SUPPLEMENT TO THE ROAD LOG

by

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1.0 NATURE AND EXTENT OF IMPACTS RELATED TO MINE WASTES

The investigation revealed five primary sources of metals and arsenic to Silver Bow Creek and the SST OU:

1. Upstream offsite sources;
2. Tailings/impacted soils;
3. Ground water;
4. Sediments; and
5. Railroad materials.

The relative significance of each of these sources varies from subarea to subarea. Control of upstream/offsite sources is the primary factor impacting the quality of surface water and sediments within the SST OU. Tailings/impacted soils are the primary onsite source of potential risk to human health and the environment that will be addressed by the SST OU.

1.1 Upstream Offsite Sources

Upstream sources include, but are not limited to, mine wastes in and near the city of Butte, the Weed Concentrator and Butte Operations areas. Additional sources of impacts to Silver Bow Creek include industrial and urban pollution sources, such as the Butte Waste Water Treatment Plant and urban runoff. Contaminants from these source areas enter the SST OU primarily in Silver Bow Creek. Offsite contaminants may also enter via ground water from the Colorado Tailings area and the Rocker Timber Framing and Treating Plant.

1.2 Tailings/Impacted Soils

Relatively persistent and sometimes wide-spread expanses of mine and mill tailings and placer workings are present along nearly the entire reach of Silver Bow Creek within the SST OU. Tailings are mixed with native soils and are derived of materials that are the direct or indirect geologic parents of the soils, so that visual identification of impacted soils is sometimes difficult. Tailings were primarily carried downstream in a large flood event in 1908. The widest and thickest deposits are generally upstream of railroad trestles and bridges that existed in 1908 and restricted the flood flows. There has been minor movement and re-working of the deposits in the floodplain since 1908 related to flood flows smaller than the 1908 flood. The lateral and vertical extent of tailings/impacted soils were determined by analysis of 625 samples of tailings/impacted soils and nonimpacted soils. The volume and nature of the tailings/impacted soils is presented in Table 1. The volume of these materials were estimated to be 2.4 to 2.8 million cubic yards within 1,270 acres. The tailings/impacted soils range in thickness from a few inches to greater than 5 feet. Most of these tailings/impacted soils are in deposits less than 1.5 feet thick and contain arsenic, cadmium, lead, and zinc. In many locations, the tailings/impacted soils also contain mercury related to extensive placer mine workings throughout the SST OU.

Table 1
Results and Statistical Summary of Analyses of Tailings and Soil Samples
Streamside Tailings Operable Unit

Sample Type	Number of Samples	Statistical Parameter	Total Metals (mg/Kg)					
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc
Tailings/Impacted Soils	350	Median	15.8	1.60	114	45	0.14	329
		Semi-Interquartile Range	33.4	2.77	312	150	0.47	706
		Number of Analyses	298	350	350	350	108	348
Nonimpacted Soils	228	Median	316.5	8.60	1,535	710	2.05	2,650
		Semi-Interquartile Range	240.0	7.11	1,301	691	4.35	2,150
		Number of Analyses	218	228	228	228	45	227
Tailings and Soil	578	Median	77.0	3.60	486	246	0.75	1,110
		Semi-Interquartile Range	171.6	4.95	976	459	1.31	1,634
		Number of Analyses	516	578	578	578	153	575

Note:
Non-parametric statistics are used to describe the tailings/impacted soil because the concentrations of constituents of concern are best described by a gamma distribution rather than a normal distribution. The measure of central tendency for a gamma distribution is a median, comparable to the geometric mean of a normal distribution. The measure of data spread is the semi-interquartile range, comparable to the standard deviation for a normal distribution.
Semi-interqartile range = (third quartile - first quartile)/2
For calculations, non-detect values are used as one-half of the method detection limit.

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1.3 Ground Water

The main objectives of the ground water investigation were to determine if ground water was contaminated and to define the interaction between ground water and Silver Bow Creek. A total of 49 monitoring wells and drive points were installed and monitored onsite. The 49 wells installed in the alluvium have been screened at two different depths, within twenty feet of the ground surface (upper alluvial aquifer) and greater than twenty feet below the ground surface (lower alluvial aquifer). The screen interval and average concentrations of ground water from each of these 49 wells is presented in Table 2. Ground water flows toward and into the creek except in a few reaches where surface water flows into ground water. Elevated concentrations and exceedances of drinking water standards (MCLs) for metals were found in ground water samples from scattered areas and were confined to samples from the shallow alluvial aquifer. Metals contaminants were found at concentrations exceeding MCLs for arsenic and cadmium in several wells located near, but outside of the SST OU and Rocker OU and up-gradient of tailings. Wells in the Rocker area are reported as part of the Rocker OU investigations.

1.4 Sediments

A portion of the tailings and impacted soil eventually resides as stream bed sediments at the bottom of Silver Bow Creek, at least for a time, before the sediments are carried downstream to Warm Springs Ponds. Bed sediments are composed of a mixture of tailings and native materials. While in the stream, these sediments may serve as a source of metals to the surface water system or may impact aquatic life in the stream bottom. The volume and nature of the sediments is presented in Tables 3a and 3b. Studies of the stream show that even if metals and arsenic were removed from surface water and sediments, urban and industrial impacts would make it unlikely that a strong, diverse natural aquatic system would become established.

1.5 Railroad Materials

Certain portions of several historic and existing railroad embankments along Silver Bow Creek were constructed with mine waste. This material represents a potential minor source of metals to ground water or to Silver Bow Creek via runoff. The volumes and nature of the railroad materials containing mine wastes are presented in Tables 4a and 4b.

Table 2a

Summary of Field Parameters and Analytical Results from Lower Alluvial Aquifer Ground Water Monitoring Wells Located Within Tailings (1) Streamside Tailings Operable Unit Draft Remedial Investigation Report

Well ID	Field pH (SU)	Electrical Conductivity (umhos/cm)	Sulfate (mg/l)	Average Dissolved Metals: Arsenic (ug/l)	Cadmium (ug/l)	Copper (ug/l)	Iron (ug/l)	Lead (ug/l)	Manganese (ug/l)	Mercury (ug/l)	Zinc (ug/l)
RH-8	ND	ND	ND	17.27	1.50	1.23	ND	0.73	ND	0.05 U	1.45 U
GS-03	7.20	456.25	ND	8.98	0.66	15.38	ND	1.73	ND	0.05 U	32.95
C-9	6.18	275.60	ND	4.90	0.37	1.90	ND	0.91	ND	ND	71.47
C-10	6.90	1,763.68	901.00	5.44	0.40	4.92	16.10	2.07	3.90	ND	71.36
C-11	6.88	1,693.10	903.00	5.88	0.46	9.04	17.77	2.39	45.37	ND	19.70
C-12	7.03	370.40	54.67	6.34	0.40	5.21	21.47	1.24	3.90	ND	17.37
C-13	6.77	525.66	133.00	4.62	0.43	4.60	17.10	0.99	3.57	ND	101.31
TS-01	6.79	704.35	292.00	3.06	2.44	29.20	21.00	2.74	14,000.00	ND	117.60
GS-06	6.50	1,269.00	ND	13.00	3.20	8.95	ND	3.30	ND	ND	1,116.00
GS-05	6.70	1,020.00	ND	6.60	0.50	10.00	ND	1.00	ND	ND	11.00
C-8	7.11	767.60	172.67	9.16	0.14	2.06	1,095.33	1.08	1,583.33	ND	6.16
C-1	7.08	829.71	234.67	3.36	0.32	2.74	39.70	1.11	8.30	0.09	10.85
C-5	6.35	903.72	346.00	4.04	0.59	3.41	1,036.67	1.26	4,580.00	0.09	155.67

Notes:

(1) The lower alluvial aquifer includes wells in which the bottom of the screened interval is more than to 20 feet below ground surface..

Averages calculated with non-detect entered as one-half the method detection limit.

U - Every value used to calculate this average was a non-detect.

SU = Standard Units.

umhos/cm = Micromhos per centimeter.

mg/l = milligrams per liter.

ug/l = micrograms per liter.

ND = No data available.

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Table 2b

Summary of Field Parameters and Analytical Results from Upper Alluvial Aquifer Ground Water Monitoring Wells Located Within Tailings (1) Streamside Tailings Operable Unit Draft Remedial Investigation Report

Well ID	Field pH (SU)	Electrical Conductivity (umhos/cm)	Sulfate (mg/l)	Average Dissolved Metals Arsenic (ug/l)	Cadmium (ug/l)	Copper (ug/l)	Iron (ug/l)	Lead (ug/l)	Manganese (ug/l)	Mercury (ug/l)	Zinc (ug/l)
C-16	7.40	1,749.67	612	14.30	4.50	9.76	85	1.12	61	0.10	789
C-17	7.08	1,558.25	608	13.45	1.88	94.43	154	0.85	258	0.07	378
DP-5	ND	ND	ND	74.67	ND	ND	ND	ND	ND	ND	ND
GS-01	6.98	343.50	ND	2.99	0.46	12.10	ND	3.70	ND	ND	18
GS-02	6.60	307.00	ND	2.23	0.40	13.50	ND	1.00	ND	ND	81
RH-2	5.22	711.00	ND	5.27	2.17	45.95	ND	0.87	ND	ND	2,200
RH-3	6.28	1,260.00	ND	5.53	3.93	5.83	ND	4.33	ND	ND	83
RH-4	5.73	762.00	ND	38.43	1.50	4.67	ND	1.17	ND	ND	2,847
GS-04	7.14	508.00	128	30.75	3.61	36.42	423	4.10	16,667	0.14	790
C-13S	6.75	469.10	134	8.66	0.73	28.57	24	1.27	44	ND	71
C-18	6.72	782.75	207	9.03	8.05	12.08	3,853	0.75	3,683	0.20	835
C-19	6.80	426.38	104	6.10	1.01	15.33	17	1.25	1,261	ND	228
C-20	6.75	499.68	102	5.08	1.04	17.00	12	1.04	710	ND	214
C-21	6.30	376.57	54	54.98	0.26	4.62	1,176	1.14	1,697	ND	44
C-22	6.65	1,179.50	438	34.95	0.37	1.17	18,800	0.87	7,970	ND	2,778
C-23	6.91	1,365.25	513	27.20	0.26	2.40	26,600	0.69	15,733	0.12	4,973
C-7	6.20	759.60	424	8.82	7.58	56.80	3,743	0.99	6,503	ND	2,258
C-2	6.12	375.00	108	1.42	1.68	7.94	26	0.88	55	0.10	255
C-3	4.80	391.34	128	1.49	9.64	316.40	36	27.86	836	0.11	1,652
C-4	5.87	475.44	181	5.58	36.42	447.60	3,350	4.43	5,250	0.20	9,968
C-4S	6.02	474.56	173	12.12	0.43	2.82	10,033	1.24	5,673	0.16	8,520
C-6	6.77	541.40	166	8.16	0.33	1.86	3,403	0.98	1,190	0.11	163
C-24	6.59	716.30	232	3.60	6.05	17.88	83	1.40	4,167	0.08	506
C-25	6.79	1,145.10	570	3.05	11.78	21.18	145	0.91	5,543	0.09	2,442
C-26	6.67	891.48	202	5.70	0.55	4.35	337	1.50	1,405	0.12	16
C-28	6.79	905.00	245	11.55	0.33	3.80	2,730	1.33	882	0.09	41
C-27	6.94	719.61	240	5.88	0.45	2.75	20	1.51	172	0.07	77

Notes:

(1) The upper alluvial aquifer includes wells in which the bottom of the screened interval is less than or equal to 20 feet below ground surface.

Averages are calculated using one-half the method detection limit for non-detect analyses.

SU = Standard Units.

umhos/cm = Micromhos per centimeter.

mg/l = milligram per liter

ug/l = micrograms per liter.

ND = No data available.

Table 3a
Results and Statistical Summary of Inorganic Analysis of Sediment Samples
Streamside Tailings Operable Unit

Statistical Parameter	Total Metals Concentration (mg/Kg)					
	Arsenic	Cadmium	Copper	Lead	Mercury	Zinc
Median	113.0	6.7	1,390	367	0.64	2,170
Semi-interquartile Range	462.2	27.75	8012.5	1226.15	0.855	7213.75
Number of Samples	43	43	43	43	43	43

Notes:
mg/Kg = milligram per Kilogram.
Samples used for this statistical summary are those deemed applicable and of sufficient validity or quality to be used for the Draft Remedial Investigation Report.

Table 3b
Volume of Sediments
Streamside Tailings Operable Unit

Stream Reach	Sediment Volume (1) (cubic yards)				
	Subarea 1	Subarea 2	Subarea 3	Subarea 4	Entire SST OU
Riffle	2,002	2,994	3,514	4,987	13,497
Run	34,320	51,333	14,056	72,307	172,016
Pool	4,805	7,187	0	4,189	16,180
Total	41,127	61,514	17,569	81,482	201,693

Notes:
(1) Average of the minimum and maximum values determined in the Draft Remedial Investigation Report.

Table 4a
Railroad Bed and Ballast Materials Analytical Statistical Summary
Streamside Tailings Operable Unit

Material Type	Median Total Metals Concentration (mg/kg)				
	Arsenic	Cadmium	Copper	Lead	Zinc
Impacted Material	358	11.2	2,468	1,219	3,056
Concentrate Spill	4540	19.8	98,900	1,520	3,542
Slag	1,660	18.0	9,390	2,030	19,500
Waste Rock	375	2.0	1,081	587	687

Notes:
mg/kg=milligrams per kilogram
Calculations are made with 1/2 the undetected values.

Table 4b
Railroad Bed and Ballast Volume Summary
Streamside Tailings Operable Unit

Material Type	Volume (cubic yards)				
	Subarea 1	Subarea 2	Subarea 3	Subarea 4	Total SST OU
Waste Rock	202,654	18,560	60,246	8,317	289,777
Impacted Materials	0	954	0	22,933	23,887
Ore Concentrate	1	0	0	0	1
Slag	74,527	48,474	35,013	0	158,014
Total	277,182	67,988	95,259	31,250	471,679

Notes:
mg/kg=milligrams per kilogram
Calculations are made with 1/2 the undetected values.

2.0 TRANSPORT AND MIGRATION OF IMPACTS RELATED TO MINE WASTES

Figures 1 through 4 show the current generalized conceptual model of contaminant movements within the SST OU. Contaminants move through the area and between environmental media in response to a variety of processes. Some of the primary means by which contaminants may move within the SST OU include:

1. Erosion and runoff;
2. Surface water flow;
3. Tailings/impacted soils and ground water interaction; and
4. Ground water and surface water interaction.

2.1 Erosion and Runoff

Erosion and runoff are a transport mechanism that carries constituents of concern to Silver Bow Creek. Particularly, precipitation-generated and snowmelt runoff moves metals-bearing materials via erosion and carries the contaminants to Silver Bow Creek. During much of the summer, the arid conditions of the site cause dissolved metals in soil moisture to be wicked to the surface of tailings due to evaporation. Evaporation causes salts to form on the surface of the tailings/impacted soils. These salts may be eroded or dissolved and transported by runoff to the stream. Silver Bow Creek may erode banks and cause direct erosion of streambank materials. Ice buildup in the stream during winter months may cause streambank erosion and people and animals may also cause streamside tailings to directly enter the stream.

2.2 Surface Water Flow

Water entering the SST OU from upstream areas (inflow) is contaminated by mining wastes, urban and industrial effluents. Data presented in Table 5 illustrate the water quality and flow volume at various locations within the SST OU. The water quality data indicate that contaminants may be added to Silver Bow Creek in the upper portion of the SST OU during low flow conditions. Aquatic systems are particularly sensitive to elevated levels of copper and zinc. Below the mouth of Durant Canyon, water quality generally improves as Silver Bow Creek flows to the Warm Springs Ponds during low flows. There is a net decrease in loading of metals through the SST OU. As mentioned above, high flow water quality is impacted by runoff carrying dissolved salts of the constituents of concern.

2.3 Tailings/Impacted Soils and Ground Water Interaction

In some areas ground water is in direct contact with tailings for a portion of the year. The average ground water level fluctuation is estimated at one to two feet. Saturation of tailings/impacted soils may mobilize metals from the tailings and in turn may contaminate the ground water. As shown by the formation of salts on the surface of tailings/impacted soils,

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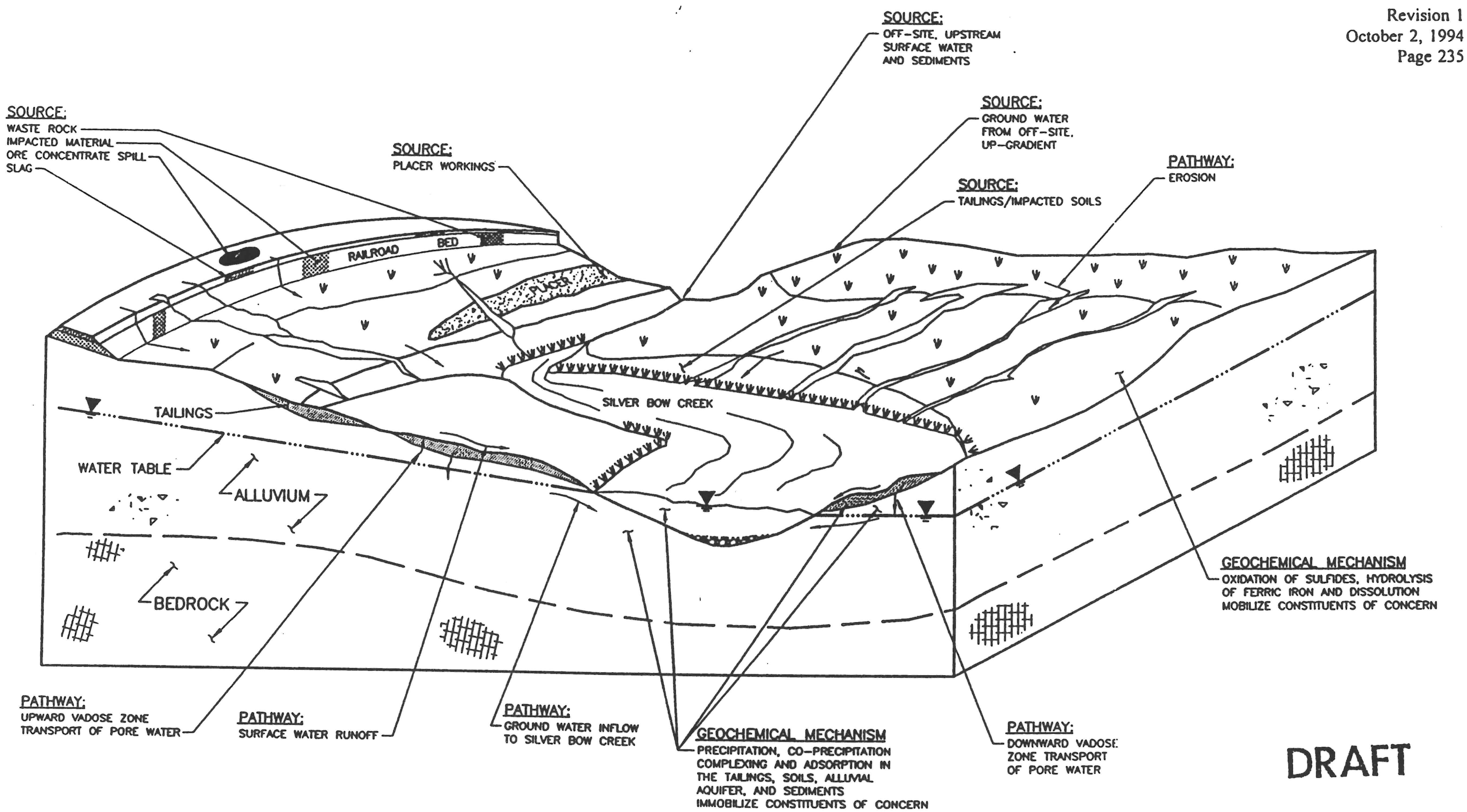

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CONCEPTUAL MODEL
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DATE: 9-12-94	~~FIGURE 4-28~~	DRAWING NUMBER 3109-B109
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Fig. 1

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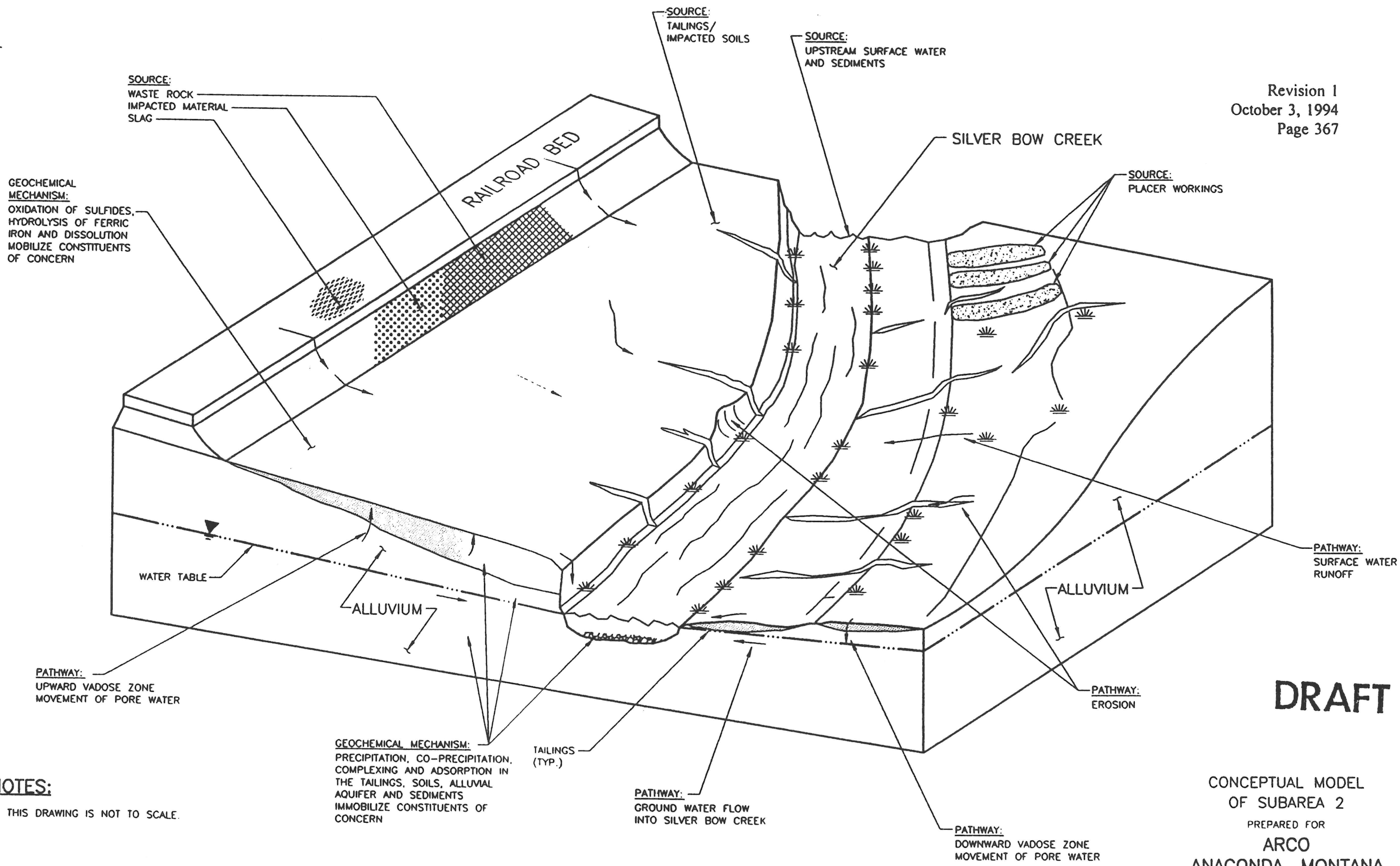

