

Transport of Antimony Processing Wastes in the Prospect Creek Drainage, Western Montana

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Abstract

We investigated the hydrogeologic behavior of the United States Antimony Corporation's 10-acre waste impoundment. We found that waste fluids from the impoundment contribute measurable concentrations of antimony, sulfate, and sodium to the underlying ground water system. The concentrations and transport of these contaminants are strongly influenced by large fluctuations in the water table beneath the disposal impoundments. Water table fluctuations are, in turn, driven by seasonally variable ground water recharge from Prospect Creek.

Prospect Creek carries a measurable dissolved antimony load attributable to the impoundment site. We found this flux to be maximized under high spring streamflow conditions. Under the conditions studied, the discharged antimony is unlikely to significantly degrade the mainstem Clark Fork River. However, we have estimated the impounded wastes contain up to 100,000 pounds of water-soluble antimony, and under the existing hydrologic conditions they will continue to provide the alluvial ground water system and Prospect Creek with a low-grade source of this metal.

Introduction

Prospect Creek is a western tributary of the Clark Fork River, joining the mainstem at Thompson Falls, Montana (fig.1). Its 182-mi² drainage basin is underlain almost entirely by Belt Series metasediments (4). Accumulations of alluvial and reworked glacial sediments form discontinuous valley bottom deposits up to 1/2 mile wide and >300 feet thick along the middle and lower reaches of the drainage.

The United States Antimony Corporation (USAC) facility is located next to Prospect Creek, about 14 miles west of Thompson Falls. It includes a waste impoundment of about 10 acres in surface area, excavated in a stream terrace formed on one of these deposits of unconsolidated fill. The impoundments contain about 2.8 million ft³ of tailings from the USAC flotation mill; they have also received spent leach liquor and autoclave residues from the plant's other processes.

Lolo National Forest personnel collected grab samples from standing pond fluids in 1980 and found that concentrations of dissolved antimony and arsenic were in the range of 20-35 mg/L in the high-pH pond environment. Because of these high metal concentrations and uncertainties about the permeability of the impoundments, the Forest Service raised the question of the pond's possible impacts on the Prospect Creek system. With this study, we sought to resolve the question of water quality impacts at

this site, and to identify the hydrologic mechanisms of importance in determining contaminant concentrations and transport in this type of hydrologic system.

No information pertaining to the hydrogeologic behavior of this valley fill aquifer existed prior to this study, although the generally recognized ephemeral nature of Prospect Creek through the study reach suggested substantial seasonal fluctuations in the water table. There has been considerable site-specific research on the hydrogeologic impacts of historical and current mine waste disposal practices in neighboring districts of the Coeur d'Alene mountains (11,5,7). Some of this literature documents the importance of water table fluctuations in topographically constricted alluvial aquifers (1). Although there is a considerable body of literature describing the epidemiological effects of antimony (8,9) and some aspects of its environmental behavior (2,3,6), few field data are available on the behavior of antimonial wastes in shallow ground water systems.

Methods

We measured the discharge of Prospect Creek and its tributaries at nine stations along a 3-mile reach defined as the study area (fig. 2). Ideally, these data provide a reasonably complete picture of the surface water inputs and output of this small area. Wading stream gauging was not always possible at high discharges, resulting in incomplete data for some dates.

Seven monitoring wells were eventually installed around the impoundment (fig. 3). A small budget and very difficult drilling conditions severely limited the depth of these wells. Because of the seasonally deep unsaturated zone, none reach the water table during very low water. USb-3 through 7 provided data only during late spring and early summer. The response of the local ground water system to the discharge of Prospect Creek was of primary interest in this study, so water level data for these wells usually correspond to stream discharge data from Prospect Creek and its tributaries. Additional water table elevations are available from the USAC supply wells (USAC 111 and 112).

The timing of the water sample collections from these wells and gauging stations also correspond to the collection of potentiometric and discharge data. We collected samples for general chemistry and for trace metal analyses at each station, filtered them in the field whenever possible (freezing weather prevented this on a few occasions), and preserved the trace metal samples with nitric acid.

We also installed nine suction lysimeters near the bottom of the waste impoundment to sample the in situ composition of the interstitial fluids.

Three techniques provided information on the hydraulic conductivity of Prospect Creek's unconsolidated fill. Slug tests (1) conducted on the shallow monitoring wells produced low values apparently not representative of the deposit as a whole. An aquifer test on the USAC supply wells and mass-balance calculations of the entire study reach produced the much higher values used in our ground water velocity calculations.

Finally, seven samples of USAC's waste solids (three with duplicate splits) were dried, ground, and extracted in water to estimate the quantity of antimony available in a readily soluble state to oxygenated water. The method used was adapted from the "EP Toxicity" test (10). Five gram samples of the ground material were agitated for 24 hours in 100 mL of deionized water. The pH of the samples was controlled with periodic additions of acetic acid; the initial high pH and buffering capacity of many

of the samples made this procedure difficult and the pH control inexact. However, the final pH values for these leachates were within or below the 6.8 to 7.2 range measured in Prospect Creek and the local ground water.

