins.

[2]Owing to space constraints, values for each commodity (troy oz × $/oz; lb × $/lb) are omitted here, and average values for silver, copper, and lead, originally computed to three decimal places, were rounded. The complete table appears on the database disk that accompanies the volume.

Table 1. Summary of metal production from mines in San Juan County, Colorado from 1871 to 1991.

[Data from 1871 to 1908 are estimated when italicized, see notes for details; total value of metals italicized where calculated from commodity prices; --, no data; $/T Oz, dollars per troy ounce; $/lb, dollars per pound]

Year	No. of lode mines	Crude ore treated	Total ore treated	Gold		Silver		Copper		Lead		Zinc	
		Short tons	Short tons	Troy ounces	Average value ($/T Oz)	Troy ounces	Average value ($/T Oz)	Lb	Average value ($/lb)	Lb	Average value ($/lb)	Lb	Average value ($/lb)
1871	--	--	27	196	$20.67								
1872	--	--	100	701	$20.67								
1873	--	--	*100*	629	$20.67								
1874	--	--	*100*	461	$20.67	3,166	$1.28						
1875	--	--	*1,100*	483	$20.67	68,547	$1.24			120,000	$0.06		
1876	--	--	*800*	242	$20.67	48,465	$1.16			249,348	$0.06		
1877	--	--	*800*	242	$20.67	34,010	$1.20	8,664	$0.19	400,000	$0.06		
1878	--	--	*600*	290	$20.67	24,569	$1.15	36,145	$0.17	400,000	$0.04		
1879	--	--	*900*	290	$20.67	30,938	$1.12	100,000	$0.19	500,000	$0.04		
1880	--	--	*700*	290	$20.67	11,602	$1.15	100,000	$0.21	430,000	$0.05		
1881	--	--	*600*	242	$20.67	19,336	$1.13	100,000	$0.18	140,000	$0.05		
1882	--	--	*1,100*	483	$20.67	46,406	$1.14	100,000	$0.19	320,000	$0.05		
1883	--	--	7,400	1,693	$20.67	270,703	$1.11	100,000	$0.17	1,137,000	$0.04		
1884	--	--	8,000	1,935	$20.67	464,062	$1.11	300,000	$0.13	3,400,000	$0.04		
1885	--	--	*14,000*	1,935	$20.67	700,000	$1.07	100,000	$0.11	5,300,000	$0.04		
1886	--	--	*14,700*	6,908	$20.67	718,523	$0.99	100,000	$0.11	4,300,000	$0.05		
1887	--	--	*9,000*	5,865	$20.67	401,760	$0.98	300,000	$0.14	2,040,145	$0.05		
1888	--	--	*7,500*	9,208	$20.67	223,339	$0.94	240,000	$0.17	2,382,358	$0.04		
1889	--	--	*26,000*	19,103	$20.67	508,328	$0.94	135,018	$0.14	4,096,887	$0.04		
1890	--	--	*67,000*	9,064	$20.67	321,340	$1.05	147,354	$0.16	3,462,158	$0.05		
1891	--	--	*121,000*	9,294	$20.67	769,545	$0.99	235,467	$0.13	6,857,544	$0.04		
1892	--	--	*73,000*	7,204	$20.67	397,589	$0.87	136,768	$0.12	6,406,665	$0.04		
1893	--	--	*89,000*	12,611	$20.67	327,153	$0.78	1,125,826	$0.11	8,000,000	$0.04		
1894	--	--	*76,000*	16,450	$20.67	351,114	$0.63	1,118,222	$0.10	4,000,000	$0.03		
1895	--	--	*230,000*	41,094	$20.67	1,894,453	$0.65	2,057,588	$0.11	8,098,800	$0.03		
1896	--	--	*241,000*	43,962	$20.67	2,228,031	$0.68	845,094	$0.11	5,634,586	$0.03		
1897	--	--	*163,000*	33,591	$20.67	1,101,907	$0.60	1,435,203	$0.12	8,021,414	$0.04		
1898	--	--	*232,000*	54,794	$20.67	1,048,499	$0.59	2,252,421	$0.12	14,659,999	$0.04		
1899	--	--	*237,000*	48,199	$20.67	1,191,857	$0.60	1,197,661	$0.17	16,011,677	$0.05		
1900	--	--	*205,000*	36,633	$20.67	681,317	$0.62	1,972,087	$0.17	17,579,177	$0.04		
1901	--	--	242,850	46,588	$20.67	784,218	$0.60	2,740,042	$0.17	15,473,187	$0.04		
1902	--	--	230,000	73,741	$20.67	838,102	$0.53	3,012,283	$0.12	7,699,883	$0.04		
1903	--	--	*249,500*	82,758	$20.67	781,358	$0.54	2,939,018	$0.14	6,969,093	$0.04		
1904	31	--	233,663	83,997	$20.67	1,042,044	$0.58	3,467,124	$0.13	9,288,643	$0.04	1,384,340	$0.05
1905	20	--	204,139	50,840	$20.67	750,844	$0.61	2,274,109	$0.16	8,045,126	$0.05	248,627	$0.06
1906	26	--	196,438	43,545	$20.67	690,076	$0.68	1,549,663	$0.19	4,515,317	$0.06	584,476	$0.06
1907	27	--	235,639	46,814	$20.67	1,175,176	$0.66	2,450,280	$0.20	12,483,507	$0.05	237,677	$0.06
1908	42	4,411	202,643	48,269	$20.67	1,004,287	$0.53	2,282,738	$0.13	8,402,569	$0.04	10,131	$0.05
1909	40	6,100	187,041	33,053	$20.67	793,637	$0.52	1,653,192	$0.13	9,085,068	$0.04	786,518	$0.05
1910	53	6,052	206,272	34,371	$20.67	782,250	$0.54	1,208,496	$0.13	10,688,386	$0.04	3,781,259	$0.05
1911	37	1,919	108,088	16,276	$20.67	325,604	$0.53	470,912	$0.13	6,933,822	$0.05	2,224,351	$0.06
1912	41	--	140,917	25,327	$20.67	714,974	$0.62	1,063,291	$0.17	9,114,334	$0.05	2,478,594	$0.07
1913	38	10,832	123,343	31,811	$20.67	880,409	$0.60	1,221,516	$0.16	9,508,979	$0.04	1,664,999	$0.06
1914	29	4,675	117,988	24,597	$20.67	493,917	$0.55	825,180	$0.13	5,199,000	$0.04	971,177	$0.05
1915	42	5,952	147,878	28,235	$20.67	430,637	$0.51	1,054,463	$0.18	6,791,596	$0.05	2,259,226	$0.12
1916	46	11,748	146,128	21,218	$20.67	502,342	$0.66	1,615,167	$0.25	7,285,304	$0.07	4,014,403	$0.13
1917	46	--	145,685	15,383	$20.67	658,261	$0.82	1,665,923	$0.27	10,515,535	$0.09	3,270,500	$0.10

Total value of metals produced	Sources of data	Important historical events
$4,050.00	Ransome (1901)	Discovery of Little Giant mine.
$14,500.00	Ransome (1901)	
$13,000.00	Henderson (1926)	
$13,586.00	Henderson (1926)	
$101,958.00	Henderson (1926)	Greene Smelter opens in Silverton.
$76,429.00	Henderson (1926)	
$69,458.00	Henderson (1926)	
$54,654.00	Henderson (1926)	Bland-Allison Silver Purchase Act.
$79,751.00	Henderson (1926)	Smelter moved to Durango.
$62,242.00	Henderson (1926)	
$51,770.00	Henderson (1926)	
$97,683.00	Henderson (1926)	D&RG Railroad arrives in Silverton.
$400,871.00	Henderson (1926)	
$719,909.00	Henderson (1926)	
$1,006,500.00	Henderson (1926)	
$1,063,037.00	Henderson (1926)	
$648,176.00	Henderson (1926)	
$545,411.00	Henderson (1926)	Silverton RR built to Red Mountain district.
$1,050,707.00	Henderson (1926)	
$703,548.00	Henderson (1926)	Sherman Silver Purchase Act passed.
$1,278,973.00	Henderson (1926)	
$766,943.00	Henderson (1926)	
$933,436.00	Henderson (1926)	Repeal of Sherman Silver Purchase Act.
$799,456.00	Henderson (1926)	
$2,560,129.00	Henderson (1926)	Silverton Northern RR built to Eureka for Sunnyside mine.
$2,684,076.00	Henderson (1926)	
$1,816,465.00	Henderson (1926)	
$2,587,586.00	Henderson (1926)	
$2,636,712.00	Henderson (1926)	SG&N RR built to Gladstone for Gold King mine.
$1,280,471.00	Henderson (1926)	
$2,556,439.00	Henderson (1926)	
$2,651,614.00	Henderson (1926)	
$2,827,888.00	Henderson (1926)	
$2,860,421.00	Henderson (1926)	
$2,251,535.00	Henderson (1926)	
$1,969,695.00	Henderson (1926)	
$2,999,623.00	Henderson (1926)	Financial Panic of 1907.
$2,184,801.00	Henderson (1926)	
$1,744,003.00	Henderson (1926)	
$1,960,898.00	Henderson (1926)	
$1,006,707.00	Henderson (1926)	
$1,719,894.00	Henderson (1926)	
$1,890,349.00	Henderson (1926)	
$1,143,653.00	Henderson (1926)	WWI begins in Europe.
$1,585,894.00	Henderson (1926)	
$2,207,116.00	Henderson (1926)	
$2,553,137.00	Henderson (1926)	America enters WWI.

Table 1. Summary of metal production from mines in San Juan County, Colorado from 1871 to 1991.—Continued

Year	No. of lode mines	Crude ore treated	Total ore treated	Gold		Silver		Copper		Lead		Zinc	
		Short tons	Short tons	Troy ounces	Average value ($/T Oz)	Troy ounces	Average value ($/T Oz)	Lb	Average value ($/lb)	Lb	Average value ($/lb)	Lb	Average value ($/lb)
1918	37	--	132,927	12,432	$20.67	477,322	$1.00	1,120,178	$0.25	9,485,775	$0.07	3,410,308	$0.09
1919	20	2,849	64,899	6,412	$20.67	279,667	$1.12	661,667	$0.19	5,443,906	$0.05	1,833,768	$0.07
1920	19	2,016	201,671	12,904	$20.67	746,100	$1.09	1,361,391	$0.18	16,601,025	$0.08	11,837,395	$0.08
1921	17	1,164	1,164	400	$20.67	64,179	$1.00	28,558	$0.13	557,555	$0.05	-	$0.05
1922	26	2,758	8,808	1,246	$20.67	77,864	$1.00	110,348	$0.14	1,651,982	$0.06	1,300,000	$0.06
1923	16	627	153,114	11,706	$20.67	471,750	$0.82	1,005,441	$0.15	10,738,943	$0.07	9,540,000	$0.07
1924	13	497	233,790	19,557	$20.67	689,656	$0.67	1,601,748	$0.13	1,755,913	$0.08	17,579,000	$0.07
1925	17	748	274,783	15,089	$20.67	808,254	$0.69	1,502,000	$0.14	2,083,400	$0.09	22,200,000	$0.08
1926	15	372	289,401	14,309	$20.67	869,963	$0.62	1,560,400	$0.14	18,460,600	$0.08	22,423,000	$0.08
1927	10	290	282,824	12,235	$20.67	726,291	$0.57	1,549,214	$0.13	17,271,016	$0.06	22,869,000	$0.06
1928	9	255	326,110	15,739	$20.67	827,318	$0.59	1,755,653	$0.14	16,694,449	$0.06	25,427,000	$0.06
1929	13	130	346,866	20,869	$20.67	871,544	$0.53	2,157,000	$0.18	19,012,224	$0.06	22,858,000	$0.07
1930	12	245	403,801	31,994	$20.67	1,067,496	$0.39	2,678,000	$0.12	17,788,600	$0.05	19,677,000	$0.05
1931	10	26	172,430	31,308	$20.67	430,793	$0.29	1,250,505	$0.08	1,134,000	$0.04	-	$0.04
1932	9	--	191,051	24,724	$20.67	339,965	$0.28	1,367,000	$0.06	1,031,000	$0.03	-	$0.03
1933	12	61	199,612	23,474	$25.56	389,642	$0.35	1,184,000	$0.06	1,198,400	$0.04	-	$0.04
1934	16	781	210,489	16,592	$34.95	303,012	$0.65	819,300	$0.08	2,051,000	$0.04	2,000	$0.04
1935	15	1,038	177,373	16,128	$35.00	282,418	$0.72	624,000	$0.08	2,418,200	$0.04	-	$0.04
1936	25	868	204,281	22,162	$35.00	432,603	$0.78	991,400	$0.09	3,112,900	$0.05	-	$0.05
1937	20	473	283,859	25,099	$35.00	484,362	$0.77	1,102,000	$0.12	6,680,000	$0.06	3,856,000	$0.07
1938	21	482	331,725	26,516	$35.00	647,712	$0.65	2,021,000	$0.10	8,011,000	$0.05	8,549,000	$0.05
1939	20	510	199,271	16,152	$35.00	286,150	$0.68	1,013,000	$0.10	2,092,000	$0.05	1,166,000	$0.05
1940	33	--	231,630	16,098	$35.00	362,662	$0.71	739,000	$0.11	5,378,000	$0.05	2,971,000	$0.06
1941	25	216	265,232	17,384	$35.00	532,731	$0.71	870,000	$0.12	6,145,000	$0.06	1,680,000	$0.08
1942	16	341	197,404	17,094	$35.00	394,657	$0.71	575,000	$0.12	4,297,000	$0.07	784,000	$0.09
1943	19	180	202,100	21,214	$35.00	327,098	$0.71	498,000	$0.13	5,397,000	$0.08	1,004,000	$0.11
1944	11	85	176,695	28,523	$35.00	233,027	$0.71	348,000	$0.14	4,594,000	$0.08	1,258,000	$0.11
1945	12	94	196,106	21,923	$35.00	306,374	$0.71	466,000	$0.14	5,371,000	$0.09	1,690,000	$0.12
1946	15	127	242,841	17,396	$35.00	361,328	$0.81	757,000	$0.16	7,084,000	$0.11	3,757,000	$0.12
1947	20	184	236,817	20,123	$35.00	417,451	$0.91	789,900	$0.21	5,797,100	$0.14	3,607,600	$0.12
1948	30	2,969	228,386	16,471	$35.00	542,490	$0.91	654,000	$0.22	6,004,000	$0.18	3,332,000	$0.13
1949	31	403	244,368	11,549	$35.00	584,068	$0.91	608,000	$0.20	7,026,000	$0.16	3,198,000	$0.12
1950	25	426	278,152	13,902	$35.00	596,149	$0.91	690,000	$0.21	6,784,000	$0.14	2,590,000	$0.14
1951	28	322	243,917	9,998	$35.00	453,327	$0.91	1,102,000	$0.24	9,064,000	$0.17	3,684,000	$0.18
1952	20	55	190,599	10,203	$35.00	363,530	$0.91	1,190,000	$0.24	8,446,000	$0.16	2,942,000	$0.17
1953	12	--	55,943	2,696	$35.00	122,462	$0.91	272,000	$0.29	2,958,000	$0.13	1,264,000	$0.12
1954	7	217	6,900	491	$35.00	20,395	$0.91	24,000	$0.30	458,000	$0.14	166,000	$0.11
1955	8	14	10,408	455	$35.00	35,829	$0.91	78,000	$0.37	938,000	$0.15	492,000	$0.12
1956	8	17	19,780	841	$35.00	37,283	$0.91	85,600	$0.43	1,665,800	$0.16	1,287,400	$0.14
1957	8	165	17,245	2,180	$35.00	54,757	$0.91	131,700	$0.30	1,124,800	$0.14	624,100	$0.12
1958	7	--	17,049	1,205	$35.00	33,336	$0.91	96,000	$0.26	782,000	$0.12	548,000	$0.10
1959	3	--	6,049	310	$35.00	7,303	$0.91	46,000	$0.30	290,000	$0.12	220,000	$0.12
1960	5	--	39,861	1,206	$35.00	50,284	$0.91	322,000	$0.32	778,000	$0.12	84,000	$0.13
1961	12	--	2,531	221	$35.00	5,740	$0.93	32,000	$0.30	80,000	$0.11	44,000	$0.12
1962	4	--	42,716	411	$35.00	31,306	$1.08	78,000	$0.31	1,578,000	$0.10	2,104,000	$0.12
1963	4	--	134,971	1,249	$35.00	127,497	$1.28	528,000	$0.31	5,878,000	$0.11	8,188,000	$0.12
1964	7	--	174,333	1,239	$35.00	194,724	$1.29	1,064,000	$0.32	8,214,000	$0.14	13,452,000	$0.14

Total value of metals produced	Sources of data	Important historical events
$1,994,845.00	Henderson (1926)	Sunnyside Flotation Mill at Eureka begins production.
$991,249.00	Henderson (1926)	
$3,617,422.00	Henderson (1926)	
$101,225.00	Henderson (1926)	Post war recession closes most mines.
$283,479.00	Henderson (1926)	
$2,117,067.00	Henderson (1926)	Sunnyside mine reopens.
$3,623,610.00	USBM Min.Res. of the U.S. 1924, commodity prices from Ingram (1932)	
$4,585,890.00	USBM Min.Res. of the U.S. 1925, commodity prices from Ingram (1932)	
$4,215,674.00	USBM Min.Res of the U.S. 1926, commodity prices from Ingram (1932)	
$3,419,371.00	USBM Min.Res.of the U.S. 1927, commodity prices from Ingram (1932)	Shenandoah-Dives mine opens.
$3,583,035.00	USBM Min.Res of the U.S. 1928, commodity prices from Ingram (1932)	
$3,981,967.00	USBM Min.Res of the U.S. 1929, commodity prices from Ingram (1932)	Stock Market Crash; Mayflower Mill built.
$3,254,428.00	USBM Min.Res of the U.S. 1930, commodity prices from Ingram (1932)	Sunnyside mine closes, S-D mine and Mayflower Mill start production.
$927,892.00	USBM Min.Res of the U.S. 1931, commodity prices from Ingram (1932)	Great Depression begins.
$724,013.00	USBM Minerals Yearbook 1932-33	
$741,740.00	USBM Minerals Yearbook 1934	
$917,294.00	USBM Minerals Yearbook 1935	Gold price increased to $35.00 per ounce.
$915,988.00	USBM Minerals Yearbook 1936	
$1,345,123.00	USBM Minerals Yearbook 1937	Tailings pond operations sucessful.
$2,031,242.00	USBM Minerals Yearbook 1938	Sunnyside mine reopens.
$2,323,685.00	USBM Minerals Yearbook 1939	Sunnyside mine closes.
$1,023,863.00	USBM Minerals Yearbook 1940	Strike closes Shenandoah-Dives mine.
$1,360,903.00	Vanderwilt (1947)	
$1,566,196.00	USBM Minerals Yearbook 1941	
$1,309,321.00	USBM Minerals Yearbook 1942	America enters WWII; premiums paid on metal production.
$1,553,145.00	USBM Minerals Yearbook 1943	
$1,721,925.00	USBM Minerals Yearbook 1944	
$1,704,337.00	USBM Minerals Yearbook 1945	
$2,253,957.00	USBM Minerals Yearbook 1946	
$2,519,279.00	USBM Minerals Yearbook 1947	Premium price plan expires.
$2,727,256.00	USBM Minerals Yearbook 1948	
$2,559,262.00	USBM Minerals Yearbook 1949	
$2,453,255.00	USBM Minerals Yearbook 1950	Korean War begins.
$3,265,458.00	USBM Minerals Yearbook 1951	
$2,822,276.00	USBM Minerals Yearbook 1952	
$816,116.00	USBM Minerals Yearbook 1953	Shenandoah-Dives mine closes, Korean War armistice.
$123,398.00	USBM Minerals Yearbook 1954	
$277,724.00	USBM Minerals Yearbook 1955	
$537,463.00	USBM Minerals Yearbook 1956	
$398,742.00	USBM Minerals Yearbook 1957	
$244,953.00	USBM Minerals Yearbook 1958	
$90,335.00	USBM Minerals Yearbook 1959, USGS (1999)	Standard Uranium Corp. begins American tunnel.
$292,847.00	USBM Minerals Yearbook 1960, USGS (1999)	
$35,681.00	USBM Minerals Yearbook 1961, USGS (1999)	American tunnel completed at Sunnyside mine.
$459,266.00	USBM Minerals Yearbook 1962, USGS (1999)	Production begins from Sunnyside mine through American tunnel.
$1,945,755.00	USBM Minerals Yearbook 1963, USGS (1999)	
$3,547,585.00	USBM Minerals Yearbook 1964, USGS (1999)	