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Fig. 2

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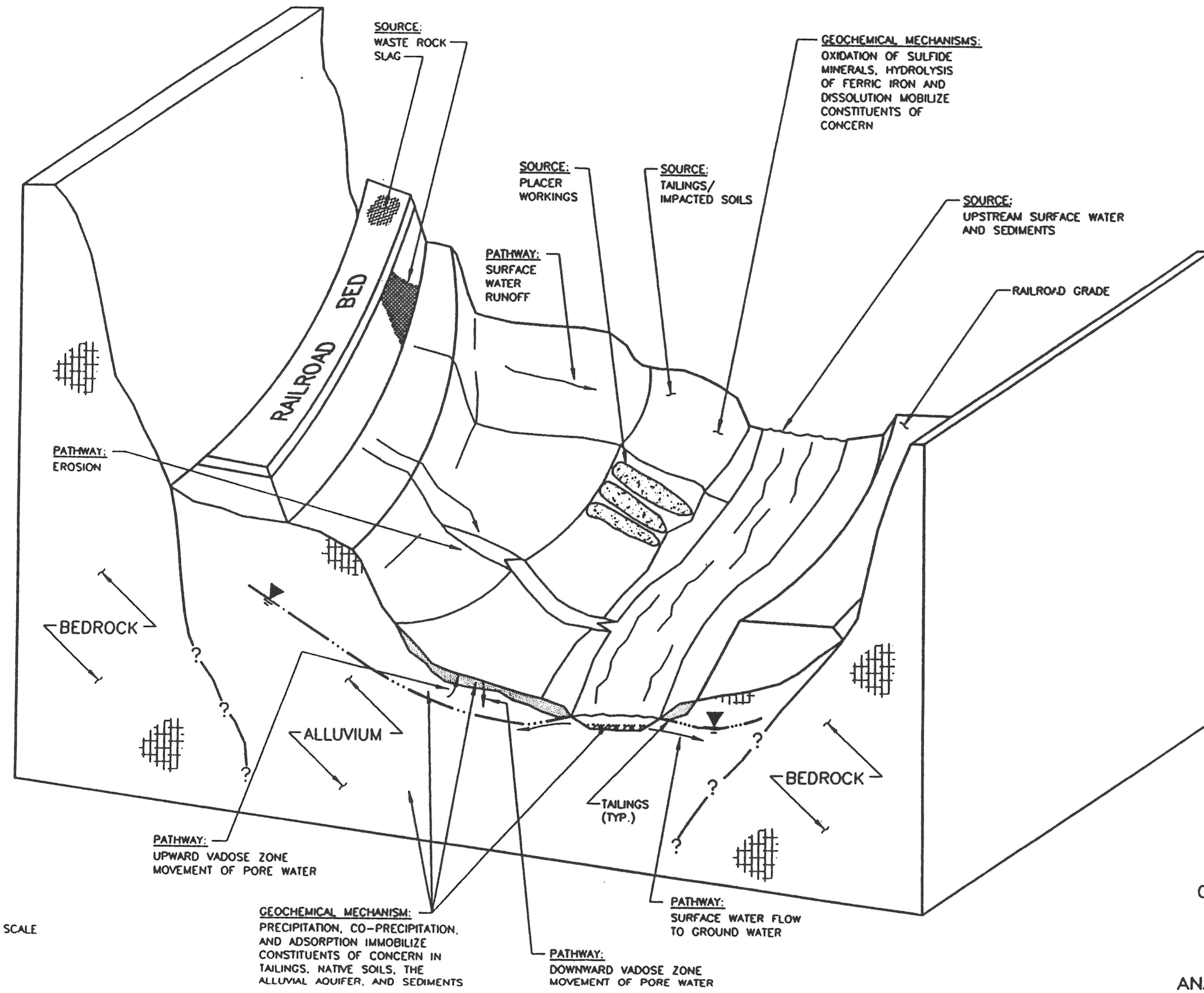

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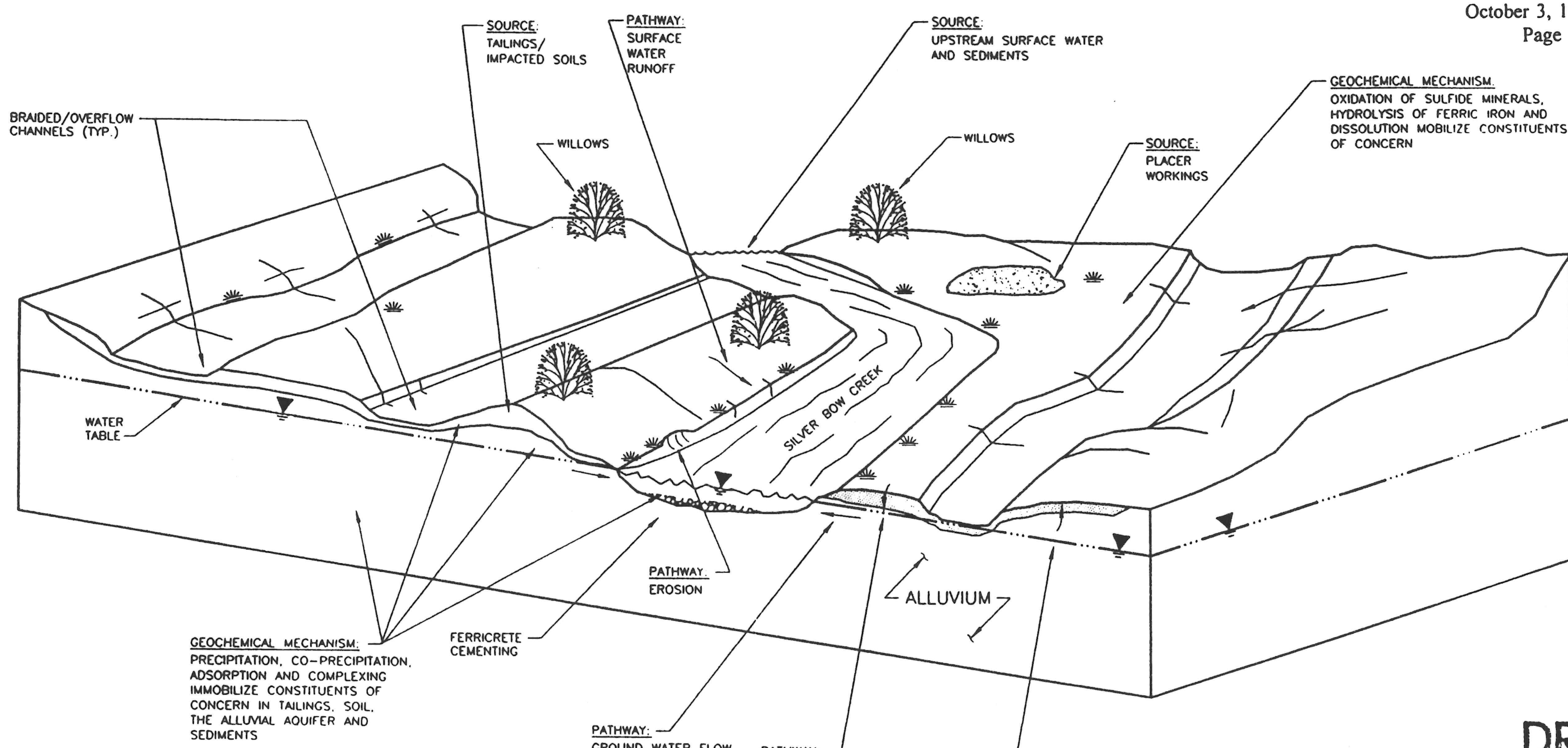
Fig. 3



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DATE: 9-12-94	FIGURE 4-102	DRAWING NUMBER 3109-B116
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Fig. 4

Table 5

Results and Statistical Summary of Inorganic Analysis of Surface Water Samples (1)

Streamside Tailings Operable Unit

Station	River Mile (2)	Statistical Parameter	Discharge (cfs)	Dissolved Metals: Arsenic (ug/l)	Cadmium (ug/l)	Copper (ug/l)	Lead (ug/l)	Mercury (ug/l)	Zinc (ug/l)
Chronic Standard (3)				850 (4)	1.1 (5)	12 (5)	3.2 (5)	0.012 (6)	110 (5)
Acute Standard (3)				NA	3.9 (5)	18 (5)	82 (5)	2.4 (6)	120 (5)
Maximum Contaminant Level (7)				50 (4)	5.0	1000 (8)		2.00	5000 (8)
SS-07	1.4	Median	20.5	13.0	3.3	90	3.6	NA	659
		Semi-Interquartile Range	1.3	3.4	0.7	11	0.7	NA	88
		Number of Analyses	8	2	2	8	2	0	8
SS-08	3.5	Median	20.5	13.3	2.5	52	1.1	0.16	605
		Semi-Interquartile Range	0.8	1.5	0.3	12	0.2	NA	118
		Number of Analyses	8	2	2	8	2	1	8
SS-09		Median	22	NA	NA	76	NA	NA	494
		Semi-Interquartile Range	1	NA	NA	6	NA	NA	140
		Number of Analyses	6	0	0	6	0	0	6
SS-09A	5.5	Median	17.9	5.0	4.0	48	1.5	0.08	151
		Semi-Interquartile Range	NA	NA	NA	NA	NA	NA	NA
		Number of Analyses	1	1	1	1	1	1	1
SS-10	6.0	Median	19.9	10.8	2.0	59	1.7	NA	382
		Semi-Interquartile Range	0.4	0.0	0.0	6	0.0	NA	205
		Number of Analyses	4	4	4	4	4	4	4
SS-11	7.9	Median	23.5	8.0	2.0	54	0.8	0.08	401
		Semi-Interquartile Range	2.8	1.7	0.0	5	0.2	NA	85
		Number of Analyses	4	2	2	4	2	1	4
SS-11C	8.7	Median	21.7	5.0	2.0	41	0.3	0.08	390
		Semi-Interquartile Range	NA	NA	NA	NA	NA	NA	NA
		Number of Analyses	1	1	1	1	1	1	1
SS-13	9.0	Median	26	NA	NA	54	NA	NA	353
		Semi-Interquartile Range	1	NA	NA	6	NA	NA	35
		Number of Analyses	2	0	0	2	0	0	2
SS-14	10.7	Median	25.1	4.4	1.1	47	3.4	NA	165
		Semi-Interquartile Range	2.2	3.8	0.9	7	0.2	NA	26
		Number of Analyses	8	4	4	8	4	0	8
SS-16	16.1	Median	27.5	4.1	1.2	48	5.1	NA	77
		Semi-Interquartile Range	3.4	3.7	0.8	4	0.4	NA	21
		Number of Analyses	8	4	4	8	4	0	8
SS-16B	19.3	Median	35.1	12.6	1.8	47	0.8	0.08	391
		Semi-Interquartile Range	3.4	3.8	0.1	8	0.5	0.03	108
		Number of Analyses	2	2	2	2	2	2	2
SS-17	20.9	Median	23.8	15.0	2.0	56	6.9	NA	55
		Semi-Interquartile Range	1.5	NA	NA	6	NA	NA	12
		Number of Analyses	3	1	1	3	1	0	3
SS-19	23.3	Median	28.2	18.2	2.0	44	1.1	NA	63
		Semi-Interquartile Range	1.0	NA	NA	NA	NA	NA	13
		Number of Analyses	3	1	1	3	1	0	3

Note:

(1) This statistical summary is of the low flow surface water quality sampling events that were determined by the MDHES/ARCO project team to be characteristic of low flow. Additional data was used to fully characterize the site.

(2) River miles measured along the channel of Silver Bow Creek, downstream from the Montana Street Bridge in Butte.

(3) Source: Environmental Protection Agency (EPA), Quality Criteria for Water, May 1991. EPA recommends that water quality standards be compared to dissolved metals values.

(4) Not based on water hardness. Values given are for Arsenic V, which is to be expected in more oxidized conditions, as found within Silver Bow Creek. Arsenic V is currently listed the Lowest Observed Effect Level (LOEL), with insufficient EPA data to develop an acurate criteria value.

(5) Based on a water hardness of 100 mg/l CaCO3.

(6) Not based on water hardness.

(7) Source: Office of Water, US EPA, December 1993.

(8) Secondary Maximum Contaminant Level.

NA = Not available for the samples chosen for this table.

the dominant water movement through tailings/impacted is upward. However, some minor amount of infiltration of water from the tailings on the surface through the unsaturated (vadose) zone and into the saturated ground water (saturated) zone may transport constituents of concern to ground water. This is most likely to happen during thunderstorms and during snowmelt events. Metals from tailings may be leached by the infiltrating water and carried into the underlying native soils and ground water. Profiles of some soils in the SST OU show evidence of metals migrations from the tailings into underlying native materials.

2.4 Ground Water and Surface Water Interaction

Ground water flows into Silver Bow Creek along several reaches of the stream. During low flow conditions where the creek gains flow from ground water, the ground water may impact the quality of Silver Bow Creek. Since many of the possible pathways for contaminant movement are inactive during low flow conditions (e.g., runoff and erosion), it is probable that the primary pathway that would explain the minor increase in surface water metals concentrations seen in Subarea 1 is ground water inflow. During high flows and in losing reaches of the stream, surface water may flow into and impact ground water. Such a mechanism of metals movement would be most probable when the stream stage is high, such as following a summer thunderstorm or spring runoff. The impact of this "bank storage" of surface water is for a relatively short distance from the stream (20 to 50 feet).

3.0 FATE OF IMPACTS FROM MINING WASTES

Silver Bow Creek surface water and bed sediments are the short-term recipient of contaminants from the tailings/impacted soils as well as from offsite sources. Silver Bow Creek discharges into the Warm Springs Ponds at the lower end of the SST OU. Contaminants are transported by Silver Bow Creek in varying forms and are, for the most part, removed from the water through the treatment system operated at the Warm Springs Ponds. Therefore, ultimately, nearly all metals which move through Silver Bow Creek will be deposited in the Warm Springs Ponds. A minor, trace amount may be carried into the upper Clark Fork River. The time required for the contaminants of concern to achieve this fate will depend on the magnitude of various mechanisms affecting movement.

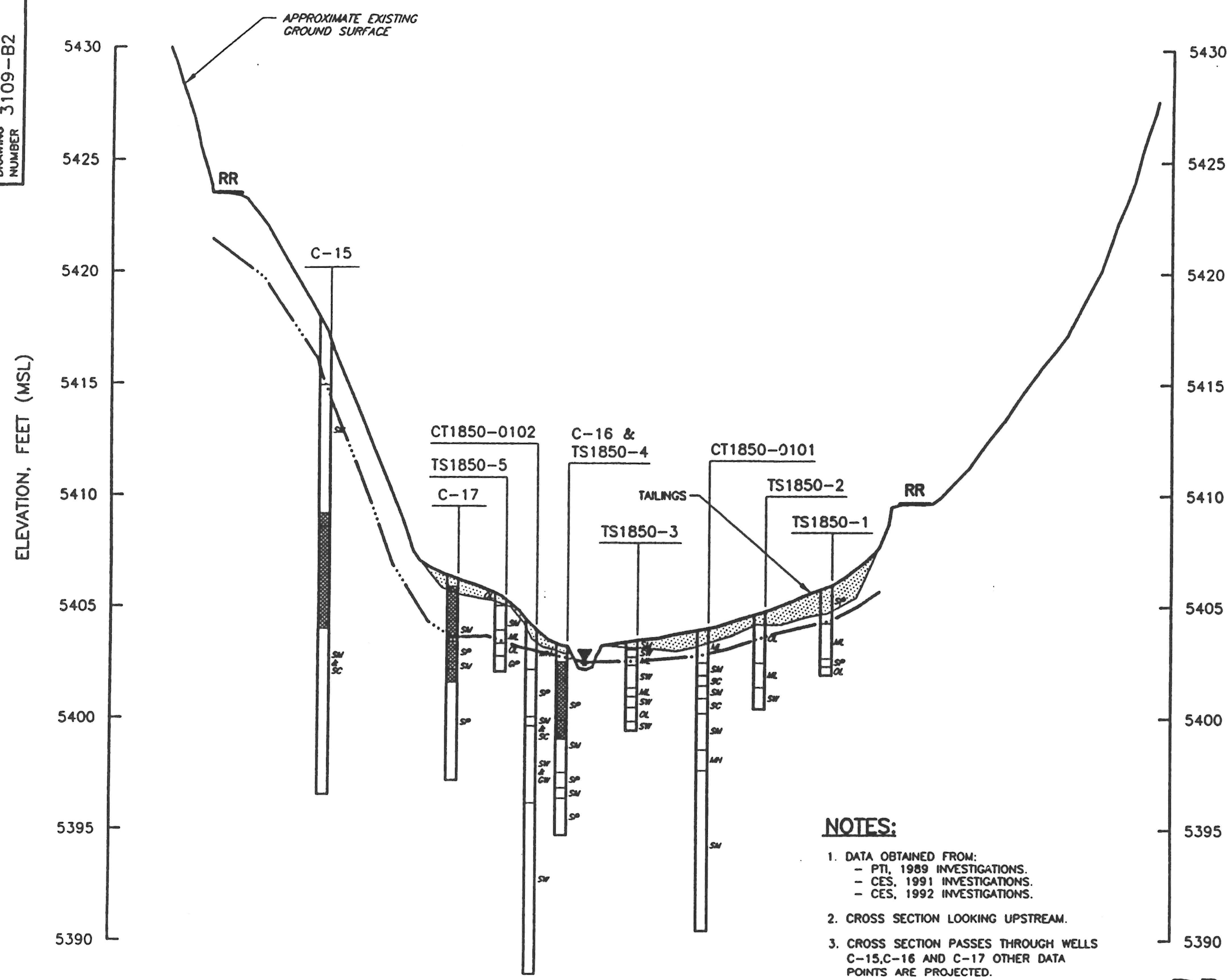
The Warm Springs Ponds are designed to treat Silver Bow Creek water at flows up to the 100-year flood flows. Only flows greater than the largest flood expected in 100 years will bypass the ponds directly into the Clark Fork River. During flows greater than the 100-year flood flows, untreated contaminants might make their way into the Clark Fork River during these higher flows.

There are numerous geochemical mechanisms that will tend to immobilize constituents of concern within the SST OU. Most of these mechanisms operate within the top few feet of soil underlying tailings/impacted soil, and serve to preserve the majority of the tailings/impacted soil in place in the floodplain surrounding Silver Bow Creek. Constituents of concern that may infiltrate to ground water will be move only a relatively minor distance within the aquifer before the geochemical system is different enough that the constituents of concern drop out of ground water by the same geochemical mechanisms operating within the unsaturated zone.

Constituents of concern within and attached to the floodplain soils will remain in an immobile, stable form unless geochemical conditions alter the chemical stability of the soil system to re-release the metals. There are no natural mechanisms that are expected to alter the current in-situ soil geochemical system on the scale of tens or hundreds of years.

ATTACHMENT A:

Cross Sections and Analytical Data of the SST OU



LEGEND:

(boring symbol)	BORING
(shaded symbol)	SCREENED INTERVAL OF MONITORING WELL
(stippled symbol)	BASE OF TAILINGS AND IMPACTED SOILS
RR	RAILROAD BEDS
—···—	GROUND WATER TABLE
C-15	GROUND WATER MONITORING WELL
CT-1350-0202 TS-1350-1	SOIL/TAILINGS TRANSECTS WITH SAMPLING LOCATION
(symbol)	SURFACE WATER ELEVATION
CL	CLAYS OF LOW TO MEDIUM PLASTICITY
CH	CLAYS OF HIGH PLASTICITY
ML	SILTS OF LOW TO MEDIUM PLASTICITY
MH	SILTS OF HIGH PLASTICITY
OL	ORGANIC SILTS
SC	CLAYEY SANDS
SM	SILTY SANDS
SP	POORLY GRADED SANDS
SW	WELL GRADED SANDS
GP	POORLY GRADED GRAVEL
GW	WELL GRADED GRAVEL

HORIZONTAL SCALE

100 0 100 FEET

VERTICAL SCALE

5 0 5 FEET

VERTICAL EXAGGERATION = 10x

NOTES:

1. DATA OBTAINED FROM:
   - PTI, 1989 INVESTIGATIONS.
   - CES, 1991 INVESTIGATIONS.
   - CES, 1992 INVESTIGATIONS.
2. CROSS SECTION LOOKING UPSTREAM.
3. CROSS SECTION PASSES THROUGH WELLS C-15,C-16 AND C-17 OTHER DATA POINTS ARE PROJECTED.
4. SEE FIGURE 2-2 FOR PLAN LOCATION.
5. ANALYTICAL DATA FROM SOIL, TAILINGS, GROUND WATER AND SURFACE WATER SAMPLES ARE POSTED ON TABLE 3-2A.

CROSS SECTION OF WHISKEY GULCH AREA

PREPARED FOR

ARCO

ANACONDA, MONTANA

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TITAN Environmental

DATE: 2-15-94	FIGURE 3-2A	DRAWING NUMBER 3109-B2
SCALE: AS SHOWN		

No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
△		ISSUED FOR DRAFT REMEDIAL INVESTIGATION REPORT.	T.M.G.		

DRAWING NUMBER 3109-B2

Table 3-2a
Analytical Data for Geologic Cross Sections
Whiskey Gulch Area
Streamside Tailings Operable Unit

Tailings/Soils									
		pH	Electrical Conductivity	Totals (mg/kg)					
Cross Section	Depth (ft)	(Std. Units)	(umhos/cm)	As	Cd	Cu	Pb	Zn	Hg
Whiskey Gulch Area									
C-17	0-0.4	4.27	402	314	9.5	683	556	2400	—
	0.4-1.2	5.1	112	317	6.6	411	633	2360	—
	1.5-2.6	6.4	114	227	ND2.6	369	440	1430	—
TS 1850-5	0-0.2	4.7	5300	365	17.1	4230	476	4110	—
	0.5-0.83	5	720	671	10.9	2540	3480	7310	—
	0.7-1.2	6.9	850	921	9.2	12700	20400	26800	—
	1.2-2.8	7.3	730	262	18.6	951	3910	6560	—
	2.8	5.6	800	17.3	4	278	390	1010	—
	6-8	6.8	1820	871	23.9	5310	1530	5890	—
CT 1850-0102	0	—	—	521	7.5	3500	850	2530	—
	3.4-3.9	—	—	5.6	ND4	23.1	47.2	123	—
	5	—	—	21.1	ND0.21	112	142	597	—
	15.3	—	—	1.6	ND0.23	10.3	7.7	53.6	—
CT 1850-0101	0-0.5	—	—	888	12.1	3470	4750	9550	—
	3-3.5	—	—	410	18.2	513	3740	8700	—
	4.5	—	—	81.6	1.1	91.7	252	499	—
	9	—	—	285	1.6	351	1460	2370	—

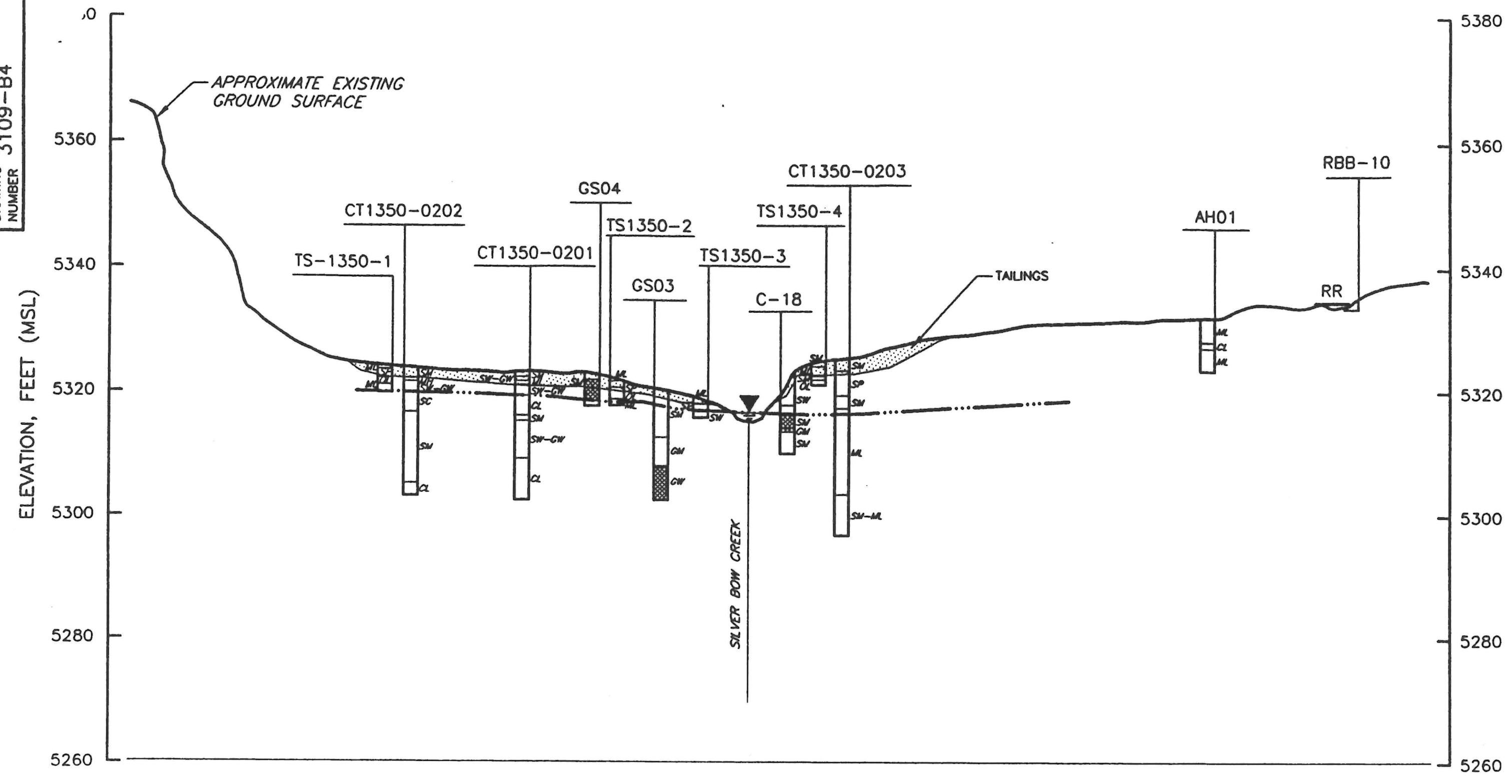
Ground Water									
		pH	Electrical Conductivity	Dissolved (ug/l)					
ID	Date	(Std. Units)	(umhos/cm)	As	Cd	Cu	Pb	Zn	Hg
Whiskey Gulch Area									
C-15	11/25/91	7.49	3382	6.70	ND2.8	ND35.9	ND1.1	24.50	—
C-15	10/27/92	7.34	1100	11.00	0.15	ND4	ND0.7	ND17	ND0.16
C-15	3/12/93	7.06	1520.00	12.80	ND0.11	ND2.2	4.40	ND6.3	ND0.1
C-15	6/7/93	7.49	2078.00	8.20	0.12	3.90	2.20	ND6	ND0.06
C-15	8/20/93	7.50	1631.00	18.30	ND0.04	ND3.1	ND1.6	ND7.6	0.14
C-16	10/27/92	7.59	2092	11.50	6.20	ND21	ND2.8	1,060.00	ND0.16
C-16	6/7/93	7.34	1736.00	16.10	2.90	18.70	1.60	1,300.00	0.07
C-16	8/27/93	7.26	1421.00	15.30	4.40	ND1.6	0.72	8.13	0.12
C-17	10/26/92	6.54	1380	14.70	2.00	104.00	ND3.2	434.00	ND0.16
C-17	3/12/93	7.15	1446.00	13.40	1.70	151.00	1.40	450.00	ND0.1
C-17	6/7/93	7.38	1759.00	13.80	2.30	104.00	1.00	351.00	0.10
C-17	8/20/93	7.26	1648.00	11.90	1.50	18.70	0.72	277.00	0.12