Results and Discussion

Figure 4 shows the cross-sectional geometry and area of the unconsolidated sediments near the USAC plant and disposal site. The cross-sectional area of fill increases abruptly from 90,000 to over 200,000 ft² between profiles A and B. The high infiltration capacity of the creek channel and the increase in aquifer thickness and cross-sectional area result in rapid infiltration of Prospect Creek's flow into the underlying sediments below 5-1. As much as 35.6 ft³/s of surface flow entered the alluvial ground water system between 5-1 and 5-2 during one stream-gauging period.

The water table in the vicinity of the USAC impoundments responds rapidly to changes in the rate of this recharge. Figure 5 shows continuous water level records from wells Usb-1 and Usb-2 relative to the Prospect Creek discharge record at the downstream USGS station. Runoff events during winter and spring of 1984 produced water table changes as rapid as 1.9 ft/d and 1.0 ft/d, respectively. This Usb-1 rate was sustained for a period of at least 9 days during the spring of 1984.

Analyses of our limited head data by flow net construction suggest that the high heads associated with the stream channel recharge create a steep gradient to the northeast of 5-1 toward the ponds (fig. 6). Ground water flows beneath the waste site and then to the east, paralleling the creek until the creek channel crosses the flow path and ground water discharge to the channel begins.

Table 1 shows partial chemical analyses of samples of the interstitial pond fluid. Although the precision of the anion analyses was reduced by unspecified interferences (probably caused by organic milling reagents), sulfate and sodium levels are high. In addition, variable but high dissolved antimony and arsenic levels occur throughout the impoundment.

Background ground water concentrations at USb-2 and the USAC supply well show concentrations of TDS (total dissolved solids) at or below 20 mg/L, sodium and sulfate in the 2- to 3-mg/L range, and dissolved antimony concentrations which never exceed the detection limit of 0.005 mg/L. Results of chemical analyses for selected dates are shown in table 2. Wells located downgradient from the ponds contain elevated levels of TDS, sodium, sulfate, and antimony. Wells located southeast of the ponds did not usually show elevated levels of USAC waste constituents. The distribution of sodium, sulfate, and antimony in the ground water system further substantiates the extrapolated ground water flow field.

Figure 7 presents the observed relationship between water table elevations and the concentrations of TDS, sodium, and sulfate at USb-1. A water table rise in mid-March, following declining levels in February and early March, is accompanied by sulfate, sodium, and TDS maxima. The relatively stable position of the water table from late March through early July corresponds to a general decline of ground water contaminant concentrations. With the apparent exception of the June sampling date, dissolved antimony concentrations follow a similar pattern (fig.8).

During the period of our study, waste inputs to the USAC impoundments appeared to average less than 5 gpm. We believe the inflow rate was insufficient to create a ground water mound beneath the ponds. Under these conditions, a vadose zone varying in depth from less than 5 to more than 50 feet underlay

the ponds. The maximum depth of this unsaturated zone occurred during the late summer/fall dry season; this water table minimum and another low period in midwinter dropped the water table below the depth of our monitoring wells.

The leakage of fluids from the ponds, the presence of the underlying vadose zone, and the rapid rise and fall of the water table are key elements in conceptually modeling the changes we observed in ground water and surface water chemistry.

Figure 9 shows schematically our model of the interrelationship of the vadose zone, water table position, and the resulting concentrations of USAC waste constituents in the down gradient ground water. Unsaturated flow under a vertical hydraulic gradient moves waste fluids from the ponds toward the water table. However, some of that fluid is temporarily stored as soil moisture in the vadose zone. During periods of low water table and a correspondingly thick vadose zone, waste fluids are distributed over a zone extending more than 50 feet below the pond surface (fig.9A).

As the water table rises in response to recharge from Prospect Creek, the waste stored in the area newly saturated with ground water is entrained in the rising ground water (fig. 9B). This produces increased concentrations of waste constituents in the ground water underlying the pond, and the mixing of poorer quality water throughout the 50+ foot zone of periodic saturation. The result is a pulse of relatively high-solute water migrating from beneath the pond area to the east in a down gradient direction (fig. 9C). A sustained high water table allows the ground water to purge that portion of the aquifer, which during low recharge and water table periods stores leaking pond fluids.

Variations in the fluid inputs to the impoundments, caused by seasonal precipitation patterns and by changes in USAC's operations, will also generate fluctuations in the ground water concentrations of the plant's waste products. These variations can be independent of the water table's position. We did not attempt to quantify the relative inputs of direct recharge from the impoundments and vadose zone waste entrainment. However, based on the small 1984 plant output and the low hydraulic conductivity of the waste solids, we believe vadose water entrainment to be the dominant process affecting containment concentrations in ground water during 1984. As shown in figure 7, Concentrations of TDS, sodium, and sulfate decline with time as the high water table flow system is sustained. With low flows in Prospect Creek, the corresponding decline in the water table allows the vadose waste accumulation cycle to begin again.