Table 1. Summary of metal production from mines in San Juan County, Colorado from 1871 to 1991.—Continued

Year	No. of lode mines	Crude ore treated	Total ore treated	Gold		Silver		Copper		Lead		Zinc	
		Short tons	Short tons	Troy ounces	Average value ($/T Oz)	Troy ounces	Average value ($/T Oz)	Lb	Average value ($/lb)	Lb	Average value ($/lb)	Lb	Average value ($/lb)
1965	9	--	182,704	2,052	$35.00	218,665	$1.29	906,000	$0.35	8,656,000	$0.16	17,316,000	$0.15
1966	13	--	197,989	3,364	$35.00	252,979	$1.29	710,000	$0.36	9,492,000	$0.15	16,678,000	$0.14
1967	8	--	211,979	1,742	$35.00	261,873	$1.55	738,000	$0.38	11,054,000	$0.14	17,084,000	$0.14
1968	9	--	194,888	3,026	$40.06	247,123	$2.14	778,000	$0.41	7,948,000	$0.13	14,998,000	$0.14
1969	5	--	214,735	6,090	$41.51	266,579	$1.79	888,000	$0.47	10,572,000	$0.15	15,416,000	$0.15
1970	7	--	242,695	14,884	$36.41	271,758	$1.77	1,386,000	$0.58	13,138,000	$0.16	17,454,000	$0.15
1971	5	--	191,154	14,703	$41.25	219,790	$1.55	1,096,000	$0.52	9,574,000	$0.14	10,402,000	$0.16
1972	1	--	180,112	31,424	$58.60	291,204	$1.68	898,958	$0.51	10,040,542	$0.15	15,532,814	$0.18
1973	2	--	191,350	30,926	$97.81	290,316	$2.56	686,000	$0.60	9,474,000	$0.16	12,872,000	$0.21
1974	2	--	192,041	28,493	$159.74	237,476	$4.71	642,000	$0.77	7,062,000	$0.22	11,616,000	$0.36
1975	2	--	186,615	27,689	$161.49	206,287	$4.42	584,000	$0.64	6,734,000	$0.21	9,324,000	$0.39
1976	1	--	214,134	23,555	$125.32	235,547	$4.35	728,050	$0.70	7,280,555	$0.23	11,991,500	$0.37
1977	7	--	268,957	49,410	$148.31	329,968	$4.62	1,004,000	$0.67	9,648,000	$0.31	9,878,000	$0.34
1978	1	--	122,702	18,405	$193.55	196,323	$5.40	711,670	$0.66	4,908,080	$0.34	8,098,330	$0.31
1979	3	--	20,082	2,410	$307.50	26,106	$11.09	80,330	$0.92	602,460	$0.53	923,770	$0.37
1980	3	--	126,541	31,635	$612.56	202,466	$20.63	759,240	$1.01	4,302,390	$0.43	6,327,050	$0.37
1981	3	--	198,616	35,070	$459.64	216,099	$10.52	846,820	$0.84	5,554,100	$0.37	6,407,680	$0.45
1982	3	--	224,067	37,953	$375.91	284,391	$7.95	973,400	$0.73	9,151,220	$0.26	12,169,180	$0.39
1983	1	--	274,579	39,739	$424.00	348,095	$11.44	1,155,740	$0.77	8,946,920	$0.22	12,054,980	$0.41
1984	1	--	237,969	27,337	$360.66	360,510	$8.14	1,432,000	$0.67	9,632,000	$0.26	11,706,000	$0.49
1985	1	--	19,360	4,840	$317.66	44,528	$6.14	174,240	$0.67	1,200,320	$0.19	1,626,240	$0.40
1986	1	--	133,016	22,112	$368.24	211,183	$5.47	822,000	$0.66	4,730,000	$0.22	9,663,060	$0.38
1987	1	--	255,712	47,093	$477.95	446,330	$7.01	2,251,620	$0.83	13,816,760	$0.36	18,422,350	$0.42
1988	1	--	197,504	31,291	$438.31	395,033	$6.53	1,909,540	$1.21	10,695,320	$0.37	14,483,720	$0.60
1989	1	--	179,391	29,612	$382.58	367,723	$5.50	1,817,800	$1.31	10,226,820	$0.39	16,037,060	$0.82
1990	1	--	237,829	21,784	$384.93	346,378	$4.82	1,787,720	$1.23	10,632,700	$0.46	15,509,220	$0.75
1991	1	--	141,534	19,940	$363.29	227,613	$4.04	1,267,500	$1.09	7,220,560	$0.34	10,807,640	$0.53
TOTAL		73,694	18,136,276	2,288,923		51,306,907		112,279,546		765,645,442		604,213,443	

Total value of metals produced	Sources of data	Important historical events
$4,553,906.00	USBM Minerals Yearbook 1965, USGS (1999)	
$4,554,795.00	USBM Minerals Yearbook 1966, USGS (1999)	
$4,661,184.00	USBM Minerals Yearbook 1967, USGS (1999)	
$4,048,972.00	USBM Minerals Yearbook 1968, USGS (1999)	Standard Metals announces plan to close Sunnyside mine.
$4,978,000.00	USBM Minerals Yearbook 1969, USGS (1999)	Gold discovered in Sunnyside mine.
$6,548,203.00	USBM Minerals Yearbook 1970, USGS (1999)	
$4,512,584.00	USBM Minerals Yearbook 1971, USGS (1999)	Standard Metals bankruptcy closes Sunnyside mine.
$5,645,698.00	Standard Metals Corp 1973 Annual Report, production and total value; commodity prices from USGS (1999)	Standard reopens Sunnyside mine.
$8,378,947.00	USBM Minerals Yearbook 1973, silver and base metal values calculated from commodity prices (USGS, 1999)	Government removes restrictions on gold price.
$11,924,712.00	USBM Minerals Yearbook 1974, silver and base metal values calculated from commodity prices (USGS, 1999)	
$10,842,267.00	USBM Minerals Yearbook 1975, silver and base metal values calculated from commodity prices (USGS, 1999)	
$10,601,928.06	Sunnyside mine production only (Hutchinson, 1988); values calculated from commodity prices USGS (1999)	Mayflower Mill increases capacity to 1000 short tons per day
$15,883,716.00	USBM Minerals Yearbook 1977, silver and base metal values calculated from commodity prices (USGS, 1999)	
$7,136,916.00	Sunnyside mine production from Hutchinson (1988); total value from Standard Metals 1982 report	Lake Emma floods Sunnyside mine.
$2,129,133.00	Sunnyside mine production from Hutchinson (1988); total value from Standard Metals 1982 report	
$17,904,380.00	Sunnyside mine production from Hutchinson (1988); total value from Standard Metals 1982 report	Sunnyside mine reopens.
$24,882,000.00	Production from Standard Metals 1984 Report, Sunnyside mine only. Total value from USBM Yearbook 1983	
$25,895,000.00	Producton from Standard Metals 1984 Report, Sunnyside mine only. Total value from USBM Yearbook 1984	
$21,019,112.00	Production from Standard Metals 1984 Annual Report; value from 1986 backruptcy disclosure	
$21,905,397.82	Production from Standard Metals 1984 Annual Report; values calculated from commodity prices (USGS, 1999)	
$2,813,704.96	Sunnyside mine production from Hutchinson (1988); values calculated from commodity prices (USGS, 1999)	Standard Metals bankruptcy closes Sunnyside mine.
$14,718,148.80	USBM Minerals Yearbook 1986 except zinc from Hutchinson (1988); commodity prices from USGS (1999)	Echo Bay Mines purchases, reopens Sunnyside mine.
$40,173,640.64	Base metal production from Hutchinson (1988), tonnage, gold, and silver from Echo Bay Mines 1987 Annual Report	
$31,282,882.56	Sunnyside Gold Corp. (written commun., 2002); commodity prices and value calculated from USGS (1999)	
$32,910,691.94	Sunnyside Gold Corp. (written commun., 2002); commodity prices and value calculated from USGS (1999)	
$28,716,460.52	Sunnyside Gold Corp. (written commun., 2002); commodity prices and value calculated from USGS (1999)	
$17,674,258.14	Sunnyside Gold Corp. (written commun., 2002); commodity prices and value calculated from USGS (1999)	Sunnyside mine closes August 15, 1991.
$529,838,329.44		

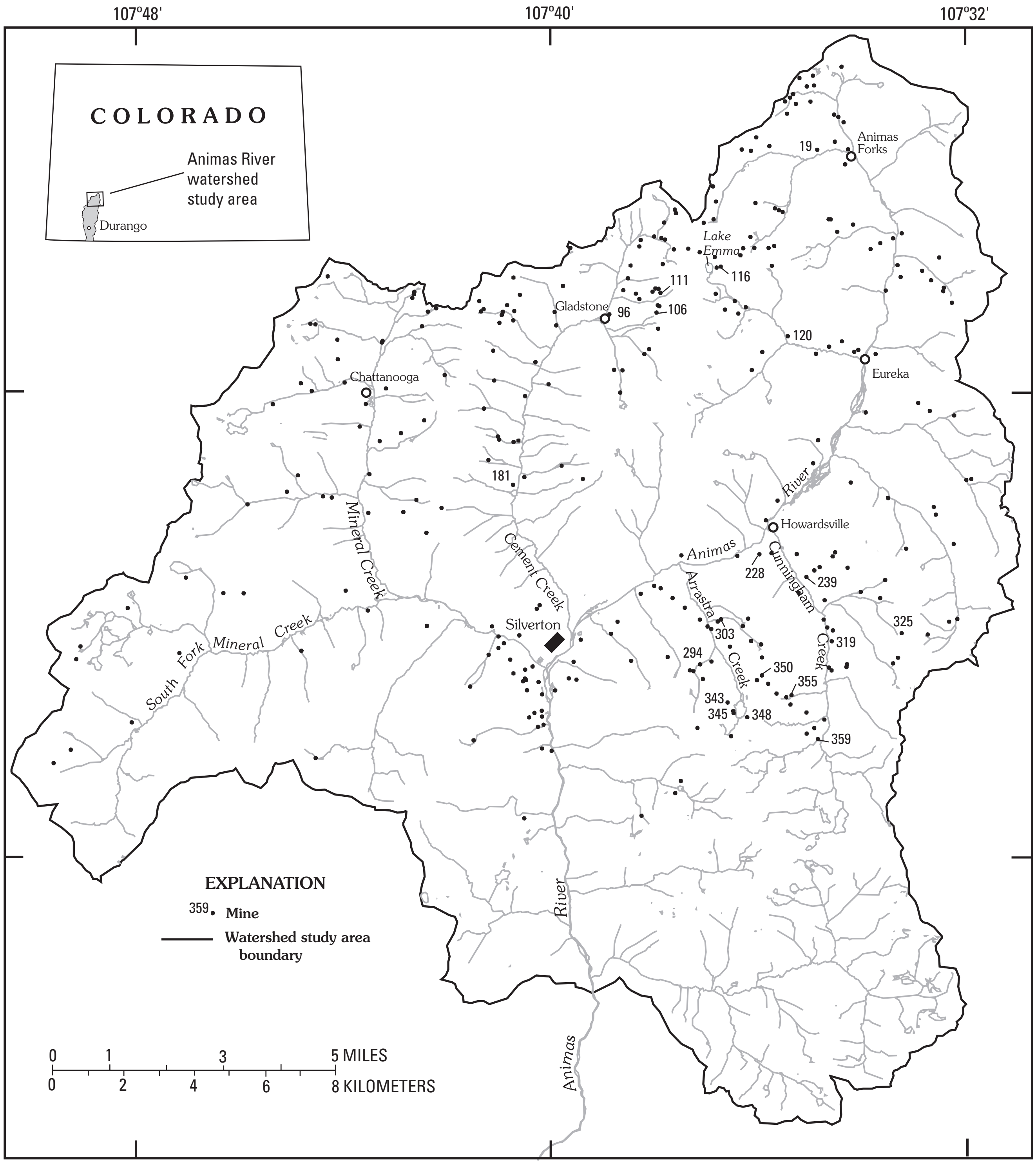

Figure 1. Locality map of mines, Animas River watershed study area (Church, Mast, and others, this volume, Chapter E5). Mine sites referred to in this chapter are: Frisco tunnel (site # 19), Gold King Mill level tunnel (site # 96), Lead Carbonate (mine # 106), Gold King (mine # 111), Sunnyside (mine # 116), Terry tunnel, Sunnyside (mine # 120), May Day (mine # 181), Little Nation (mine # 228), Old Hundred mine, mill level (site # 239), Unity tunnel of the Silver Lake (mine # 294), Little Giant (mine # 303), Pride of the West mine, # 1 level (mine # 319), Buffalo Boy (mine # 325), Silver Lake mine, # 1 level (mine # 343), Iowa (mine # 345), Royal Tiger (mine # 348), North Star (mine # 350, later a part of the Shenandoah-Dives mine, 1700 level), Shenandoah-Dives mine, 900 level (mine # 355), and Highland Mary mine, # 7 level (mine # 359).

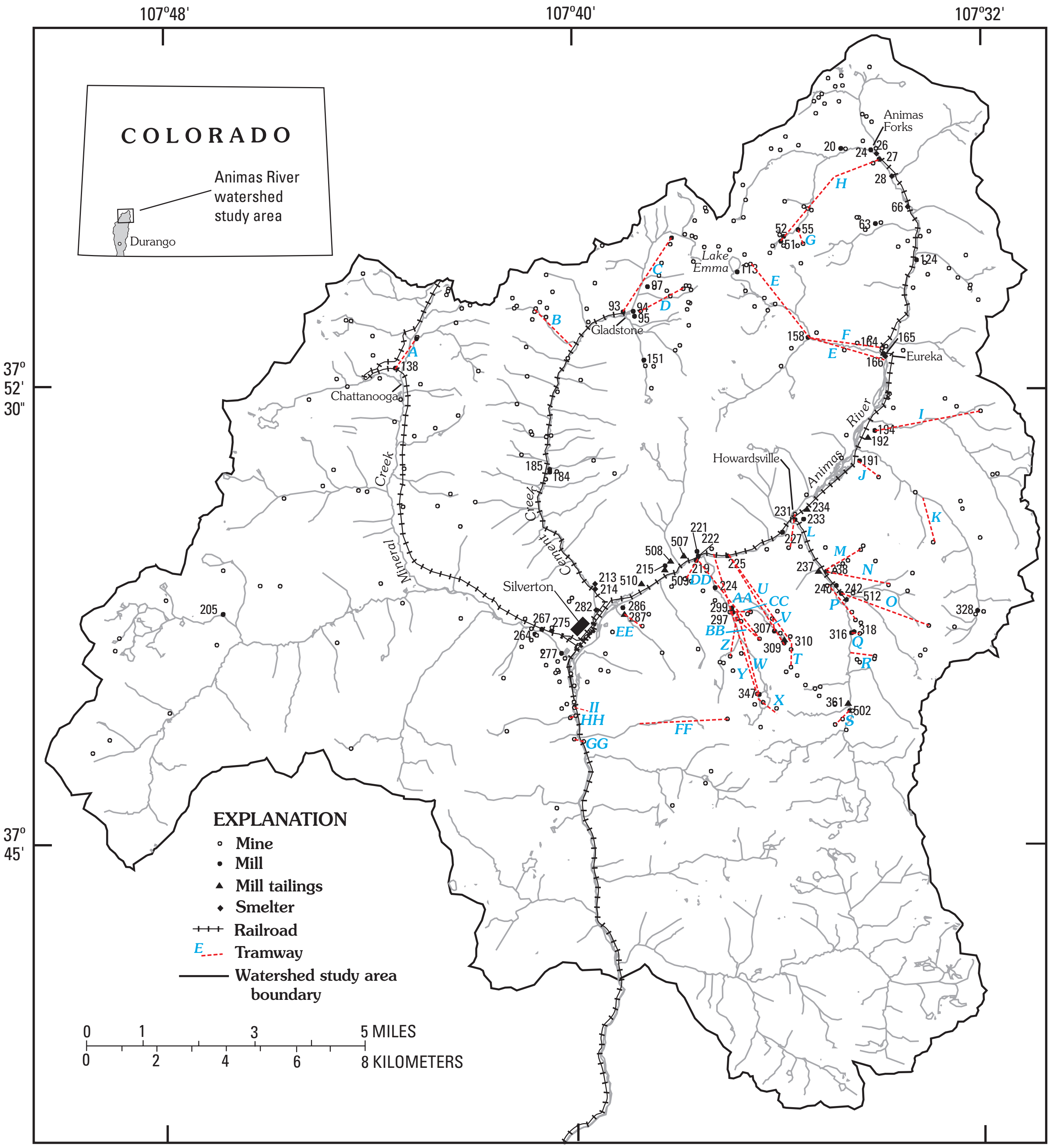

Figure 2. Locality map of mills, smelters, tramways, and railroads (mill and smelter localities from Church, Mast, and others, this volume; railroads from Sloan and Skowronski, 1975). Mills, their processing capacities, and dates of construction or expansion are summarized in table 2. Trams and their dates of construction are in table 3. Narrow gauge railroad segments and dates of their construction are in table 4. Large mill tailings present today are the Kittimack tailings (site # 192), Pride of the West Mill [# 4] tailings (permitted; site # 234), Old Hundred tailings (site # 237), Lackawanna tailings (site # 286, removed by the U.S. Bureau of Land Management in 2000 to the May Day mine site # 181, fig. 1), North Star tailings (site # 310), and Highland Mary tailings (site # 361).