Surface Water										
		pH	Electrical Conductivity	Streamflow	Dissolved (ug/l)					
ID	Location	(Std. Units)	(umhos/cm)	(cfs)	As	Cd	Cu	Pb	Zn	Hg
Whsikey Gulch Area										
SS-07	4224' Upstream	7.80	---	22.6	---	---	78	---	534	---
SS-07	4224' Upstream	7.90	---	31.6	---	---	80	---	487	---
SS-07	4224' Upstream	6.70	---	35.1	---	---	106	---	633	---
SS-07	4224' Upstream	7.60	---	28.8	---	---	67	---	596	---
SS-07	4224' Upstream	7.50	---	31.8	12.4	1.9	ND97	3	531	ND0.1
SS-07	4224' Upstream	7.58	---	18.1	19.8	2	65	5	579	ND0.16
SS-07	4224' Upstream	7.20	---	22.7	---	---	88	---	625	---
SS-07	4224' Upstream	7.30	---	21.2	---	---	72	---	584	---
SS-07	4224' Upstream	7.30	---	19.2	---	---	91	---	801	---
SS-07	4224' Upstream	7.40	---	19.6	---	---	100	---	745	---
SS-07	4224' Upstream	7.20	---	21.9	---	---	99	---	693	---
SS-07	4224' Upstream	7.20	---	19.7	6.1	4.6	100	2.1	1590	---
SS-07	4224' Upstream	7.58	---	18.1	19.8	ND4.0	65	5	579	---
SS-08	6840' Downstream	7.82	---	19.2	16.3	1.7	69	0.77	417	ND0.16
SS-08	6840' Downstream	7.50	---	21.6	---	---	64	---	712	---
SS-08	6840' Downstream	7.70	---	21.2	---	---	43	---	668	---

Table 3-2a
Analytical Data for Geologic Cross Sections
Whiskey Gulch Area
Streamside Tailings Operable Unit
(Continued)

Surface Water											
		pH	Electrical Conductivity	Streamflow	Dissolved (ug/l)						
ID	Location	(Std. Units)	(umhos/cm)	(cfs)	As	Cd	Cu	Pb	Zn	Hg	
SS-08	6840' Downstream	7.20	- - -	21	- - -	- - -	40	- - -	618	- - -	
SS-08	6840' Downstream	7.60	- - -	19.9	- - -	- - -	56	- - -	438	- - -	
SS-08	6840' Downstream	7.30	- - -	19.8	- - -	- - -	72	- - -	591	- - -	
SS-08	6840' Downstream	7.30	- - -	18.5	10.2	3	48.8	1.4	1540	- - -	
SS-08	6840' Downstream	7.82	- - -	19.2	16.3	ND4.0	69	0.77	417	0.16	
SS-08	6840' Downstream	7.50	- - -	21.4	- - -	- - -	ND50	- - -	444	- - -	
SS-08	6840' Downstream	7.70	- - -	32.2	- - -	- - -	91	- - -	513	- - -	
SS-08	6840' Downstream	7.30	- - -	32.4	- - -	- - -	89	- - -	540	- - -	
SS-08	6840' Downstream	7.70	- - -	29.6	- - -	- - -	61	- - -	536	- - -	
SS-08	6840' Downstream	7.00	- - -	34.1	13.1	0.79	ND51	3.4	320	ND0.10	

Notes:
As = Arsenic
Cd = Cadmium
Cu = Copper
Pb = Lead
Hg = Mercury
Zn = Zinc
ND = Not detected to the limit stated.
- - - = No data available.
umhos/cm = micromhos per centimeter.
mg/kg = milligrams per kilogram.
mg/l = milligrams per liter.
cfs = cubic feet per second.



NOTES:

1. DATA OBTAINED FROM:
   - PTI, 1989 INVESTIGATIONS.
   - CES, 1991 INVESTIGATIONS.
   - CES, 1992 INVESTIGATIONS.
2. BORINGS AND GS-03 PROJECTED TO LINE THROUGH C-18 AND GS-04.
3. CROSS SECTION LOOKING UPSTREAM.
4. SEE FIGURE 2-2 FOR PLAN LOCATION.
5. ANALYTICAL DATA FROM SOIL, TAILINGS, GROUND WATER AND SURFACE WATER SAMPLES ARE POSTED ON TABLE 3-2B.

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LEGEND:

- BORING
- SCREENED INTERVAL OF MONITORING WELL
- BASE OF TAILINGS AND IMPACTED SOILS
- GROUND WATER TABLE
- RR — RAILROAD BEDS
- C-18 — GROUND WATER MONITORING WELL
- CT-1350-0202, TS-1350-1 — SOIL/TAILINGS TRANSECTS WITH SAMPLING LOCATION
- SURFACE WATER ELEVATION

CL	CLAYS OF LOW TO MEDIUM PLASTICITY
CH	CLAYS OF HIGH PLASTICITY
ML	SILTS OF LOW TO MEDIUM PLASTICITY
MH	SILTS OF HIGH PLASTICITY
OL	ORGANIC SILTS
SC	CLAYEY SANDS
SM	SILTY SANDS
SP	POORLY GRADED SANDS
SW	WELL GRADED SANDS
GP	POORLY GRADED GRAVEL
GW	WELL GRADED GRAVEL

HORIZONTAL SCALE
100 0 100 FEET

VERTICAL SCALE
20 0 20 FEET

VERTICAL EXAGGERATION = 5x

CROSS SECTION OF
SILVER BOW AREA
PREPARED FOR
ARCO
ANACONDA, MONTANA

TITAN Environmental

No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
1	2-17-94	ISSUED FOR DRAFT REMEDIAL INVESTIGATION REPORT	T.M.G.		

DATE: 2-17-94 SCALE: AS SHOWN	FIGURE 3-2B	DRAWING NUMBER 3109-B4

DRAWING NUMBER 3109-B4

Table 3-2b
Analytical Data for Geologic Cross Sections
Silver Bow Area
Streamside Tailings Operable Unit

Tailings/Soils

Cross Section	Depth (ft)	pH (Std. Units)	Electrical Conductivity (umhos/cm)	Total (mg/kg) As	Cd	Cu	Pb	Zn	Hg
Silver Bow Area									
TS 1350-1	0-0.6	4.4	3200	1700	25.3	3440	2670	5860	—
	0.6-1.2	4.8	200	250	8	1420	583	2670	—
	1.2-1.9	5.2	890	29	8.4	5400	116	1470	—
	1.9-2.2	4.9	1600	9.2	9	3450	24	1530	—
CT 1350-202	0-0.5	—	—	885	14	1290	1430	6540	—
	0.5-1	—	—	914	14.3	2390	4620	7450	—
	8-8.3	—	—	4.9	ND0.19	18.5	37.9	73.9	—
	20-20.5	—	—	4.3	ND0.25	20.3	15.9	56.9	—
CT 1350-201	0.8-1.3	—	—	607	6.8	2560	573	3140	—
	3.5-4	—	—	304	9.7	2280	534	2820	—
	9-9.5	—	—	13.3	0.4	445	32.8	298	—
	19.5-20	—	—	3.9	ND0.23	17.1	13.3	45.6	—
CT 1350-203	2-4	—	—	26.6	ND4	1890	ND9.5	987	---
	6-8	—	—	7.3	ND0.22	29.1	20.5	148	ND0.05
	8-10	—	—	2.4	ND0.32	24.6	16.5	76.2	0.12
	14-16	—	—	2	0.29	17.3	26.3	64.1	ND0.07
	27-29	—	—	2.3	ND0.28	12.4	18.4	53.6	0.12
C-18	0-1	5.28	51	37.4	ND2.6	96.2	175	188	—
	2.5-3.2	6.12	97	15.1	ND2.6	43.9	31.6	341	—
AH01	0-1	—	—	12	ND2.6	59.9	ND11.5	67.8	—
	1-2	—	—	7.2	ND2.6	60.3	ND11.5	93.5	—

Ground Water

ID	Date	pH (Std. Units)	Electrical Conductivity (umhos/cm)	Dissolved (ug/l) As	Cd	Cu	Pb	Zn	Hg
Silver Bow Area									
C-18	10/27/92	5.98	682	13	12.1	ND35	ND2	1380	ND0.16
C-18	3/11/93	6.93	380.12	0.50	0.38	4.00	2.80	37.00	---
C-18	6/9/93	7.08	724.00	5.80	7.20	8.90	ND0.38	657.00	0.29
C-18	8/19/93	6.83	932.00	11.80	6.10	7.90	ND0.38	582.00	0.30
GS-03	1/15/85	7.4	396	ND7.0	ND1	ND40	1.5	ND27	---
GS-03	2/28/85	7.2	455	12	ND0.1	ND27	ND1.0	ND10	---
GS-03	6/11/85	6.8	492	12	ND1	ND14	ND1.0	18	---
GS-03	8/19/88	7.4	482	8.4	1.6	21	3.4	95.3	---
GS-04	1/16/85	7.7	490	41	6.9	41	7.1	1700	---
GS-04	2/28/85	7.2	476	29	7.4	115	7.5	1170	---
GS-04	6/11/85	6.8	489	27	5	42	4.6	843	---
GS-04	3/11/93	7.13	591	21	1.1	10	2.4	412	ND0.10
GS-04	6/9/93	7.07	563	26.7	0.71	7	0.81	348	0.19
GS-04	8/19/93	6.95	439	39.8	0.56	3.5	2.2	264	0.18

Surface Water

ID	Location	pH (Std. Units)	Electrical Conductivity (umhos/cm)	Streamflow (cfs)	Dissolved (ug/l) As	Cd	Cu	Pb	Zn	Hg
Silver Bow Area			---							
SS-10	OnTransect	7.8	---	26.4	---	---	69	---	641	---
SS-10	OnTransect	8	---	23.3	---	---	54	---	507	---
SS-10	OnTransect	7.9	---	20.6	---	---	46	---	521	---
SS-10	OnTransect	8	---	18.9	---	---	63	---	242	---
SS-10	OnTransect	8.2	---	19.6	---	---	69	---	105	---
SS-10	OnTransect	7.7	---	20.2	10.8	2	54.6	1.7	908	---
SS-10	OnTransect	8.1	---	24.1	---	---	57	---	432	---
SS-10	OnTransect	8.1	---	32.6	---	---	69	---	385	---
SS-10	OnTransect	7.4	---	34.8	---	---	ND76	---	447	---
SS-10	OnTransect	7.8	---	30.4	---	---	67	---	479	---
SS-9A	7000' Upstream	7.7	---	---	19	0.32	ND67	2.5	414	ND0.10

Table 3-2b
Analytical Data for Geologic Cross Sections
Silver Bow Area
Streamside Tailings Operable Unit
(Continued)

Surface Water											
		pH	Electrical Conductivity	Streamflow	Dissolved (ug/l)						
ID	Location	(Std. Units)	(umhos/cm)	(cfs)	As	Cd	Cu	Pb	Zn	Hg
SS-9A	7000' Upstream	7.54	---	17.9	ND10.0	ND4	48	1.5	ND302	ND0.16
SS-11	5700' Downstream	7.9	---	35.1	---	---	ND50.0	---	337	---
SS-11	5700' Downstream	7.4	---	46.1	---	---	65	---	411	---
SS-11	5700' Downstream	7.6	---	55.4	---	---	ND76.0	---	354	---
SS-11	5700' Downstream	7.4	---	44.4	---	---	63	---	438	---
SS-11	5700' Downstream	7.77	---	25.5	8.9	1.2	41	0.33	91	---
SS-11	5700' Downstream	7.5	---	39.6	---	---	45	---	384	---
SS-11	5700' Downstream	8.2	---	38	---	---	26	---	357	---
SS-11	5700' Downstream	7.6	---	35.4	---	---	25	---	347	---
SS-11	5700' Downstream	7.8	---	28.6	---	---	57	---	365	---
SS-11	5700' Downstream	7.6	---	21.5	---	---	61	---	511	---
SS-11	5700' Downstream	8.1	---	18.5	11.4	2	51.6	1.3	436	---
SS-11	5700' Downstream	7.7	---	25.5	ND9.0	ND4.0	41	ND0.66	ND92	ND0.16

Notes:
As = Arsenic
Cd = Cadmium
Cu = Copper
Pb = Lead
Hg = Mercury
Zn = Zinc
ND = Not detected to the limit stated.
- - - = No data available.
umhos/cm = micromhos per centimeter.
mg/kg = milligrams per kilogram.
mg/l = milligrams per liter.
cfs = cubic feet per second.

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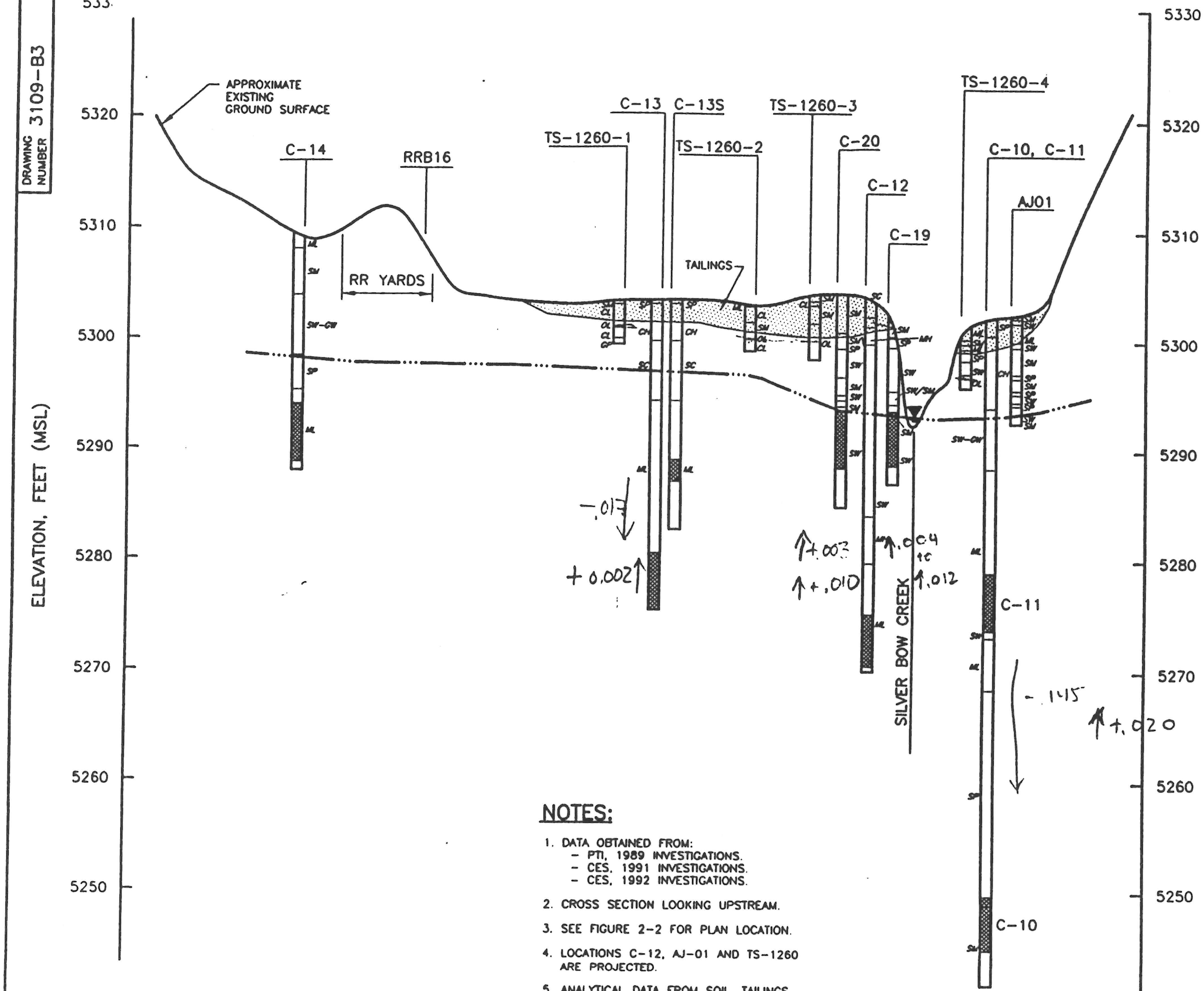

LEGEND:

(boring symbol)	BORING
(shaded symbol)	SCREENED INTERVAL OF MONITORING WELL
(stippled symbol)	BASE OF TAILINGS AND IMPACTED SOILS
—···—	GROUND WATER TABLE
C-14	GROUND WATER MONITORING WELL
TS-1260-1	SOIL/TAILINGS TRANSECTS WITH SAMPLING LOCATION
▼	SURFACE WATER ELEVATION
CL	CLAYS OF LOW TO MEDIUM PLASTICITY
CH	CLAYS OF HIGH PLASTICITY
ML	SILTS OF LOW TO MEDIUM PLASTICITY
MH	SILTS OF HIGH PLASTICITY
OL	ORGANIC SILTS
SC	CLAYEY SANDS
SM	SILTY SANDS
SP	POORLY GRADED SANDS
SW	WELL GRADED SANDS
GP	POORLY GRADED GRAVEL
GW	WELL GRADED GRAVEL

HORIZONTAL SCALE
200 0 200 FEET

VERTICAL SCALE
10 0 10 FEET

VERTICAL EXAGGERATION = 20x

NOTES:

1. DATA OBTAINED FROM:
   - PTI, 1989 INVESTIGATIONS.
   - CES, 1991 INVESTIGATIONS.
   - CES, 1992 INVESTIGATIONS.
2. CROSS SECTION LOOKING UPSTREAM.
3. SEE FIGURE 2-2 FOR PLAN LOCATION.
4. LOCATIONS C-12, AJ-01 AND TS-1260 ARE PROJECTED.
5. ANALYTICAL DATA FROM SOIL, TAILINGS, GROUND WATER AND SURFACE WATER SAMPLES ARE POSTED ON TABLE 3-2C.

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CROSS SECTION OF RAMSAY FLATS AREA

PREPARED FOR

ARCO

ANACONDA, MONTANA

TITAN Environmental

DATE: 2-15-94	FIGURE 3-2C	DRAWING NUMBER 3109-B3
SCALE: AS SHOWN		

No	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
1	2-17-94	ISSUED FOR DRAFT REMEDIAL INVESTIGATION REPORT	T.M.G.		

DRAWING NUMBER 3109-B3

Table 3-2c
Analytical Data for Geologic Cross Sections
Ramsay Flats Area
Streamside Tailings Operable Unit

Tailings/Soils									
		pH	Electrical Conductivity	Total (mg/kg)					
Cross Section	Depth (ft)	(Std. Units)	(umhos/cm)	As	Cd	Cu	Pb	Zn	Hg
Ramsay Flats Area									
TS 1260-3	0-0.3	3.7	440	1850	25.9	5040	1620	6620	—
	0.7-0.8	3.7	600	1300	17.2	3110	1980	5180	—
	0.8-1.3	3.5	2050	552	9.8	1650	1160	3680	—
	1.5-2	3.7	1400	1610	32.2	6560	5390	9480	—
	2-2.5	5.5	1800	1310	61.9	18100	11900	18500	—
	2.5-2.8	5.9	4200	726	61.6	8540	14400	25700	—
	3-3.3	5.9	1600	640	47.8	2230	7920	17000	—
	4.1-4.5	6.5	2300	228	48	1450	9150	17600	—
	4.7-5.3	5.9	1160	38.5	ND4.0	65.8	136	659	—
	5.8-6.2	5.7	700	6.3	ND4.0	33.1	69.1	176	—
C-19	0-1.8	3.43	2728	1820	19.3	3640	2610	6180	—
	2.5-3.6	5.6	1549	127	45.3	967	3730	10800	—
	4-5.4	5.4	598	ND5.9	ND2.6	56.6	241	1720	—
AJ01	0.9-1.5	5.15	518	1410	18.9	21400	10500	9420	—
	2.4-2.8	4.68	91	163	ND2.6	3250	1250	1270	—
RRB-16	Surface	5.57	—	35.2	ND4	247	114	381	—
Sediment SS-11	Stream Bed	7.77	374	145	5.8	1510	769	2430	—

Ground Water									
		pH	Electrical Conductivity	Dissolved (ug/l)					
ID	Date	(Std. Units)	(umhos/cm)	As	Cd	Cu	Pb	Zn	Hg
Ramsay Flats Area									
C-10	11/25/91	7.07	1,788.0	2.3	ND2.8	ND29.8	ND1.1	324.0	—
C-10	10/28/92	6.85	517.0	1.8	0.27	ND4	ND3.5	ND17	—
C-10	3/10/93	7.20	1,650.0	6.7	0.06	ND5	2.20	7.0	—
C-10	6/7/93	7.41	2,034.0	7.7	0.06	ND2.5	ND0.38	13.5	—
C-10	8/20/93	5.97	1,829.4	3.7	ND0.16	ND0.16	0.72	ND7.6	—
C-11	11/25/91	6.99	1,701.0	1.7	ND2.8	ND42	ND1.1	40.8	—
C-11	10/28/92	6.83	410.0	8.9	0.47	6.0	ND6.6	ND29	—
C-11	3/10/93	7.16	1,652.0	5.7	0.25	ND13	2.60	22.0	—
C-11	6/7/93	7.53	1,995.0	9.0	0.12	ND5.1	ND0.38	17.4	—
C-11	8/20/93	5.90	1,707.5	4.1	ND0.16	ND0.16	ND0.72	ND7.6	—
C-12	11/24/91	6.27	411.0	6.0	ND2.8	ND32.5	1.30	73.9	—
C-12	10/28/92	7.15	330.0	5.7	0.11	ND4	ND2.6	ND6	—
C-12	3/10/93	7.10	346.9	7.0	0.38	3.0	2.40	ND6.3	—
C-12	6/8/93	7.40	387.0	9.1	0.05	2.0	0.86	ND6	—
C-12	8/19/93	7.25	377.1	3.9	ND0.16	2.8	ND0.72	ND7.6	—
C-13	11/24/91	6.41	581.0	4.6	ND2.8	ND18.8	1.90	378.0	—
C-13	10/28/92	6.92	400.0	5.3	0.14	9.0	ND2.0	111.0	—
C-13	3/10/93	7.06	473.2	6.8	0.23	ND2.2	1.50	ND6.3	—
C-13	6/8/93	7.55	565.0	2.9	0.32	3.4	ND0.38	10.6	—
C-13	8/20/93	5.89	609.1	3.5	ND0.16	ND0.16	ND0.72	ND7.6	—
C-13S	11/24/91	6.41	642.0	7.7	ND2.8	ND28.9	1.10	205.0	—
C-13S	10/28/92	6.93	164.0	9.1	0.53	4.0	ND2.1	ND13.0	—
C-13S	3/11/93	7.01	439.5	11.6	0.56	5.0	2.90	ND6.3	—
C-13S	6/8/93	7.53	556.0	8.1	0.95	114.0	ND0.38	133.0	—
C-13S	8/19/93	5.88	544.0	6.8	0.23	5.4	1.10	ND7.6	—
C-14	11/25/91	7.22	777.6	5.2	ND2.8	ND30.8	ND1.1	25.9	—
C-14	10/28/92	6.47	394.0	8.9	0.51	ND4	0.92	ND33	ND0.16
C-14	3/12/93	7.08	383.1	7.3	0.21	3.0	2.20	ND6.3	ND1.0
C-14	6/9/93	7.48	469.0	1.1	0.10	ND1.4	2.90	ND6	ND0.06
C-14	8/20/93	6.10	492.7	6.0	ND0.04	ND3.2	ND1.6	8.0	0.15
C-19	10/28/92	5.86	406.0	6.3	0.42	5.0	ND2.4	86.0	—
C-19	3/11/93	6.93	380.1	8.5	0.38	4.0	2.80	37.0	—
C-19	6/8/93	7.34	448.0	4.9	0.72	48.2	ND0.38	151.0	—
C-19	8/19/93	7.07	471.4	4.7	2.50	4.1	0.79	637.0	—