Our estimates of ground water transport times for this system, 13 to 34 ft/d, suggest that 369 to 141 days are required for ground water delivery of USAC material from the impoundment site 4,800 feet to Prospect Creek. The entrainment mechanism described implies that water table fluctuations may strand some of the contaminant load as vadose soil moisture at intermediate points along the flow path between the ponds and Prospect Creek. This material can be re-entrained later by a rising water table. These processes probably act to "smear" the pulses of solute generated below the pond site into a longitudinally continuous zone of low-grade ground water and vadose zone contamination.

The impact of the ponds on the chemistry of Prospect Creek can be seen by comparing the ionic concentrations of the creek at S-1 and S-2, stations which are upgradient of the ponds, with those of S-3 through S-6 (table 2). Table 3 shows the apparent flux of anthropogenic antimony out of the study reach (ending at S-6 in fig. 2) on two 1984 dates. "Low background" and "high background" scenarios are based on measured antimony concentrations at S-6 and hypothesized natural concentrations of 0.001

and 0.004 mg/l, respectively. Since the" background concentrations of dissolved antimony were below our detection limit of 0.005 mg/L on these dates, these two hypothetical correction values were chosen to give a range of conservative values for sources within the study reach. In fact, the normal background levels of dissolved antimony may be below the 0.001 mg/L value. It appears that most dissolved antimony transport out of the study area occurs under high flow conditions at relatively dilute concentrations. Sodium and sulfate budgets for the study reach yield similar results.

Figure 10 summarizes the preliminary results of agitated water leach tests run on a limited selection of samples of USAC waste solids. Although these provide only a general picture of the occurrence of soluble antimony within the impoundments, it is clear that substantial quantities are distributed throughout the site. These data indicate the impoundment probably contains between 60,000 and 100,000 pounds of antimony in a water-soluble and environmentally mobile form.

Conclusions

Our study shows the effects of large seasonal water table fluctuations on a waste impoundment discharging small but significant quantities of effluent to the underlying sediments. Although the facility itself was virtually inoperative during the study, levels of waste constituents in the down gradient ground water and in Prospect Creek appear to vary substantially under the influence of the site's natural hydrogeologic system. This emphasizes the importance of the specific hydrogeologic system to the performance of such waste disposal impoundments.

The concentrations of USAC waste constituents we found in Prospect Creek are generally low. Under the existing conditions, Prospect Creek's contribution of dissolved antimony must generate very low concentrations when diluted by the Clark Fork's flow. However, without changes in the design or operation of the impoundment, generation of low-grade contamination of local ground water and of Prospect Creek will continue.

Special care should be taken at this site to prevent physical erosion and mechanical transport of USAC's stored waste solids. Our preliminary results indicate that they include a rather high fraction of soluble antimony; if a large quantity of these were to reach Prospect Creek, we would expect high local concentrations of dissolved antimony and possible impacts to the down- stream Clark Fork reach to result.

Acknowledgements

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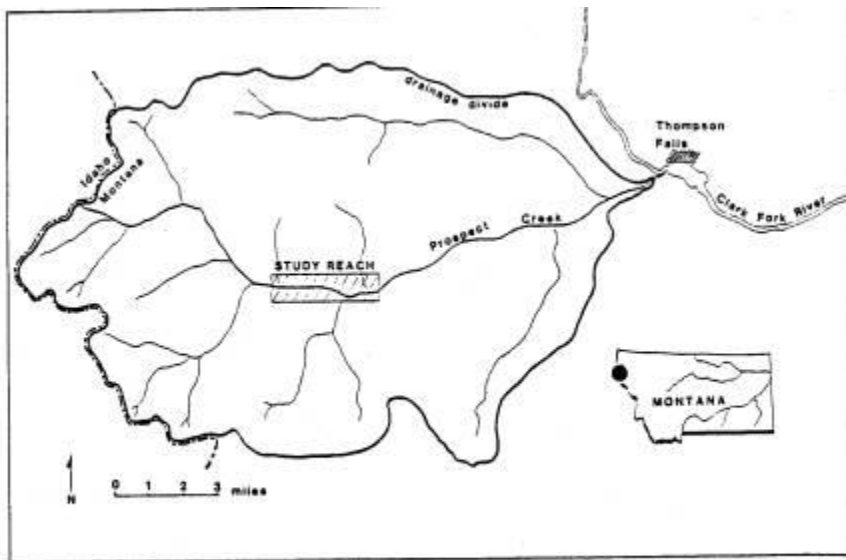


Figure 1. Location map.