Table 2. Mills and smelters, San Juan County.

[Localities shown in fig. 2; dates mill built or enlarged where approximate are indicated; size of mill capacity in italics where estimated; mercury used in gold recovery indicated by Y (yes) or N (no) if known, ? if uncertain; method of ore processing, C, concentrator; F, Flotation, S, Stamps; Lix, Lixivation; Rolls/pan, rolls crusher and pan amalgamation]

Name	Site No. (fig. 2)	Mill method (Stamp, Concentrator, or Flotation)	Date built or enlarged	Capacity (tons/day)	Amalgamation (used mercury for gold recovery)
Bagley Mill (aka Frisco)	20	C	1912	150	N
Big Giant Mill	307	C	c. 1896	20–40	Y
Boston & Silverton Mill (aka Yukon)	185	S, C	1890s	75	?
Columbus Mill	24	F	1940s	50	N
Contention Mill (aka Arpad, North Star [#2])	225	S,C	c. 1905	100	N
Green Mountain Mill (Osceola)	240	C	1904	300	N
Gold King Mill	94	S, C	c. 1897, 1899, 1903, 1904	65, 100, 250, 325	Y
Gold Prince Mill	27	S,C	1905–1906	500	Y
Hamlet Mill	191	C	c. 1905	50, 75	N
Hanson Mill (aka Sunnyside Extension Mill)	51	S, C	1896	50	N
Hercules Mill (aka Empire)	277	S, C	1889, 1899	50, 100, 140, 200	Y
Highland Mary Mill (aka Gold Tunnel M & M)	502	C, F	1902, 1940, 1944	150, 100	N
Ice Lake Mill	205	S, C	1890s	40	Y
Intersection Mill	328	S, C	1890s	30	Y
Iowa Mill	297	C	1890s, 1901	50, 100, 150, 200	Y
Kittimack Mill	194	C	c. 1908	100	N
Lackawanna Mill	287	C, F	1920s	*50*	N
Lead Carbonate Mill	95	F	1947	50	N
Little Giant Mill	299	Rolls/pan	1873	*5*	Y
Little Nation Mill	231	C, F	1923	50	N
Mastodon Mill	52	F	1952	50	?
Mayflower Mill (aka Shenandoah-Dives Mill)	221	F, C	1929, 1935, 1944, 1976	300, 600, 750, 1,200	Y
Mears-Wilfley Mill	222	C, F	1914	500	N
Mogul Mill	93	C	1900	75	N
Natalie/Occidental Mill	151	S, C	1899	75	N
North Star (Sultan) Mill	264	S, C	1883	70, 100	Y
North Star (Soloman) Mill [#1]	309	S	1882	40	?
Old Hundred Mill	238	S, C, F	1905, 1950	200, 65	Y
Pride of the West Mill [#1] (Schoelkopf)	318	S	1881	*20*	?
Pride of the West Mill [#2] (aka Howardsville Conc.)	227	S, F	1901	40	?
Pride of the West Mill [#3]	316	F	1928	65	N
Pride of the West Mill [#4] (aka Dixilyn, P&G)	233	F	1940, 1968, 1981	50, 90, 300	N
Red and Bonita Mill	97	S	1899	75	?
Silver Lake Mill #1	347	S, C	1893, 1899, 1901	100, 200, 250	N
Silver Lake Mill #2	219	C, F	1900, 1902, 1907, 1914	200, 300, 450	N
Silver Ledge Mill	138	C	1883, 1898, 1902	50, 125, 200	N

Table 2. Mills and smelters, San Juan County.—Continued

Name	Site No. (fig. 2)	Mill method (Stamp, Concentrator, or Flotation)	Date built or enlarged	Capacity (tons/day)	Amalgamation (used mercury for gold recovery)
Silver Wing Mill	124	S, C	1898	40, 100	N
Sound Democrat Mill	55	S, C	c. 1900	30	Y
Sunnyside Eureka Mill	164	F	1917, 1925	600, 750, 1,100	N
Sunnyside Mill #1 (Midway)	158	S, C	1889	40, 50	Y
Sunnyside Mill #2	165	S, C, F	1899, 1901, 1915	40, 50, 150, 200	Y
Sunnyside-Thompson Mill	113	S, C	1888	20	Y
Titusville Mill*		C	c. 1896	85	?
Treasure Mountain Mill	63	F	1941	25	N
Vertex Mill	242	F	1929	100	N
Victoria Mill	267	S, C	1890s	100	Y
Ward and Shepard Mill	224	S	1881	10–20	Y
William Crooke Mill	215	S, Lix, C	c. 1882	50	N
Yukon Mill	184	F, C	1977	10	N
San Juan Smelting Co.	26		1874		
Brown, Epley & Co. Smelter	28		1876		
Eclipse Smelter	66		1880		
Greene & Co. Smelter	214		1874		
Kendrick-Gelder Smelter (Ross)	213		1900		
Martha Rose Smelter	275		1882, 1894		
Rough & Ready Smelter	282		1875		
Winspear Smelter	166		1878		

*Locality uncertain, assumed to be at terminus of Titusville tram (FF, table 3, fig. 2).

Mining in Silverton followed the "boom and bust" pattern associated with the mining industry. International and national events such as war, economic depression, and government policies often triggered these cycles, which were quickly reflected in the price of metals and subsequent production. Ores in the district are typically polymetallic, containing gold, silver, lead, copper, zinc, cadmium, iron, and other trace metals. Mining evolved from small "high-grade" mines with limited processing, to larger mines producing lower grade ores, but at lower cost. This increasing output was processed in mills, which grew in size and efficiency. But unlike many other mining areas, which continued this progressive increase in size, large mines in San Juan County reached an upper limit of 700–1,000 short tons of ore produced per day around 1920. Annual production in the county was remarkably steady at 200,000–250,000 short tons per year when economic conditions were favorable to sustain profitable mining operations in the county (table 1 and fig. 3).

The sources of this production were varied, but a pattern developed that remained typical to the end of mine production in 1991: one or two "large" mines would account for the majority of production in any single year. Note that production records for individual mines are not generally available. After 1930, only two mines, the Shenandoah-Dives (1930–1953; mine # 355), which produced 4.099 million short tons of ore (Varnes, 1963) and Sunnyside (1962–1991, mine # 116 and # 96), which produced more than 7 million short tons of ore (Sunnyside Gold Corp., written commun., 2002) account for around 90 percent of all mine production for these years. Other earlier "large" mines include the Pride of the West (mine # 319—346,000 tons; Varnes, 1963), Silver Lake (mine # 343 and # 294—849,000 tons; Varnes, 1963), Iowa and Royal Tiger mines (mine # 345 and # 348—376,000 tons; Varnes, 1963), and the Gold King (mine # 111—665,000 tons; Taylor, 1988). Numerous small mines added to production during periods of high

Table 3. Aerial tramways built in San Juan County.

[Locations, code letters, fig. 2; approximate dates where uncertain]

Name	Built	Code
Silver Ledge tram	c. 1890	A
Henrietta tram	c. 1905	B
Mogul tram	1900	C
Gold King tram	1899	D
Sunnyside tram	c. 1889	E
Sunnyside tram (relocated)	1917	F
Sound Democrat tram	1900	G
Gold Prince tram	1905	H
Kittimack tram	c. 1907	I
Hamlet tram	c. 1903	J
Ridgeway tram	1946	K
Little Nation tram	c. 1928	L
Old Hundred tram	1904	M
Gary Owen tram	c. 1925	N
Buffalo Boy tram	c. 1926	O
Green Mountain tram	1904	P
Pride of the West (level # 3) tram	c. 1910	Q
Little Fanny tram	c. 1946	R
Highland Mary tram	1904, 1940	S
North Star tram	1898	T
Contention tram	c. 1900	U
Big Giant tram	c. 1910	V
Silver Lake #1 and #2 trams	c. 1899	W
Royal Tiger tram	c. 1890	X
Iowa tram	c. 1890	Y
Unity tram	c. 1905	Z
Shenandoah-Dives tram	1929	AA
Mayflower tram	c. 1915	BB
Little Giant tram	1872	CC
Aspen tram	c. 1906	DD
Lackawanna tram	c. 1928	EE
Titusville tram	c. 1900	FF
Royal Mining Co. tram	c. 1905	GG
Detroit tram	c. 1900	HH
Champion tram	c. 1900	II

metal prices or wars, only to close when prices dropped or Federal Government price supports were removed after the conflicts. The term “large mine” is relative to the historical period. In 1890, “large” was 100–200 short tons per day; by 1940, “large” had risen to 600–700 short tons per day.

Purpose and Scope

The purpose of this report is to identify the major historical mining, milling, and ore processing practices, technology, economics, and events that influenced mining production in San Juan County, Colo., and to place these historical practices in context with possible environmental effects in the Animas River watershed.

Period I—The Smelting Era 1871–1889

Mining Development and Practices

Lode mining began in 1871 with the discovery of the Little Giant (mine # 303, fig. 2 and table 2) in Arrastra Creek. Mining was performed by hand methods in small operations producing only a few tons of ore per day. Shafts, adits, and cuts were excavated directly into exposed or near-surface outcrops. Tunnels and shafts were short, typically not more than a few hundred feet. Only the higher grade ore was mined, usually the silver-lead ores. Lower grade ores and waste were typically left unmined when possible. Little mechanical processing or milling was done at the mine. The best ores were sacked and hauled off the mountains with mules as “crude ore” and eventually shipped to smelters as far away as Wales in the United Kingdom (fig. 4).

Ores were typically hand sorted, meaning the best ore chunks were hand selected and separately shipped to the smelters as “first class ore.” The sorting was done both underground in the stopes and at the surface in sorting houses (fig. 4). Often, a slightly lower grade ore was again hand sorted and shipped as “second class ore.” The hand “cobbing” technique upgraded lower grade ores when miners hammered off chunks of good ore mineral from the lower grade ore and waste rock. After the cobbed-off chunks were sacked, the mine waste was deposited on the surface dumps. To provide a work surface in the stopes, the void left from ore extraction was filled with mine waste and low-grade ores in a mining method called “cut-and-fill stoping” (Ransome, 1901). Owing to the difficulty and cost of breaking rock, mine development avoided tunneling through unmineralized, valueless “country” rock. Thus, much waste rock left both underground in stopes and on surface mine-waste dumps contained a significant amount of mineralized rock (fig. 5).

As the period progressed, mines became larger as outside capital financed new mines and expansion of existing mines. The Greene & Co. Smelter (site # 214, fig. 2), which could reduce the sulfide lead-silver ores to metallic bullion, opened in Silverton in 1875. This stimulated production by providing a local market for the ores, which avoided expensive and difficult transportation out of the basin either by mule train or by wagon. However, the smelter operated only intermittently and was dismantled and moved to Durango in 1880, where deposits of needed coal and limestone flux were located (Ransome, 1901, p. 20). The anticipated completion of the Denver & Rio Grande Railway’s San Juan Extension also influenced the smelter’s move. The railroad arrived in Durango in July 1881 and in Silverton in July 1882 (table 4). Mining production increased dramatically as reduced transportation costs for both ores and supplies stimulated development (Ransome, 1901). Ores were shipped by rail to the San Juan and New York Smelter in Durango for processing. In 1899, this facility became the American Smelting and Refining Co.

Table 4. Narrow gauge railroads built in San Juan County.

[Data from Sloan and Skowronski, 1975; locations shown in fig. 2; blank, date uncertain]

Name	From	To	Length (mi)	Started	Completed
Denver & Rio Grande Railway	Durango	Silverton	45.1	July 1881	July 1882
Silverton Railroad	Silverton	Red Mountain	11.5	July 1887	Sept. 1888
	Red Mountain	Ironton	6.0		Fall 1889
Silverton Northern Railroad	Silverton	Silver Lake Mill #2 (# 219)	2.2	Nov. 1895	Spring 1896
		Eureka	4.0		Summer 1896
		Animas Forks	3.9	Spring 1904	Nov. 1904
Green Mountain Branch	Howardsville	Green Mountain Mill (# 240)	1.6	Spring 1905	Fall 1905
Silverton, Gladstone, and Northerly Railroad	Silverton	Gladstone	7.1	Spring 1899	Sept. 1899

(ASARCO) Smelter in Durango, which was the regional smelter for lead-silver and quartz-gold ores and concentrates until it closed in 1930 (fig. 6). Rail connection to the smelters was an important component of the economic success of mining in Silverton well into the 1950s, when trucks finally replaced rail shipping.

As the mines expanded production, mining and ore-sorting practices continued as just described, but on a larger scale. More men were employed in additional working areas to achieve this higher production. Larger ore-sorting houses were built at the mines. By the end of the period, the larger mines were producing over 100 short tons of ore per day from tunnels as much as hundreds of feet long with multiple levels interconnected by internal and surface shafts.

The Federal Government supported mining development in several ways during this period. The General Mining Law of 1872 codified the ability to claim and later purchase government land for mining purposes. Purchase of government land by individuals and companies was a tenet of government policy throughout the late 19th and early 20th century. It was one of the primary ways the government raised revenues prior to income tax. In 1878, the Bland-Allison Act directly helped silver mining by requiring the Federal treasury to purchase about 24 million dollars worth of silver a year for minting coins for monetary purposes (Brown, 1984).

Milling Development and Practices

Most of the ores mined in the district were lead-silver ores (galena and tetrahedrite) that contained minor gold and were not very amenable to the mercury amalgamation processes used successfully in California and the Comstock District in Nevada. For this reason, direct smelting of crude ores of the various classes was the normal method of ore processing. San Juan County produced little “free milling” gold ore, though some gold was present in the Animas district ores (Varnes, 1963). According to published data, five stamp mills were built in the 1870s and nine were constructed in the 1880s (table 1). All were small, ranging in size from 10 to 70 tons per day capacity. Most included both amalgamation and concentration processes. Of the 14 stamp mills, only 4 are known to have survived into the 1890s; two of these were built in 1888 and 1889. The milling processes used during this time could not effectively treat the polymetallic ores of the county.

Environmental Aspects

Smelters in this and later periods could not treat ores containing more than 10 percent zinc due to metallurgical factors (Henderson, 1926). The smelters levied stiff charges against the mines for zinc contained in the shipped ore. Therefore, miners worked hard to leave the zinc in place in the mine, or sorted and cobbed the zinc off by hand. The zinc mineral, sphalerite, was disposed in waste dumps at the mine and as part of the waste ore used to fill the stopes. This “waste” still contained a relatively large amount of metal-bearing mineral. Thus, significant sulfide material including sphalerite was left where surface and underground water could potentially dissolve and mobilize metals, particularly the discarded zinc. Both copper and zinc contamination have been identified as limiting factors for aquatic life in several sections of the Animas River and tributaries (Besser and others, 2001).

The Greene & Co. Smelter (site # 214, fig. 2) and other pioneer smelters in the Silverton area operated for a short period prior to and during World War I. These smelters were tied to the mines by the local narrow gauge railroads (fig. 2 and table 4) and emitted acid- and metal-bearing flue dusts and gases from the oxidation of sulfur in the ores (fig. 7). These products were released directly into the environment. The stamp mills used the mercury amalgamation process to recover native or “free” gold. Industry practice at this time was to discharge mill tailings directly into a nearby creek. Some mercury may have been introduced into the environment by these mills (table 2).

Total tonnage mined in the period 1874–1889 is estimated at 93,527 short tons with most of this having been shipped to the smelters (table 1). Thus, only a small amount of this production was probably discharged as mill tailings into the Animas River watershed.

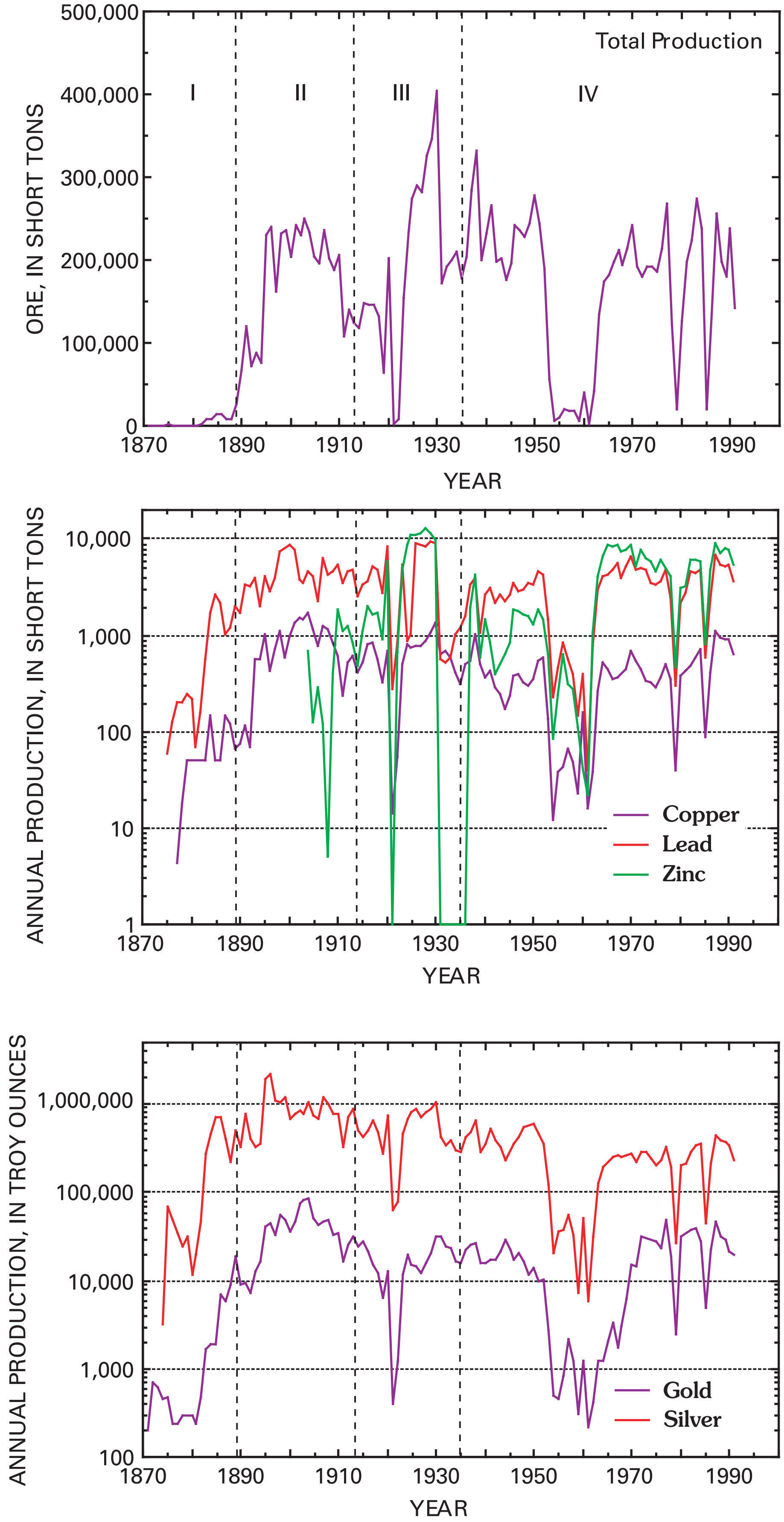
Total Production
I
II
III
IV
ORE, IN SHORT TONS
500,000
400,000
300,000
200,000
100,000
0
1870
1890
1910
1930
1950
1970
1990
YEAR
ANNUAL PRODUCTION, IN SHORT TONS
10,000
1,000
100
10
1
Copper
Lead
Zinc
ANNUAL PRODUCTION, IN TROY OUNCES
1,000,000
100,000
10,000
1,000
100
Gold
Silver

Figure 3 (facing page). Historical production for San Juan County, 1871–1991 (table 1). Total ore production and annual production of copper, lead, and zinc are in short tons; gold and silver in troy ounces. Periods of production also shown.