Table 3-2c
Analytical Data for Geologic Cross Sections
Ramsay Flats Area
Streamside Tailings Operable Unit
(Continued)

Ground Water

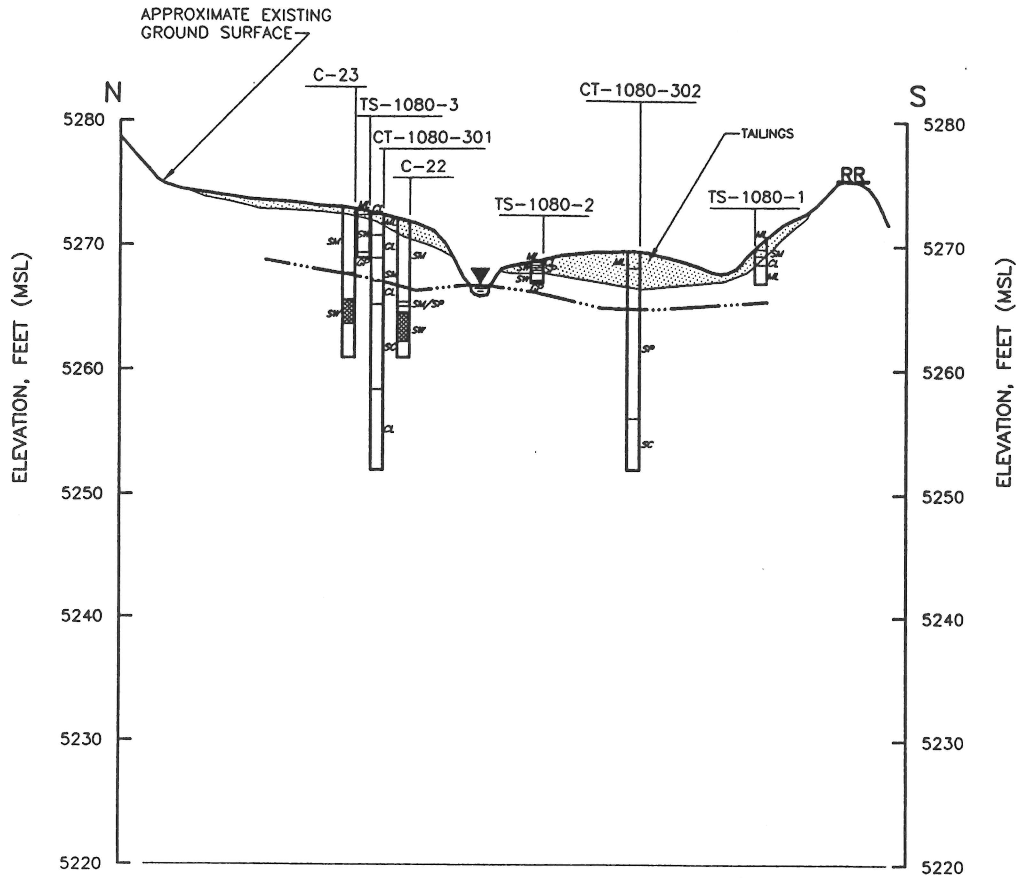
ID	Date	pH (Std. Units)	Electrical Conductivity (umhos/cm)	Dissolved (ug/l) As	Cd	Cu	Pb	Zn	Hg
C-20	10/28/92	5.93	496.0	5.7	1.4	22.0	ND2.3	233.0	—
C-20	3/11/93	6.93	450.4	6.9	0.96	8.0	1.6	213.0	—
C-20	6/8/93	7.20	527.0	2.8	1.4	34.7	ND0.38	375.0	—
C-20	8/19/93	6.93	525.3	4.9	0.4	3.3	1.2	36.5	—

Surface Water

ID	Location	pH (Std. Units)	Electrical Conductivity (umhos/cm)	Streamflow (cfs)	Dissolved (ug/l) As	Cd	Cu	Pb	Zn	Hg
Ramsay Flats Area										
SS-11	On Transect	7.77	---	25.5	8.9	1.2	41	0.66	91	ND0.16
SS-11	On Transect	7.9	---	35.1	---	---	ND50.0	---	337	---
SS-11	On Transect	7.4	---	46.1	---	---	65	---	411	---
SS-11	On Transect	7.6	---	55.4	---	---	ND76.0	---	354	---
SS-11	On Transect	7.4	---	44.4	---	---	63	---	438	---
SS-11	On Transect	7.5	---	39.6	---	---	45	---	384	---
SS-11	On Transect	8.2	---	38	---	---	26	---	357	---
SS-11	On Transect	7.6	---	35.4	---	---	25	---	347	---
SS-11	On Transect	7.8	---	28.6	---	---	57	---	365	---
SS-11	On Transect	7.6	---	21.5	---	---	61	---	511	---
SS-11	On Transect	8.1	---	18.5	11.4	2	51.6	1.3	436	---
SS-11	On Transect	7.7	---	25.5	ND9.0	ND4.0	41	ND0.66	ND92	ND0.16

Notes:
As = Arsenic
Cd = Cadmium
Cu = Copper
Pb = Lead
Hg = Mercury
Zn = Zinc
ND = Not detected to the limit stated.
--- = No data available.
umhos/cm = micromhos per centimeter.
mg/kg = milligrams per kilogram.
mg/l = milligrams per liter.
cfs = cubic feet per second.

DRAWING NUMBER 3109-B5



LEGEND:

- BORING
- SCREENED INTERVAL OF MONITORING WELL
- BASE OF TAILINGS AND IMPACTED SOILS
- GROUND WATER TABLE
- RR — RAILROAD BEDS
- C-23 — GROUND WATER MONITORING WELL
- CT-1080-301, TS-1080-1 — SOIL/TAILINGS TRANSECTS WITH SAMPLING LOCATION
- SURFACE WATER ELEVATION
- CL — CLAYS OF LOW TO MEDIUM PLASTICITY
- CH — CLAYS OF HIGH PLASTICITY
- ML — SILTS OF LOW TO MEDIUM PLASTICITY
- MH — SILTS OF HIGH PLASTICITY
- OL — ORGANIC SILTS
- SC — CLAYEY SANDS
- SM — SILTY SANDS
- SP — POORLY GRADED SANDS
- SW — WELL GRADED SANDS
- GP — POORLY GRADED GRAVEL
- GW — WELL GRADED GRAVEL

DRAFT

HORIZONTAL SCALE: 100 — 0 — 100 FEET

VERTICAL SCALE: 10 — 0 — 10 FEET

VERTICAL EXAGGERATION = 10x

NOTES:

1. DATA OBTAINED FROM:
   - PTI, 1989 INVESTIGATIONS.
   - CES, 1991 INVESTIGATIONS.
   - CES, 1992 INVESTIGATIONS.
2. CROSS SECTION LOOKING UPSTREAM.
3. SEE FIGURE 2-2 FOR PLAN LOCATION.
4. LOCATIONS FROM TRANSECTS CT-1080, TS-1080 ARE PROJECTED.
5. ANALYTICAL DATA FROM SOIL, TAILINGS, GROUND WATER AND SURFACE WATER SAMPLES ARE POSTED ON TABLE 3-2D.

No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
1	2-16-94	ISSUED FOR DRAFT REMEDIAL INVESTIGATION REPORT	T.M.G.		

CROSS SECTION OF MILES CROSSING AREA

PREPARED FOR

ARCO

ANACONDA, MONTANA

TITAN Environmental

DATE: 2-15-94	FIGURE 3-2D	DRAWING NUMBER 3109-B5
SCALE: AS SHOWN		

Table 3-2d
Analytical Data for Geologic Cross Sections
Miles Crossing Area
Streamside Tailings Operable Unit

Tailings/Soils

Cross Section	Depth (ft)	pH (Std. Units)	Electrical Conductivity (umhos/cm)	Total (mg/kg) As	Cd	Cu	Pb	Zn	Hg
Miles Crossing Area									
TS 1080-1	0-0.6	3.6	1580	439	8.3	2230	849	2670	—
	0.6-1	3	1010	341	4.6	460	489	1840	—
	1.7-2.2	3.2	320	297	13	354	346	854	—
CT 1080-301	4.5-5	—	—	17.1	ND4	25.1	45	69.5	—
C-22	0.6-1.8	6.87	991	73.6	3.9	650	897	1480	—
	2-3.7	4.22	244	7.8	5	49.3	23.6	1890	—
C-23	0.6-1.7	5.43	472	191	15	4930	1250	4400	—

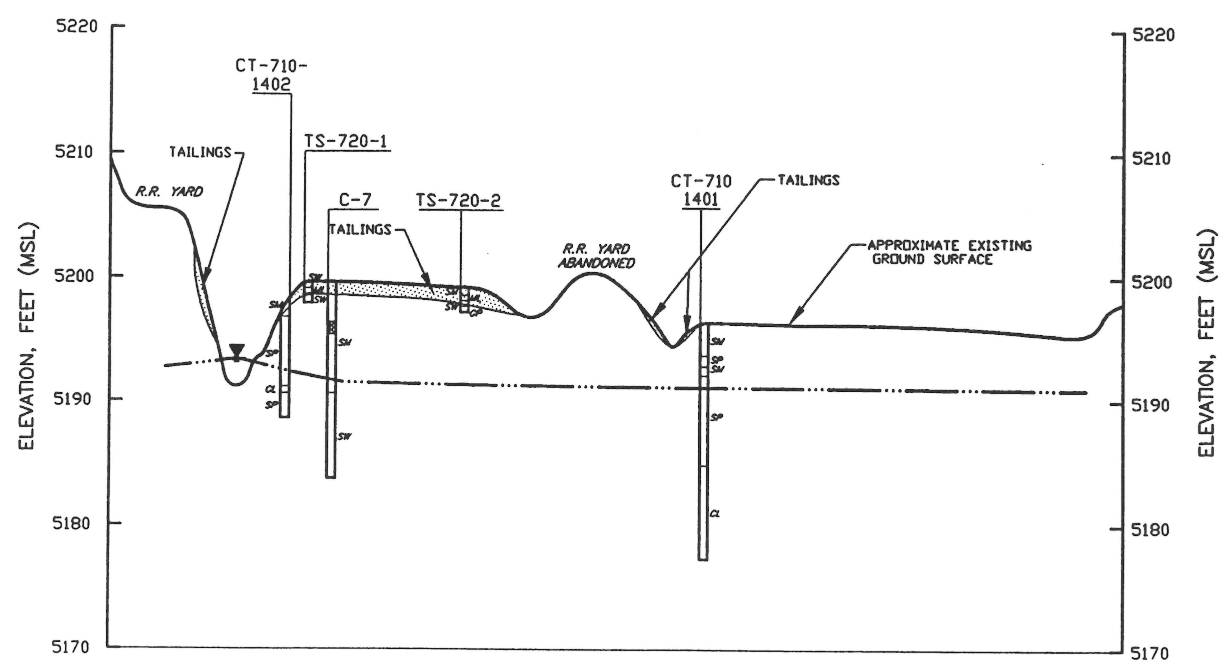
Ground Water

ID	Date	pH (Std. Units)	Electrical Conductivity (umhos/cm)	Dissolved (ug/l) As	Cd	Cu	Pb	Zn	Hg
Miles Crossing Area									
C-22	10/27/92	5.8	700	72.2	0.76	ND4	ND2.7	3800	---
C-22	3/11/93	6.90	1244.00	28.00	0.31	ND2.2	1.60	3060.00	---
C-22	6/9/93	7.16	1035.00	20.70	0.18	1.50	ND0.38	ND6.0	---
C-22	8/19/93	6.73	1220.00	18.90	0.21	ND1.6	ND0.72	4250.00	---
C-23	10/28/92	6.65	1397	27.5	0.5	5	ND1.6	4950	---
C-23	3/11/93	6.96	1758.00	25.40	0.23	3.00	2.30	5720.00	---
C-23	6/9/93	7.24	1144.00	24.60	0.23	1.50	ND0.38	4190.00	---
C-23	8/19/93	6.80	1162.00	31.30	ND0.16	ND1.6	ND0.38	5030.00	0.12

Surface Water

ID	Location	pH (Std. Units)	Electrical Conductivity (umhos/cm)	Streamflow (cfs)	Dissolved (ug/l) As	Cd	Cu	Pb	Zn	Hg
Miles Crossing Area										
SS-14	1250' Downstream	8.32	472	26.6	14.4	1.1	36	4.1	56	---
SS-14	1250' Downstream	8.0	---	37.1	---	---	53	---	379	---
SS-14	1250' Downstream	8.0	---	48.0	---	---	77	---	422	---
SS-14	1250' Downstream	7.2	---	74.7	---	---	78	---	276	---
SS-14	1250' Downstream	7.7	---	58.0	---	---	61	---	352	---
SS-14	1250' Downstream	8.0	---	36.7	---	---	204	1.7	633	0.17
SS-14	1250' Downstream	8.1	---	35.0	---	---	ND97.6	2.0	601	0.16
SS-14	1250' Downstream	7.2	---	42.6	25.3	3.7	ND230	2.8	680	0.1
SS-14	1250' Downstream	7.6	---	46.8	---	---	48.0	---	368	---
SS-14	1250' Downstream	7.9	---	42.4	---	---	26.0	---	344	---
SS-14	1250' Downstream	8.1	---	34.0	---	---	38.0	---	381	---
SS-14	1250' Downstream	8.0	---	29.5	---	---	43.0	---	158	---
SS-14	1250' Downstream	7.8	---	23.6	---	---	63.0	---	200	---
SS-14	1250' Downstream	8.6	---	20.7	14.3	2	51.9	2.7	171	---
SS-14	1250' Downstream	8.3	---	26.6	ND14.4	ND4.0	36	4.1	ND56	---

Notes:
As = Arsenic
Cd = Cadmium
Cu = Copper
Pb = Lead
Hg = Mercury
Zn = Zinc
ND = Not detected to the limit stated.
- - - = No data available.
umhos/cm = micromhos per centimeter.
mg/kg = milligrams per kilogram.
mg/l = milligrams per liter.
cfs = cubic feet per second.



LEGEND:

	BORING
	SCREENED INTERVAL OF MONITORING WELL
	BASE OF TAILINGS AND IMPACTED SOILS
	GROUND WATER TABLE
C-7	GROUND WATER MONITORING WELL
CT-710-1402 TS-720-1	SOIL/TAILINGS TRANSECTS WITH SAMPLING LOCATION
	SURFACE WATER ELEVATION
CL	CLAYS OF LOW TO MEDIUM PLASTICITY
CH	CLAYS OF HIGH PLASTICITY
ML	SILTS OF LOW TO MEDIUM PLASTICITY
MH	SILTS OF HIGH PLASTICITY
OL	ORGANIC SILTS
SC	CLAYEY SANDS
SM	SILTY SANDS
SP	POORLY GRADED SANDS
SW	WELL GRADED SANDS
GP	POORLY GRADED GRAVEL
GW	WELL GRADED GRAVEL

NOTES:

1. DATA OBTAINED FROM:
   - PTI, 1989 INVESTIGATIONS.
   - CES, 1991 INVESTIGATIONS.
   - CES, 1992 INVESTIGATIONS.
2. CROSS SECTION FACING DOWNSTREAM.
3. BORING CT-710 IS PROJECTED TO CROSS SECTION LINE.
4. SEE FIGURE 2-2 FOR PLAN LOCATION.
5. ANALYTICAL DATA FROM SOIL, TAILINGS, GROUND WATER AND SURFACE WATER SAMPLES ARE POSTED ON TABLE 3-2E.

HORIZONTAL SCALE

100 0 100 FEET

VERTICAL SCALE

10 0 10 FEET

VERTICAL EXAGGERATION = 10x

DRAFT

CROSS SECTION OF
CANYON C-7
PREPARED FOR
ARCO
ANACONDA, MONTANA

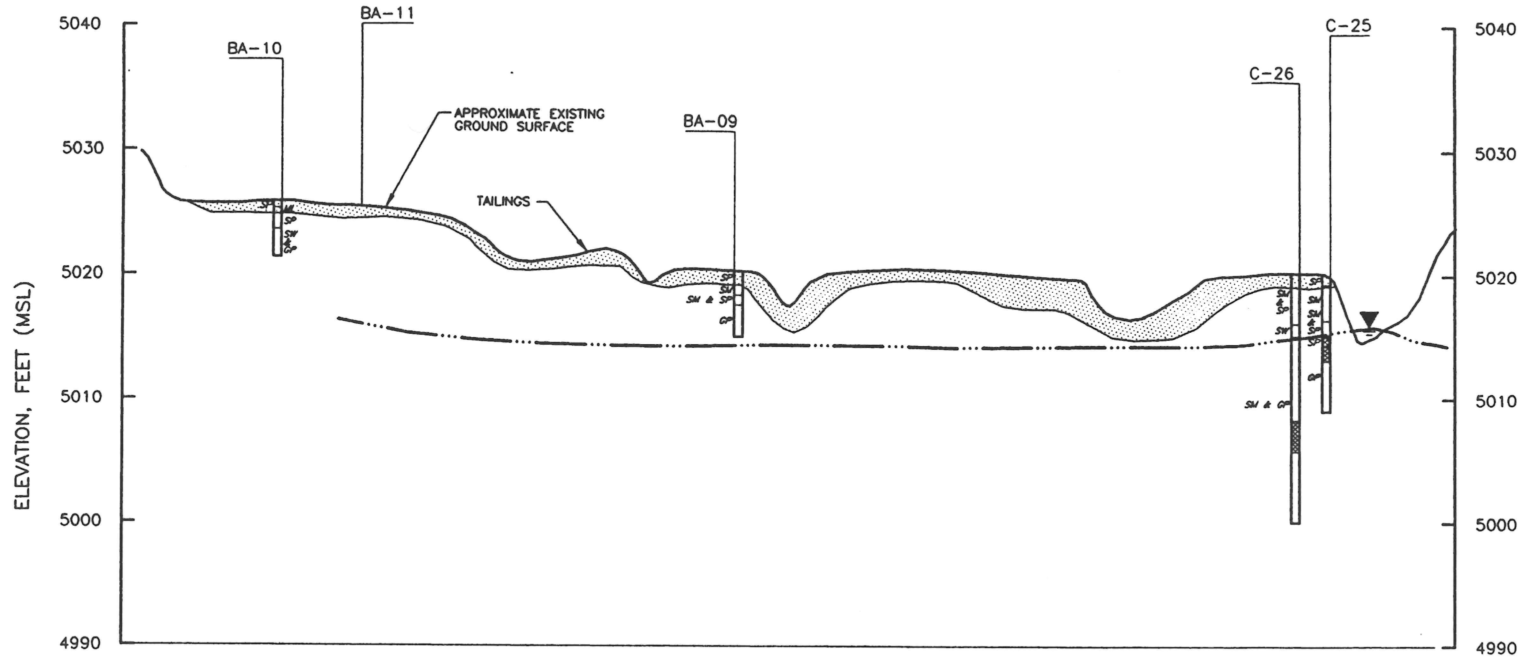
TITAN Environmental

DATE: 2-15-94 SCALE: AS SHOWN	FIGURE 3-2E	DRAWING NUMBER 3109-B6

No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
1	2-22-94	ISSUED FOR DRAFT REMEDIAL INVESTIGATION REPORT	T.M.C.		

DRAWING NUMBER 3109-B6

DRAWING NUMBER 3109-B8



NOTES:

1. DATA OBTAINED FROM:
   - PTI, 1989 INVESTIGATIONS.
   - CES, 1991 INVESTIGATIONS.
   - CES, 1992 INVESTIGATIONS.
2. LOCATIONS BA-12, BA-09, AND BA-10 ARE PROJECTED TO THE LINE OF THE MONITORING WELLS.
3. CROSS SECTION LOOKING UPSTREAM.
4. SEE FIGURE 2-2 FOR PLAN LOCATION.
5. ANALYTICAL DATA FROM SOIL, TAILINGS, GROUND WATER AND SURFACE WATER SAMPLES ARE POSTED ON TABLE 3-2F.

LEGEND:

(open bar)	BORING
(shaded bar)	SCREENED INTERVAL OF MONITORING WELL
(stippled)	BASE OF TAILINGS AND IMPACTED SOILS
—··· —	GROUND WATER TABLE
C-24	GROUND WATER MONITORING WELL
TS-520-3	SOIL/TAILINGS TRANSECTS WITH SAMPLING LOCATION
▼	SURFACE WATER ELEVATION
CL	CLAYS OF LOW TO MEDIUM PLASTICITY
CH	CLAYS OF HIGH PLASTICITY
ML	SILTS OF LOW TO MEDIUM PLASTICITY
MH	SILTS OF HIGH PLASTICITY
OL	ORGANIC SILTS
SC	CLAYEY SANDS
SM	SILTY SANDS
SP	POORLY GRADED SANDS
SW	WELL GRADED SANDS
GP	POORLY GRADED GRAVEL
GW	WELL GRADED GRAVEL

HORIZONTAL SCALE: 200 0 200 FEET

VERTICAL SCALE: 10 0 10 FEET

VERTICAL EXAGGERATION = 20x

CROSS SECTION OF CRACKERVILLE AREA

PREPARED FOR

ARCO

ANACONDA, MONTANA

DRAFT

TITAN Environmental

No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
⚠	2-17-94	ISSUED FOR DRAFT REMEDIAL INVESTIGATION REPORT	T.M.G.		

DATE: 2-18-94	FIGURE 3-2F	DRAWING NUMBER 3109-B8
SCALE: AS SHOWN		

Table 3-2f
Analytical Data for Geologic Cross Sections
Crackerville Area
Streamside Tailings Operable Unit

Tailings/Soils

Cross Section	Depth (ft)	pH (Std. Units)	Electrical Conductivity (umhos/cm)	Total (mg/kg) As	Cd	Cu	Pb	Zn	Hg
Crackerville Area									
C-24	2-3	6.55	1068	18.7	24.3	1910	46.3	4300	—
C-25	2-2.9	7.39	259	15.1	3	37.5	38.6	533	—
BA 1201	0.9-1.15	—	—	33.5	7.2	4210	35	973	—
	1.15-1.5	—	—	14.9	3.6	15.4	26.6	2370	—
TS 320-2	—	—	—	478	5.4	614	891	2250	—
	—	—	—	252	ND4.0	335	563	672	—
	—	—	—	158	17.8	2470	5490	8980	—
TS 320-3	—	—	—	11.6	ND4.0	1470	33.8	751	—
	—	—	—	443	7	6360	4910	5460	—
	—	—	—	179	6.7	609	688	1170	—
	—	—	—	1260	11.5	1370	1610	4640	—
	—	—	—	497	20.4	2900	2190	7670	—

Ground Water

ID	Date	pH (Std. Units)	Electrical Conductivity (umhos/cm)	Dissolved (ug/l) As	Cd	Cu	Pb	Zn	Hg
Crackerville Area									
C-24	10/28/92	6.78	754	4.9	4.70	ND27	ND2	271.0	ND0.16
C-24	6/8/93	6.79	1020.00	4.1	9.00	21.0	2.0	774.0	0.13
C-24	8/19/93	6.04	665.30	3.5	4.70	17.0	ND0.38	603.0	ND0.12
C-24	03/12/93	6.73	425.88	1.9	5.80	20.0	2.4	375.0	ND1.0
C-25	10/28/92	7.06	[illegible]	3.0	2.70	ND16	ND2.5	247.0	ND0.16
C-25	6/7/93	6.71	1289.00	2.3	9.60	26.2	ND1.0	2060.0	0.1
C-25	8/19/93	6.36	589.40	3.4	5.00	19.5	ND0.38	1060.0	0.14
C-25	03/11/93	7.02	2033.00	3.5	29.80	ND31	1.7	6400.0	ND0.1
C-26	10/28/92	6.77	890	6.0	0.61	ND14	ND3	ND42	ND.16
C-26	6/7/93	6.60	1109.00	4.8	0.58	4.1	1.4	13.4	0.1
C-26	8/19/93	6.58	976.90	6.2	ND0.63	2.3	0.5	27.1	0.23
C-26	03/11/93	6.72	590.00	5.8	0.38	4.0	2.6	ND6.3	ND0.1

Surface Water

ID	Location	pH (Std. Units)	Electrical Conductivity (umhos/cm)	Streamflow (cfs)	Dissolved (ug/l) As	Cd	Cu	Pb	Zn	Hg
Crackerville Area										
SS-16	On Transect	8.1	—	48.2	—	—	ND50	—	311.0	—
SS-16	On Transect	8.4	—	59.5	—	—	56.0	—	349.0	—
SS-16	On Transect	7.4	—	90.7	—	—	ND76	—	200.0	—
SS-16	On Transect	7.8	—	75.3	—	—	50.0	—	199.0	—
SS-16	On Transect	7.5	—	52.3	6.5	—	ND90.2	ND1.6	89.4	0.19
SS-16	On Transect	7.8	—	56.5	6.3	—	ND81.6	ND1.6	29.5	0.19
SS-16	On Transect	7.74	—	56.5	—	1.8	ND73.8	ND1.6	82.1	0.18
SS-16	On Transect	8.6	—	46.4	26.2	1.4	ND85	3.0	179.0	ND0.10
SS-16	On Transect	—	—	—	13.2	1.2	35	6.6	36	—
SS-16	On Transect	7.7	—	62.6	—	—	57.0	—	381	—
SS-16	On Transect	7.7	—	53.5	—	—	43.0	—	321	—
SS-16	On Transect	7.8	—	45.5	—	—	37.0	—	356	—
SS-16	On Transect	8.7	—	29.8	—	—	50.0	—	81	—
SS-16	On Transect	9.0	—	25.2	—	—	55.0	—	73	—
SS-16	On Transect	9.0	—	19.1	15.7	2	46.8	3.5	163	—
SS-16	On Transect	7.3	—	32.5	ND13.2	ND4.0	35	6.6	ND36	—
SS-16B	On Transect	8.4	---	41.81	---	---	ND94.9	ND1.6	391	0.17
SS-16B	On Transect	7.2	---	---	20.1	1.5	ND133	2.7	455	ND0.10
SS-16B	On Transect	8.2	—	28.3	ND10.0	ND4.0	33	0.7	ND48.0	ND0.16

Notes:
As = Arsenic
Cd = Cadmium
Cu = Copper
Pb = Lead
Hg = Mercury
Zn = Zinc
ND = Not detected to the limit stated.
--- = No data available.
umhos/cm = micromhos per centimeter.
mg/kg = milligrams per kilogram.
mg/l = milligrams per liter.
cfs = cubic feet per second.