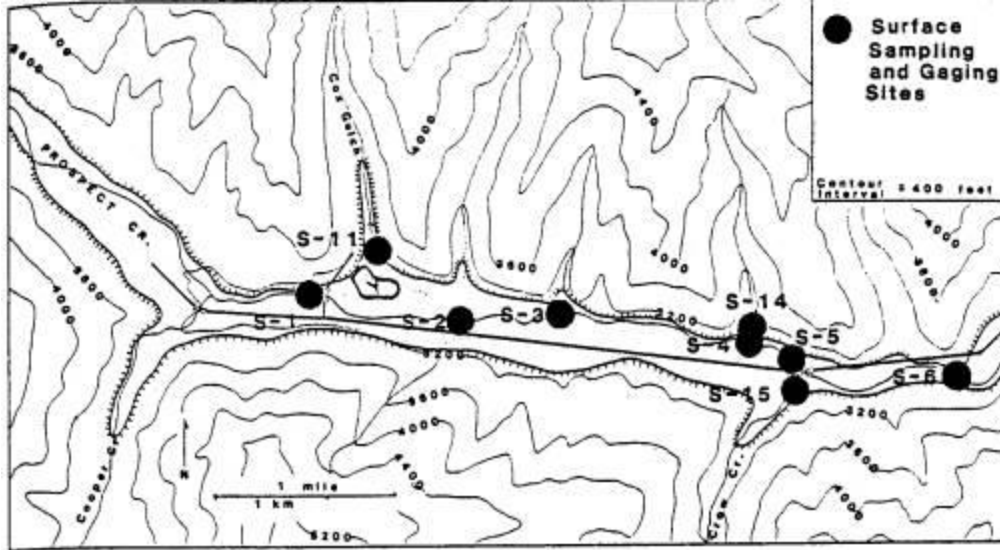


Figure 2. Map of study area, showing surface water data collection sites.

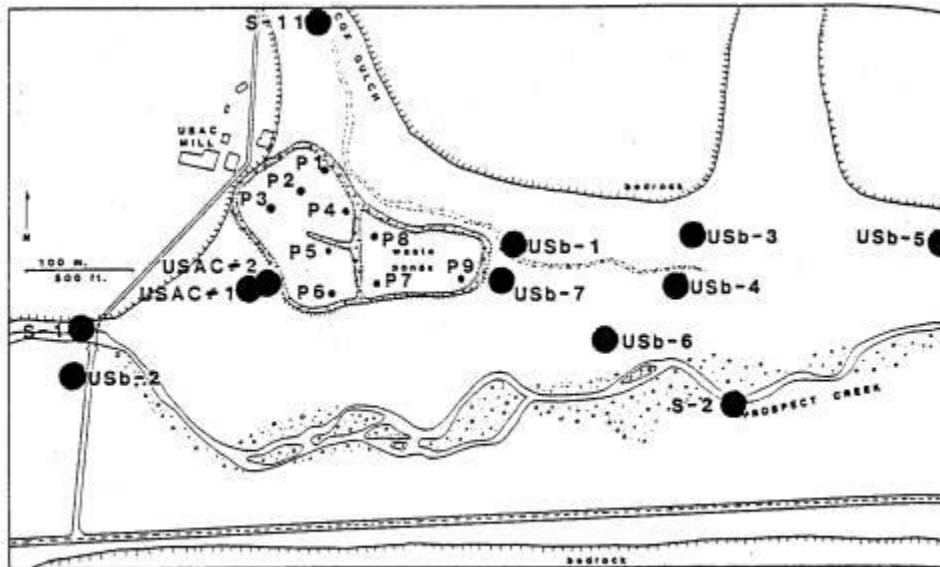


Figure 3. Location of ground water data collection sites.

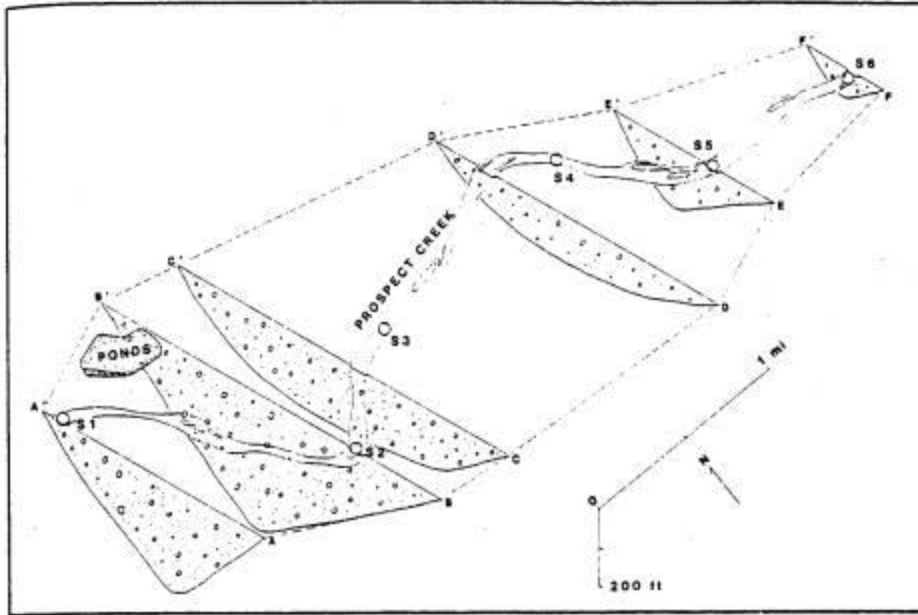


Figure 4. Geometry of unconsolidated sediments through the study reach.