Period II—The Gravity Milling Era 1890–1913

Mining Development and Practices

During this period, mining development greatly expanded due to Federal Government supports, stable to rising commodity prices, and improved technologies. In 1890, the Sherman Silver Purchase Act was passed by Congress as part of a compromise to gain the support of Senators in western mining States for import tariffs desired by Senators from eastern manufacturing States. This act required purchase of 54 million ounces per year of silver, more than twice what the Bland-Allison Act authorized. Colorado silver mining boomed as silver prices rose from $0.84 per ounce to as high as $1.50 (Brown, 1984). New mining technologies were developed in this period. First, the wire-rope aerial tramway revolutionized transportation of ore, machinery, and supplies to remote mine sites (fig. 8 and table 3). Then, compressed-air powered machine-drills increased productivity, resulting in increased production. Finally, the application of electricity to many mine and mill tasks increased efficiency and throughput to handle the increased mine output. The new tramways and mills were integrated into the narrow gauge railroad system during this period (tables 2 and 3). Three independent rail lines were built out of Silverton to serve the new milling facilities, which were located adjacent to the railroads (table 4). The railroads brought in coal and supplies to service the mines and shipped ore concentrate out of the basin to smelters (figs. 6, 9, and 10; Sloan and Skowronski, 1975).

In the large mines, tonnages exceeding 200 short tons per day became practical, and upward of 400 men could work year around at a remote high-altitude site such as Silver Lake (mine # 343) or Sunnyside (mine # 116). The larger mines had several thousand linear feet of drifts and tunnels. Ore sorting in surface houses continued to expand as increased mine production yielded lower grade ores. Most mines still used cut-and-fill stoping methods, or open “stull”

Figure 4. Sacking sorted crude ore for shipment to the smelter (Silverton Standard folio, 1904). Early mining was by hand methods. Ores were sorted and sacked for shipment to the smelters. Low-grade and sphalerite-containing waste was cast aside manually.

Figure 5. Miners working inside a cut-and-fill stope, Gold King (mine # 111; circa 1899, Silverton Standard folio, 1904). This rare view inside a stope was staged for promotional purposes, but the photo shows hand drilling on a stope hanging wall and ore being cobbed with a hammer while an engineer studies samples. Miners are working off a fill pile while timbers support mined-out area above.

(timber-supported) stopes. Milling became the predominant ore processing method as the tonnage increased and ore values dropped. Several classes of ore were mined and sorted for both direct smelting and milling, depending on the grade of the ore. During this period near-surface "bonanza ores" were mined out, and improved milling technology encouraged mining of larger portions of the veins, both of which resulted in lower average ore grades. Frederic L. Ransome (1901, p. 24) of the U.S. Geological Survey accurately predicted: "It is very probable that the future will see a great and permanent increase in the productive development of such large and persistent ore bodies of low average grade."

The development of the wire-rope aerial tramway was a unique feature of San Juan County mining (fig. 2), and most of the trams in the county were built during this period (table 3). These allowed large tonnages of ore to be transported down from high-altitude mine portals to mills along the river and the narrow gauge railroad system. Crude ore was shipped straight through to loading bins on the railroad, while milling-grade ores were off-loaded separately into the mill (fig. 10). These trams could be as long as 2 or 3 miles in length. Coal, supplies, men, and machinery all rode trams to and from the mines; ores were shipped down in buckets. By 1907 nineteen tramways totaling 119,850 linear feet were constructed (Silverton Miner, 1907). Both the Iowa (Y, fig. 2) and Sunnyside (E, F, fig. 2) trams were each nearly 3 miles in length.

An 1899 report by Edward G. Stoiber, owner of the Silver Lake (mine # 343), summarizes the dramatic changes made at the mine during this period of property consolidation and expansion (Chase, 1952, p. 114):

> At the time of the purchase of the property in 1887, probably not over 500 ft of work had been done on same, and there were but two claims in the group; today the underground workings may reach a total length of 35,000 ft, and the group embraces about 100 claims.***It is claimed for this property that it is a low grade concentrating proposition, with the premises of practically unlimited vein area to draw from.

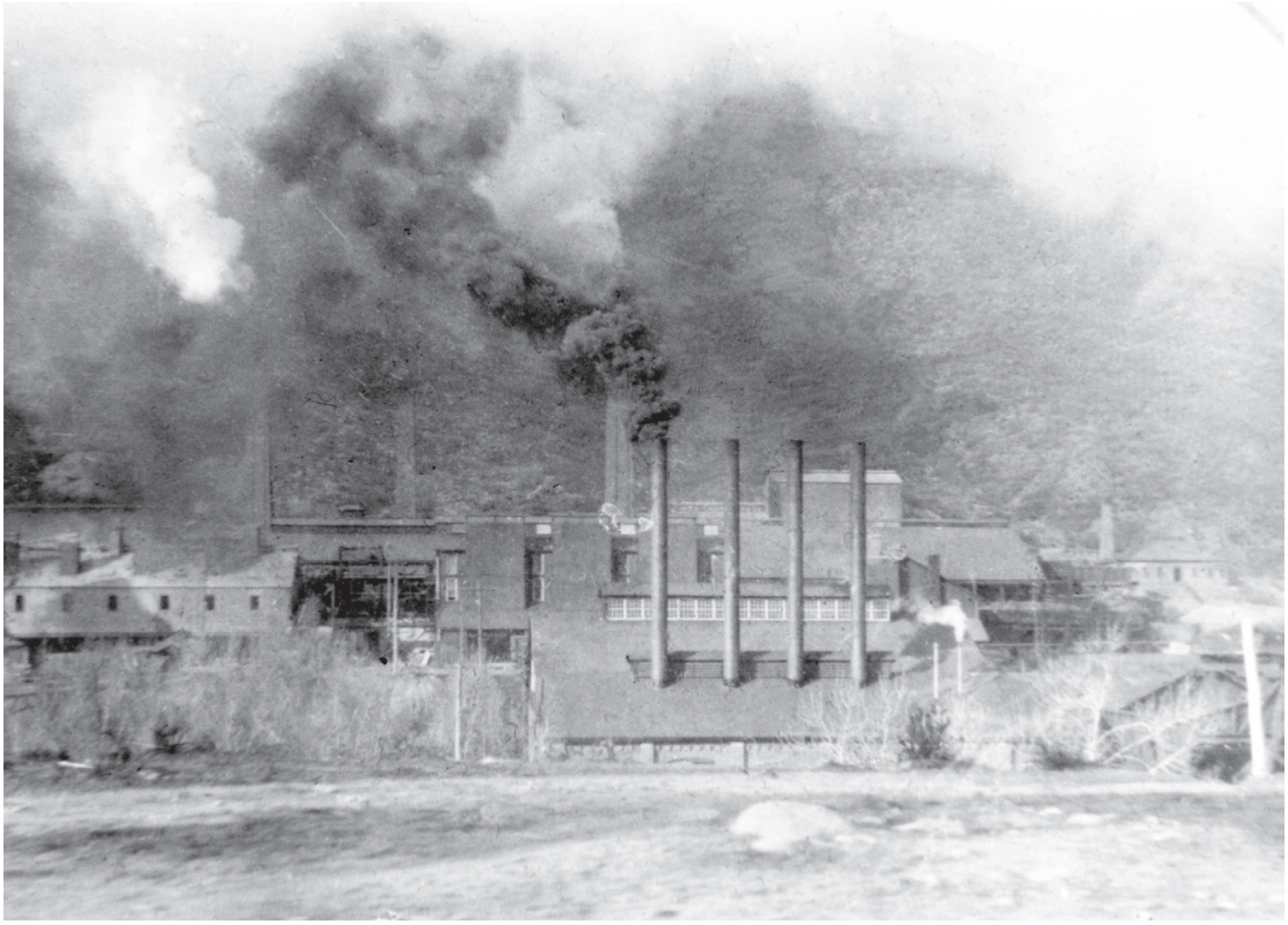

Figure 6. Durango Smelter along the Animas River, 1906 (C.A. Chase photo). Silverton lead-silver ores were shipped to the smelter in Durango for processing into metal. The process produced considerable air pollution.

Economic and political policies affected mining during this period. In the face of a mounting financial crisis caused in part by the Sherman Act, President Cleveland called a special session of Congress to repeal the act in 1893. This financial panic precipitated a national economic depression, which lasted until 1896 (Brown, 1984). Repeal of the Sherman Act caused the price of silver to fall from more than $1.00 per troy ounce, its typical value since the 1870s, to an average of $0.63 per ounce in 1893. Lead and copper prices also fell during the depression, though not as much, and they recovered faster. Silver prices languished throughout the period. Marginal mines were closed. Gold prices were supported by the Federal Government at $20.67 per ounce as part of the monetary Gold Standard, so that mines with significant gold content remained open and even expanded. After 1896, base-metal prices increased significantly as the U.S. economy expanded and many new mine and mill projects were built. In 1897, the Colorado Bureau of Mines reported that more than 160 mines were operating in San Juan County (Colorado Bureau of Mines, 1898). The Financial Panic of 1907 lowered metal prices again and greatly reduced the flow of investment capital needed for mine expansion. The beginning of World War I in 1914 led to a substantial increase in base-metal prices, resulting in the reopening of many mines and the expansion of others—notably the Sunnyside (mine # 116, fig 1).

Milling Development and Practices

As improved mining technology helped increase production, milling technology also improved to cope with larger tonnages of low-grade, metallurgically complex ores. Stamp mills utilized mechanically dropped heavy iron rod-like hammers to pulverize the ore (figs. 11 and 12). To extract the gold, concentrating machines called “tables” were used to separate the various minerals by gravity into “concentrates” containing lead-silver or lead-copper. If the ore contained significant gold, mercury-coated copper plates were located after the stamps and ahead of the tables to catch the gold particles (fig. 12). Various concentrating machines were developed and relied on differences in specific gravity to separate the mineral particles from worthless rock, hence the term “gravity milling.” By 1899, the Wilfley table was established as the leader in the field (Niebur, 1986).

Figure 7. Kendrick-Gelder (aka Ross) Smelter (site # 213, fig. 2) in Silverton and SG&N Railroad (circa 1907). Silverton had several short-lived smelters, connected to the mines by the narrow gauge railroad system. These small plants were uneconomic except during periods of high metal prices.

Mills, of which successful ones had been something of a rarity in Silverton, now were built at all but the smallest mines (for example, fig. 11). In 1899, the Silver Lake Mill # 1 (# 347, fig. 2) concentrator was built on the shore of Silver Lake at 12,125 ft elevation (table 2 and fig. 13) (Ransome, 1901). This mill was more than twice the size of the next largest in the county. The economic advantages of milling were significant. Low-grade ores could be concentrated into valuable high-grade concentrates that could be smelted more profitably than crude ore. Because smaller tonnages of material went to the smelter, both smelting and shipping costs were reduced and net revenue increased. However, zinc ores were still unmarketable during most of this period, because the mills could not efficiently separate it from the waste rock and local smelters could not process zinc ores. In 1897, twelve mills and two crude ore-purchasing stations called "samplers" were reported in operation. The largest mills were 200 short tons per day capacity, but most processed around 50 short tons per day. Total daily capacity of the crude ore samplers was 200 short tons per day and the mills 850 short tons per day in the county. Production was not continuous all year at all mills, however, in part because of severe weather at the high-elevation mine and mill sites. By 1901, additional mills increased combined active production to 1,470 short tons per day; annual production exceeded 200,000 short tons (table 1; Henderson, 1926). In 1897, six of the twelve mills included mercury amalgamation as part of the process. One mill used "lixivation," a sodium thiosulfate leaching process, to recover silver (Colorado Bureau of Mines, 1898).

The interrelationship of ore grades, tonnage produced, milling technology, and profitability is well summarized by the following excerpts from a February 12, 1913, report on the Silver Lake mine (mine # 343) by Lawrence R. Clapp, Superintendent.[3] The report was written for the mine's [now corporate] owners, American Smelting and Refining Company (ASARCO), who purchased the mine from E.G. Stoiber in 1901 and owned the smelter in Durango.

[3]Ore conditions at the Silver Lake mines, Silverton, Colo., in Shenandoah-Dives Collection, Center for Southwest Studies, Fort Lewis College, Durango, Colo., 15 p. (unpublished).

Figure 8. Iowa aerial tram (Y, fig. 2 and table 3) in Arrastra Creek (C.A. Chase Photo 1925). Aerial tramways provided the key link between high-altitude mines and the mills and railroads located along the river. The Iowa tram is nearly 3 miles long and climbed the steep cliff to Arrastra Basin in the background. The Silver Lake tram is out of sight in the trees to the left.

> The future of the Silver Lake Mines in my opinion, lies wholly in the solution of the problem of making this [low grade] material profitable and not in the search of better grade ore; the former company and Mr. Stoiber before them, both fought a losing battle in the attempt to keep their reserves of $9.00 or $10.00 [per ton] ore in advance of their [mill] consumption. In so doing they exposed a very large tonnage of lower grade material.*** To make $6.00 ore profitable, will require a total cost of $4.75 per ton and a mill extraction of at least 80%. Neither of these are beyond possibility. A $4.75 cost would mean a big tonnage, the avoidance of an expensive tram, an adequate modern equipment, and a high [milling] concentration ratio. [This is] considerably more than our present mill is capable of.

The solution recommended by Mr. Clapp was to try a new milling technique called "froth-flotation," which indeed was set to revolutionize mineral processing both locally and nationally.

Environmental Aspects

As mines and mills increased in size and scope, their effect on the environment also increased. Mining techniques were similar to those of prior periods, but were larger in scale owing to increased mechanization. Waste dumps from the sorting houses became large, some exceeding 50,000 short tons by the end of the period. Water drainage became more of an issue as longer tunnels intercepted ground water. When shaft mining was used, water infiltrating into the mines had to be pumped out. In the nearby Red Mountain mining district, acidic water was a major problem because it dissolved pumps and piping and finally contributed to the closure of the Yankee Girl and Guston mines (Ransome, 1901). In most San Juan County mines, such highly acidic water appears not to have been a major problem. However, water infiltrating the "filled"-type stopes and dumps probably became acidic, and it would have transported metals to the aquatic environment. By the end of the period, many mines were operated through long haulage tunnels, which were built at lower elevations to lower costs

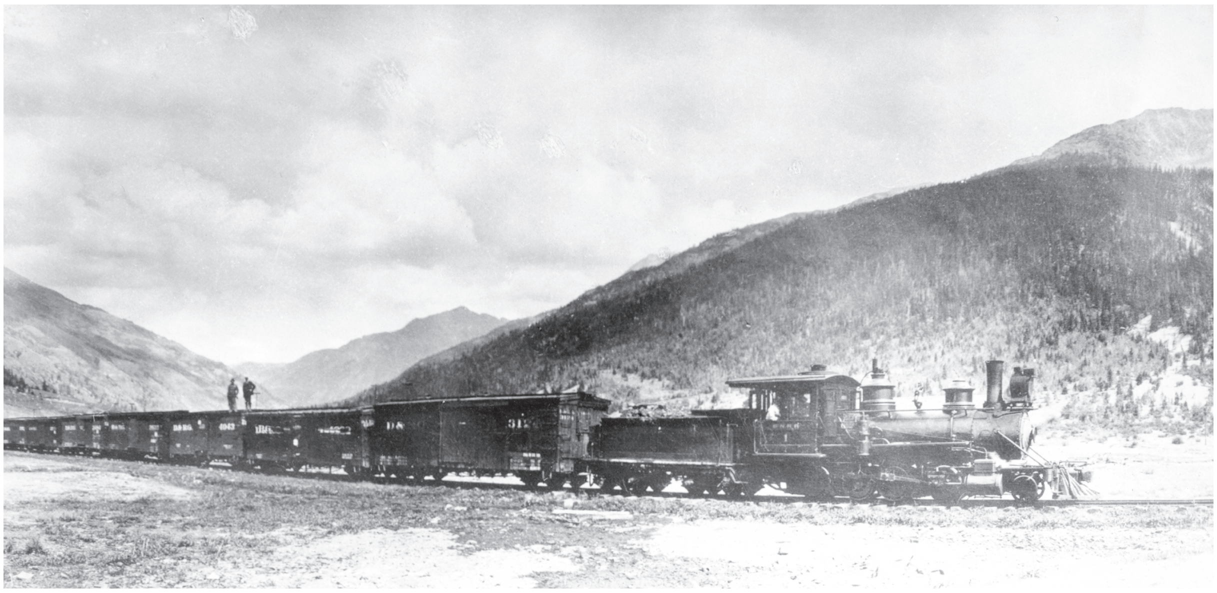

Figure 9. Silverton Northern Railroad and the Sunnyside mine's first "zinc train" (1915). Sunnyside began producing a zinc concentrate in 1915, which was shipped to a smelter out of the area. This special narrow gauge train was used to transport the powdered concentrate in 25-ton capacity boxcars, about half the size of standard gauge cars.

Figure 10. Silver Lake Mill #2 (site # 219, fig. 2) and tram (W, fig. 2) along the Animas River and Silverton Northern Railroad (circa 1904). The mill was built in 1900 and burned in 1906. It was later rebuilt and closed in 1914. The Silver Lake Mill #2 integrated tramlines, ore processing, and railroads. Crude ore could travel straight into the rail loading bins at far left. Low-grade ores were dumped into the terminal at the top of the mill for concentration. Tailings discharged in a flume at the base of the mill building on the right and were piped into the Animas River.

Figure 11. Small mills, such as the Intersection Mill located at the head of Minnie Gulch (fig. 2), became common around the beginning of the 20th century. At right is a five-stamp Fraser & Chalmers #56 crusher at Intersection Mill (site # 328, fig. 2) built in 1909–1910. A second crusher, a five-stamp Allis Chalmers #77 (at left), was added about 1915 (U.S. Bureau of Mines, 1910, 1915). Stamps were powered by steam engine (lower right corner of photo). Concentrates were produced using a Wilfley table, the remains of which are in the depression in front of the stamps. Note mine-waste pile adjacent to mill (about 100 tons).

and to minimize damage and loss of life from frequent high-elevation avalanches. These haulage tunnels served to drain the ground water down to that level, leaving upper mine workings relatively dry. Some of these haulage tunnels such as Silver Lake's Unity tunnel (site # 294) and Sunnyside's Terry tunnel (site # 120) reached several thousand feet in length.