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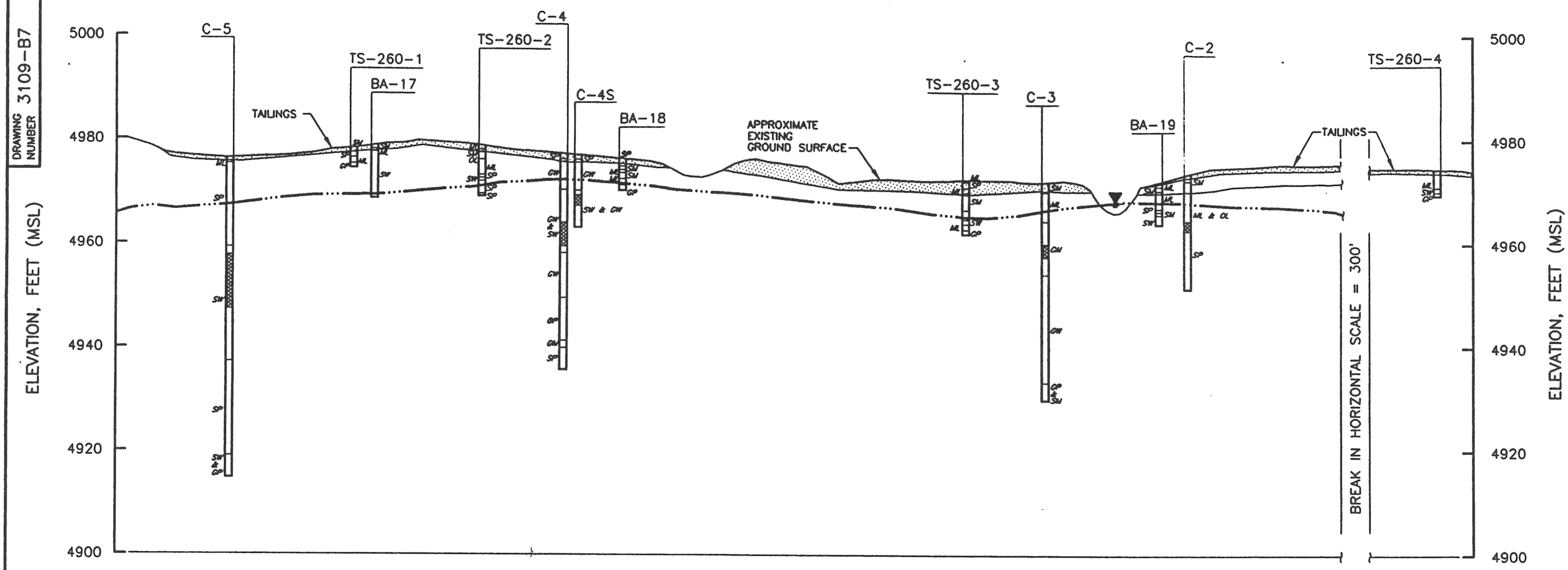
Table 3-2g
Analytical Data for Geologic Cross Sections
Durant Canyon Area
Streamside Tailings Operable Unit

Tailings/Soils									
		pH	Electrical Conductivity	Total (mg/kg)					
Cross Section	Depth (ft)	(Std. Units)	(umhos/cm)	As	Cd	Cu	Pb	Zn	Hg
Durant Canyon Area									
CT 710-1401	2-3.5	---	---	25	ND1.4	1340	61.8	84.6	---
	4.2-5.2	---	---	6.4	ND0.25	30.7	18.5	243	---
	5.2-5.7	---	---	4.8	ND2.8	145	10.2	86.6	---
	8.5-10	---	---	21.5	ND0.22	50.7	20.5	50.7	---
	12-14	---	---	0.93	ND0.2	10.2	10.8	45.1	---
CT 710-1402	0-1.2	---	---	200	ND0.18	218	386	1140	---
	2-3	---	---	247	ND3	533	206	1600	---
	5-5.5	---	---	31.4	ND0.2	92.7	28.4	312	---
	6-7.5	---	---	1.2	ND0.21	13.1	13.9	31.4	---

Ground Water									
		pH	Electrical Conductivity	Dissolved (ug/l)					
ID	Date	(Std. Units)	(umhos/cm)	As	Cd	Cu	Pb	Zn	Hg
C-7	1/21/92	5.67	418.00	16.30	2.70	ND40.4	1.90	ND370	---
C-7	10/28/92	6.14	548.00	11.20	2.40	17.00	ND3.9	850.00	---
C-7	6/9/93	6.29	1519.00	4.30	21.00	121.00	ND0.38	6040.00	---
C-7	8/19/93	6.20	808.00	3.50	5.80	64.80	ND0.72	2340.00	---
C-7	03/11/93	6.69	505.00	8.80	6.00	61.00	ND1.3	1690.00	---

Notes:
As = Arsenic
Cd = Cadmium
Cu = Copper
Pb = Lead
Hg = Mercury
Zn = Zinc
ND = Not detected to the limit stated.
- - - = No data available.
umhos/cm = micromhos per centimeter.
mg/kg = milligrams per kilogram.
mg/l = milligrams per liter.
cfs = cubic feet per second.



NOTES:

1. DATA OBTAINED FROM:
   - PTI, 1989 INVESTIGATIONS.
   - CES, 1991 INVESTIGATIONS.
   - CES, 1992 INVESTIGATIONS.
2. BORINGS AND TEST PITS ARE PROJECTED TO THE LINE OF THE MONITORING WELLS.
3. CROSS SECTION FACING DOWNSTREAM.
4. SEE FIGURE 2-2 FOR PLAN LOCATION.
5. ANALYTICAL DATA FROM SOIL, TAILINGS, GROUND WATER AND SURFACE WATER SAMPLES ARE POSTED ON TABLE 3-2G.
6. LOCAL VARIATIONS IN WATER TABLE DUE TO CHANNEL BY-PASSING AND BEAVER ACTIVITY.

LEGEND:

- BORING
- SCREENED INTERVAL OF MONITORING WELL
- BASE OF TAILINGS AND IMPACTED SOILS
- GROUND WATER TABLE
- C-4 — GROUND WATER MONITORING WELL
- TS-260-4 — SOIL/TAILINGS TRANSECTS WITH SAMPLING LOCATION
- SURFACE WATER ELEVATION
- CL — CLAYS OF LOW TO MEDIUM PLASTICITY
- CH — CLAYS OF HIGH PLASTICITY
- ML — SILTS OF LOW TO MEDIUM PLASTICITY
- MH — SILTS OF HIGH PLASTICITY
- OL — ORGANIC SILTS
- SC — CLAYEY SANDS
- SM — SILTY SANDS
- SP — POORLY GRADED SANDS
- SW — WELL GRADED SANDS
- GP — POORLY GRADED GRAVEL
- GW — WELL GRADED GRAVEL

HORIZONTAL SCALE: 200 0 200 FEET

VERTICAL SCALE: 10 0 10 FEET

VERTICAL EXAGGERATION = 20x

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1	2-18-94	ISSUED FOR DRAFT REMEDIAL INVESTIGATION REPORT	T.M.G.		

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CROSS SECTION OF STUART AREA

PREPARED FOR

ARCO

ANACONDA, MONTANA

TITAN Environmental

DATE: 2-15-94

SCALE: AS SHOWN

FIGURE 3-2G

DRAWING NUMBER 3109-B7

Table 3-2e
Analytical Data for Geologic Cross Sections
Stuart Area
Streamside Tailings Operable Unit

Tailings/Soils

Cross Section	Depth (ft)	pH (Std. Units)	Electrical Conductivity (umhos/cm)	Total (mg/kg) As	Cd	Cu	Pb	Zn	Hg
Stuart Area									
CT-250	2-2.5	—	—	13.5	0.54	581	20.5	523	—
401	4-4.5	—	—	ND5.6	ND4	85.5	30.7	164	—
	6-6.5	—	—	7.9	ND0.22	167	33.3	178	—
	10.4-10.9	—	—	2.8	ND0.19	133	11.9	195	—
CT-250	0-0.4	—	—	635	7.3	2600	884	3460	—
402	0.4-0.8	—	—	123	12.6	2800	542	4040	—
	4.5-5	—	—	14.4	ND4	19.7	21.7	92.1	—
	6.6-7.1	—	—	4.8	ND0.24	37	21	69.1	—
CT-250-0406	0-0.3	—	—	1690	10.4	5580	6380	5210	—
CT-250-0403	0.3-0.8	—	—	305	15.2	3400	3810	3830	—
	2-2.3	—	—	106	1.3	627	651	768	—
	2.4-2.8	—	—	7.1	ND0.21	21.9	21.6	40.1	—

Ground Water

ID	Date	pH (Std. Units)	Electrical Conductivity (umhos/cm)	Dissolved (ug/l) As	Cd	Cu	Pb	Zn	Hg
Stuart Area									
C-2	7/21/83	—	—	ND1.0	ND2.0	5.00	---	ND3.0	---
C-2	1/21/92	5.45	321	1.5	1.5	ND20.2	1.5	ND179	---
C-2	10/28/92	5.95	443	2.4	1.7	ND18	ND3.4	258	0.16
C-2	6/9/93	6.67	443.00	ND0.98	2.00	9.50	ND0.38	285.00	0.12
C-2	8/20/93	5.85	331.50	ND1.2	1.80	ND1.6	ND0.72	308.00	ND0.12
C-2	03/11/93	6.66	337.00	2.10	1.40	11.00	ND1.3	243.00	ND0.1
C-3	11/23/91	5.01	347	ND1.6	10.4	281	134	2110	ND0.19
C-3	10/27/92	4.74	342	1.9	9.2	283	ND2.6	1240	ND0.16
C-3	6/9/93	4.75	450.00	ND0.98	8.80	360.00	0.66	1740.00	0.14
C-3	8/19/93	4.69	345.70	ND1.2	8.90	355.00	0.93	1690.00	---
C-3	03/10/93	4.79	472.00	4.40	10.90	303.00	2.40	1480.00	ND0.1
C-4	11/25/91	6.08	413	6.1	25.7	86	15.6	9250	---
C-4	10/27/92	5.8	456	8.3	29.2	200	ND2.7	8190	ND0.16
C-4	6/9/93	5.79	539.00	4.10	41.90	633.00	1.40	11000.00	0.19
C-4	8/19/93	5.77	433.20	3.60	44.20	760.00	1.60	11300.00	0.47
C-4	03/10/93	5.93	536.00	5.80	41.10	559.00	2.20	10100.00	ND1.0
C-4S	1/20/92	5.8	364	11.2	0.4	ND9.6	2.2	ND6200	---
C-4S	10/27/92	6	484	16.4	0.45	ND9.0	ND2.1	7390	ND0.16
C-4S	6/9/93	6.10	543.00	9.10	0.25	1.70	ND0.38	10300.00	0.16
C-4S	8/19/93	5.94	443.00	12.00	ND0.45	ND0.16	0.47	9920.00	0.23
C-4S	03/10/93	6.27	539.00	11.90	0.62	3.00	2.30	8790.00	0.15
C-5	1/22/92	6.2	913	2.4	1.3	ND18.5	2.4	ND52.7	---
C-5	10/27/92	6.61	966	3.6	0.16	ND4	ND2.7	ND68	ND0.16
C-5	6/8/93	6.40	971.00	4.20	0.42	1.70	1.70	253.00	0.06
C-5	8/19/93	6.17	663.00	3.90	0.56	ND0.16	ND0.38	281.00	0.15
C-5	03/10/93	6.38	1006.00	6.10	0.49	4.00	ND1.3	184.00	ND1.0

Table 3-2e
Analytical Data for Geologic Cross Sections
Stuart Area
Streamside Tailings Operable Unit
(Continued)

Surface Water											
		pH	Electrical Conductivity	Streamflow	Dissolved (ug/l)					
ID	Location	(Std. Units)	(umhos/cm)	(cfs)	As	Cd	Cu	Pb	Zn	Hg
Stuart Area										
SS-16B	50' Downstream	8.2	387	28.3	ND10.0	ND4.0	33	0.7	ND48.0	ND0.16
SS-16B	50' Downstream	8.4	---	41.81	---	---	ND94.9	ND1.6	391	0.17
SS-16B	50' Downstream	7.2	---	---	20.1	1.5	ND133	2.7	455	ND0.10

Notes:
As = Arsenic
Cd = Cadmium
Cu = Copper
Pb = Lead
Hg = Mercury
Zn = Zinc
ND = Not detected to the limit stated.
- - - = No data available.
umhos/cm = micromhos per centimeter.
mg/kg = milligrams per kilogram.
mg/l = milligrams per liter.
cfs = cubic feet per second.

ATTACHMENT B:

Detailed Geological and Geochemical Discussion

4.0 CONTAMINANT CHARACTERIZATION

This section presents an evaluation of data collected during this RI and pertinent data collected by previous investigators of the SST OU. This evaluation describes the nature and extent of impacts of contaminants of concern at the site, which is the primary objective of the RI. This section is organized to:

- Provide a general understanding of the current conceptual model of characteristics and movement of contaminants in the study area (Section 4.1);

- Describe some of the terms and methods of data analysis that are common to the various subarea discussions that follow (Section 4.2);

- Provide more detailed descriptions of the nature and extent, transport and fate of contaminants of concern, and interactions between environmental media for each subarea (Sections 4.3 to 4.6); and

- Discuss media that were studied on a site-wide basis, including air and terrestrial and aquatic resources (Sections 4.7 and 4.8).

4.1 Site-Wide Conceptual Model

A preliminary site-wide conceptual model was developed to support the preparation of the SST OU Work Plan (ARCO, 1991a). In this model, the SST OU was divided into four subareas (Section 3.1), differentiated primarily by geologic features. These geologic features affect stream characteristics, ground water occurrence and movement, and distribution and movement of contaminants of concern. In addition, the geologic features are a controlling factor for the geomorphology of the area, which in turn control features such as the extent of tailings/impacted materials, and current and future likely land use of the operable unit.

To provide a basis for understanding the conceptual models presented in this section, the logic for dividing the SST OU into four subareas is summarized below. Subsequent discussions included in this subsection present the general explanation of sources, transport mechanisms, pathways, and fate of contaminants of concern within the SST OU.

4.1.1 General Physiographic Controls

The general bedrock geology of the SST OU was illustrated in Figures 3-1 and 3-2. Figure 3-1 shows a cross-section through the site of the generalized geology of the four subareas that comprise the SST OU. Figure 3-2 presents the generalized geologic map. The primary means of transport of contaminants of concern from tailings/impacted materials are related to surface and ground water movement and occurrence. In general, the geologic characteristics that appear to affect surface water and ground water occurrence and movement and the distribution and movement of contaminants of concern in the SST OU include the following:

- *Bedrock Control* -- Near surface bedrock is present beneath Silver Bow Creek in both Subareas 1 and 3. Because of this, only a very thin and narrow alluvial system has developed in these areas. As well, Silver Bow Creek exhibits relatively higher stream gradients in these reaches (about 0.5%) as compared to Subarea 2. These high energy stream reaches are characterized by straight channels sections and relatively small areas of mine and mill tailings deposition along the stream.

- *Fault Control* -- The Rocker Fault, located near the center of Subarea 1 (Figure 3-1), created a down-dropped block which resulted in the formation of a basin between Rocker and Durant Canyon filled with several hundred feet of sediments at its eastern end. This down-dropped block lies within both Subarea 1 and Subarea 2 and contains relatively large expanses of streamside tailings, many of which are present in flat areas within the first stream terrace.

- *Volcanics* -- The extrusion of Lowland Creek Volcanics in Durant Canyon (Subarea 3) has impacted the character of the lower reaches of Silver Bow Creek. Materials shed from these volcanics were transported into the upper Deer Lodge Valley (Subarea 4) by various processes, including fluvial transport (Figure 3-2). The presence of these relatively recently deposited materials in a basin which contains a substantial amount of other types of unconsolidated sediments, may have caused Silver Bow Creek to become braided in this reach. The braided nature of the water course in Subarea 4 is indicative of a relatively high energy environment. The physiography of Subarea 4 also allows for ice jams to occur relatively frequently during winter months which sometimes causes out-of-bank flows to occur in Silver Bow Creek (MultiTech, 1987). Because of out-of-bank streamflow events caused by ice jams, precipitation, and snowmelt, mine and mill tailings in Subarea 4 are relatively widespread.

4.1.2 Occurrence and Distribution of Contaminants of Concern

As discussed in Section 3.0, the primary contaminants of concern at the SST OU include arsenic, cadmium, copper, lead, mercury, and zinc. These contaminants are present in varying concentrations in soil and tailings, surface water, ground water and potentially in air at the SST OU (MultiTech, 1987). The potential sources of contaminants of concern at the SST OU include the following:

- *Off-site Sources* -- Upstream sources include, but are not limited to: mine wastes in and near the City of Butte; discharges from the Butte Sewage Treatment Plant; materials containing organic contaminants at the Montana Pole NPL site; and, mine and mill tailings in the Colorado Tailings and Butte Reduction Works. Contaminants from these source areas enter the SST OU primarily within Silver Bow Creek, at the eastern end of the study area. Off-site contaminants may also enter the SST OU via ground water throughflow from the LAO and the Rocker OU from airborne and/or water borne transmission of contaminants of concern from various locations (e.g., mine waste dumps located west of Butte) and from irrigation return flow, especially near the lower end of the SST OU.

- *Streamside Tailings and Impacted Soils* -- Mine and mill tailings are present along nearly the entire reach of Silver Bow Creek within the SST OU. These tailings were primarily derived from mines and mills historically located in and near Butte. The tailings were stored beside and placed in Silver Bow Creek as a disposal measure and were carried downstream by stream flows (MultiTech, 1987). Tailings deposits visible today along Silver Bow Creek are located on the floodplain of the stream, and were deposited primarily by flood events. Sparsely vegetated areas beside the stream are generally associated with areas of tailings deposition. The edge of tailings deposits on the outside of the floodplain, away from Silver Bow Creek, generally coincides with either the base of a higher stream terrace or railroad embankments.

  Tailings materials were mixed with native soils as they were transported downstream by Silver Bow Creek, which makes the precise identification of tailings difficult. In addition, the underlying soils may also contain contaminants of concern where these constituents have been transported from the tailings deposits to the underlying soils or where underlying soils were derived from rock enriched in these constituents.

  Detectable concentrations of contaminants of concern in tailings and tailings impacted soils reflect, to some degree, the native ore that was mined in Butte. In addition, some of the tailings deposits and/or soil at the site contain detectable mercury concentrations. Mercury was used in gold and silver mining and milling processes (Malone, 1981). The probable source of the mercury in the tailings and soils in the Silver Bow Creek flood plain is either in-situ wastes from historical placer operations along Silver Bow Creek or transported wastes associated with gold and silver milling operations in Butte that employed mercury.

- *Streambed Sediments* -- A portion of the tailings and/or impacted soil that either enters the SST OU from off-site or is present on-site enters Silver Bow Creek and contributes to the bed sediments. These bed sediments are naturally moved downstream by Silver Bow Creek. While in the stream, bed sediments containing a component of tailings/impacted soils may serve as a source of contaminants to the surface water system.

- *Railroad Materials* -- Portions of several historical and existing railroad beds along Silver Bow Creek within the SST OU were constructed with mine waste rock and/or mine and mill tailings. Portions of the railroads also contain ballast comprised of slag. Impacted materials have also been identified. This material represents a potential source of metals to ground water through infiltration of precipitation or snowmelt, or to Silver Bow Creek through surface water run-off.

4.1.3 Geochemical Considerations

In this section, mechanisms that may release and move contaminants of concern from the sources discussed in Section 4.1.2 are explained and discussed. The basis for determining potential mechanisms include (1) data from the SST OU, (2) theoretical geochemistry, and (3) geochemistry of similar areas. Citations included here are not necessarily site-specific. Site-specific data illustrating and supporting this discussion are presented within the subarea discussions in Sections 4.3 through 4.7.

Contaminants of concern impact the environment within the SST OU when present in a concentrated form. Contaminants become mobile in soil pore water, surface water or ground water. The potential mobility of each constituent is determined by chemical reactions occurring in tailings that release metals and arsenic in soluble forms, and the physical and chemical mechanisms that allow dissolved contaminants to be transported from the tailings in pore water.

Contaminants of concern were originally present in tailings as sulfide minerals, such as enargite (Cu_3AsS_4) and sphalerite (ZnS) (Meyer, et al, 1968). The tailings also contain pyrite (FeS_2). These minerals become unstable when exposed to oxygen in subaerial conditions (Mason and Moore, 1982). As a result of this exposure, chemical reactions occur that result in mobilization of metals, arsenic and sulfate.

4.1.3.1 Release of Contaminants of Concern from Sulfide Minerals

The primary chemical reactions in tailings that affect constituent mobility are acidification by oxidation of sulfide minerals and hydrolysis of ferric iron ions to form ferric hydroxide. Each of these reactions create acid [hydrogen ions (H^+)]. In general, the solubility of contaminants of concern increases as pH decreases (Butler, 1964; Snoeyink and Jenkins, 1980; Sawyer and McCarty, 1978). Arsenic behaves somewhat differently than the other metal contaminants as it tends to have a lower solubility at low pH and its solubility increases as the pH rises.

When exposed to oxygen, pyrite (FeS_2) and other sulfide minerals become unstable and slowly oxidize. Oxygen, with bacteria acting as a catalyst, causes the oxidation of pyrite, and produces sulfate ($SO^{-2}{}_4$), ferric iron (Fe^{3+}), and protons (H^+) according to the following reactions (Singer and Stumm, 1970):

$$FeS_2 + 7/2\ O_2 + H_2O = Fe^{2+} + 2\ SO^{-2}{}_4 + 2\ H^+ \qquad (1)$$

$$Fe^{2+} + 1/4\ O_2 + H^+ = Fe^{3+} + 1/2\ H_2O \qquad (2)$$

$$FeS_2 + 14\ Fe^{3+} + 8\ H_2O = 15\ Fe^{2+} + 2\ SO^{-2}{}_4 + 16\ H^+ \qquad (3)$$

In a low pH environment, the rate of Reaction No. 2 is slow. However, the bacterium *Thiobacillus ferrooxidans*, which is ubiquitous in most environments, greatly accelerates the reaction rate (Dugan, 1975; Fenchel and Blackburn, 1970; Freney and Williams, 1983).