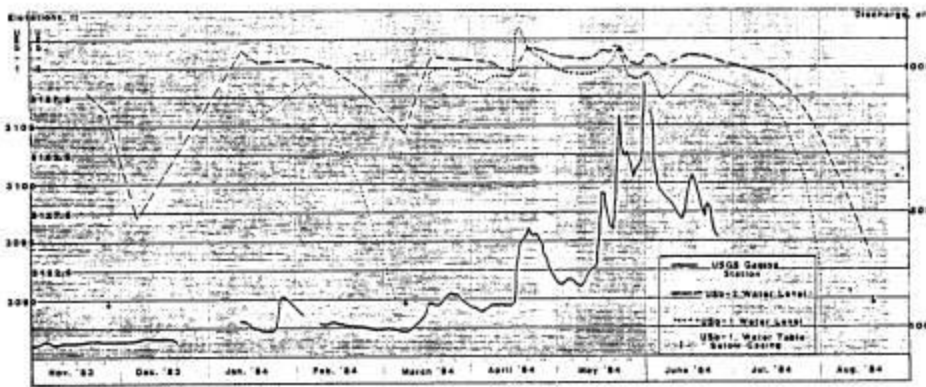


Figure 5. Hydrographs of USB-1, USB-2, and Prospect Creek at the USGS station.

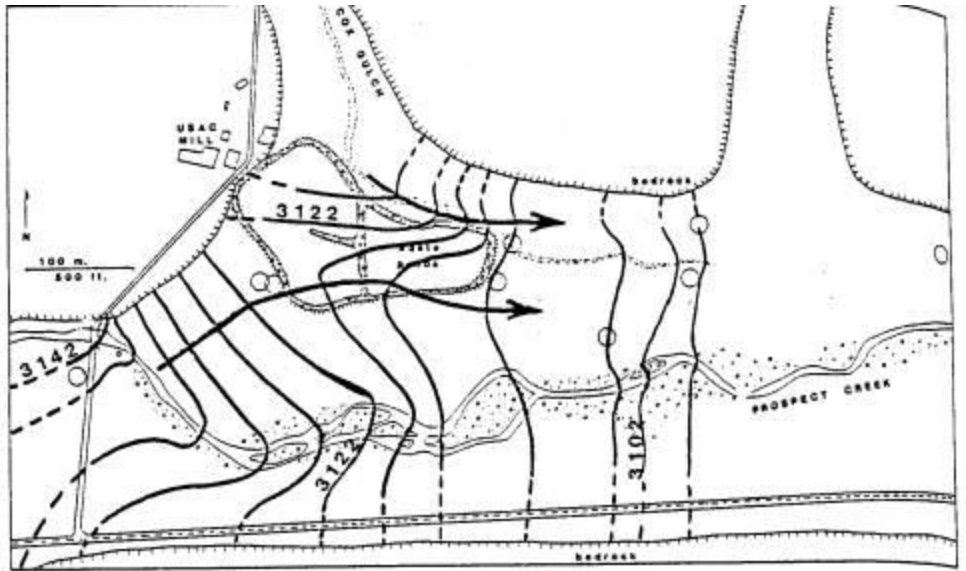


Figure 6. Potentiometric map of the study area for June 16, 1984.

Table 1.--Partial chemistry of interstitial waste fluids. (All values as mg/L)

Lysimeter Samples										
	P-1 2/6/84	P-2 11/27/83	P-2 8/18/84	P-4 12/6/83	P-4 2/6/84	P-4 8/18/84	P-5 11/27/83	P-7 11/27/83	P-9 12/6/83	P-9 2/6/84
Sodium	2185	---	630	---	2575	---	---	---	638	---
Sulfate	2063	---	---	---	4800	---	---	---	572	---
Antimony	---	89.0	100	6.3	---	4.7	15.0	11.0	---	29.0
Arsenic	---	410.0	380	40.0	---	28.0	24.0	6.3	---	34.0
Iron	---	BDL	0.40	3.4	---	2.7	0.53	BDL	---	BDL
Manganese	---	0.12	0.17	3.0	---	2.5	0.047	0.064	---	BDL
Cadmium	---	---	---	---	---	---	---	0.052	---	0.29
Copper	---	---	---	---	---	---	---	BDL	---	BDL
Lead	---	---	---	---	---	---	---	BDL	---	BDL
Nickel	---	---	---	---	---	---	---	BDL	---	BDL
Zinc	---	---	---	---	---	---	---	0.017	---	0.014

Table 2.--Water chemistry data for selected dates.