Increased milling during this period had a serious negative effect on surface-water quality. Mills produced a muddy slurry waste product called "tailings." These mill tailings were commonly discharged directly into a nearby stream for disposal (Smith, 1987, p. 117). Sometimes they were discharged haphazardly on the ground or riverbanks near the mill, and crude impoundments were occasionally constructed (fig. 14). Stamp-mill tailings contained both a coarse sand fraction and fine particles called "slimes." Because the ore particles were soft, they tended to slime, making efficient recovery using the Wilfley table difficult. Recovery using gravity milling methods was 40–60 percent efficient (Bird, 1999). Upon discharge of the tailings into a stream, the coarse sands tended to settle out closer to the mills, whereas the finer material would stay suspended in the stream for long distances, affecting water quality as far south as Durango, 45 miles downstream from Silverton (Durango Evening Herald, July 18, 1902). Gravity mills typically recovered as much as 80 percent of the metals in the ore, such as gold, silver, and lead. Zinc, iron pyrite, and a portion of the copper were not recoverable by gravity mills (Niebur, 1986, p. 134). Thus, significant amounts of metal were left in the mill tailings, and particularly in the very fine "slime" particles that could be widely distributed into the aquatic and riparian environment. The water quality was degraded sufficiently in Durango to require an entirely new reservoir and delivery system to be constructed on the Florida River for a public water supply, to avoid using water from the tailings-laden Animas River (Durango Democrat, August 1–15 and November 18, 1902).

Silverton's first large concentrating mill was located beside Silver Lake and deposited tailings directly into it (fig. 15). Ransome (1901, p. 145) commented, "The original beauty of this little sheet of water has been marred by mining operations, particularly by a partial filling with tailings

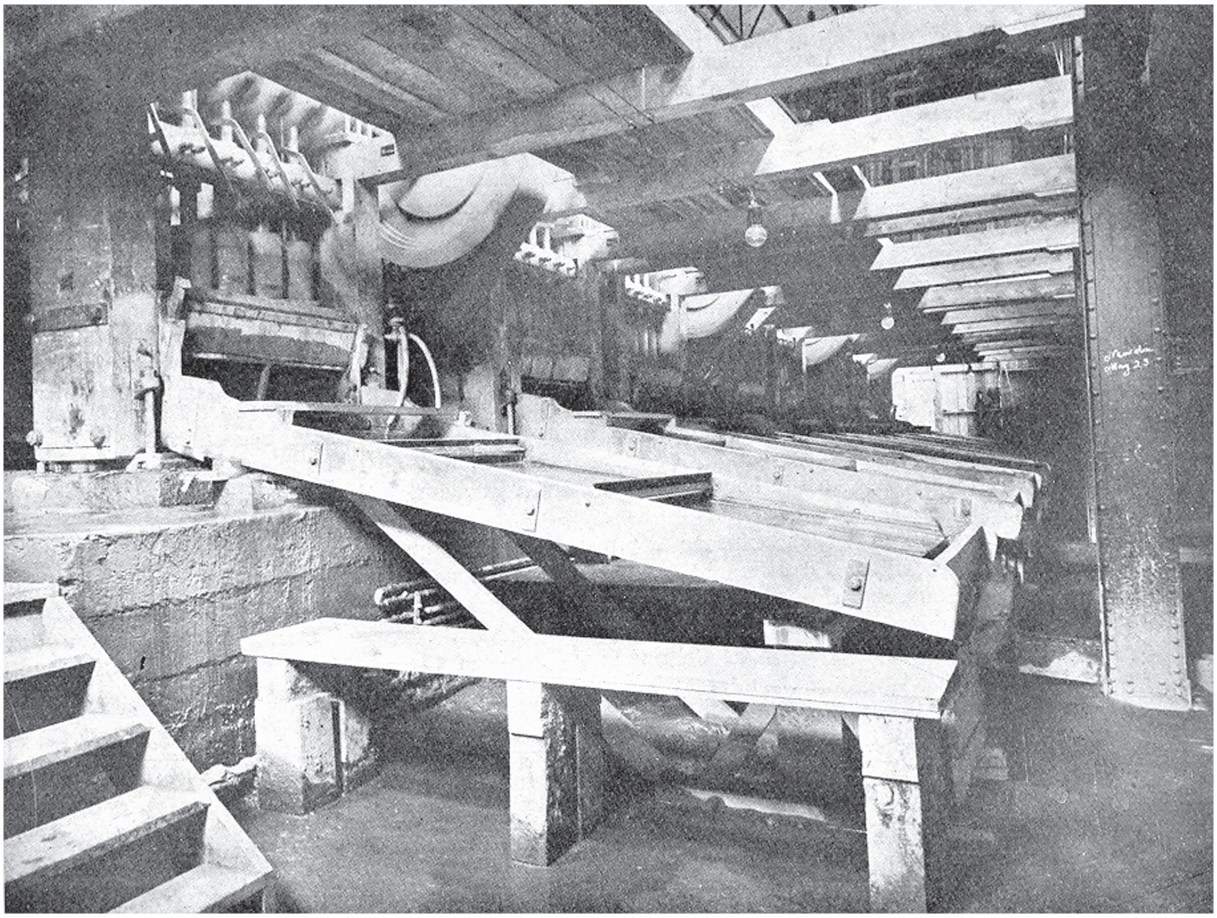

Figure 12. Stamps and mercury amalgamation plates, Old Hundred Mill (site # 238, fig. 2) (Silverton Miner, 1907). Inside the mills, heavy iron stamps pounded the ore to sand size, which washed over mercury-coated copper plates to catch the coarse gold and thence to concentrating tables.

from the Silver Lake Mill" (mill # 1, site # 347, fig. 2). About 500,000 short tons of mill tailings were reported to be in Silver Lake by 1903 (figs. 13 and 15; Niebur, 1986). Despite a long-held Silverton legend of a "pool of mercury" in the lake bottom, no mercury amalgamation was used at this mill (Ransome, 1901). Later improvements in milling technology resulted in about 400,000 tons of these tailings being pumped out of Silver Lake between 1914 and 1919 for reprocessing in a new mill built especially for this purpose by Arthur R. Wilfley (inventor of the concentrating table of that name) and Otto Mears (owner of the Silverton Northern Railroad) and located along the Animas River (site # 222, figs. 2 and 16). Although more metals were removed from the mill tailings, 500 short tons per day of these reprocessed tailing residues were then discharged directly into the Animas River near the mouth of Arrastra Creek (Niebur, 1986).

Chemical reagents were not used in the typical gravity concentration mill, although mercury-coated amalgamation plates were commonly used. Mercury was lost by physical attrition off the plates. Because of the high value of mercury, mill operators installed special mercury traps, such as the "Black Hills Trap," canvas tables, and other recovery devices prior to tailings discharge to minimize mercury losses (Adams, 1899). This may help explain why mercury contamination has not been generally detected in the watershed (Church and others, 1997). Sodium thiosulfate was used in one short-lived "lixivation" mill to dissolve certain silver minerals, this being the same chemical as photographic "hypo" developer solution.

Total ore tonnage produced during 1890–1913 is estimated at 4.3 million short tons. Based on typical milling practice of the time, a large majority of this tonnage would have been discharged as mill tailings directly into surface streams. Crude ore shipments decreased dramatically during this period as most mines now produced low-grade ores for milling. For example, during the period 1909–1913, for which data are available, only 29,314 short tons of crude ore was shipped, whereas 938,990 short tons, representing 96.97 percent of all tonnage produced, was milled (Henderson, 1926). These numbers show the importance milling had achieved compared to the prior period.

Figure 13. Silver Lake (mine # 343) and adjacent mines, mill, and mill tailings (Silverton Miner, 1907). The Silver Lake Mill # 1 (site # 347, fig. 2) at lower right was the first successful low-grade concentrator in the area. Tailings slowly filled the north end of the lake but were later removed. See also figures 15 and 16. The Iowa (mine # 345) is in center on right side of lake; Royal Tiger (mine # 348) is on left side of lake.

Period III—The Early Flotation Era 1914–1935

Mining Development and Practices

World War I in Europe caused the consumption of huge quantities of metals. The United States entered the war in 1917, whereupon an already brisk wartime economy boomed. Base-metal prices soared as the war continued to increase demand (Henderson, 1926). Improvements in both smelting and milling, coupled with wartime demand, made zinc ores a marketable commodity for the first time (Bird, 1986). Mines with zinc, such as the Sunnyside (mine # 116) expanded, whereas those without, such as the Silver Lake (mine # 343), closed.

The new froth-flotation milling process could do much of the separation formerly done by hand sorting and selective mining of ores and could recover zinc. Mining practices began a major shift to larger scale “bulk” mining methods and away from more selective lower tonnage methods. A new mining method called “shrinkage stoping” was developed. Here the entire vein was mined, instead of only the richest part (fig. 17). When the stope was completed, all the broken ore was removed from the mine, leaving a large void. In the “cut-and-fill” stope, the void was backfilled with low-grade ore or waste rock. With shrink stopes, no ore sorting was done and all mined rock was milled. Average ore grade decreased, but so did the cost per ton of mining and milling. This was to become the dominant underground mining method throughout the 20th century in San Juan County.

Other technological changes contributed to this increase in tonnage. Larger, more efficient compressed air drills replaced the early types. “Wet” drills, also known as Leyner drills, increased productivity by reducing dust and improving working conditions for the miners (fig. 17). Mines continued to increase in length, depth, and vertical extent. In 1916, Sunnyside (mine # 116) became the largest ore producer in the

Figure 14. Gold King Mill (site # 94, fig. 2) at Gladstone and SG&N Railroad (circa 1903). Tailings from the Gold King Mill can be seen crudely impounded by log dams along Cement Creek. The aerial tram (D, fig. 2) entered the building from the upper right; boxcars for concentrate shipment waited along the railroad sidings.

county. By 1917, its daily production increased to 500 short tons. In 1918, 600 short tons per day was reached and, by 1928, daily production exceeded 1,000 short tons per day (USBM, 1928). Wartime prices also saw many smaller mines open, and the old Kendrick-Gelder Smelter (# 213, fig. 2) was reopened to treat pyritic copper ores from the Red Mountain district (fig. 7; USBM, 1918).

The high metal prices caused by the war were unsustainable, and in 1921–1922, a sharp postwar recession hit the Nation. Mining activity in Silverton collapsed. In 1921, the county's total production was a mere 1,100 short tons, whereas in 1920 more than 200,000 short tons of ore had been produced (Henderson, 1926). Mining recovered in 1923 with the reopening of the Sunnyside (mine # 116), but the character of the mining industry had changed permanently. Many small and medium-sized mines closed, some permanently, along with some older large mines such as the Silver Lake (mine # 343) in 1921 and Gold King (mine # 111) in 1925. By the late 1920s, some new mines were opened as the national economy grew, notably the Shenandoah-Dives (mine # 355), Buffalo Boy (mine # 325), and Little Nation (mine # 228, fig. 1). But metal prices again collapsed with the onset of the Great Depression in 1930, and only two mines sustained any continuous production for the next 61 years. Small mines played a decidedly secondary role. The Sunnyside (mine # 116) closed in September 1930 leaving the 3-year-old Shenandoah-Dives (mine # 355) as the only major producer in the district for the next 23 years (Chase, 1952).

Milling Development and Practices

Ball mill grinding and froth flotation for concentrating ores revolutionized mining in the decade of 1910–1920 (Rickard, 1932). The impact of this new technology was dramatic. Instead of coarsely pulverizing ores with crude stamps, high capacity wet grinding with steel balls in a rotating drum ball mill created a more uniform and finer product. Early flotation used bubbles in an acidified pine-oil and water mixture to float off and separate the valuable mineral particles from the worthless quartz (fig. 18). More importantly for

Silverton, the process could separate zinc (sphalerite) from the lead and copper sulfide minerals, and worked well on the small-particle-sized “slimes” that were not amenable to gravity concentration. In addition, new smelting processes made the zinc concentrates produced by flotation marketable at last (Rickard, 1932).

The “remarkable success” of flotation on copper ores was noted in 1913 by Superintendent Clapp, who did his own laboratory experiments on Silver Lake ore (unpublished report in Shenandoah-Dives collection, Center for Southwest Studies, Fort Lewis College, Durango, Colo.). The first large-scale mills for lead-zinc ores were built at Butte, Mont., in 1914, using the patented Minerals Separation Syndicate process (Rickard, 1932; fig. 18). Stamp mills and Wilfley tables quickly became obsolete for primary milling of base-metal ores. The Silver Lake Mill # 2 (site # 219) and Gold King Mill (site # 94) in Silverton (fig. 2) added full-sized Minerals Separation flotation sections in 1914 with Sunnyside Mill # 2 (site # 165) following in 1915 (Henderson, 1926). Even the famed table inventor A.R. Wilfley installed flotation in his tailings reprocessing mill (site # 222, fig. 2) in 1916 (Niebur, 1986). The process worked so well that the Terry family, long-time owners of the Sunnyside (mine # 116), sold their controlling interest in the mine to the U.S. Smelting Refining and Mining Company. This large corporation had the financial resources to build a huge state-of-the-art 600 short ton per day flotation mill at Eureka in 1917–1918 (site # 164, figs. 2 and 19). The new mill recovered as much as 90 percent of the valuable minerals, including sphalerite as a separate zinc-rich concentrate. The mill tailings now had less metal in them, but were finer in size, and the tonnage produced increased to 1,000 short tons per day in the late 1920s. Wilfley tables still used in the new Sunnyside Flotation Mill at Eureka (site # 164) were relegated to the minor role of breaking down froth on flotation concentrates (Taggart, 1927). The new mill was the first large lead-zinc flotation mill in the State (Bunyak, 1998). Remaining gravity/stamp mills in the district became obsolete and when closed by the 1921 recession, never reopened. Most were burned to recover scrap iron during World War II.

Environmental Aspects

In the mines the trend continued toward larger and more extensive workings, with more potential impact on groundwater hydrology. Very long haulage tunnels such as the Gold King Mill level tunnel (later known as the American tunnel, site # 96) and the Frisco tunnel (site # 19) were nearly a mile

Figure 15. Silver Lake Mill # 1 (site # 347, fig. 2) discharging tailings into Silver Lake (Silverton Standard folio, 1904). The tailing flume from the mill is discharging tailings onto the sand pile now filling Silver Lake (see fig. 13). The large building is the miners’ bunkhouse.

Figure 16. Silver Lake in 1978 showing that early tailings had been removed. Improved milling and pumping technology resulted in much of the Silver Lake tailings being removed leaving a circular "crater" where the sands once were piled (see fig. 13).

in length (fig. 1). Significant localized drainage of ground water from the mine workings now had considerable potential for discharge of acid or metals into the creeks that was not documented at the time. Improved milling had some indirect benefits during the period. Low-grade and zinc-bearing ores were no longer left in stopes or on mine-waste dumps where they could come in contact with the environment. Instead these ores were processed and much of the galena and sphalerite was removed. However, some of the galena, sphalerite, and most of the pyrite in the original ore were discharged into the environment as mill tailings.

Flotation milling adversely impacted the Animas River, compared to earlier stamp milling (Vincent and Elliott, this volume, Chapter E22). Ball-milled tailings were much finer than stamp mill tailings. Although the mill tailings contained less metal per ton, milled tonnage increased dramatically, yielding a net increase in the amount of tailings being deposited in the streams. In 1926, Sunnyside's Flotation Mill tailings (south of site # 164, fig. 2; Church, Fey, and Unruh, this volume, Chapter E12, fig. 4, locality B19; Vincent and Elliott, this volume) were reported to contain 0.015 oz/ton gold, 1.0 oz/ton silver, 0.6 percent lead, 0.08–0.13 percent copper, and 0.8–1.1 percent zinc (Taggart, 1927).

The finer tailings traveled farther, and their presence began to elicit serious, formal complaints from downstream water users. In the late 1920s, Durango ditch companies sued the Sunnyside mine's owner, U.S. Smelting Refining and Mining Company, over the pollution originating from the Sunnyside Flotation Mill at Eureka (site # 164, fig. 2 and fig. 19).[4] The main issue alleged was suspended material that clogged irrigation ditches rather than any concern about possible metal contamination. Whether the case was actually tried is unknown, but the company prepared a vigorous defense. It hired Durango assayer Albert P. Root to take weekly samples of the Animas River for clarity comparisons in Durango from March through September 1930, when the mine and mill closed. These samples were stored under seal for the next 2 years as legal wrangling continued. Root's field notes survive, and the Animas River was typically described as "gray and turbid" during normal and low-flow periods. During high flow, the tailings' gray color was obscured by natural sediment (A.P. Root, unpub. field

[4]1931–1932 correspondence of U.S. Smelting Refining and Mining Company with A.P. Root, Root and Norton Assayers; author's collection.

notes, 1930). Mining companies at the time typically argued that these sediments were not harmful to fish or agriculture, but the attitudes of the courts and the public were changing. The mining companies had successfully rebuffed similar complaints 25 years earlier, but now, legal action was being taken against them (Smith, 1987).

The oil flotation process used various chemical compounds, but the amounts released were not monitored at the time. In the early Minerals Separation Syndicate process, the mill water was acidified with dilute sulfuric acid and pine oil was added as the frothing reagent. The Mayflower Mill (site # 221, fig. 2) used this pine oil process for the first few years of operation (figs. 2, 18, and 20). Precisely what the Sunnyside Mill at Eureka (site # 164, fig. 2) used in the 1918–1925 period is unknown, but lead-zinc mill practice at the time used alkaline rather than acidic solutions. The 1926 mill circuit and reagents are described in detail in Taggart (1927). Reagents included small amounts of coal tar, creosote, naphthalene, pine oil, and potassium xanthate as the main frothing reagents. Large amounts of sodium carbonate (soda ash) were used to make the mill pulps and solutions alkaline. The xanthate chemicals, as an alcohol-like liquid, were patented in 1925 and became the basis of modern flotation processes. They completely supplanted oil flotation within a few years of their introduction (Rickard, 1932). Because no State or Federal regulations on chemical discharges existed, chemicals used in the mill water were likely discharged with the tailings.

In contrast to districts such as Telluride and Cripple Creek, there is no record of direct use of cyanide for recovery of gold in San Juan County, probably because of its chemical incompatibility with the zinc and copper sulfides associated with gold in the ores. Cyanide was used in small amounts as a pyrite depressant in flotation beginning in the 1930s.

Total tonnage produced from 1914 to 1935 was reported as 4.2 million short tons of ore with only 36,232 short tons reported as being shipped directly to the smelter. Nearly all production during this period was milled. Judging from tailings disposal practices of the time, most tailings were deposited into the Animas River and tributaries (Vincent and Elliott, this volume).

