CHARACTERIZATION OF AN ACID MINE DRAINAGE SITE IN SOUTHERN ILLINOIS[1]

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Abstract: Two seams at the Tab-Simco abandoned underground coal mine site in southern Illinois were mined intermittently from the 1890's until 1955, and later surface mined. The stripping operations resulted in several break-ins into the old underground works which were later buried by mine spoil. The resulting mine pool in the lower of the two seams has been producing an average of ~150 m^3 per day of acid mine drainage (AMD) for the past few decades. After exiting through the break-ins, the contaminated water flows along discrete pathways through the base of the spoil and emerges as 5 perennial seeps. The AMD has contaminated a nearby stream and has produced a 4 ha "kill zone" within its otherwise forested floodplain. AM production at this site is a result of the interplay among (1) site geology, (2) mine geometry and location, and (3) climate. Limited hydrologic and geochemical data gathered over a 9-month period in 1997 and 1998 suggest that AMD production is strongly influenced by seasonal mine pool elevation changes. These elevation changes may govern the cycles of formation and release of acid sulfate salts (stored acidity) within the underground mine works.

Additional Key Words: room and pillar mining, mine pool, hydrogeochemistry.

Introduction

The Tab-Simco site is considered to be one of the most contaminated acid mine drainage (AMD) sites in the mid-continent region (Kiser, 1996). The ~12 ha site is a "U" shaped upland remnant, locally known as the "horseshoe", which rises 37 m above the surrounding lowland. It lies 4.2 km southeast of Carbondale, IL near the southern edge of the Illinois Basin. The Pennsylvania age bedrock in this area consists of gently north-northeast dipping sedimentary

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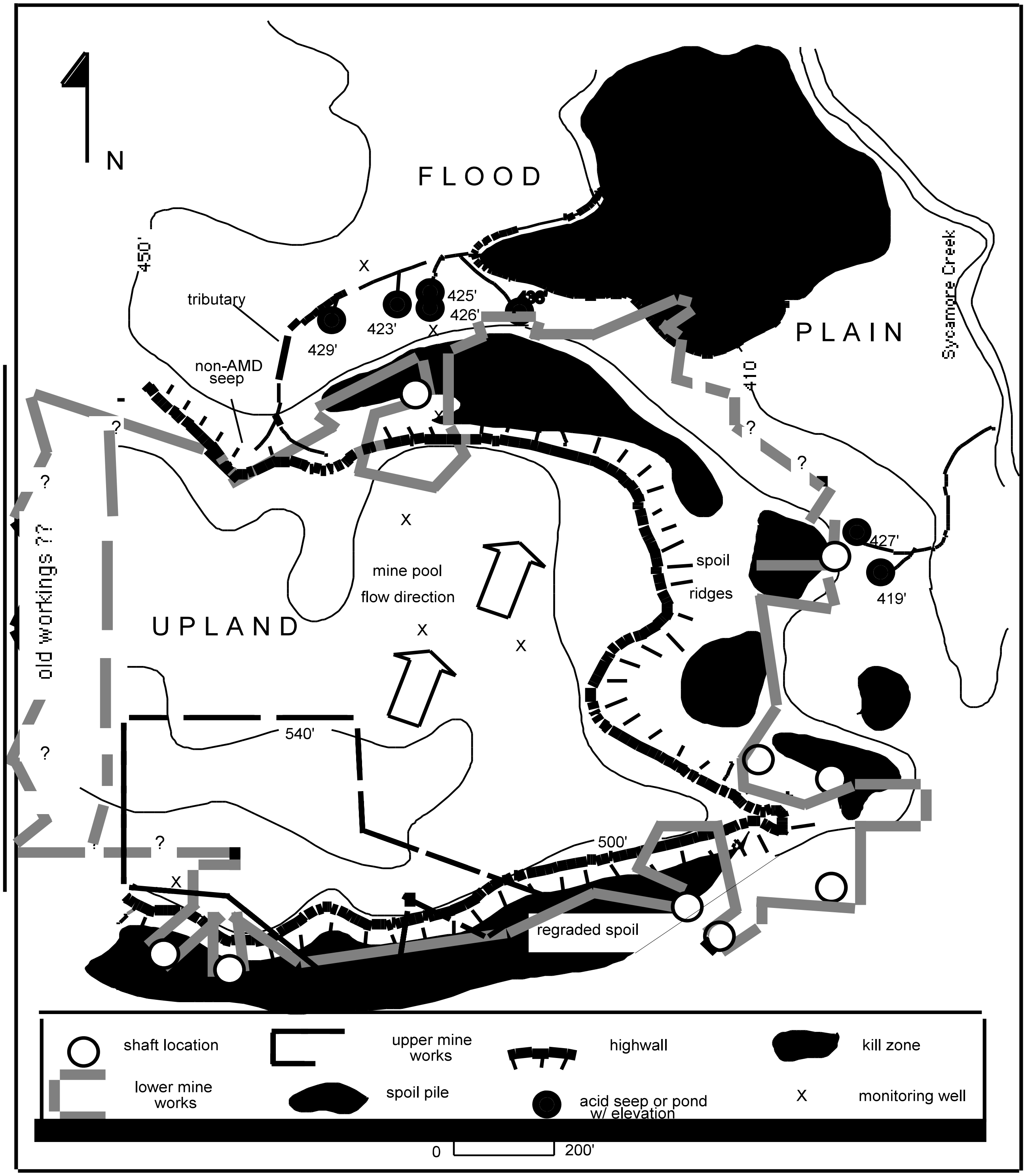
sequences or "cyclothems" (Willman et al, 1975), comprised of shales, sandstones, coals and minor limestone. Two coals within the Spoon Formation have been underground mined at the site; a continuous ~2.5 m thick lower seam - the Murphysboro Coal, and a patchy, discontinuous upper seam, 0 to 1.5 m thick, - the Mount Rorah Coal (Fuller, 1933; Wanless, 1933). These coals are separated by 3 to 8 m of shale and capped by a fine to medium grained, pyritic "channel" sandstone up to 10 m thick. The jointed, locally fractured permeable sandstone lies directly on the Mount Rorah coal and locally cuts it out. The entire sequence dips gently to the north.