	S-1	S-3	S-5	S-6	S-15	S-11	USB-1	USB-2	USB-5	USB-6
pH	7.0	6.8	6.8	7.2	7.3	7.0	6.7	6.8	---	---
(lab)	7.1 ^B	6.7 ^{**}	7.1*	7.2*	7.6*	7.0*	7.0*	---	---	---
	7.0	7.0	7.0 ^{**}	7.1 ^{**}	7.6 ^{**}	7.2 ^{**}	7.1 ^{**}	6.8 ^{**}	6.6 ^{**}	6.8 ^{**}
TDS	19.2	33.8	27.5	31.0	51.7	21.0	93.4	18.8	---	---
	16.9*	42.2*	26.4*	30.5*	57.2*	19.4*	66.2*	---	---	---
	10.9 ^{**}	12.7 ^{**}	14.5 ^{**}	16.2 ^{**}	27.4 ^{**}	18.0 ^{**}	86.3 ^{**}	14.4 ^{**}	26.6 ^{**}	13.5 ^{**}
bicarbonate (calculated)	11.3	14.4	15.8	17.8	37.2	14.2	18.1	11.0	---	---
	10.2*	9.9*	13.0*	16.4*	41.1*	10.5*	24.8*	---	---	---
	6.7 ^{**}	7.0 ^{**}	8.5 ^{**}	10.1 ^{**}	24.4 ^{**}	9.8 ^{**}	28.3 ^{**}	8.2 ^{**}	12.1 ^{**}	8.4 ^{**}
Sulfate	2.5	10.4	5.1	5.5	1.7	2.1	45.6	2.6	---	---
	2.3*	21.5*	6.4*	6.2*	1.6*	4.1*	29.8*	---	---	---
	1.3 ^{**}	2.0 ^{**}	1.8 ^{**}	1.7 ^{**}	1.0 ^{**}	3.0 ^{**}	35.1 ^{**}	1.8 ^{**}	6.2 ^{**}	1.4 ^{**}
Chloride	0.22	0.33	0.23	0.22	0.22	0.25	0.79	0.19	---	---
	0.17*	0.52*	0.24*	0.27*	0.21*	0.21*	0.91*	---	---	---
	0.13 ^{**}	0.13 ^{**}	0.14 ^{**}	0.11 ^{**}	0.16 ^{**}	0.14 ^{**}	0.55 ^{**}	0.16 ^{**}	0.23	0.13
Sodium	1.4	6.9	3.4	3.3	1.4	2.0	27.2	1.4	---	---
	1.4*	9.5*	3.7*	3.4*	1.4*	1.9*	22.1*	---	---	---
	0.9 ^{**}	1.5 ^{**}	1.4 ^{**}	1.3 ^{**}	0.7 ^{**}	1.8 ^{**}	27.2 ^{**}	1.3 ^{**}	3.6 ^{**}	1.1 ^{**}
Calcium	2.1	1.8	2.5	3.4	8.0	2.1	0.8	2.2	---	---
	1.8*	2.2*	2.2*	3.0*	6.9*	1.9*	0.8*	---	---	---
	1.2 ^{**}	1.3 ^{**}	1.4 ^{**}	1.8 ^{**}	5.2 ^{**}	1.6 ^{**}	0.2 ^{**}	1.4 ^{**}	1.7 ^{**}	1.4 ^{**}
Magnesium	0.8	0.7	1.0	1.1	2.2	1.0	0.3	0.7	---	---
	0.7*	1.1*	0.9*	1.2*	2.4*	0.9*	0.4*	---	---	---
	0.4 ^{**}	0.4 ^{**}	0.5 ^{**}	0.6 ^{**}	1.4 ^{**}	0.7 ^{**}	0.1 ^{**}	0.5 ^{**}	0.9 ^{**}	0.5 ^{**}
Potassium	0.4	0.5	0.3	0.3	0.3	0.4	0.8	0.4	---	---
	0.3*	0.4*	0.3*	0.3*	0.3*	0.4*	0.9*	---	---	---
	0.3 ^{**}	0.2 ^{**}	0.3 ^{**}	0.3 ^{**}	0.3 ^{**}	0.4 ^{**}	0.6 ^{**}	0.3 ^{**}	0.7 ^{**}	0.4 ^{**}
Antimony	BDL	0.080	0.020	0.022	BDL	BDL	1.30	BDL	---	---
	BDL*	0.064*	0.024*	0.019*	BDL*	BDL*	0.14*	---	---	---
	BDL ^{**}	0.025 ^{**}	0.012 ^{**}	0.087 ^{**}	BDL ^{**}	BDL ^{**}	1.90 ^{**}	BDL ^{**}	0.017 ^{**}	BDL ^{**}
Arsenic	BDL	BDL	BDL	BDL	BDL	BDL	0.012	BDL	---	---
	BDL*	BDL*	BDL*	BDL*	BDL*	BDL*	BDL*	---	---	---
	BDL ^{**}	BDL ^{**}	BDL ^{**}	0.007 ^{**}	BDL ^{**}	BDL ^{**}	0.019 ^{**}	BDL ^{**}	BDL ^{**}	0.006 ^{**}
	2.5 = value for 3/17/84 All concentrations as milligrams per liter									
	2.5* = value for 4/7/84									
	2.5 ^{**} = value for 6/16/84 BDL = less than .005 milligrams per liter									