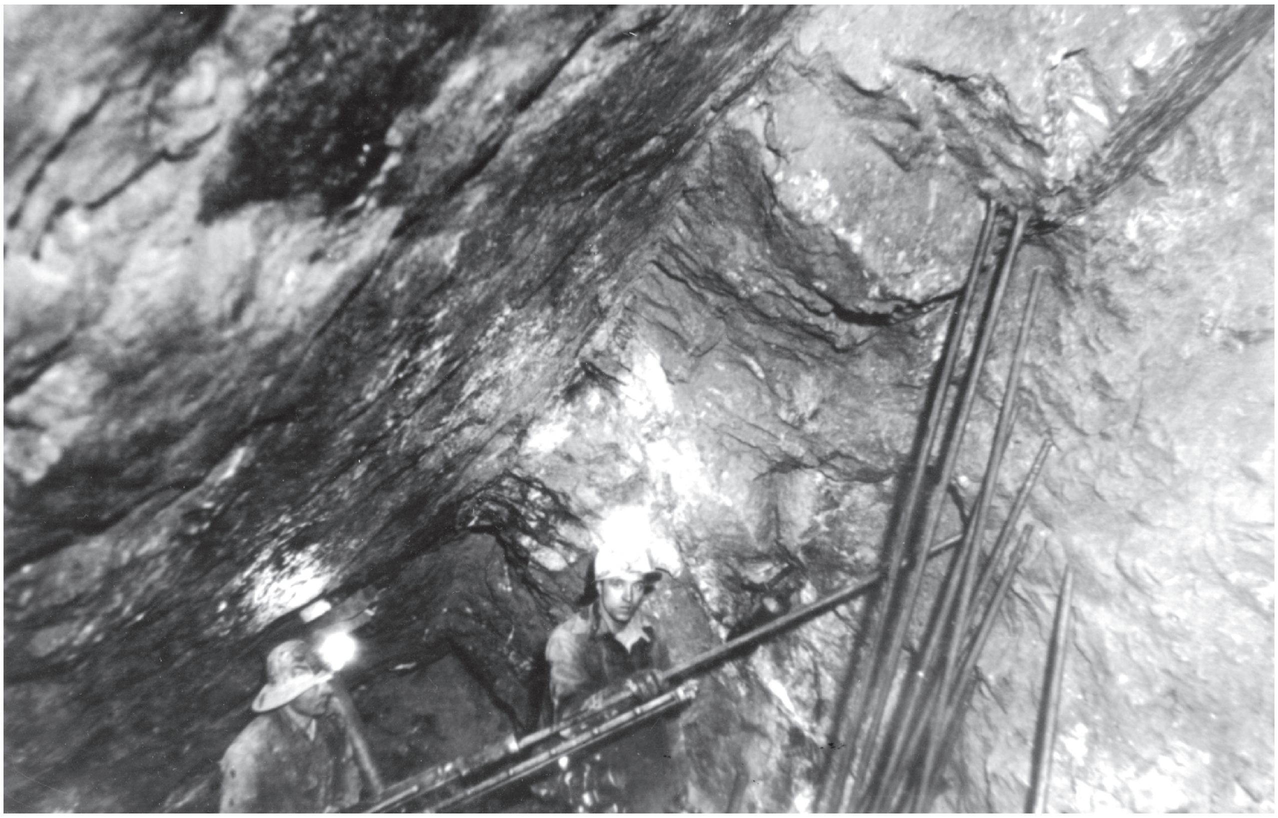

Figure 17. Shrink stope mining in Shenandoah-Dives (mine # 355, 1937; C.A. Chase photo). Air drills increased productivity and size of the mines. Here a Leyner type drill is working a flat-lying stope. In the shrinkage method, the miners stand on the ore pile which is later completely removed for processing, leaving a void. Vein exposed is about 3 ft thick.

Figure 18. Minerals Separation flotation cells, Mayflower Mill, 1930 (site # 221, fig. 2; C.A. Chase photo). The flotation process created froth, which floated the ore particles out of the redwood cells or tanks. The Minerals Separation Syndicate was the leading patent holder in the early years.

Period IV—The Modern Flotation Era 1936–1991

Mining Development and Practices

The Great Depression was a very difficult time for the base-metal mining industry. Declining industrial production saw the lowest nominal prices of the century for silver, lead, copper, and zinc. Gold was an exception: the government devalued the dollar in 1934 by raising the price of gold 75 percent from its long-time $20.67 per ounce level to $35.00 per ounce (USBM, 1934). This new price support sparked a renewed interest in gold exploration, but it had no significant effect on production in San Juan County, because of the scarcity of gold ore in the area. It did help to keep the Shenandoah-Dives (mine # 355), with low-grade gold ore, operating through the Depression. The Federal Government's new involvement in the mining business through New Deal programs generally helped mining, but at the expense of increased regulation (Smith, 1987).

The Shenandoah-Dives Mining Company survived the Depression by increasing tonnage mined to reduce per ton unit costs, and by improving the efficiency of the Mayflower Mill (site # 221, fig. 2 and fig. 20). Starting at 300 short tons per day in 1930, the Shenandoah-Dives (mine # 355, fig. 1) soon changed from cut-and-fill mining to large shrinkage stope mining methods and increased production to 600 short tons per day. Virtually every ton of rock broken underground was milled. As base-metal prices slowly recovered in the late 1930s, a few small high-grade lead-zinc mines were developed in the district, such as the Pride of the West (mine # 319), which, in 1940, built its own 50 (later 90) short tons per day capacity mill (site # 227, fig. 2) at Howardsville (Denver Equipment Company, 1947). The size and extent of the mines continued to increase. The Shenandoah-Dives (mine # 355) reached a vertical extent of more than 2,500 ft by 1941, and a horizontal extent exceeding 7,600 ft by 1948 (fig. 21; Chase, 1952).

The Sunnyside (mine # 116) reopened for 10 months in 1937–1938, due to a surge in metal prices, but closed due to sagging metal prices, high operating costs, and "excessive water which forced the***owners to abandon the work"

(Standard Metals Corp., 1961). World War II began to affect the mining industry. When the United States entered the war after Pearl Harbor, there was a severe shortage of zinc and other base metals. In 1942, the Federal Government closed all gold mines so that scarce mining labor and resources could be focused on base-metal production. At that time the Shenandoah-Dives (mine # 355), a nominal gold mine, was ordered closed by the War Production Board (WPB). Silverton mining leaders put political pressure on the WPB through Colorado's governor and congressional delegation. The WPB actually rewrote its national regulations to permit Shenandoah-Dives to meet new criteria and avoid the closure order (Chase and Kentro, 1942). The mine and Silverton were revived, which incidentally helped save the Durango to Silverton narrow gauge railroad for its future as a tourist line. The remaining equipment and track of the other small narrow gauge lines around Silverton were purchased by the U.S. Army for use in Alaska during construction of the Alaskan Highway (Sloan and Skowronski, 1975).

As flotation milling technology improved and wartime demand for metals increased, Shenandoah-Dives and other mines began to remine old underground stope fills and surface dumps left by previous mine operators. By 1952 Shenandoah-Dives Mining Company reported recovering 117,238 tons of dump from Dives Basin, 80,158 tons of pre-1925 underground stope fills, and 29,597 tons from "other sources" (fig. 22). Such "dump recovery" was widespread in the county during World War II and the Korean War. Government policy further stimulated mining and recovery of material from old mine-waste dumps when it began to pay bonus price subsidies called "premiums" for every pound of metal recovered. Begun in February 1942, the Government's Metals Reserve Company paid premiums for every pound produced above a quota based upon 1941 production. Lead and zinc premiums were 2.75 cents/pound, whereas copper received 5 cents/pound. In mid-1943, these premiums were increased to 6.50 cents/pound for lead, 8.25 cents/pound for zinc and 11.775 cents/pound for copper. Premiums were paid at varying levels through June 1947, when the plan expired (USBM, 1942, 1943, 1947).

Road building and mineral exploration were also subsidized by the U.S. Bureau of Mines through the Defense Minerals Exploration Act (DMEA) and later through the Office of Mineral Exploration (OME). The Reconstruction Finance Corporation (RFC) actively loaned money for mining

Figure 19. New Sunnyside Eureka Flotation Mill (site # 164, fig. 2), a large flotation mill built at Eureka, Colo. (circa 1925, SJCHS collection). The new 600 ton/day (later 1,000 ton/day) Sunnyside Eureka Mill dwarfs the original 150 ton/day concentrator (Sunnyside Mill # 2, site # 165, fig. 2) built in 1899, graphically showing the dramatic increase in size and scope of later milling operations.

Figure 20. Mayflower Mill (site # 221) and reclaimed tailings (sites # 507–510, fig. 2; 2002). Also known as the Shenandoah-Dives Mill, it operated for over 60 years (1930–1991). The aerial tram (AA, fig. 2) entered the plant at far right while tailings were stacked in tailings ponds on the left (# 507–510). These tailings were capped and seeded during 1990s reclamation work by Sunnyside Gold Corp. In 2001 the mill was designated a National Historic Landmark by the Secretary of the Interior.

projects, and the Metals Reserve Corporation bought metals and ores directly for Government strategic metals stockpiles. Some of these programs survived into the early 1960s (USBM, 1960).

With such favorable economic and Federal Government policies, operators reopened many dormant mines. Ore was shipped to Shenandoah-Dives' Mayflower Mill (site # 221, fig. 2) for custom processing, and when its capacity was reached, the ore was shipped by rail to the Golden Cycle Mill in Colorado Springs, Colo. Many of these reopened mines were small, often mining only a few short tons per day. Shenandoah-Dives (mine # 355) remained the main producer at 600 short tons per day; about 100 short tons per day of "custom ore" were being milled (Mayflower Mill, site # 221, fig. 2) in summer months for the small mines. The Pride of the West (mine # 319), Highland Mary (mine # 359), and Lead Carbonate (mine # 106) built or expanded their own small mills (sites # 233, # 502, and # 95 respectively, fig. 2) and increased production during the war. Production would have increased more during the war, except for the shortage of labor. Anecdotal evidence suggests that this labor shortage was the main reason the Sunnyside (mine # 116) never reopened during World War II, despite large zinc reserves.

The Shenandoah-Dives Mining Company continued steady development of its property (mine # 355) and the adjacent Silver Lake (mine # 343), which it leased, into the early 1950s. Metals prices increased in 1951 in response to the Korean War, but they declined after the 1952 election because of a perception that President Eisenhower would soon end the conflict. In 1953, the new Congress withdrew Korean War price supports for lead and zinc. Production at Shenandoah-Dives ceased on March 17, 1953, which also caused most of the remaining small mines dependent on the Mayflower Mill to close. A Government DMEA exploration grant kept the Shenandoah-Dives Mining Company going for a few more years, though without any production.[5] The company later became the Marcy-Shenandoah Corporation, which obtained key leases on the Gold King Mill level tunnel (site # 96) at Gladstone and the Sunnyside (mine # 116) in 1958.

In 1959 a new company, Standard Uranium Corporation, formed a joint venture with Marcy-Shenandoah Corporation to reopen the Sunnyside mine by building a new lower haulage

[5]Memorandum of C.A. Chase, June 29, 1953, in C.A. Chase Collection, San Juan County Historical Society Archives, Silverton, Colo.

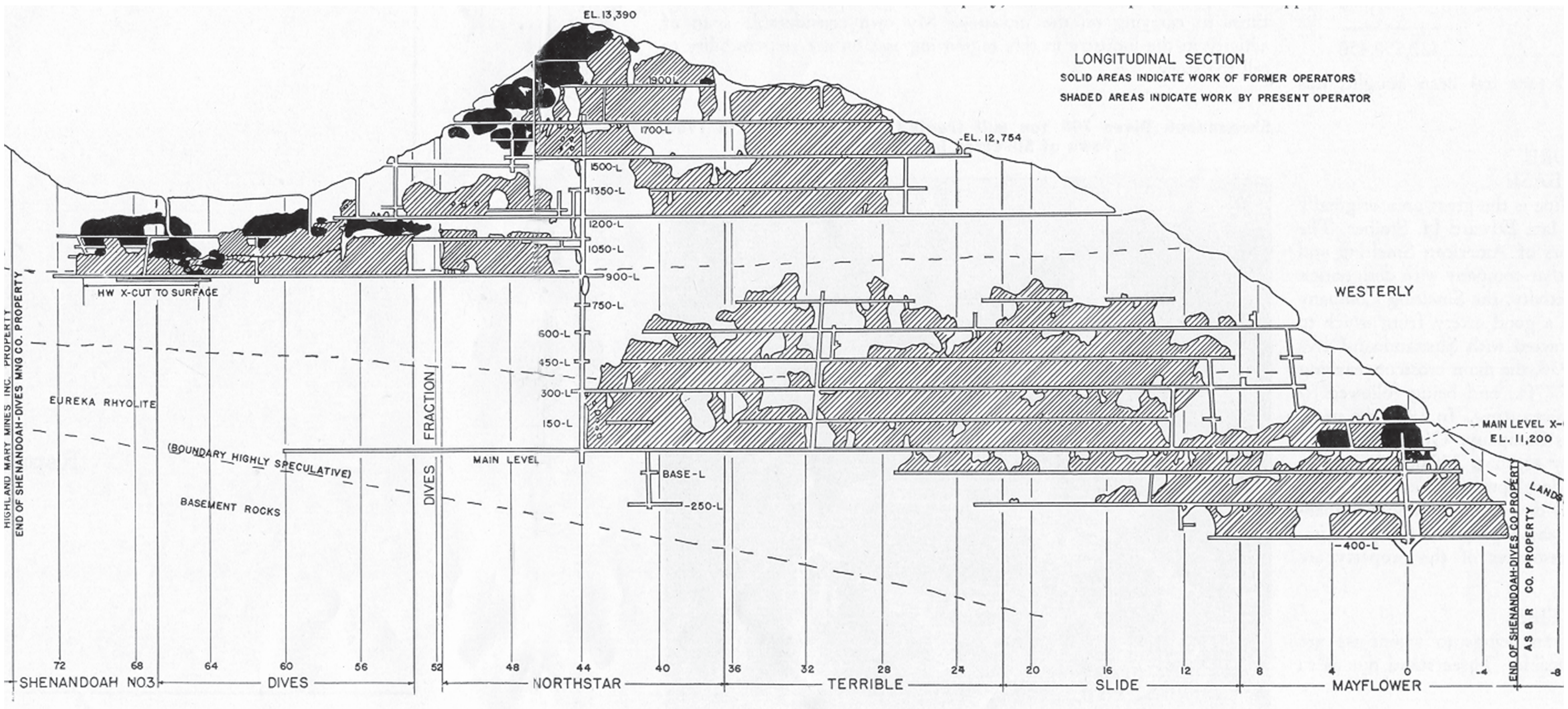

Figure 21. Cross section of Shenandoah-Dives mine in 1950 (Chase, 1952). This cross section view of the Shenandoah-Dives (mine # 355) shows 1880–1925 mined-out areas in black and 1926–1950 stoped areas in shaded gray diagonal lines. The figure graphically shows the difference in size and extent of the mined area removed during the latter “modern” period, when air drills and power equipment were used, relative to that achieved using earlier hand methods. Map shows mining over a vertical extent of 2,500 ft and horizontal extent of 7,600 ft.

Figure 22. 1940s dump reclamation on Shenandoah-Dives vein, Dives Basin, photographed in 1978. Dumps left by early hand sorting operations were often reclaimed by later innovative methods. This is the North Star mine dump in Dives Basin (mine # 350, fig. 1), which was scraped into a shaft of the Shenandoah-Dives mine for transport through the tunnel and aerial tram system to the Mayflower Mill (site # 221, fig. 2) three miles away and 3,000 ft lower. Snow patch in center of photo is approximately 150 ft in length.

tunnel (mine # 96). In 1960, Standard Uranium Corporation changed its name to Standard Metals Corporation, bought out Marcy-Shenandoah Corporation's interest, and became sole owner of the former Shenandoah-Dives (mine # 355) and the Mayflower Mill (# 221, fig. 2). Work began to widen and extend the old Gold King Mill level tunnel (site # 96, prior to 1960) at Gladstone another mile under the Sunnyside mine workings. The goal was to avoid the costly hoisting and tramway operations of the former operators, whose main shaft was located beside Lake Emma at 12,300 ft (fig. 23). The renovated and extended haulage tunnel was renamed the American tunnel. The work is described in the 1960 Standard Metals Corporation Annual Report (p. 3):

> The [American] Tunnel was driven in order to provide an economical means for removal of ore as well as drainage. The original schedule for reaching the Washington vein was January 1961. This has been accomplished in spite of a water flow of 3,000 gallons per minute encountered from the 9,000 foot mark. *** Prior to driving the American Tunnel, the drainage of eight million gallons of water in the Sunnyside mine workings was *** a potential major problem. Fortunately the tunnel intersected a fault zone with fissures resulting in a gradual drainage of the old workings. The water level has been dropping an average of more than three ft per day in the old Washington Incline [shaft]. At this rate, when the raise is ready for the breakthrough the volume of water remaining in the upper level will be negligible.

The American tunnel (mine # 96) was successful at draining the workings, but the new mine drainage flowing into Cement Creek would later become a substantial problem when water-quality standards were enacted in the 1970s. Production from the Sunnyside (mine # 116) through the 11,000-ft long haulage tunnel (mine # 96) began in August 1962, and continued at 700 short tons per day, increasing to 1,000 short tons per day for a few years in the late 1970s. Unexpected gold discoveries in the early 1970s kept the Sunnyside (mine # 116) going long after other similar base-metal mines in Colorado had closed.