Thiobacillus ferrooxidans and Reaction Nos. 1 and 2 require oxygen (Dugan, 1975; Fenchel and Blackburn, 1970; Freney and Williams, 1983). Therefore, this bacterially-mediated chemical reaction is also influenced by physical factors that control the amount of reactants (*i.e,* oxygen) that are available. In fine tailings where pore spaces are filled with water and percolation of water through the tailings is slow, oxygen may become depleted within the tailings. Oxygen depletion limits oxidation of pyrite, acid formation, and metals and arsenic mobility. In coarser tailings, water may move more rapidly through the pore spaces, bringing a fresh supply of oxygen that facilitates acidification and metals movement.

Where oxygen depletion is occurring, boring logs indicate tailings are fine grained and change in color from yellow (oxidized) near the surface to gray (unoxidized) at depth. Where tailings are typically coarser grained, pore water carries oxygen (and dissolved metals) through the tailings, and no distinct color zones are evident.

The mobility of metals and arsenic also is limited by the hydrolysis of ferric iron to form amorphous ferric hydroxide:

$$Fe^{3+} + 3\ H_2O = Fe(OH)_{3\ (am)} + 3\ H^+ \qquad (4)$$

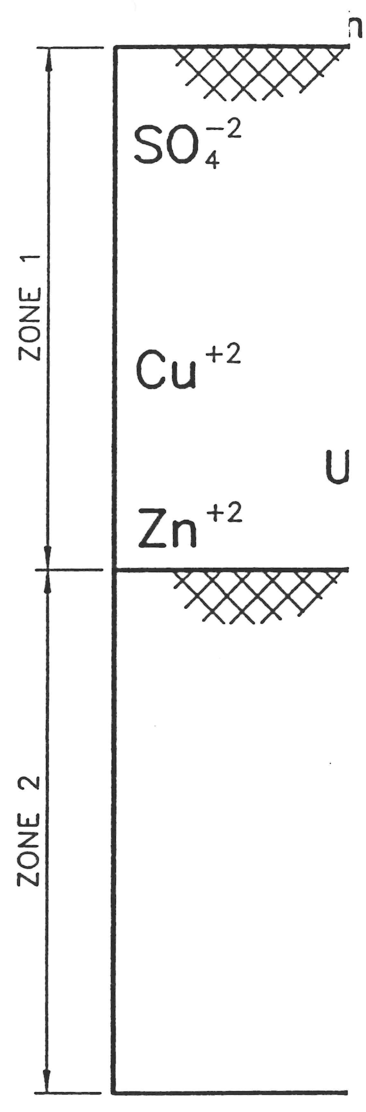
or other minerals, including jarosite $[(H,Na,K)Fe_3(SO_4)_2(OH)_6]$, or poorly crystallized oxyhydroxysulfate of iron (Bigham, et al, 1990). Precipitation reactions, such as shown in equation no. 4, result in some proton production but the precipitates formed have the beneficial effect of removing metals from pore water through adsorption and coprecipitation reactions (Mason and Moore, 1982). Soluble arsenic is adsorbed by ferric hydroxides (Pierce and Moore, 1982; Fuller, et al, 1993; Bowell, 1994) as are lead, copper, zinc and cadmium (Benjamin and Leckie, 1981; Schultz, et al, 1987). Precipitation of ferric hydroxides and adsorption of metals increases as pH increases.

The protons resulting from Reaction Nos. 1 and 3 in tailings cause the pore water pH in the tailings to decrease. However, within the tailings and underlying soils there is a definite trend of increasing pH in the pore water as depth below the surface of the tailings increases. Figure 4-1 is a schematic diagram of the geochemical processes occurring in the tailings and underlying soils and illustrates this trend. The increase in pH as depth increases indicates that protons are being removed from the pore water. The most likely cause for this is reaction of the pore water with other components of the tailings and native soils. This pH increase demonstrates that the tailings and underlying soils have an inherent capacity to remove protons resulting in increased pH. This may be referred to as "buffering capacity" (Stumm and Morgan, 1981; Butler, 1964; Snoeyink and Jenkins, 1980). Figure 4-1 illustrates the relationship between pH and buffering capacity.

In general, buffering capacity depends on mineral composition (Stumm and Morgan, 1981; Sawyer and McCarty, 1978). The mineralogy of the tailings is not documented because RI work and previous investigations focused on metals content of the tailings rather than the bulk mineralogy. However, the major mineral components of the tailings and underlying soils are likely to include gangue (non-ore) minerals from the Butte ore body and host rock, alluvial material from the Silver Bow Creek drainage, and sulfide minerals. As discussed in Section 3.3, the ore bodies mined in Butte are hosted by the Boulder Batholith which is composed

DRAWING NUMBER 3109-B9

SOLUE



MOBILITY PROCESSES:

ZONE 1. Oxidation of sulfide minerals generates sulfuric acid. Acid mobilizes metals.

ZONE 2. Natural buffering in tailings and soils raises pH resulting in adsorption, and coprecipitation of metals with precipitating amorphous iron hydroxide in the 4.5 to 8.5 pH range. This process may also occur in the lower portion of zone 1 where tailings are thicker.

CONCEPTUAL
GEOCHEMICAL MODEL
PREPARED FOR
ARCO
ANACONDA, MONTANA

TITAN Environmental

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1	12-9-94	ISSUED FOR DRAFT REMEDIAL INVESTIGATION REPORT	T.M.G.

DATE: 3-16-94
SCALE: N.T.S.

FIGURE 4-1

primarily of highly mineralized quartz monzonite. Bedrock in the highlands surrounding the SST OU that are the source of the alluvium in the SST OU contain intrusive igneous rocks associated with the Boulder Batholith, later rhyolitic extrusive igneous rocks, and Paleozoic shallow marine carbonates (USGS and MBMG, 1955). The main components of these rocks are quartz, feldspar (orthoclase and plagioclase), hornblende and biotite (Meyer, et al, 1968). Clays (primarily kaolin and montmorillonite) from the weathering of the quartz monzonite and volcanic rocks are also expected to be components of tailings (Feth, Roberson and Polzer, 1964; Grim, 1968). Sulfide minerals occur naturally in soils and alluvium due to the close proximity of the very large ore body in Butte.

Reactions of pore water with the components of the tailings result in change in pore water chemistry with increasing depth, including changes in pH illustrated on Figure 4-1. Reactions with pyrite, particularly near tailings surfaces, have been discussed. Similar reactions with other sulfides, such as enargite and sphalerite, result in mineral dissolution and mobilization of copper, arsenic, zinc and sulfate. Reactions with feldspars result in dissolution and mobilization of calcium, sodium and potassium, and removal of protons from solution (Strömberg and Banwart, 1994). These reactions of feldspar that consume protons are the primary weathering reactions of feldspar and are the source of clay minerals (Press and Seiver, 1986; Leeder, 1982; Freidman and Sanders, 1978). Clays remove dominant cations from pore water through cation exchange and through adsorption (Grim, 1968). Quartz is stable between pH values of approximately 3 and 9, so quartz in the tailings may act as a substrate for precipitation of ferric hydroxide (Reaction No. 4).

Not all of these reactions occur at the same rate. Generally, adsorption and exchange reactions are faster than precipitation and dissolution reactions (Langmuir and Mahoney, 1985; Berner, 1980; Nordstrom and Munoz, 1985). In tailings deposits dominated by fine-grained particles, pore water movement is slow, providing time for dissolution and precipitation reactions and resulting in effective pH buffering. In tailings deposits dominated by coarse-grained particles, pore water movement may be more rapid, thereby decreasing the time available for dissolution and precipitation reactions and resulting in less buffering and less pH increase.

Additionally, coarse-grained tailings have less of the clays that provide a portion of the buffering capacity that buffers acidic pore water from the tailings. Coarse-grained tailings also have less net surface area available for reaction, cation exchange, and adsorption to occur. Therefore, coarser soils tend to have less buffering capacity than finer grained soils.

4.1.3.2 Mechanisms that Allow Transport of Mobile Contaminants of Concern in the Vadose Zone

Following mobilization of contaminants of concern by the reactions and mechanisms described above, the contaminants of concern may move via pore water transport in the vadose (unsaturated) zone to regions with different geochemical conditions. For example, the increase in soil water pH related to the buffering capacity of the tailings and native soils has been discussed previously. When the pH of pore water in the tailings or native soils increases, dissolved metals and arsenic become unstable in solution. Iron hydroxides precipitate and arsenic and other metals precipitate with or adsorb onto the iron hydroxide (Stumm and Morgan, 1981; Garrels and Christ, 1965). As a result, the pore water concentrations of arsenic and metals decrease as the pore water percolates through tailings and native soils that have buffering capacity.

The direction and rate of transport depend on tailings porosity and permeability, on meteorological conditions, and on the presence and type of vegetation. As pore moisture decreases, the tendency for downward pore water movement decreases because the soil has greater capacity to store the water. Upward pore water movement results in sulfate and metals being wicked to the surface of the tailings. This mechanism is amplified where low porosity and permeability inhibit downward moisture movement and evapotranspiration by vegetation is limited. Evaporation of pore water containing contaminants of concern results in the formation of soluble metal salts on the tailings surface.

Precipitation following a warm, dry period in which soluble salts have formed on the tailings surfaces may re-dissolve the salts. The precipitation may infiltrate through the tailings/soil and percolation may carry arsenic and metals into soil pore water. Additionally, when the precipitation rate exceeds the infiltration capacity of the tailings/soils, surface water runoff will occur, carrying contaminants to Silver Bow Creek.

Vegetation inhibits downward percolation of water by consumption of water in the tailings or soils (Freeze and Cherry, 1979; Driscoll, 1986). In those areas where vegetation can grow in tailings, the geochemical environment may be modified by addition of carbon dioxide and organic matter. The overall result is reduction or elimination of the formation of low pH pore water containing metals and arsenic (RRU, Schafer and CH2M Hill, 1989a). Vegetation inhibits the formation of soluble salts by shielding the tailings surface from air movement and heat that increase evaporation. Vegetation also inhibits runoff of precipitation by reduction of surface water runoff flow rate by baffling and by increased infiltration due to increased soil porosity and permeability (Linsley, Kohler and Paulhus, 1982).

Pore water moves downward through soil when soil moisture exceeds the field capacity of the soil. Field capacity is the moisture left in the soil after gravity drainage ceases. Downward pore water movement may follow periods of precipitation and snowmelt when available moisture exceeds the field capacity of the soil. When downward pore water movement occurs, the metals and arsenic carried by the pore water may be retained in tailings or underlying soils, depending on the interactions of pore water with tailings and soils. As discussed previously, the soils underlying tailings have buffering capacity from chemical reactions such as dissolution that neutralizes the acidity of downward-moving pore water. The buffering capacity can result in the co-precipitation and adsorption of metals from pore water depending upon kinetic and thermodynamic conditions. Because precipitation reactions are relatively slow, the potential for metals and arsenic to move through pore water in the dissolved form also exists.

Additionally, buried soil horizons may contain organic or calcium carbonate-rich (calcareous) materials. Calcareous materials, common in Subarea 4, can neutralize low pH solutions, promoting precipitation and adsorption of metals. Organic layers resulting from roots or vegetative debris covered by overbank deposits during past flood events (Reading, 1978) may facilitate the removal of metals by adsorption due to the tendency of metals, particularly copper and mercury to form strong complexes with organic material (Thurman, 1986; Sigg, 1987; Senaratne and Dissanayake, 1989).

The effectiveness of geochemical factors described above to limit movement of contaminants of concern increases as thickness of the unsaturated zone and time of pore water/soil contact increase. Time of contact is longer for fine-grained tailings and underlying soils than for coarser materials. Boring logs from the SST OU indicate the occurrence of fine-grained tailings, silt and clay layers interbedded with coarser-grained strata. Where fine-grained layers are the dominant lithology, the downward movement of contaminants of concern to ground water is restricted.

Chemical reactions and hydrogeologic properties of the vadose zone may combine to effectively prevent transport of metals and arsenic to the saturated zone. Copper, lead, iron and aluminum tend to respond very strongly to increasing pH by precipitating or adsorbing. Zinc, cadmium, and manganese are relatively more mobile and may still be present in relatively high concentrations even when pore water pH increases above 7.0 su. Other more mobile constituents such as calcium and sulfate do not precipitate until they reach high concentrations in the pore water (Berner, 1980). As a result, concentrations of calcium and sulfate and certain metals may continue to migrate where pore water percolates through the tailings and underlying native soils. Arsenic becomes more soluble at a higher pH, particularly above a pH of 6.0 su

(RRU and Schafer, 1993), but this effect if buffered to some extend by the tendency for arsenic to be adsorped to the surface of iron oxide minerals.

4.1.3.3 Reactions in Ground and Surface Water

If factors combine so that the mobile contaminants enter ground water or surface water, geochemical reactions will continue to affect the solubility and mobility of metals and arsenic. The primary parameters impacting the mobility and solubility of contaminants of concern in solution in ground water or surface water include pH (acidity) and Eh (redox potential), which determine solid phase equilibrium relationships and reaction kinetics (Garrels and Christ, 1965; Nordstrom and Munoz, 1985). The magnitude of concentrations of metals and arsenic and the means by which constituents are transported in Silver Bow Creek or in ground water are controlled by a number of hydrochemical and biological mechanisms (MultiTech, 1987). Some of these mechanisms are very similar to those occurring in the vadose zone and include:

- Metal ion uptake and removal associated with dissolution and precipitation, and

- Adsorption of metals onto sediment and precipitates.

The degree to which any one of these mechanisms is operative in Silver Bow Creek is largely dependent upon the specific conditions in the stream at a particular point in time and the antecedent conditions (MultiTech, 1987). A brief discussion of these geochemical mechanisms is presented below.

Dissolution/Precipitation

Metal compounds are typically most soluble at low pH. Iron hydroxides are an exception to this, and are soluble in both acidic and alkaline conditions. Within the SST OU, acidic ground water which may transport contaminants of concern is most likely to occur where tailings are separated from ground water by a thin, coarse-grained vadose zone lacking buffering capacity, or where the ground water intersects the tailings. Where acidic ground water containing contaminants of concern enters the relatively higher pH water (7 s.u. or more) of Silver Bow Creek, contaminants of concern may precipitate out of solution as oxides and hydroxides, or adsorb onto precipitating iron hydroxides.

In Silver Bow Creek, several factors, in addition to pH, affect the solubility of metals and arsenic. These include carbonate/bicarbonate concentrations, complexation of metals with organic compounds, and algal activity, among others (MultiTech, 1985). Redox (Eh) conditions and dissolved oxygen may also effect metals and arsenic solubility. Measurements in the stream water of less than 4 to 9 parts per million (ppm) dissolved oxygen and from -17.1 to 332 milliVolts (mV), indicate that most of the stream has oxidizing conditions that would favor precipitation of metals as oxides and hydroxides. In the sediments in the stream, there may be zones that have reducing conditions. In these zones, precipitation of metals as sulfides would be favored.

The concentration of soluble metals at any given time in the stream is also a function of the reaction kinetics and thermodynamics of the system. The time required for chemical equilibrium to occur varies among the metal species from hours to years in a stream environment, depending upon the specific reactions and conditions of the system (Nordstrom and Munoz, 1985). Often in natural systems, the equilibrium state described by theoretical thermodynamic relationships is not obtained due to kinetic complexities and requirements of particular reactions (Mason and Moore, 1982; Berner, 1980) so that conditions in the natural system are not necessarily supported by geochemical theory.

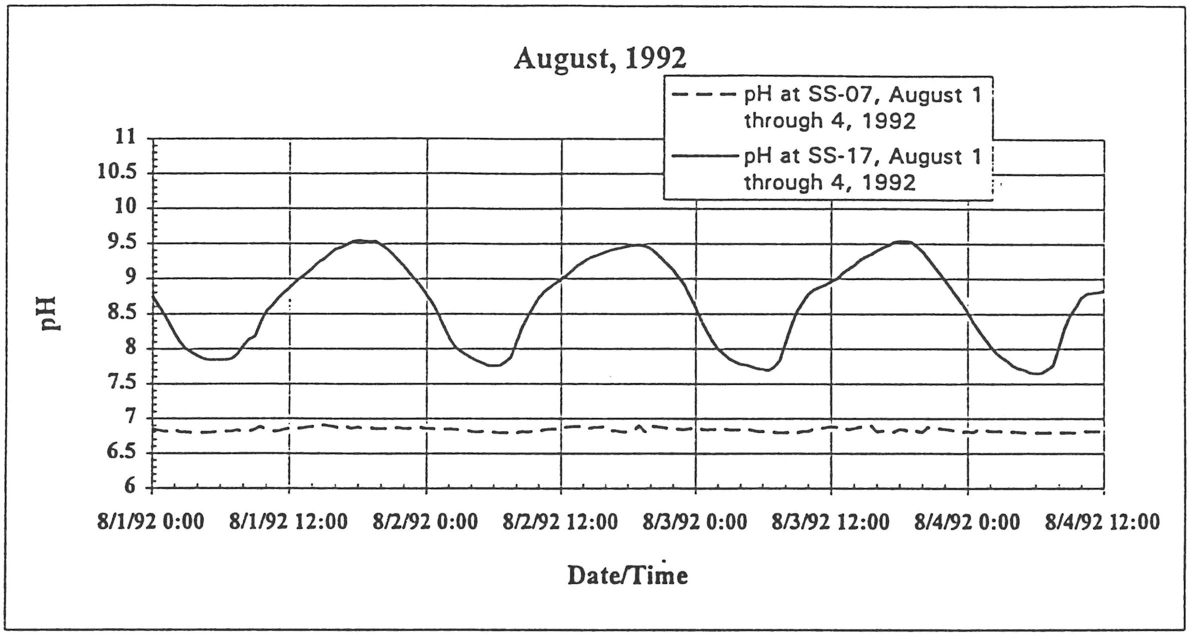
Adsorption

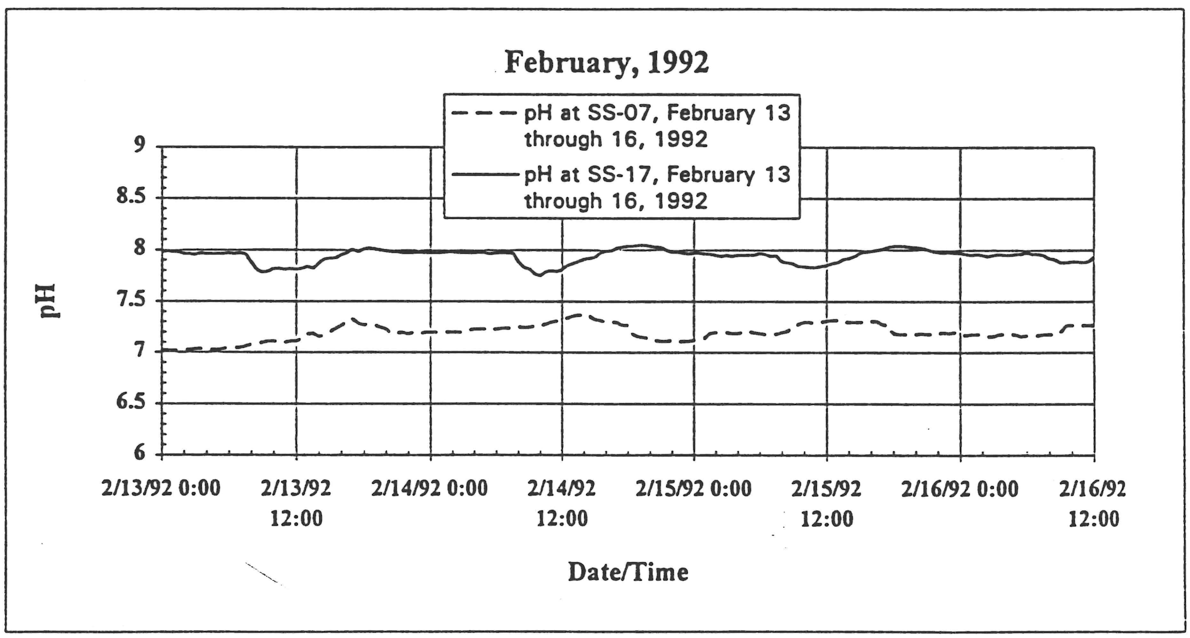
Adsorption of contaminants of concern on sediment, algae and precipitates also influences the dissolved loads of contaminants of concern in Silver Bow Creek (MultiTech, 1987). Adsorption is the accumulation of constituents in the boundary region of solid-liquid interfaces. Adsorption of metals is generally influenced by pH, the surface area available for adsorbing, the presence and concentration of complexing ligands, competing adsorbates, and adsorbate concentrations (Mills and Mok, 1984). Adsorption of uncomplexed metal cations usually increases with increasing pH and with increasing total suspended solids concentrations (increased surface area). Adsorption of metals by hydrous manganese and particularly by amorphous iron hydroxide is important in controlling dissolved metal and arsenic concentrations (Jenne, 1968; Horowitz and Elrick, 1987; Fuller, et al, 1993).

In some areas of Silver Bow Creek, adsorption may also be affected by diurnal changes in stream water chemistry associated with algal photosynthesis. Diurnal swings of as much as two pH units, from 7.6 to 9.5, have been documented in Silver Bow Creek. This phenomenon is illustrated on Figure 4-2. At the upper end of the pH range, arsenic may desorb from amorphous ferric hydroxide, then readsorb at the lower end of the pH range. Similar processes have been documented in other drainages (Fuller and Davis, 1989).

Figure 4-2

Examples of Diurnal Variation in pH at Surface Water Stations SS-07 and SS-17
Streamside Tailings Operable Unit Draft Remedial Investigation Report





Note:
Data obtained from Montana Bureau of Mines and Geology continuous measuring datasonde.

4.1.4 Movement of Contaminants of Concern

Figure 4-3 is a block diagram that shows the conceptual model of movement of contaminants of concern within the SST OU. Contaminants of concern move through the SST OU and between environmental media in response to a variety of processes. Some of the primary processes include:

- *Airborne Transmission* -- Contaminants of concern could potentially be carried by the wind under certain conditions. The variables influencing the degree to which contaminants of concern are transported by this mechanism include climatic conditions and the amount of exposed, nonvegetated tailings surface. Transport of contaminants of concern by this mechanism would be most likely during windstorms following dry periods.

- *Erosion/Runoff* -- Erosion and runoff is one of the most important transport mechanisms in the SST OU. Precipitation- or snowmelt-generated runoff entrains tailings/impacted and railroad materials to the stream. Metallic salts that have formed on the surface of the tailings may be dissolved or eroded and carried to the stream by surface water runoff. Stream flow, especially high flows or ice buildup within Silver Bow Creek may cause streambank materials containing contaminants of concern to erode directly into the stream. Animals and human beings may also cause streamside tailings/impacted soils to directly enter the stream.

  The variables influencing the degree to which contaminants of concern may be transported by this mechanism primarily include climatic conditions, amount of animal/human activity within the area, the proximity of tailings/impacted soils to streambanks, and the nature of the tailings/impacted soil particles. Transport of contaminants of concern by this mechanism would be most likely during rain when the soil is saturated, sudden warm spells when there is snowpack, or a heavy rain following hot dry conditions that favor the formation of salts.