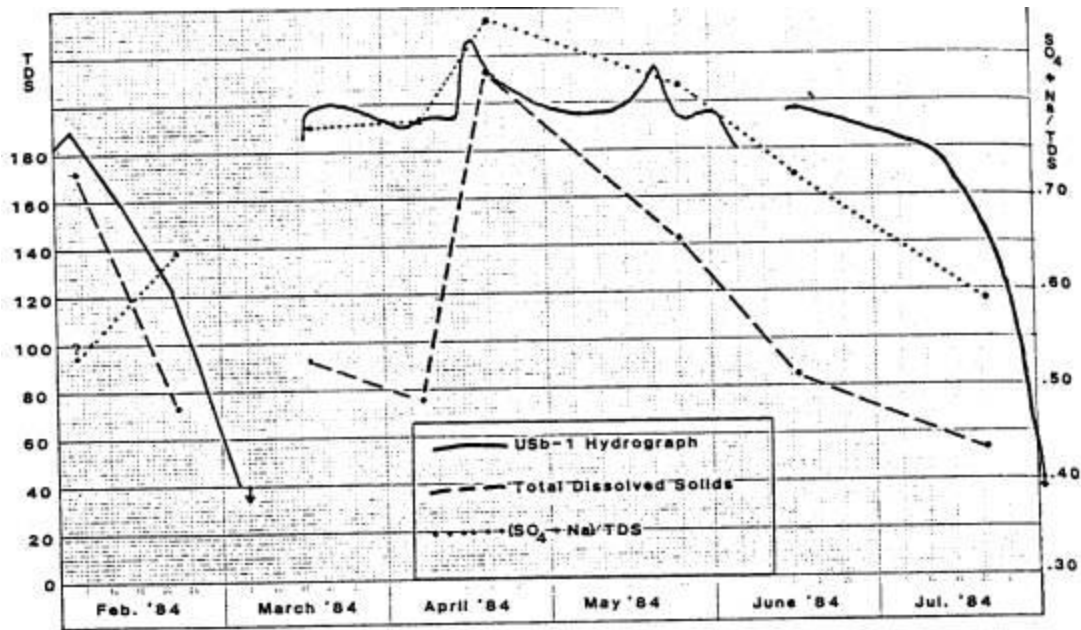


Figure 7. Relationship of selected chemical parameters to water levels in USB-1. (TDS as mg/L.)

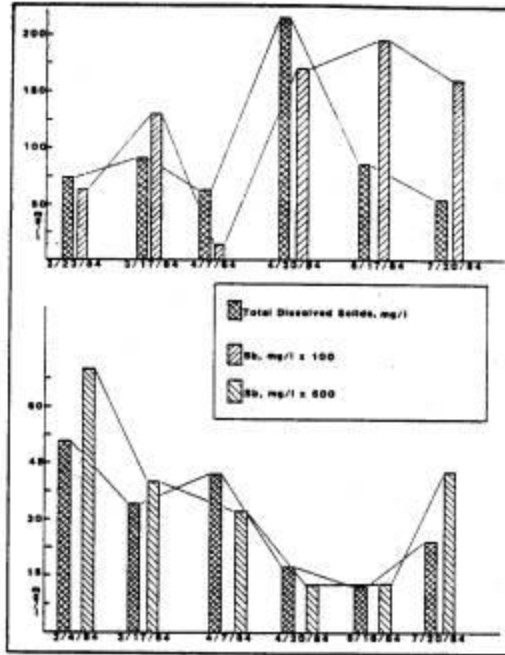


Figure 8. Total dissolved solids and antimony concentrations at USB-1 (top) and S-3 (bottom).