Other than Sunnyside (mine # 116), only a few small mines produced ore intermittently after 1953, usually in conjunction with the Pride of the West Mill (site # 233, fig. 2) in Howardsville. In 1967, a Texas oil company, the Dixilyn Corporation, began a large mineral exploration and development project at the Old Hundred (mine # 239). It found little ore, but constructed more than 15,000 linear feet of new tunnels and expanded the Pride of the West Mill [# 4] (site # 233, fig. 2) to 400 short tons per day capacity. Mill

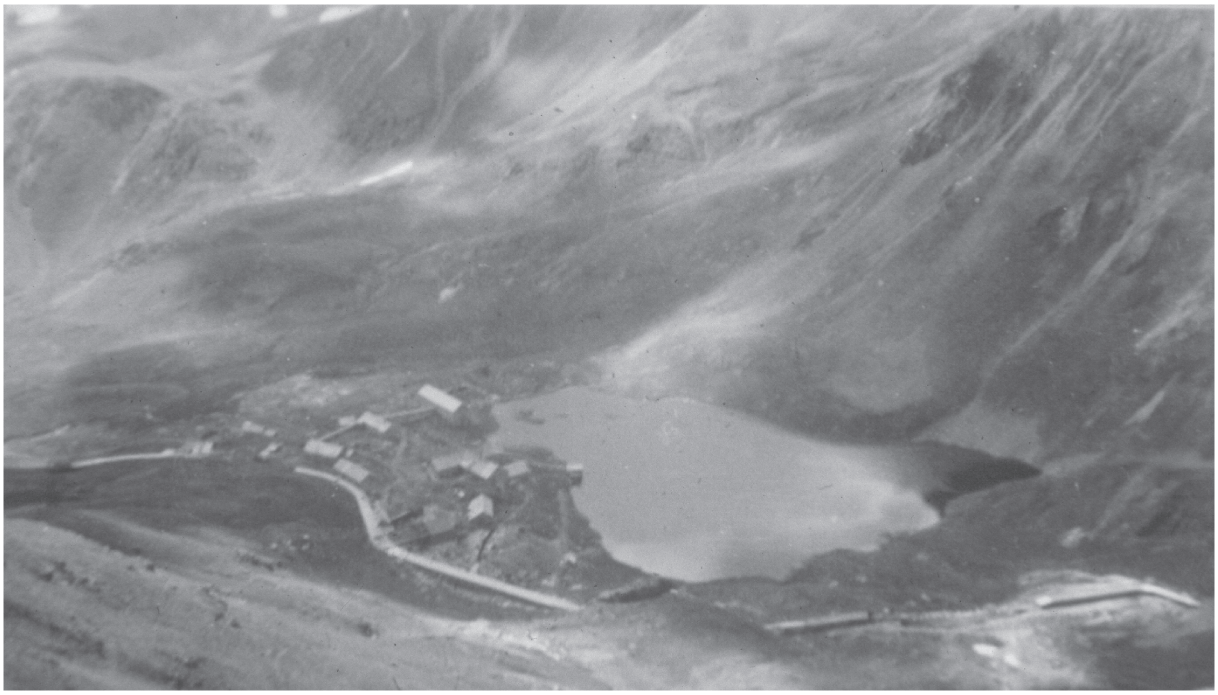

Figure 23. Lake Emma and Sunnyside mine from Hanson Peak (circa 1940; H.H. Mellus photo, SJCHS collection). The original Sunnyside mine (mine # 116, fig. 1) was located at 12,300 ft on the shore of Lake Emma, which was dammed to provide water to mills downstream. Men lived in the building complex; snow sheds connected them to the tunnels and shafts.

tailings are impounded in a permitted repository at the site (site # 234, fig. 2). High gold and silver prices in the late 1970s and early 1980s caused another increase in mineral exploration activity around Silverton. A few new access tunnels were built, but again, little ore was developed or produced. About 40,000 short tons of mostly waste dump material was processed at the Pride of the West Mill (site # 233, fig. 2) between 1970 and 1990, mainly during periods of high metal prices. Several old mines were explored, but gold and silver prices did not maintain a high level long enough to sustain large-scale new mine development. Sustained mining continued to be confined to the Sunnyside (mine # 116), which benefited from both high gold prices and high gold content in the ore. Sunnyside also recovered and milled mine-waste dumps from the original Sunnyside workings at Lake Emma in the late 1980s (figs. 1 and 2).

In the late 1970s, new surface reclamation laws in Colorado began to affect ongoing mining operations. In 1983, aggressive legal action under the Federal Superfund law against Newmont Mining's nearby Idarado mine in Telluride, Colo., coupled with declining gold and silver prices, caused all major United States and Canadian mining companies then exploring in San Juan County to soon terminate leases and exploration activities. After 1984, no major U.S. mining company initiated any new exploration activity in San Juan County. The continued exception was the Sunnyside (mine # 116), which developed into the State's largest gold producer in the 1970s. However, its operator, Standard Metals Corporation, went bankrupt in 1984, closing the mine. Its troubles began in 1978 with the flooding of the mine by Lake Emma. This precipitated a corporate takeover fight, and the ensuing debt load and subsequent fall in gold prices bankrupted the company. In November 1985 the mine and the Mayflower Mill were purchased by Echo Bay Mines and reopened as Sunnyside Gold Corporation in early 1986. By August 1991, the mine's higher grade gold ore reserves were exhausted, base-metal prices were falling, and the mine closed except for reclamation work, which continued for 12 more years. Low metal prices, coupled with increased expenses related to complex environmental regulations, resulted in a cessation of mining and exploration activity in the county after 1991, following a pattern similar to that of other mining districts in Colorado. Since 1991, no ore production has occurred in San Juan County, after 121 years of continuous mining production.

Milling Development and Practices

In the 1930s, the Mayflower Mill was the only milling operation in the upper Animas River basin. As a result of both downstream complaints and the personal philosophy of management, the first successful steps were taken to prevent water contamination caused by mill tailings. When the Mayflower Mill (site # 221, fig. 2) was built in 1929, Shenandoah-Dives' manager, Charles A. Chase, with the support of concerned stockholders, intended *not* to discharge mill tailings into the Animas River at all. Instead, special tanks and machinery were installed to settle the mill tailings and haul the sand back up the tramline, where it would be dumped as a surface pile, thereby keeping it out of the Animas River. Mill water would be filtered and recycled. Unfortunately the equipment did not work, and being in financial difficulty because of the Great Depression, the company discharged mill tailings into the Animas River as mills had before (Smith, 1987). In 1935, Chase received recommendations for a tailings impoundment built from its own sand that was being used in Butte, Mont. under operating conditions similar to those at Silverton. The technique relied on the fact "***that a single spigot will draw off sand in such a ratio to water as will permit the sand to build in a firm pile; and of course a series of such piles will merge into a continuous wall of sand" (fig. 24; Chase and Kentro, 1938, p. 19).

By 1936, nearly all Shenandoah-Dives mill tailings were being retained in sand-walled ponds (site # 507, fig. 2), keeping them out of the Animas River (fig. 25). The slimes and fine suspended material settled out in the pond formed behind the sand wall. As the water cleared, it was decanted out of the pond through wooden culverts (called decants) buried under the sand wall, and thence into the Animas River. When Sunnyside (mine # 116) briefly reopened their Eureka Mill in 1937–1938 (# 164, fig. 2), it too built settling ponds in the Animas River valley below Eureka (Church, Fey, and Unruh, this volume, fig. 4, locality B19; Vincent and Elliott, this volume). Variations of this method and improvements on it were used by all mills operating after 1935, until the end of milling in 1991 (site # 507–510, fig. 2).

Although this method of transport and emplacement of tailings was effective, the settling-pond system designed to contain the material was not perfect. The crudely constructed sand walls built on the hillside near the Mayflower Mill were plagued by springs, entrained ice, and slimes, and were therefore not structurally stable. The sand wall on tailings pond # 1 (site # 507, fig. 2) collapsed in 1947 (fig. 26) and again in 1974. The latter collapse released more than 100,000 short tons of tailings into Boulder Gulch and the Animas River and resulted in abandonment of the pond (site # 507, fig. 2; Bird, 1986). In 1947, the accident resulted in no legal actions against the company. The settling pond wall was promptly repaired, and the company even received a commendation for its pollution control efforts from the Colorado Fish and Game Department. By 1974, however, the story was different. Standard Metals Corp. was fined $40,000 (later reduced to $15,000) for contaminating the Animas River. Active water-quality monitoring of the mill tailings decant water became standard practice about 1977, with the advent of the National Pollution Discharge Elimination System (NPDES) permitting system.

Figure 24. Mill tailings spigots at tailings pond # 1, Mayflower Mill (site # 221, circa 1934; C.A. Chase photo). Wooden flumes were used to slurry tailings for disposal into tailings ponds (# 507, fig. 2) rather than into the river. Holes in the bottom of the flume let coarser sands flow down the planks into piles, which were shoveled together to create the pond wall while water settled behind the resulting dam.

From 1935 to 1991 milling technology gradually improved in efficiency but remained similar in method and operations. Metal recovery was often as high as 95 percent by the 1940s, and only incremental improvements were made into the 1970s. The one large change was the abandonment in the mid-1930s of the old oil flotation chemistry at the Mayflower Mill (site # 221, fig. 2), replaced by more efficient xanthate flotation reagents for the separation of a zinc concentrate. Tailings ponds also improved with the use of hydro-cyclone type classifiers replacing wooden launders, sluices, and spigots for dam construction. In its 1965 annual report, Standard Metals (1966, p. 7) noted, “Tailing disposal systems were improved in line with current stream and river pollution regulations and practices.” This is an example of Colorado’s efforts at water-quality regulations prior to national legislation.

During the period 1936–1991, a reported 9.5 million short tons of ore was mined and milled with all but an estimated 200,000 tons of mill tailings being impounded in settling ponds. Crude ore shipments for the period 1936–1957 amounted to only 8,148 tons.

Environmental Aspects

Changing public attitudes and government philosophy resulted in new legislation and legal proceedings in both the 1930s and 1970s. These changes forced mine operators to modify or improve practices to reduce environmental degradation caused by mining and milling (Smith, 1987). Required improvements tended to increase operating costs, though metals prices continued to decline in both nominal and real terms. The number of operating mines markedly decreased after 1953 as mining economics became less favorable. Underground mining practices continued much as in the past, but longer haulage tunnels at lower elevations increased mine drainage discharges, as at the Sunnyside (American tunnel, mine # 96), and Old Hundred (mine # 239).

Wartime demand and Federal Government policy in the 1940s and 1950s resulted in significant road building, processing of old mine-waste dumps, and reopening of old mines. Little regard was paid to the condition of the surface after such war-inspired activity. Most old stamp mills were burned and their scrap metal salvaged in support of the

Figure 25. Tailings pond # 1 sand wall (site # 507) at Mayflower Mill (1936; C.A. Chase photo). As tailings were deposited the sand walls became higher. Tall flumes (shown on left of sand wall) called "launders" now were needed to transport the sand and water.

war effort. Underground workings of the larger mines were expanded to tens of thousands of linear feet with multiple working levels. This resulted in ground water being drained from the vicinity of the mine workings and discharged out of the lowest haulage tunnel directly into the surface streams. Few large surface mine-waste dumps were created during the 1936–1991 period because most mineralized material was milled. The several new access tunnels built did generate large mine-waste dumps of mostly unmineralized "country" rock. Colorado passed one of the first comprehensive surface reclamation laws in 1976, which required surface disturbances to be reclaimed after mining was completed on both private and Federal lands.

Key legal actions in the 1930s finally pushed the mining industry to find solutions to the problem of turbid mill tailing discharges. In March 1935, the Colorado Supreme Court upheld a lower court ruling against the Chain-O-Mines Company in the town of Central City and ordered it to cease mill tailings discharges into adjacent Clear Creek (Smith, 1987). Legal action was never taken against Shenandoah-Dives Mining Co., who instead cooperated with downstream farmers and ditch companies to find a solution it could afford. Mill tailings settling ponds were begun in July 1935, and by June 1936 the majority of the mill tailings produced in the Animas River watershed were retained (site # 507, fig. 2). According to manager Chase, by August 1937 the system achieved "complete retention" of the mill tailings. "Decanted water is, for the most part above reproach as to clarity *** The Animas is reported a first-class fishing stream." Still, noting new grass growing on the sand wall he wrote, "we may yet demonstrate to the farmers that they are deprived of good soil building material" (Chase and Kentro, 1938, p. 21). Charles Chase was ahead of his time, but he still maintained the industry's long-held belief that the tailings themselves were benign or even beneficial.

When the Sunnyside (mine # 116) reopened in 1937, mill tailings pond dams were built with mechanical excavators on the flat river gravels south of Eureka (south of site # 164, fig. 2). After the mine was abandoned and the Sunnyside Mill at Eureka was scrapped in 1949, these tailings dams partly washed out and some of these tailings entered the Animas River (Vincent and Elliott, this volume). Remaining mill tailings were removed to the Mayflower tailings pond # 4 repository (site # 510, fig. 2) during reclamation activities in the 1990s.

Besides the occasional accident or error, decant water quality varied due to a number of factors. Wind and thunderstorms would sometimes stir up the shallow water in the settling pond, allowing slimes into the discharge. Close attention by operators was needed to keep the decanted water clear. Occasional complaints were registered with the State against

Figure 26. Failure of tailings pond # 1 sand wall dam (site # 507) at Mayflower Mill (1947; C.A. Chase photo). As sand walls became higher, structural instabilities also increased. Ice lenses in the wall were partly to blame for this 1947 collapse. The 1974 wall failure would be just out of this view to the left. Reclaimed tailings are shown in figure 20 to left of Mayflower Mill.

Shenandoah-Dives Mining Co. when conditions downstream deteriorated—even if the company was not to blame. Smith (1987, p. 131) noted, even though Charles Chase's

> enlightened attitude put to shame many of his contemporaries [in the mining industry] *** he discovered growing sentiment against mining's activities, and found his company in the role of the scapegoat, simply because Shenandoah-Dives represented the largest and most obvious local operation. *** Chase's problems [in Silverton] portended what would come on a larger scale.

Chemical and metallic constituents of decant water were not regulated until the late 1970s. Beginning in 1937, small amounts of cyanide (less than 10 ppm) were used in the mill water to depress iron in the flotation process (Taggart, 1945). Small amounts of cyanide were used until the end of milling in 1991, although in reduced amounts followed by treatment in the pond water, as discharge regulations became more stringent. Even at the time of the closure of the Mayflower Mill in 1991, the biotoxicity of various mill reagents was not well understood. Xanthate concentrations in mill water discharges were never regulated by State or Federal agencies during the period of operation of the Mayflower Mill, 1930–1991.

Potential ground-water contamination by mill tailings pond deposits was also not addressed by regulators or industry until the 1980s. Settling ponds built in prior years were not sealed and infiltration into ground water or near-surface water is known to have occurred below some ponds (Jim Herron, Bruce Stover, and Paul Krabacher, Unpublished Lower Animas River reclamation feasibility report, Upper Animas River Basin, Colorado Division of Minerals and Geology, 2000). This seepage process can result in ground water contamination by metals leached from the mill tailings. Though none of the older settling ponds were sealed to prevent contact with ground water, not all old tailings ponds resulted in surface or ground-water contamination. The 1940s tailings pond at the Highland Mary (site # 361, fig. 2) is an example. Some mill tailings material is chemically neutral or contains sufficient alkaline minerals, or the pH of water is sufficiently high, that any pyrite contained in the mill tailings will not be oxidized (Unpub. Reclamation feasibility report, CDMG, 2000).

One dramatic event did adversely affect the Animas River for a short time in 1978. Standard Metals Corp. was mining the Spur Vein, a high-grade gold vein in the Sunnyside (mine # 116) 85 ft below Lake Emma, located at 12,300 ft elevation in Sunnyside basin (fig. 23). About 6:00 p.m. on Sunday, June 4, 1978, Lake Emma broke through into the 2580 Stope on C level, flooding the mine on the only day of the week when no miners worked underground (fig. 27). The effect on the mine was cataclysmic, stripping timbers from the main shaft, crushing equipment, and filling tunnels with mud. At the Gladstone portal (mine # 96, fig. 1) an estimated 5 to 10 million gallons of water blew out the walls of the portal building under the pressure of a 1,700-ft head from the lake and covered everything with black mud (figs. 28 and 29). Sheriff Virgil Mason, on his way to the Gladstone portal, told reporters he saw "a wave that must have been eight to ten feet high rushing down the creek. At the portal it was like a UFO movie. Everything was black and timbers were shooting out like they were shot from a launcher" (Daily Sentinel, June 11, 1978). Alongside other townspeople, the author, who was employed by Standard Metals as an assayer at the time, watched Cement Creek flood. Main shaft timbers floated by in the roiling black water, which smelled strongly of diesel fuel and sulfides, but the tension of the close call with human tragedy outweighed any thoughts of the environmental effect of the event being witnessed.

Standard Metals Corp. explained the cause of the accident briefly in its Annual Report issued in May 1979:

> Studies of the breakthrough, made on behalf of the Company, have indicated that it was caused by a fault, filled with glacial till and other gangue material, which resulted in substantial amounts of water, mud and debris entering the mine, and blocking entrance through the tunnels.

Indeed, unknown to the miners and geologists, thousands of years before, glaciers had gouged a crack along the weak vein rock that was filled with permafrost sediments. Heat from the mine melted the frozen mud and Lake Emma drained into the stope (R.C. Dwelley, Cripple Creek, Colo., oral commun., 1985). One of the first mine geologists to examine the hole found clear glacial ice embedded in the fault (F.D. Taylor, Silverton, Colo., oral commun., 2003).

The Animas River turned black from the glacial mud and sediment well past Farmington, N. Mex., more than 70 mi downstream (fig. 30). (An analysis of the Lake Emma

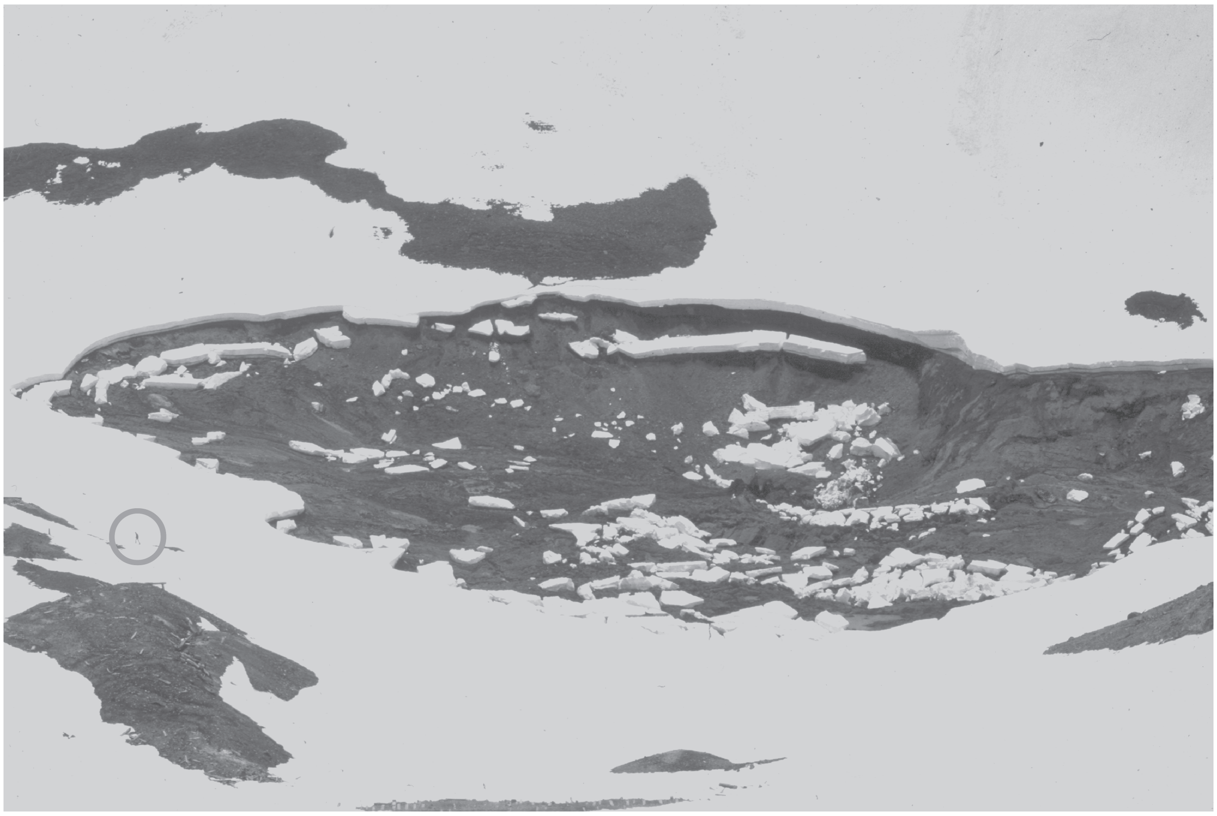

Figure 27. Lake Emma after collapse (photo taken June 11, 1978; note man (circled) in photo for scale). Lake Emma collapsed into the Sunnyside mine (mine # 116) after permafrost filling a fault on the Spur Vein failed from the heat in the mine. The resulting crater is about 300 ft wide, 800 ft long, and as much as 85 ft deep. Glacial mud and debris filled much of the mine. Standard Metals Corp. spent nearly 2 years cleaning and repairing the mine before it went back into production in January 1980.