- *Infiltration and Vadose Zone Transport* -- Percolation of water from the surface downward through the vadose zone and into the saturated zone is another method by which contaminants of concern may move within the SST OU. This process is most likely to occur during precipitation events and/or during snowmelt. Soluble metals and arsenic in the tailings may be leached by the infiltrating water and carried into the underlying native soils and ground water. The primary variables influencing the degree to which metals and arsenic may be transported by this mechanism include rainfall or

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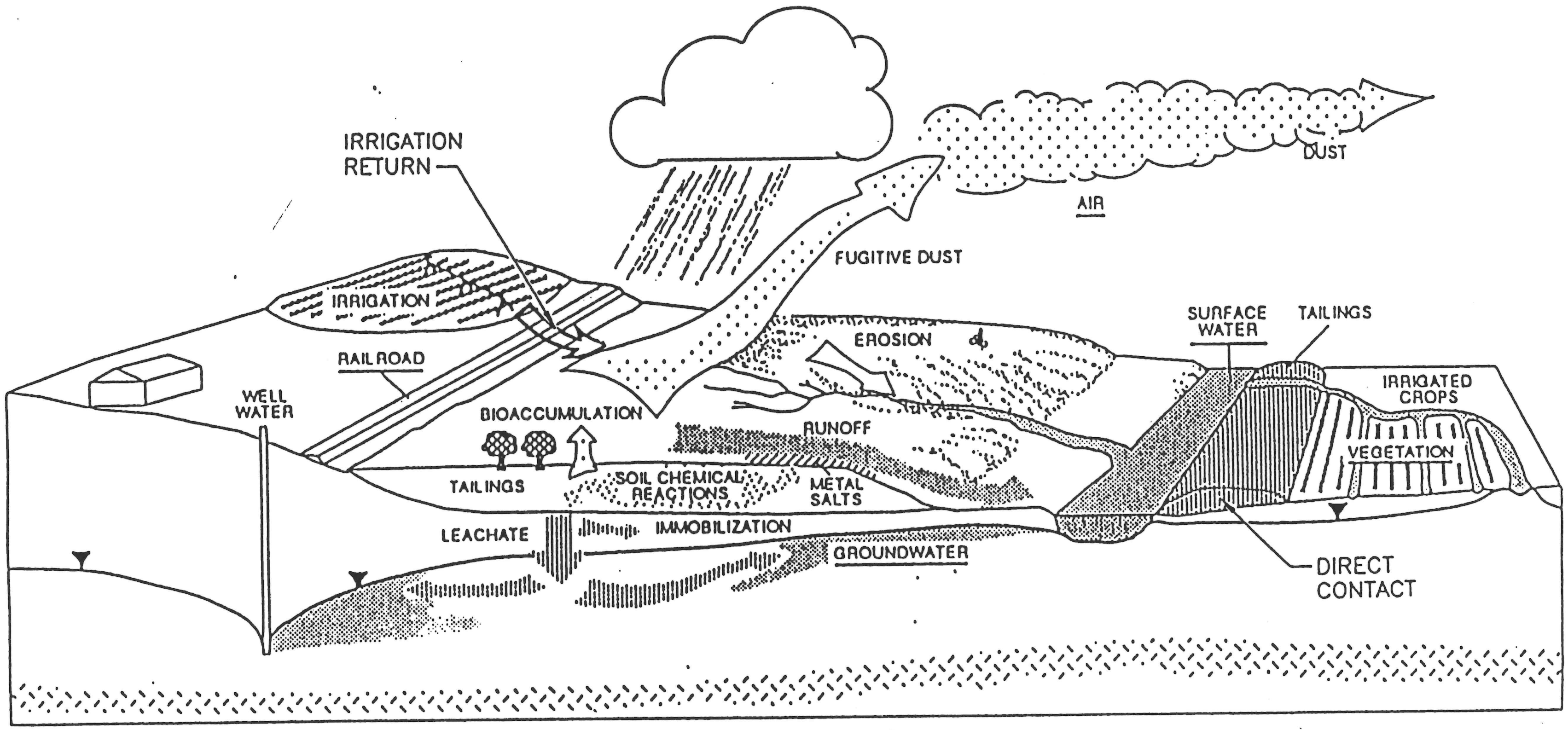

Release Mechanism

AIR — Contaminated Media

WELL WATER — Exposure Routes

Groundwater

SCHEMATIC OF POTENTIAL CONTAMINANT MIGRATION PATHWAYS AND EXPOSURE ROUTES FOR THE SILVER BOW CREEK STREAMSIDE TAILINGS OPERABLE UNIT DRAFT REMEDIAL INVESTIGATION REPORT

PREPARED FOR

ARCO

ANACONDA, MONTANA

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1	12-6-94	ISSUED FOR DRAFT REMEDIAL INVESTIGATION REPORT	I.M.G.	[illegible]	[illegible]

DATE: 10-4-94
SCALE: N.T.S.

FIGURE 4-3

DRAWING NUMBER 3109-A117

snowmelt and evaporation, proximity of tailings/impacted soils to ground water and the geochemistry of the specific tailings, native soil and pore water system. Infiltration that may transport contaminants of concern to ground water would be most likely during extended wet periods such as long rains or snowmelt.

- *Ground Water Flow* -- Ground water flow within the SST OU is primarily toward Silver Bow Creek (near stream) and down the Silver Bow Creek drainage. Therefore, the only area where ground water containing contaminants of concern may flow off-site is at the boundary of the SST OU and the WSP OU. The degree of transport of contaminants by this mechanism depends on the rate of ground water flow, mixing of contaminated ground water with nonimpacted ground water, and the buffering of contaminants with alluvial aquifer material.

- *Ground Water Inflow to Surface Water* -- Movement of ground water impacted by contaminants of concern into the stream is another transport mechanism that is possible within the SST OU. This transport mechanism occurs where the surface water system gains flow from ground water. Transport of contaminants of concern by this mechanism would be most likely during low flow.

- *Physical Transport* -- Metalliferous sediment transport by moving water is another mechanism whereby contaminants of concern are transported in the operable unit.

- *Surface Water Flow to Ground Water* -- Movement of contaminants of concern from surface water to ground water may occur in reaches of the stream that lose flow to the adjacent alluvial ground water system. Transport of contaminants by this mechanism would be most likely during spring runoff, when the stream stage is high. This condition may occur during storm events even in reaches of the stream that do not normally lose stream flow to ground water. This ephemeral condition is called "bank storage." During bank storage, water that has flowed from the stream to the banks during high flow returns to the stream as the elevation of the stream drops.

- *Bioaccumulation* -- In some areas of the SST OU, buried tailings or tailings mixed with native soil support vegetative growth. Plants may accumulate metals and arsenic in their leaves and flowers and grazing animals may ingest these contaminants through consumption of vegetation. Grazing animals may also ingest contaminants by directly ingesting soil or soil on the exterior of plants. Humans might potentially also ingest metals and arsenic by eating garden produce grown in impacted soil.

Contaminants of concern may be also be concentrated and transported by algae within the SST OU (MultiTech, 1987). Certain phytoplankton and periphyton species are able to concentrate the contaminants of concern (Fenchel and Blackburn, 1979). Iron, copper and zinc are required micronutrients for algae (Nichols, 1973); sulfur is a macronutrient for most plants (Freney and Williams, 1983). The contaminants of concern are either assimilated into algal biomass or adsorbed on the cell surface (Jennett, et al, 1983). Algal material containing contaminants of concern is then subject to physical transport through stream action or continues to reside as a crust on bed material and serve as a metals trap.

4.1.5 Fate of Contaminants of Concern

In time contaminants of concern from sources within the SST OU will either be bound to or contained in solid materials remaining within the SST OU, bound to or contained in solid materials that have moved into Silver Bow Creek, or transported downstream to the Warm Springs Ponds. Silver Bow Creek is the primary recipient of contaminants of concern derived from the SST OU and from off-site sources. Contaminants primarily enter the stream within the SST OU through runoff during precipitation and snowmelt events and possibly from ground water inflow at effluent reaches of the stream. As described previously, the quality of Silver Bow Creek is degraded by releases from sources in the Butte area prior to entering the SST OU.

Silver Bow Creek discharges into the Warm Springs Ponds at the lower end of the operable unit. Contaminants are transported by Silver Bow Creek in varying forms and are, for the most part, removed from the water through the treatment system operated at the Warm Springs Ponds. Therefore, ultimately, nearly all metals which move through the SST OU will either be deposited or treated in the Warm Springs Ponds. The Warm Springs Ponds have been designed to treat flows up to the 100-year flood event. Flows greater than this event will bypass the ponds an flow directly into the Clark Fork River.

Contaminants of concern not carried into Silver Bow Creek may be affected by natural geochemical mechanisms. These mechanisms include primarily precipitation, co-precipitation and adsorption of the contaminants of concern within the tailings/impacted soils. Additionally, contaminants of concern may also be chelated and complexed to organic materials present in buried soil horizons. Sulfide minerals that become buried with organic material may be stabilized because of reducing conditions present in the organic material. Tailings that have been oxidized and are coated with iron hydroxide can be stable in contact with the oxidized stream water because the hydroxide coating armors against further weathering. These metals will remain in this stable form until geochemical conditions alter the chemical stability of the soil system. A minor portion of the contaminants may also be taken up in plants.

4.2 Definition of Terms and Methodologies

Several of the terms and methodologies used to complete the analyses of environmental data are common among all the subareas. This section describes those terms and methods which are common among the subareas. The discussion is organized by environmental matrix or media, with tailings/soil methods and terms described in Section 4.2.1, surface water methods and terms in Section 4.2.2, ground water methods and terms in Section 4.2.3, and sediment method and terms in Section 4.2.4.

4.2.1 Soil and Solid Media

Soil samples have been collected within and adjacent to the SST OU to determine both the nature of tailings and native soil and to provide a frame of reference against which to assess the impact of tailings on the environment. The different types of soil sampled include reference (background) soil, tailings, tailings/impacted soil, ranch and residential soil and railroad bed and ballast materials. The purpose of this section is to define these types of soil and describe the methodology used or process by which the definitions were made. In particular, a discussion on the definition of reference soil, ranch and residential soil, and the method used for delineating tailings/impacted soil from "nonimpacted" soils within the SST OU is presented.

- *Statistical Considerations* -- Much of the discussion concerning the various soils includes references to "nonparametric" statistical summaries of different soil groups. Nonparametric statistics were used because the data do not reflect a normal, or bell-shaped distribution that lends itself to analysis by parametric statistics. The arithmetic or geometric mean, standard deviation and variance are the parametric statistics that are most commonly used to describe the distribution of samples of a normal distribution. The appropriate nonparametric statistics used to describe a non-normal distribution are minimum, first quartile, median, third quartile, maximum, and semi-interquartile range.

  Nonparametric statistics ranks the data from lowest to highest to describe a data set. Thus, the median value is the middle sample in a data set rather than the average value as described by the mean. For example, in a data set that contains ten samples, the median is the value half-way between the values measured for sample numbers five and six, so that there are five samples below the median and five samples above the median.

ATTACHMENT C:

Executive Summary, Silver Bow Creek Demonstration Project 1

EXECUTIVE SUMMARY

The Silver Bow Creek Remediation Demonstration Project I Treatability Study site is located on a 2,200-foot section of Silver Bow Creek downstream of the town of Rocker, Montana. The 16 acre site is part of the Streamside Tailings Operable Unit (SST OU) which is one component of the Silver Bow Creek/Butte NPL Site.

The treatability study objectives were to collect cost, implementability, and effectiveness data for specified design and construction methods potentially used as remedial alternatives for the SST OU and other OUs in the Upper Clark Fork River Basin (UCFRB) NPL sites. Project investigation and design were conducted from 1991 to 1993. Construction spanned a three-month period from February 1993 to May 1993, not including willow planting. Monitoring was initiated in April 1994 and is ongoing.

The project conceptual design has three basic premises. The first premise is that streamside tailings-related impacts to Silver Bow Creek can be mitigated without relocating metals-contaminated soils to an off-site repository. The second premise is that metals-contaminated soils located below the water table are not significantly impacting water quality in Silver Bow Creek because the metals of concern are not mobile in a less-oxidized environment and the stream is mildly gaining in this area. The third premise is that some removal of near-stream soil/tailings may be necessary in limited areas because in situ treatment may be less effective in areas of shallow ground water. The effectiveness and implementability data obtained from Demonstration Project I are intended to verify or disprove these premises. The design addressed these premises by: 1) excavating near-stream tailings within approximately 30 inches of ground water; 2) relocating these tailings on deposited tailings higher in the floodplain; 3) partially backfilling excavated areas; and 4) lime-amending and revegetating all tailings on site.

The project design incorporated mine tailings treatment technologies previously tested in the Streambank Tailings and Revegetation Study (STARS), the Clark Fork River Demonstration Project (the Governor's Project), and elsewhere. Approximately 15,000 bank cubic yards (bcy) of mine tailings located within 30 inches of the ground water table and within a narrow corridor adjacent to Silver Bow Creek were excavated and relocated to topographically protected areas within, or adjacent to, the boundary of the 100-year floodplain of Silver Bow Creek. Subsequently, the excavated areas were reconstructed by partially backfilling with locally-available borrow material. High, steep streambanks with tailings were stabilized by cutting the banks back to a 4H:1V slope, lime amending the tailings within them and covering them with erosion control fabric.

The relocated tailings were treated with lime kiln dust to neutralize any acid-generating potential (short- and long-term), using rates and techniques consistent with the STARS findings. Three different treatment options were investigated for the relocated tailings: 1) ag till of one foot layers of excavated tailings placed over a previously lime-treated area; 2) ag tillage of one-foot layers placed over an area of native soil; and 3) ag tillage of two, one-foot

layers over the top of a three-foot untreated layer of tailings above native soil. Additionally, approximately 43,500 bcy of mixed fluvially-deposited sediments and tailings located within the 100-year floodplain but outside of the excavated corridor were treated in situ by deep plow incorporation of lime kiln dust. At the end of the project, the entire site was graded, fertilized, mulched and seeded with a mixture of grass species and planted with willow seedlings.

The report describes the details of the construction effort, project costs, implementability, environmental impacts associated with the execution of the project design, and post-construction monitoring and effectiveness information available to date. Effectiveness of the project design will be more fully evaluated after post-construction monitoring is completed.

In general, the project was implemented as designed. Construction was performed as anticipated with the only major concern being the accuracy of tailings depth estimations. Each relocation option was implemented easily with few changes. Construction was conducted during winter months so that heavy equipment could operate on near-stream soils which would be too wet to allow construction at other times of the year. However, construction operations were slightly affected by the winter weather. Deep plow techniques were affected by the freezing conditions during construction. Tilling equipment was modified in the field to accommodate the change in soil conditions at the site. Also, wet conditions and high flows caused some minor delays and concerns as the winter conditions warmed. These modifications were successful in completing the construction phase.

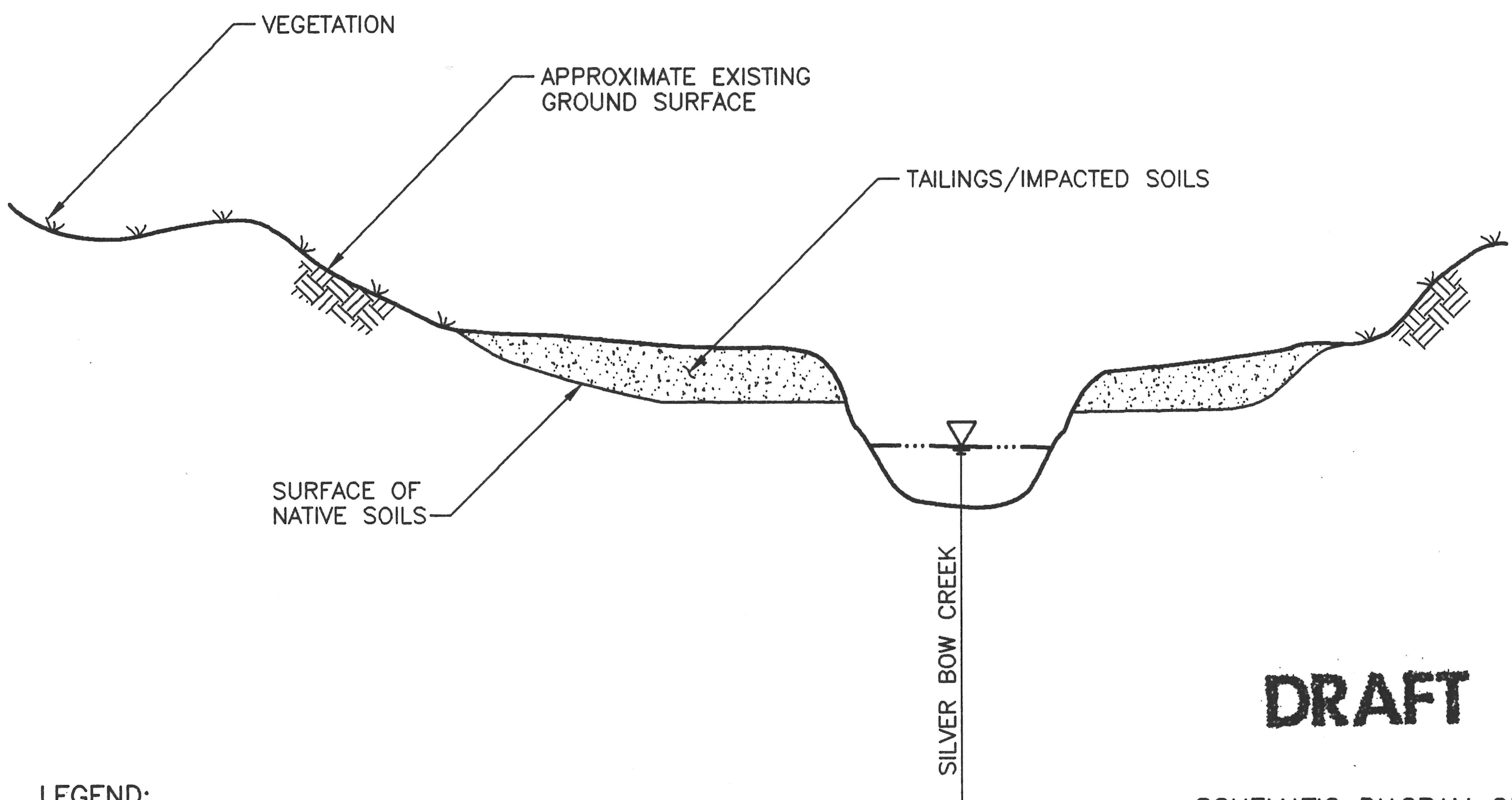
Demonstration Project I evaluated three treatment options for relocated tailings. Treatment Option 1 was the most expensive, while Treatment Option 2 was least expensive. The total cost to construct the project was $381,000 for a 15.6 acre site which produces a unit cost of $24,400 per acre. This unit cost includes all three treatment options plus the in situ treatment (deep till). Therefore, it may not be representative of a project that is based solely on only one of these options. Section 4.0, Cost Analysis, provides a breakdown of costs for each treatment option.

Monitoring activities before, during and after construction have been successfully implemented at Demonstration Project I. The effectiveness of each relocation option is still being evaluated. Differences in effectiveness can be evaluated more fully after observations have been made for an entire season. However, though final effectiveness conclusions cannot be made at this stage of the monitoring effort, observations made during monitoring activities suggest that all treatment options have shown varying degrees of effectiveness in mitigating tailings and impacted soils. Observations made to date also suggest that full-scale implementation of in situ and combined relocation and in situ treatment alternatives are feasible in effectively addressing tailings within the flood plain at Silver Bow Creek.

ATTACHMENT D:

Figures Illustrating

Remedial Activities



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LEGEND:

SURFACE WATER LEVEL

NOTE:

1. THIS DRAWING IS NOT TO SCALE.

DRAFT

SCHEMATIC DIAGRAM OF
NO ACTION
TAILINGS/IMPACTED SOILS
REMEDIAL ALTERNATIVE
STREAMSIDE TAILINGS OPERABLE UNIT

PREPARED FOR

ARCO
ANACONDA, MONTANA

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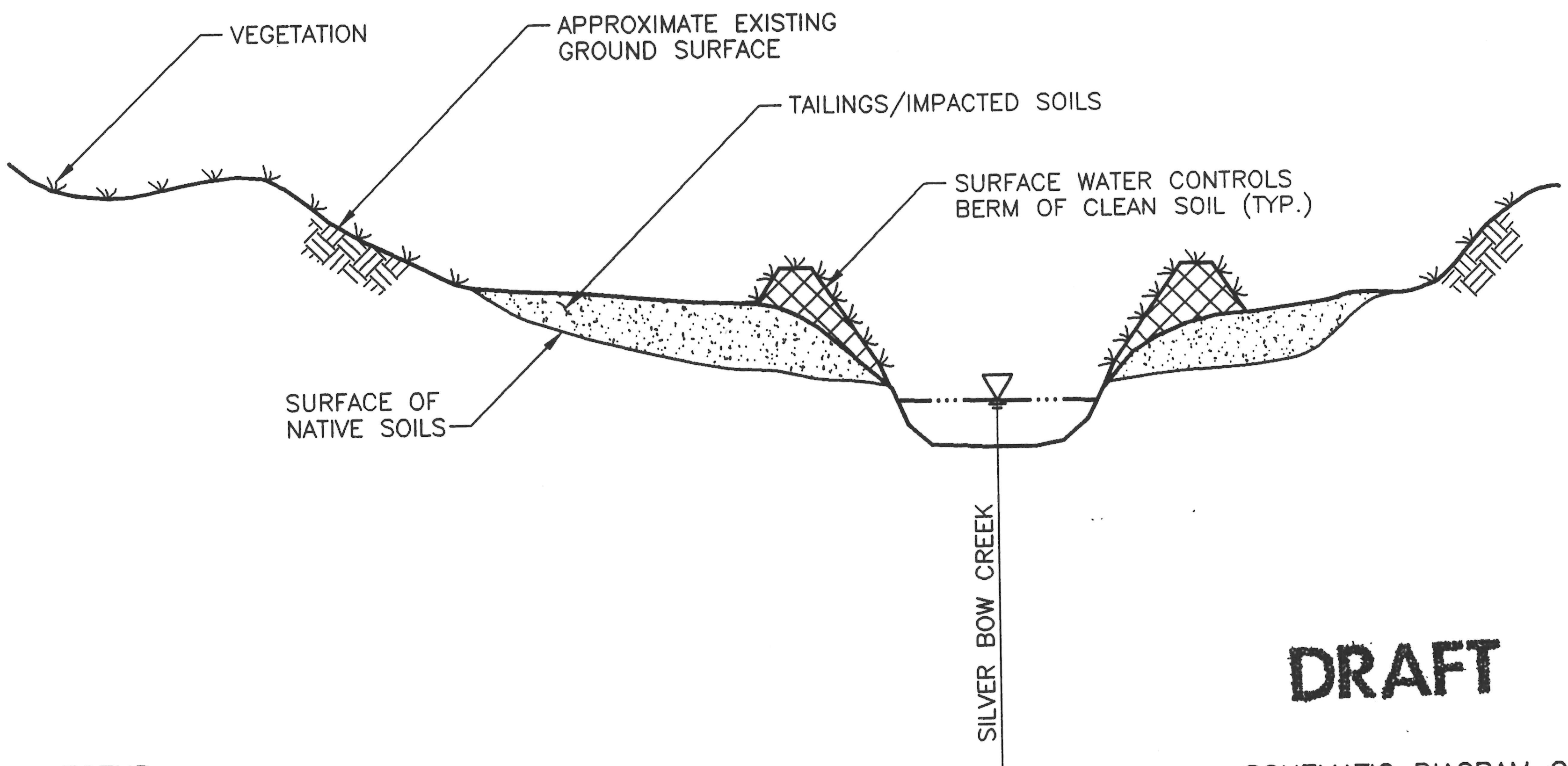
1	5/26/94	ISSUED FOR PRELIMINARY DRAFT FEASIBILITY STUDY	T.M.G.	CKL-R	[illegible]

DATE: 5-23-94 SCALE: N.T.S.	FIGURE 3-1	DRAWING NUMBER 3109-A100

1



LEGEND:

—…▽ SURFACE WATER LEVEL

NOTE:

1. THIS DRAWING IS NOT TO SCALE.

DRAFT

SCHEMATIC DIAGRAM OF
SURFACE WATER CONTROLS AND ICs
TAILINGS/IMPACTED SOILS
REMEDIAL ALTERNATIVE
STREAMSIDE TAILINGS OPERABLE UNIT

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1	5/26/94	ISSUED FOR PRELIMINARY DRAFT FEASIBILITY STUDY	T.M.G.	CAL-R	[illegible]

DATE: 5-23-94 SCALE: N.T.S.	FIGURE 3-2	DRAWING NUMBER 3109-A98

DRAWING NUMBER 3109-A98

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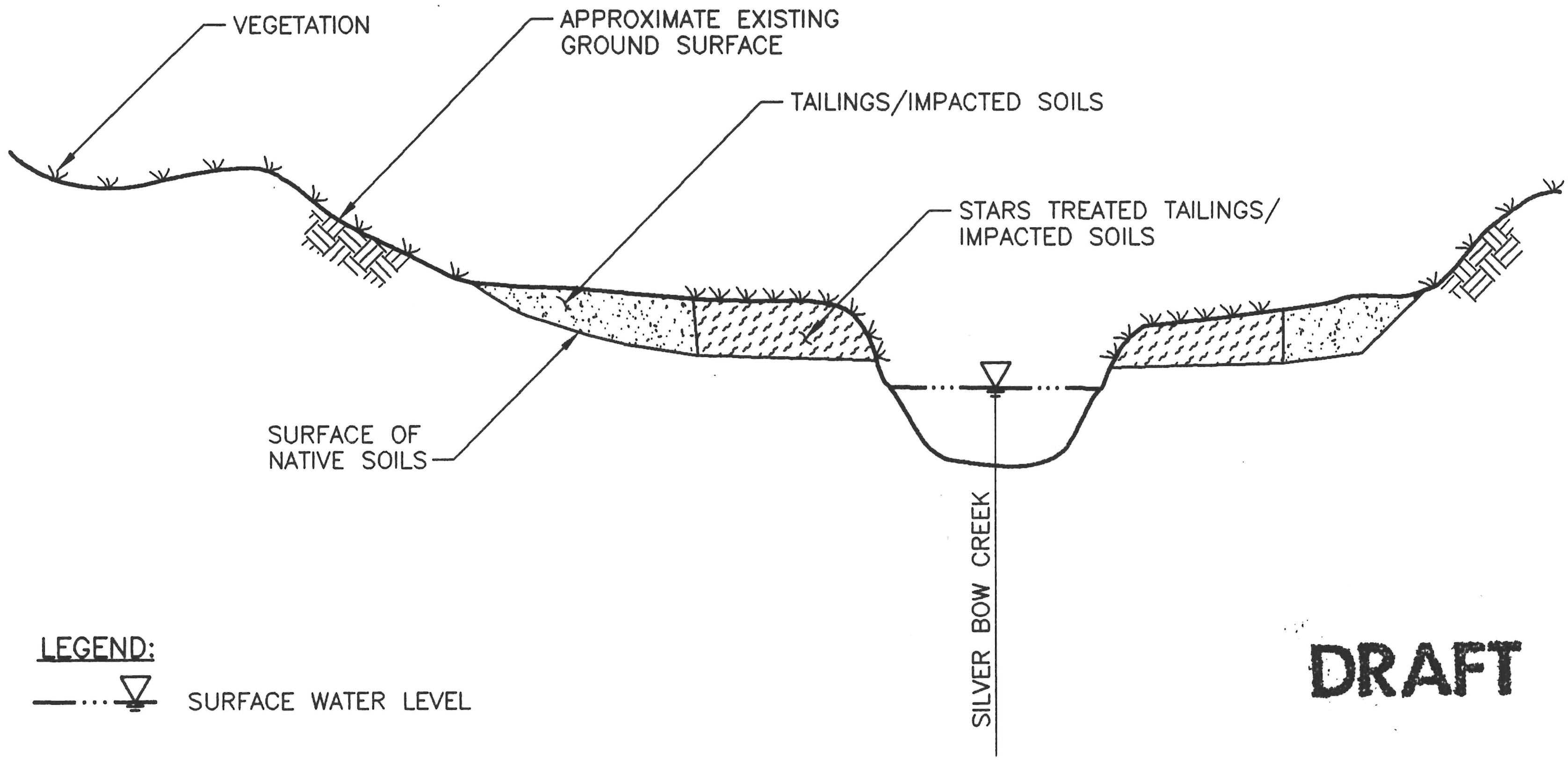