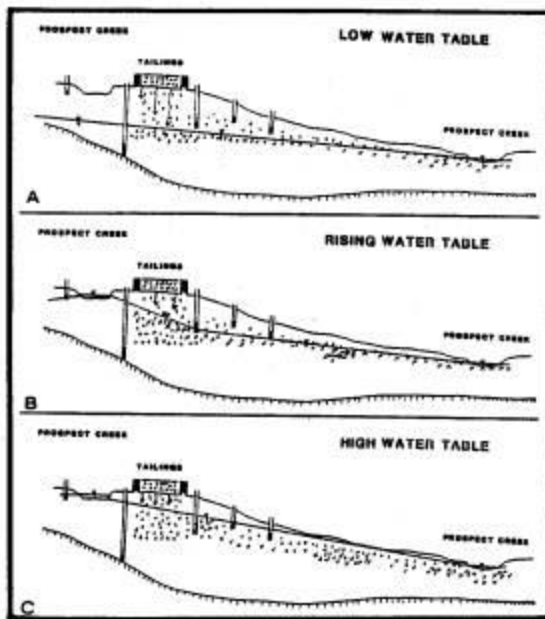


Figure 9. Conceptual model of contaminant entrainment mechanism.

Table 3.--Contaminant flux at S-6 in lbs/day and parameters used in their calculation

Chemical mass balance parameters for the dates 7/20/84 (top) and 4/7/84 (bottom)							
	S-6	S-15 + underflow	S-1	Underflow at S-1	S-14	S-11 + underflow	S-6 net attributable to waste ponds and other sources
Discharge	54.8 cfs	12.3 cfs	18.6 cfs	12.9 cfs	0.012 cfs	2.0 cfs	
SO ₄							
mg/L	2.3	1.2	1.8	1.4	8.6	3.0	
lb/day	678.7	79.5	180.4	97.2	0.56	32.3	288.8
NA							
mg/L	1.9	1.0	1.3	1.3	3.9	1.8	
lb/day	560.7	66.2	130.3	90.3	0.25	19.4	254.3
Sb							
mg/L	0.013	0.004*	0.004*	0.004*	0.004*	0.004*	
lb/day	3.84	0.265*	0.40*	0.278*	2.6 x 10 ^{-4*}	0.043*	2.85*
		0.001**	0.001**	0.001**	0.001**	0.001**	
		0.066**	0.10**	0.069**	6.5 x 10 ^{-5**}	0.011**	3.59**
<hr/>							
	S-6	S-15 + underflow	S-1	Underflow at S-1	S-14	S-11 + underflow	S-6 net attributable to waste ponds and other sources
Discharge	84.9 cfs	12.5 cfs	39.0 cfs	14.0 cfs	0.10 cfs	10.3 cfs	
SO ₄							
mg/L	6.2	1.6	2.3	2.3	6.1	4.1	
lb/day	2834.4	107.7	483.0	173.4	3.3	227.4	1839.6
NA							
mg/L	3.4	1.4	1.4	1.4	2.7	1.9	
lb/day	1554.3	94.2	294.0	105.5	1.5	105.4	953.7
Sb							
mg/L	0.019	0.004*	0.004*	0.004*	0.004*	0.004*	
lb/day	8.69	0.269*	0.84*	0.302*	2.25 x 10 ^{-3*}	0.222*	7.05*
		0.001**	0.001**	0.001**	0.001**	0.001**	
		0.067**	0.21**	0.075**	5.38 x 10 ^{-4**}	0.055**	8.28**

*High-Sb assumption.

**Low-Sb assumption.

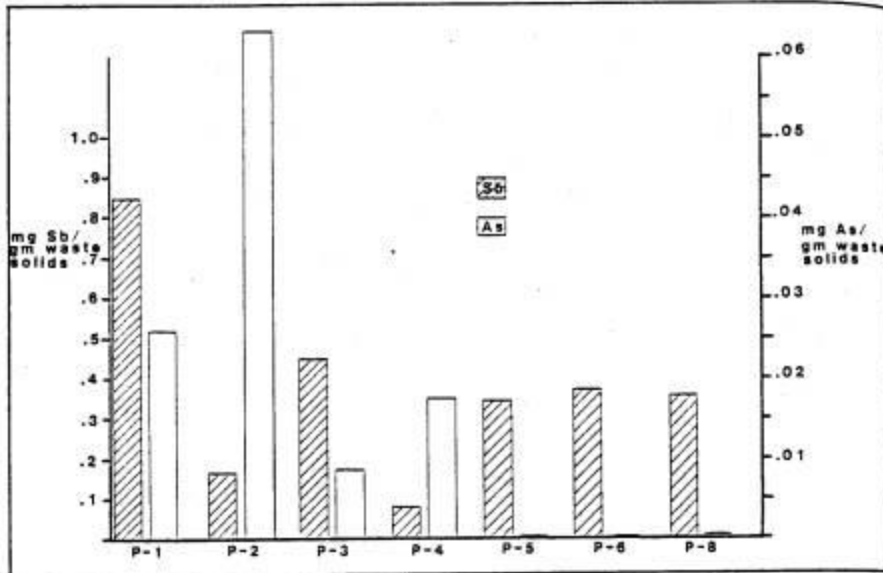


Figure 10. Results of agitated water extracts of USAC waste material.