Figure 28. American tunnel portal (mine # 96) June 5, 1978, the day after the Lake Emma flood. Lake Emma water and mud discharged at the American tunnel portal at Gladstone some 2,000 ft below and 2 miles away from Lake Emma. Black mud was deposited over the dumps and into Cement Creek. Portal buildings are on the site of the Gold King Mill (site # 94, fig. 2). Only one small house remains of the town of Gladstone circa 1903 (fig. 14). Photo taken 22 hours after the event.

sediment discharged is in table 1 of Church, Fey, and Unruh, this volume.) The towns of Durango and Aztec had to shut off intake of water at their pumping plants to prevent the polluted water from entering municipal water systems. Samples taken by health officials in Durango showed levels of 12.6 mg/L zinc and 4 mg/L lead in the water, and warnings were issued not to drink the water (Daily Sentinel, June 11, 1978). At the time of the event, most downstream users and the press thought this contamination was from mill tailings in Lake Emma. This was unlikely because the early Sunnyside mills (sites # 158, 165, fig. 2) were built considerably downstream of Lake Emma. The first Sunnyside Mill (site # 113) was built at or just below the outlet of Lake Emma, which was dammed to provide process water to the mill. Photographic evidence suggests the mill's tailings were probably discharged into Eureka Creek. Part of the B Level waste dump was deposited in the lake and sloughed in further due to the mine collapse. Natural metal content of the lake sediments as well as metals washed from the mine workings probably accounted for the metal loading. Large chunks of ore from the collapsed 2580 stope never made it past the Gladstone portal and were recovered and milled during the 2-year mine clean-up. Little ore was found in the Terry tunnel, the mine's upper entrance (# 120). Instead, these workings were filled with a black sticky mud, similar to that observed in the exposed lake bottom. Considerable mud-laden water also discharged from this portal, though in a less spectacular fashion, and blackened Eureka Gulch and the Animas River between Silverton and Eureka.

Standard Metals Corp. was not fined by any State or Federal agency, and the accident was determined to be an "act of God" in a Federal court action brought by the mine's insurance company, which was trying to avoid paying $9,000,000 in damage claims. Standard Metals Corporation won the suit and recovered $5.5 million dollars. The mine resumed production in January 1980 (Bird, 1986). Water drainage was significantly altered in Sunnyside basin, but was largely mitigated through reclamation efforts by later mine owner, Sunnyside Gold Corp.

Water drainage from long haulage tunnels, such as the American tunnel (site # 96, fig. 1), came under regulatory and environmental scrutiny when water discharges from mine tunnels became closely regulated in the 1970s. Sunnyside Gold Corp. has installed hydraulic seals in the principal access tunnels to eliminate this drainage. These seals are intended to provide a permanent solution to mining's 100-year battle with water and drainage problems, both operational and regulatory.

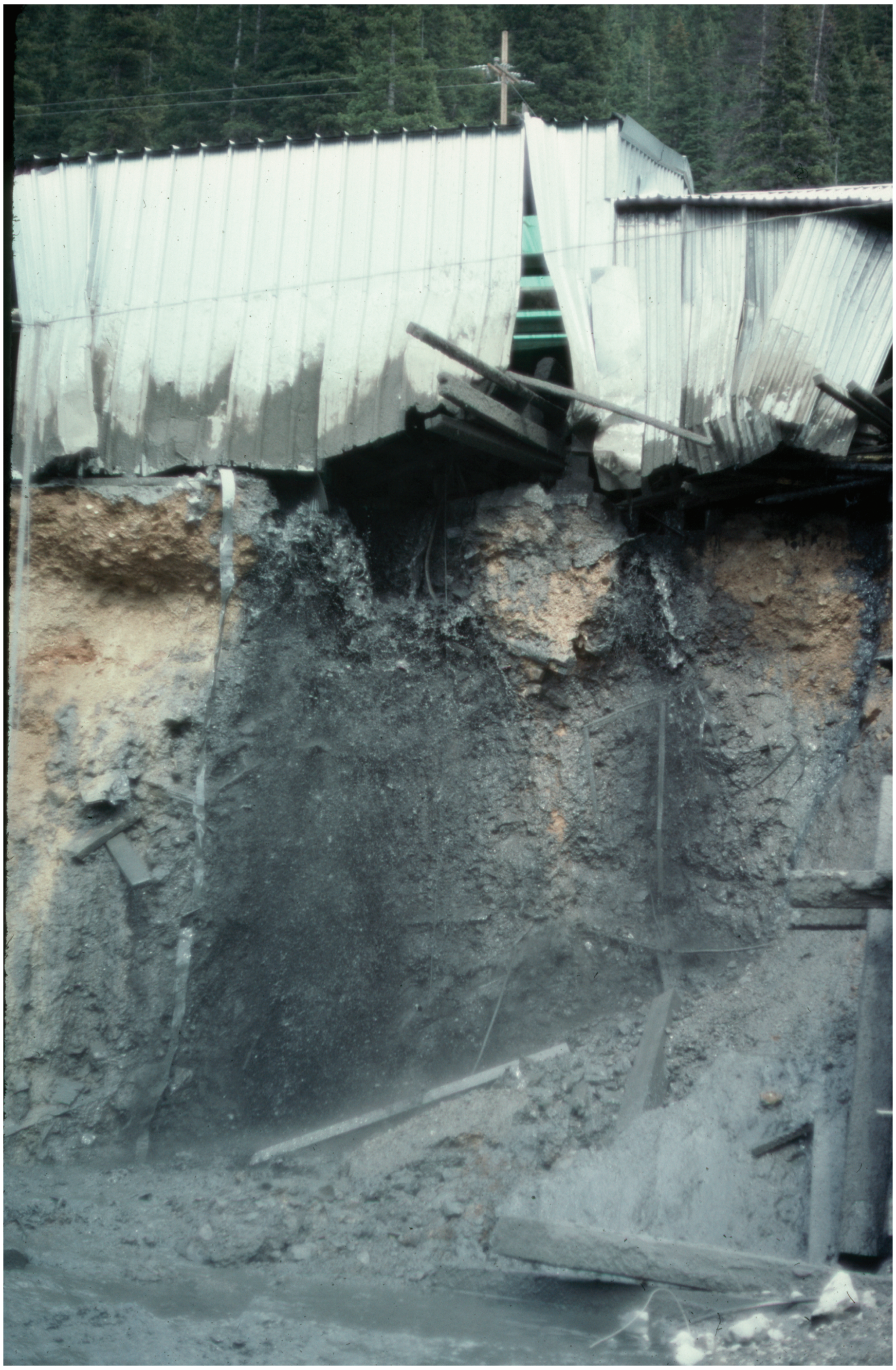

Figure 29. Erosion trench and muddy discharge at American tunnel portal, June 5, 1978, the day after Lake Emma flood. With 2,000 ft of head pressure, Lake Emma water exited the American tunnel (mine # 96) like a huge fire hose, blowing open the building wall and eroding the dump back about 15 ft, creating an erosion trench. The scene was described by witnesses as something out of a science fiction movie.

Figure 30. Crossing muddy waters of Cement Creek, June 5, 1978, the day after Lake Emma flood. The Lake Emma flood washed out bridges and blackened Cement Creek and the Animas River for a distance of 70 mi south into New Mexico, shutting down municipal water systems along the Animas River.

Conclusions

Historical mining and milling practices in San Juan County impacted the environment in various ways during the 121-year period of active mining. These practices in turn, were influenced by national and international economics, events, industrial policy, public perceptions, and technological trends in the mining industry. Knowledge of these historical practices can assist us in understanding current environmental issues in the Animas River watershed and in developing investigations of specific environmental problems that may be related to historical practices. Mining and milling practices, particularly prior to 1935, tended to release mining wastes directly into the aquatic and riparian environment. The magnitude of these releases was directly proportional to the level of production and number of operating mines and mills. After 1890, technological advances in both mining and milling fostered larger scale production averaging more than 200,000 short tons per year. The majority of this production was milled, and the resultant mill tailings were discharged directly into the watershed until the mid-1930s. Based on reported and estimated mine production during the period 1890–1935, an amount totaling 8.6 million short tons of mill tailings is estimated to have been deposited into the Animas River and various tributaries. This represents 47.5 percent of the total reported and estimated mine production of 18.1 million short tons produced during the 121-year period of production. These mill tailings as well as mine dumps both on the surface and underground contain varying amounts of metals unrecoverable at the time of their production. Mill tailings entering the watershed often affected downstream water users. After tailings retention in settling ponds became standard practice in the mid-1930s, direct physical contamination of surface waters was nearly eliminated. Accidents and operator error did cause occasional tailings releases.

Mine workings expanded in length, depth, and vertical extent from the beginning of mining in 1871. As tunnels became longer and were constructed at lower elevations, mine drainage locally affected ground-water hydrology and resulted in point source discharges into the watershed. Earlier mining methods left mineralized rock underground in the stopes. Later mining methods tended to extract more of the mineralized material leaving larger voids and less mineralized waste. Fewer surface dumps were created at mine sites when improved flotation milling techniques allowed for nearly all mined material to be economically milled.

Federal Government policies actively encouraged mining until the early 1960s. During wartime direct and indirect financial incentives for increased production and exploration intensified mining activity. Remilling of dumps and stope fills during these and other periods of high prices removed some mined material from direct contact with ground water at the mine sites and transferred it to tailings repositories. Environmental regulations enacted in the 1970s required mine operators to perform surface reclamation and regulate quality of water discharges from both mines and mills. These regulations increased both current and future costs of mining, which, coupled with decreased metal prices, effectively ended San Juan County mining production in 1991 after 121 years.

References Cited

Adams, W.J., 1899, Hints on amalgamation and the general care of gold mills: Chicago Ill., Modern Machinery Publishing Co., 111 p.

Besser, J.M., Brumbaugh, W.G., May, T.W., Church, S.E., and Kimball, B.A., 2001, Bioavailability of metals in stream food webs and hazards to brook trout (*Salvelinus fontinalis*) in the upper Animas River watershed, Colorado: Archives of Environmental Contamination and Toxicology, v. 40, p. 48–59.

Bird, A.G., 1986, Silverton gold: Lakewood, Colo., privately published, 152 p.

Bird, A.G., 1999, Silverton gold (revised edition): Lakewood, Colo., privately published, 223 p.

Brown, R.L., 1984, An empire of silver: Denver, Colo., Sundance Books, 224 p.

Bunyak, D., 1998, Frothers, bubbles and flotation—A survey of flotation milling in the twentieth-century metals industry: Denver, Colo., National Park Service, Intermountain Support Office, 92 p.

Burbank, W.S., and Luedke, R.G., 1969, Geology and ore deposits of the Eureka and adjoining districts, San Juan Mountains, Colorado: U.S. Geological Survey Professional Paper 535, 73 p.

Chase, C.A., 1952, Shenandoah-Dives at its Quarter Century, Colorado Mining Association, 1951: Mining Yearbook, Denver, Colo., p. 112–114.

Chase, C.A., and Kentro, D.M., 1938, Tailings disposal practice of Shenandoah-Dives Mining Company: Mining Congress Journal, v. 24, p. 19–21.

Chase, C.A. and Kentro, D.M., 1942, The Shenandoah-Dives Mine: Mining World Magazine, v. 4, p. 3–7.

Church, S.E., Kimball, B.A., Fey, D.L., Ferderer, D.A., Yager, T.J., and Vaughn, R.B., 1997, Source, transport and partitioning of metals between water, colloids, and bed sediments of the Animas River, Colorado: U.S. Geological Survey Open-File Report 97–151, 136 p.

Colorado Board of Immigration, 1932, Year book of the State of Colorado 1932: 381 p.

Colorado Bureau of Mines, 1898, Report of the State Bureau of Mines for 1897: 167 p.

Denver Equipment Company, 1947, Denver Equipment Index, Second Edition, Volume 1: Denver, Colo., 384 p.

Daily Sentinel, 1978, v. 85, June 11, 1978, Grand Junction, Colo.

Durango Democrat, 1902, editions of August 1–15, November 15, Durango, Colo.

Durango Evening Herald, 1902, July 18 edition, Durango, Colo.

Echo Bay Mines, 1988, 1987 Annual Report: Edmonton, Alberta, 66 p.

Henderson, C.W., 1926, Mining in Colorado—History, development, and production: U.S. Geological Survey Professional Paper 138, 263 p.

Hutchinson, R.M., ed., 1988, Epithermal base-metal and precious-metal systems, San Juan Mountains, Colorado: Society of Economic Geology Guidebook, v. 3, 126 p.

Ingram, T.R., 1932, Year book of the state of Colorado 1932: Denver, Colo., State Board of Immigration, 381 p.

Niebur, J.E., 1986, Arthur Redman Wilfley—Miner, inventor, and entrepreneur: Denver, Colo., Colorado Historical Society, 245 p.

Ransome, F.L., 1901, A report on the economic geology of the Silverton quadrangle, Colorado: U.S. Geological Survey Bulletin 182, 265 p.

Rickard, T.A., 1932, A history of American mining: New York, McGraw-Hill, 419 p.

Silverton Miner, 1907, The Golden San Juan—Special illustrated edition: Silverton, Colo. v. 33, no. 11, 65 p.

Silverton Standard, 1904, Illustrated Folio of San Juan County: Silverton, Colo., 28 p.

Sloan, R.E., and Skowronski, C.A., 1975, The Rainbow Route, an illustrated history of the Silverton Railroad, the Silverton Northern Railroad, and the Silverton, Gladstone, & Northerly Railroad: Denver, Colo., Sundance Publications Ltd., , 416 p.

Smith, D.A., 1987, Mining America—The industry and the environment: Lawrence, Kans., University of Kansas, 210 p.

Standard Metals Corporation, 1961, 1960 Annual Report: Moab, Utah, 13 p.

Standard Metals Corporation, 1966, 1965 Annual Report: New York, 14 p.

Standard Metals Corporation, 1974, 1973 Annual Report: New York, 16 p.

Standard Metals Corporation, 1979, 1978 Annual Report: New York, 7 p.

Standard Metals Corporation, 1983, 1982 Annual Report: New York, 29 p.

Standard Metals Corporation, 1984, 1984 Annual Report (Form 10–K): New York, 95 p.

Taggart, A.F., 1927, Handbook of ore dressing: New York, John Wiley, 1,679 p.

Taggart, A.F., 1945, Handbook of mineral dressing: New York, John Wiley, 1,915 p.

Taylor, F.D., 1988, Geology and ore deposits of the Gold King mine, Eureka mining district, San Juan County, Colorado, *in* Hutchinson, R.M., ed., Epithermal base-metal and precious-metal systems, San Juan Mountains Colorado: Society of Economic Geology Guidebook, v. 3, p. 74–88.

U.S. Bureau of Mines, 1918, Mineral resources of the United States; Colorado: v. 1, p. 819–875.

U.S. Bureau of Mines, 1924 to 1971, Mineral resources of the United States; Colorado: variously paginated.

U.S. Bureau of Mines, 1973 to 1975, Minerals yearbook; Colorado: variously paginated.

U.S. Bureau of Mines, 1977, Minerals yearbook; Colorado: v. 2, p. 113–131.

U.S. Bureau of Mines, 1983, Minerals yearbook; Colorado: v. 2, p. 107–122.

U.S. Bureau of Mines, 1984, Minerals yearbook; Colorado: v. 2, p. 115–132.

U.S. Bureau of Mines, 1986, Minerals yearbook; Colorado: v. 2, p. 93–105.

U.S. Geological Survey, 1999, Metals prices in the United States through 1998: U.S. Geological Survey Special Publication, 179 p.

Vanderwilt, J.W., 1947, Mineral resources of Colorado: Denver, Colo., State of Colorado Mineral Resources Board, 547 p.

Varnes, D.J., 1963, Geology and ore deposits of the South Silverton mining area, San Juan County, Colorado: U.S. Geological Survey Professional Paper 378–A, 56 p.

Appendix

Notes on the Table and Chart of Reported and Estimated Mine Production

Statistics on total annual mine production were compiled by the U.S. Geological Survey, U.S. Bureau of Mines, and State agencies from 1885 through the mid 1970s. Data from 1871 to 1900 are recorded in Henderson (1926) but as annual dollar value of ores produced, not tons. For purposes of constructing figure 3, the tonnage through 1889 is estimated by assuming an average value per short ton. For 1890–1900, actual average ore values per short ton for 1901 are used to back-calculate the tonnage from the dollar figures. For 1901–1923, production data cited are from Henderson (1926). For 1924–1977, production data are from the annual Mineral Resources of the United States, later called the Mineral Yearbooks of the U.S. Bureau of Mines. However, 1972 and 1976 are Sunnyside production only from company data. For 1978–1991, production data are for the Sunnyside only, based on data furnished by Sunnyside Gold Corporation and Standard Metals Corporation annual reports; the exception is 1986, which is from U.S. Bureau of Mines (USBM, 1986). An estimate of 20,000 short tons milled by three operators at the Pride of the West Mill [# 4] during 1979–1981 is not included in the totals, because supporting data are lacking. Metals prices were reported by U.S. Bureau of Mines through 1958, except that data from 1924–1931 are from the Colorado Yearbook (1932). Metals prices after 1958 are from U.S. Geological Survey (1999).

Author Information and Notes on Sources of Photographs

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Photographs in this report constitute an important source of historical information on past mining and milling practices. They come from a variety of published and unpublished archival sources in San Juan County, principally the Archive maintained by the San Juan County Historical Society in Silverton.

Charles A. Chase, General Manager of the Shenandoah-Dives mine, took numerous detailed photographs of that operation, copies of which were donated to the Society archives by his son, Charles H. Chase, of Tucson, Ariz., who was superintendent of the Mayflower Mill 1945–1948. The early halftone photographs come from special 1904 and 1907 illustrated editions of Silverton's pioneer newspapers, the Silverton Standard and Silverton Weekly Miner, author's collection. Color photos of the Lake Emma flood were taken by the author.

Photo credits:

Silverton Standard—Illustrated Folio 1904: Figures 4, 5, 10, 15.

Silverton Weekly Miner—Golden San Juan Edition 1907: Figures 7, 12, 13.

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William R. Jones Photo: Figures 16, 20, 22, 27, 28, 29, 30.

David L. Fey Photo: Figure 11.