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LEGEND:

—··· ▽ SURFACE WATER LEVEL

NOTE:

1. THIS DRAWING IS NOT TO SCALE.

DRAFT

SCHEMATIC DIAGRAM OF
NEAR STREAM STARS AND ICs
TAILINGS/IMPACTED SOILS
REMEDIAL ALTERNATIVE
STREAMSIDE TAILINGS OPERABLE UNIT

PREPARED FOR

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No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
1	5/26/94	ISSUED FOR PRELIMINARY DRAFT FEASIBILITY STUDY	T.M.G.	CKL-R	[illegible]

DATE: 5-23-94 SCALE: N.T.S.	FIGURE 3-3	DRAWING NUMBER 3109-A97

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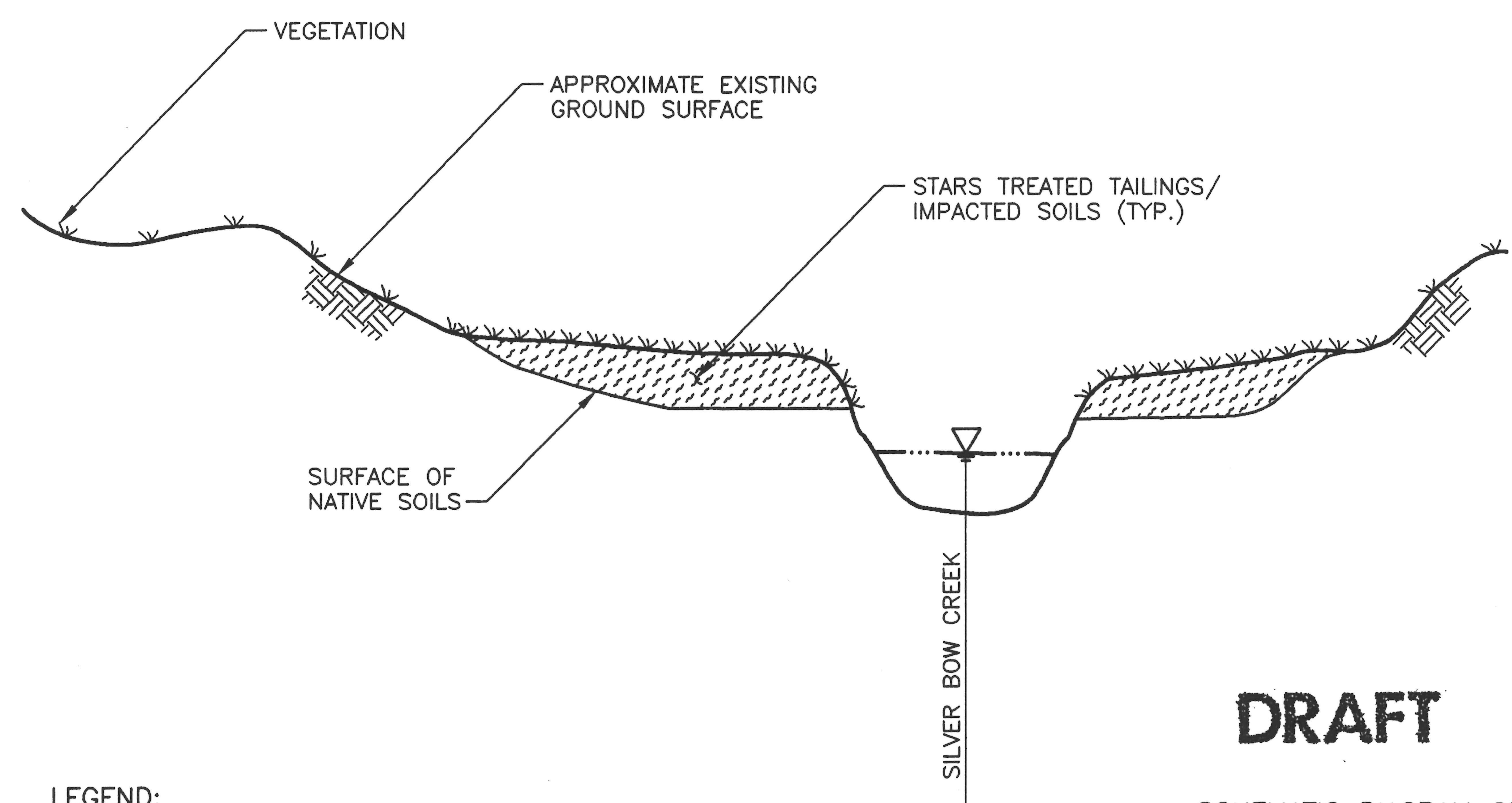

LEGEND:

—···▽ SURFACE WATER LEVEL

NOTE:

1. THIS DRAWING IS NOT TO SCALE.

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SCHEMATIC DIAGRAM OF
STARS AND ICs
TAILINGS/IMPACTED SOILS
REMEDIAL ALTERNATIVE
STREAMSIDE TAILINGS OPERABLE UNIT

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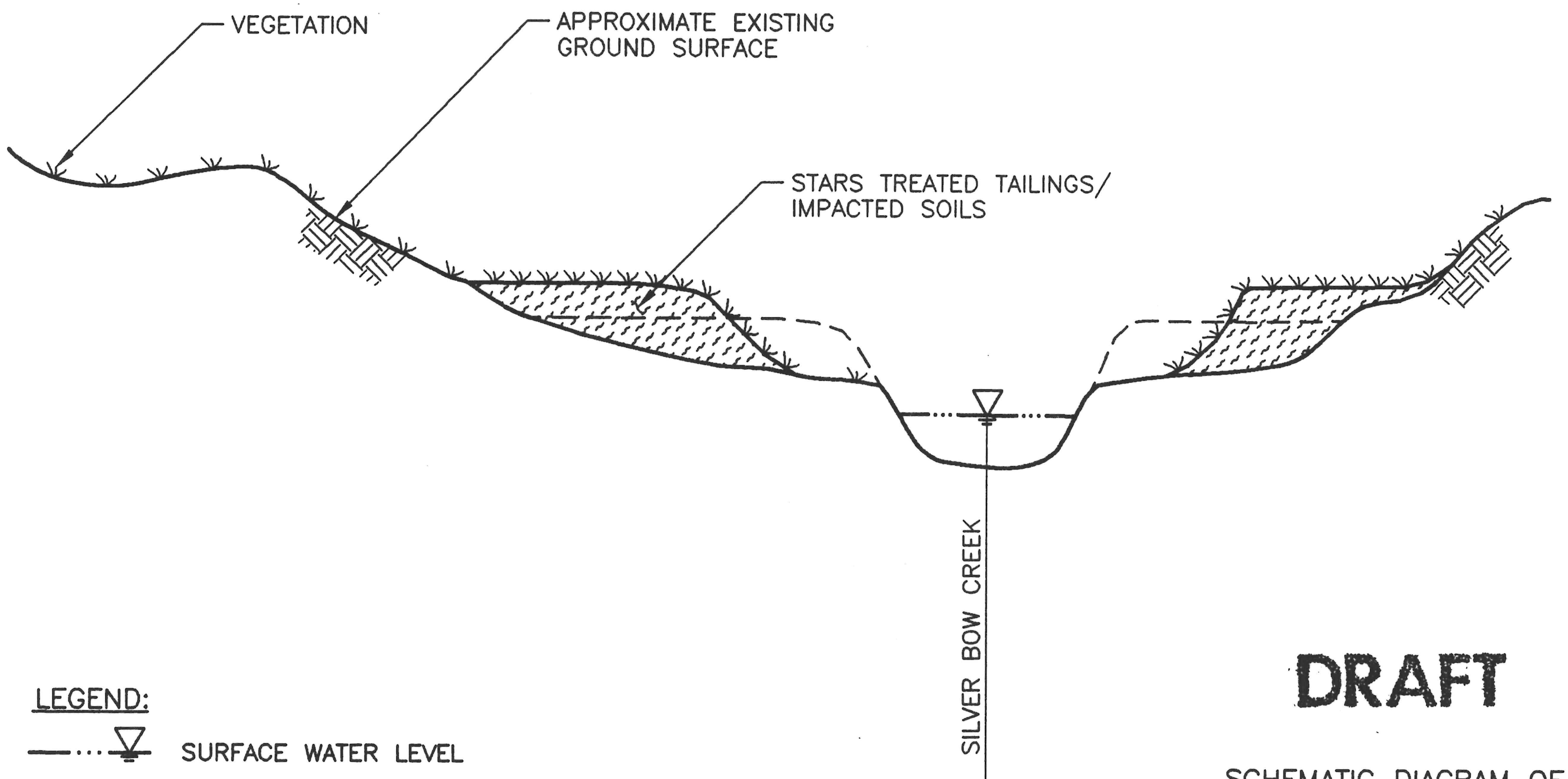
1	5/26/94	ISSUED FOR PRELIMINARY DRAFT FEASIBILITY STUDY	T.M.G.	CKL-R	mjs

DATE: 5-23-94 SCALE: N.T.S.	FIGURE 3-4	DRAWING NUMBER 3109-A101

DRAWING NUMBER 3109-A101



LEGEND:

—···▽ SURFACE WATER LEVEL

— — — — ORIGINAL TAILINGS/IMPACTED SOILS SURFACE

NOTE:

1. THIS DRAWING IS NOT TO SCALE.

DRAWING NUMBER 3109–A103

DRAFT

SCHEMATIC DIAGRAM OF
PARTIAL RELOCATION, STARS AND ICs
TAILINGS/IMPACTED SOILS
REMEDIAL ALTERNATIVE
STREAMSIDE TAILINGS OPERABLE UNIT

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1	5/26/94	ISSUED FOR PRELIMINARY DRAFT FEASIBILITY STUDY	T.M.G.	CKC-R	mjs

DATE: 5–23–94 SCALE: N.T.S.	FIGURE 3–5	DRAWING NUMBER 3109–A103

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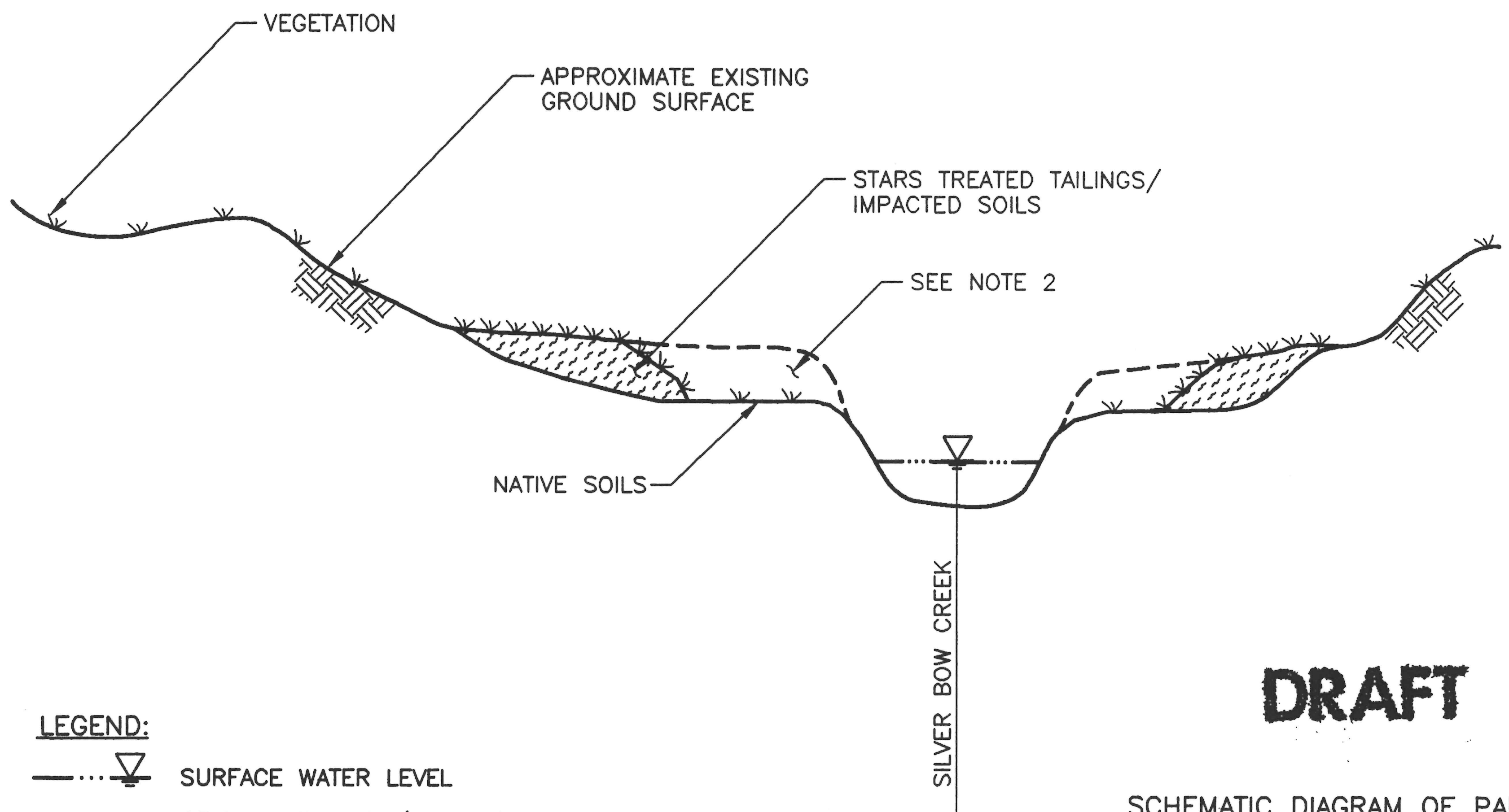

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LEGEND:

—···▽ SURFACE WATER LEVEL

– – – – ORIGINAL TAILINGS/IMPACTED SOILS SURFACE

NOTE:

1. THIS DRAWING IS NOT TO SCALE.
2. TAILINGS/IMPACTED SOILS REMOVED TO ON–SITE OR OFF–SITE REPOSITORY.

SCHEMATIC DIAGRAM OF PARTIAL REMOVAL, PARTIAL STARS AND ICs TAILINGS/IMPACTED SOILS REMEDIAL ALTERNATIVE
STREAMSIDE TAILINGS OPERABLE UNIT

PREPARED FOR

ARCO
ANACONDA, MONTANA

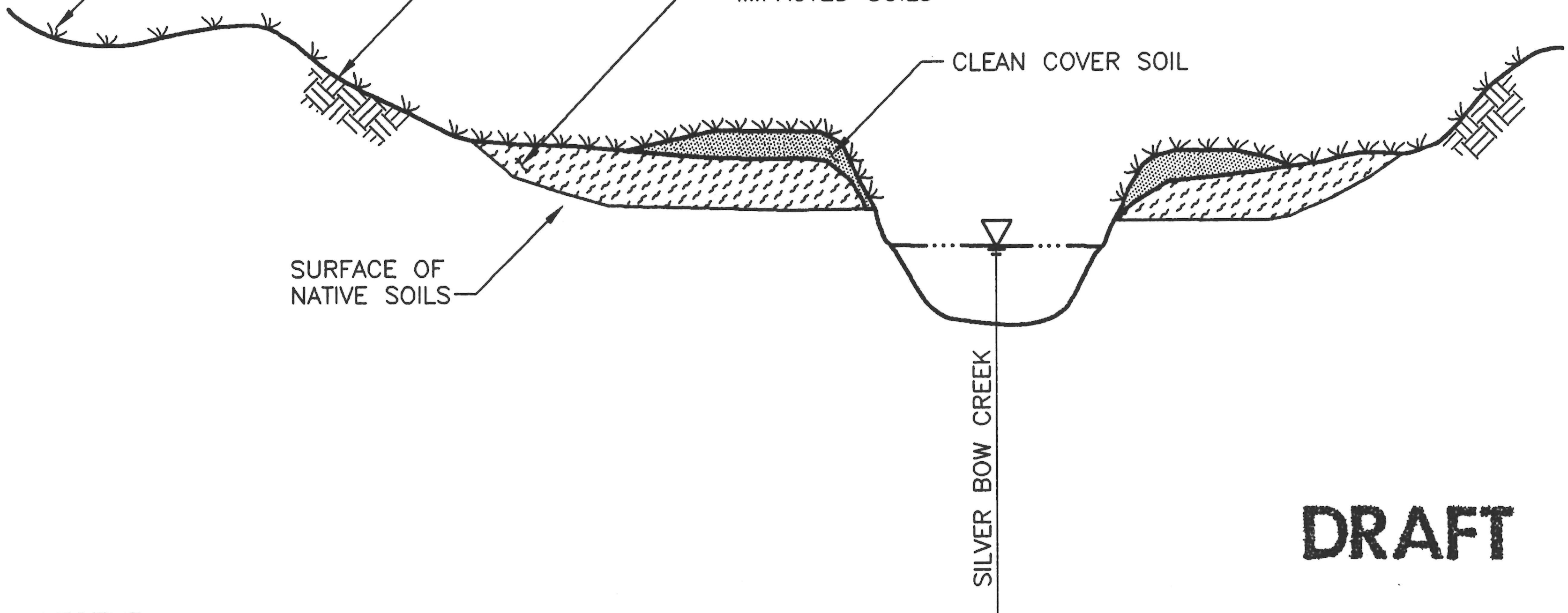
No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
1	6-1-94	ISSUED FOR PRELIMINARY DRAFT FEASIBILITY STUDY	T.M.G.	CKL-K	mjm

DATE: 5–23–94 SCALE: N.T.S.	FIGURE 3–6	DRAWING NUMBER 3109–A104

DRAWING NUMBER 3109–A104

1

DRAWING NUMBER 3109-A99



DRAFT

LEGEND:

SURFACE WATER LEVEL

NOTE:

1. THIS DRAWING IS NOT TO SCALE.

SCHEMATIC DIAGRAM OF
PARTIAL COVER, STARS AND ICs
TAILINGS/IMPACTED SOILS
REMEDIAL ALTERNATIVE
STREAMSIDE TAILINGS OPERABLE UNIT

PREPARED FOR

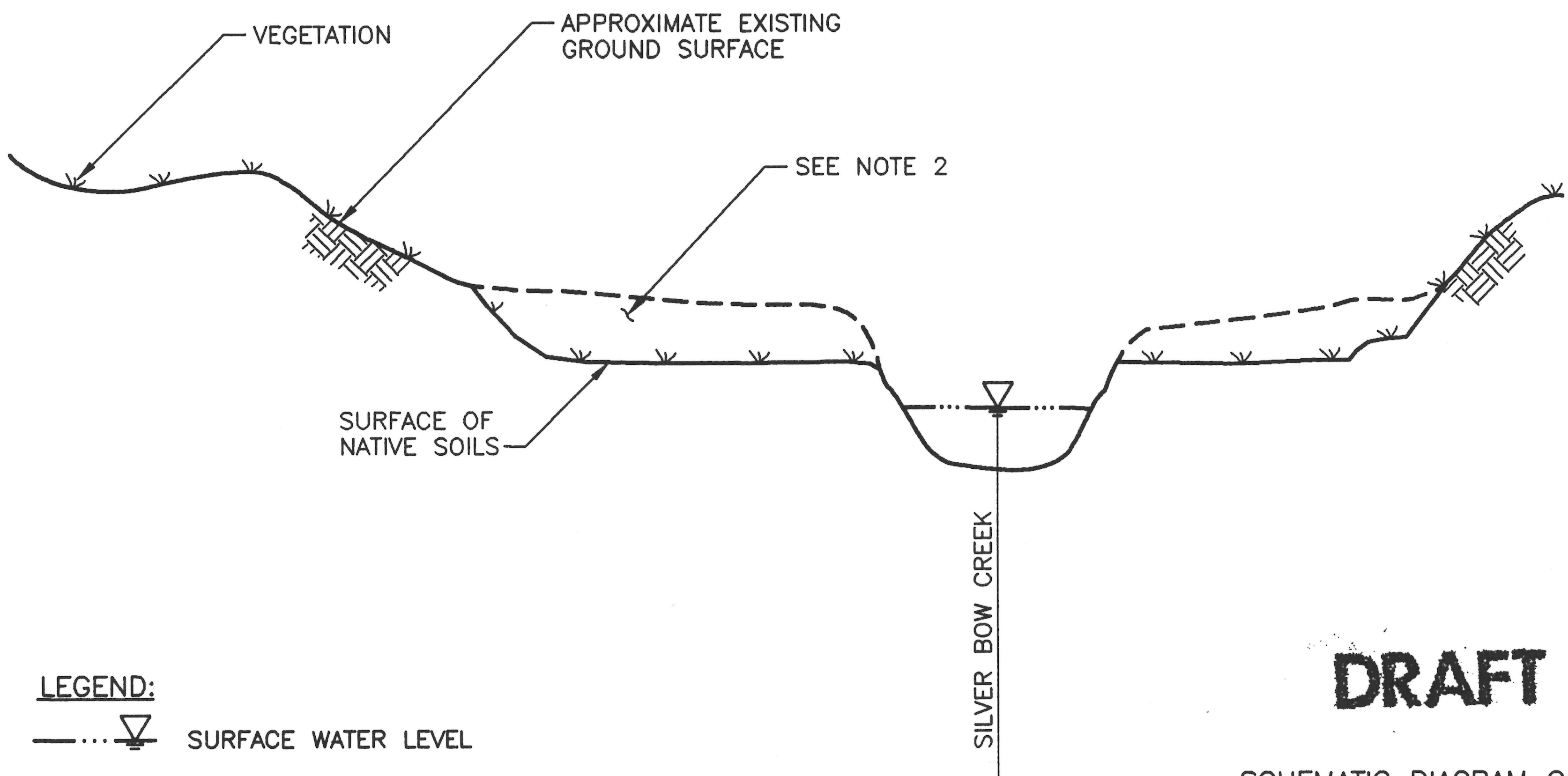
ARCO
ANACONDA, MONTANA

No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
1	5/26/94	ISSUED FOR PRELIMINARY DRAFT FEASIBILITY STUDY	T.M.G.	CKL-R	mjs

DATE: 5-23-94 SCALE: N.T.S.	FIGURE 3-7	DRAWING NUMBER 3109-A99

1

DRAWING NUMBER 3109-A102



LEGEND:

SURFACE WATER LEVEL

ORIGINAL TAILINGS/IMPACTED SOILS SURFACE.

NOTE:

1. THIS DRAWING IS NOT TO SCALE.
2. TAILINGS/IMPACTED SOILS REMOVED TO ON-SITE OR OFF-SITE REPOSITORY.

DRAFT

SCHEMATIC DIAGRAM OF EXCAVATION, REMOVAL AND ICs TAILINGS/IMPACTED SOILS REMEDIAL ALTERNATIVE STREAMSIDE TAILINGS OPERABLE UNIT

PREPARED FOR

ARCO
ANACONDA, MONTANA

No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
1	6-1-94	ISSUED FOR PRELIMINARY DRAFT FEASIBILITY STUDY	T.M.G.	CKL-R	[illegible]

DATE: 5-23-94 SCALE: N.T.S.	FIGURE 3-8	DRAWING NUMBER 3109-A102

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