Underground mining at the site began in the 1890's and ceased in 1955. The Murphysboro has been room-and-pillar mined under the entire 12 ha of the "horseshoe", whereas the overlying Mount Rorah mine works are confined to a 3 ha area along its southern portion (Fig's 1 & 2). Based on available mine maps, the upper and lower works are probably connected by one or more vertical connecting shafts (Fig. 2) Strip mining operations in the 1960's and 1970's by the Tab Mining Co. around the north, east and south fringes of the "horseshoe" removed 6 of the original 18 undermined hectares. The stripping operations have resulted in numerous break-ins into the underground works along the entire highwall. The down-dip (northern) break-ins are now exit points for an extensive mine pool in the lower works. The mine pool is perched 3 to 5 m above the local water table and contains an estimated 40,000 to 77,000 m^3 of severely contaminated water (Fig. 2).

Acid mine drainage from the mine pool flows downdip (northward) towards the north highwall and emerges from mine spoil and coal washings 15 to 20 m north of the partially buried highwall. Almost all mine pool drainage appears as 5 discrete, perennial seeps with a measured pH of 2.3 - 2.9. These stationary seep locations can be traced up-gradient to suspected break-ins. Coherence of flow between break-ins and seeps implies that sufficient hydraulic head is generated at the break-ins to produce conduit or mega-pore flow through the spoil with a resultant head loss of about 3 m. Flow from the seeps, with intermittent contribution from other, non-AMD sources, has formed a small perennial tributary which discharges onto the floodplain of Sycamore Creek, a large north flowing stream. Deposition onto the floodplain has produced a ~4 ha "kill zone" underlain by 0.3 m of highly acidic sediment. AMD exiting the "kill zone" has contaminated Sycamore Creek for about 2 km downstream.

FIG. 1: Generalized map of Tab-Simco site



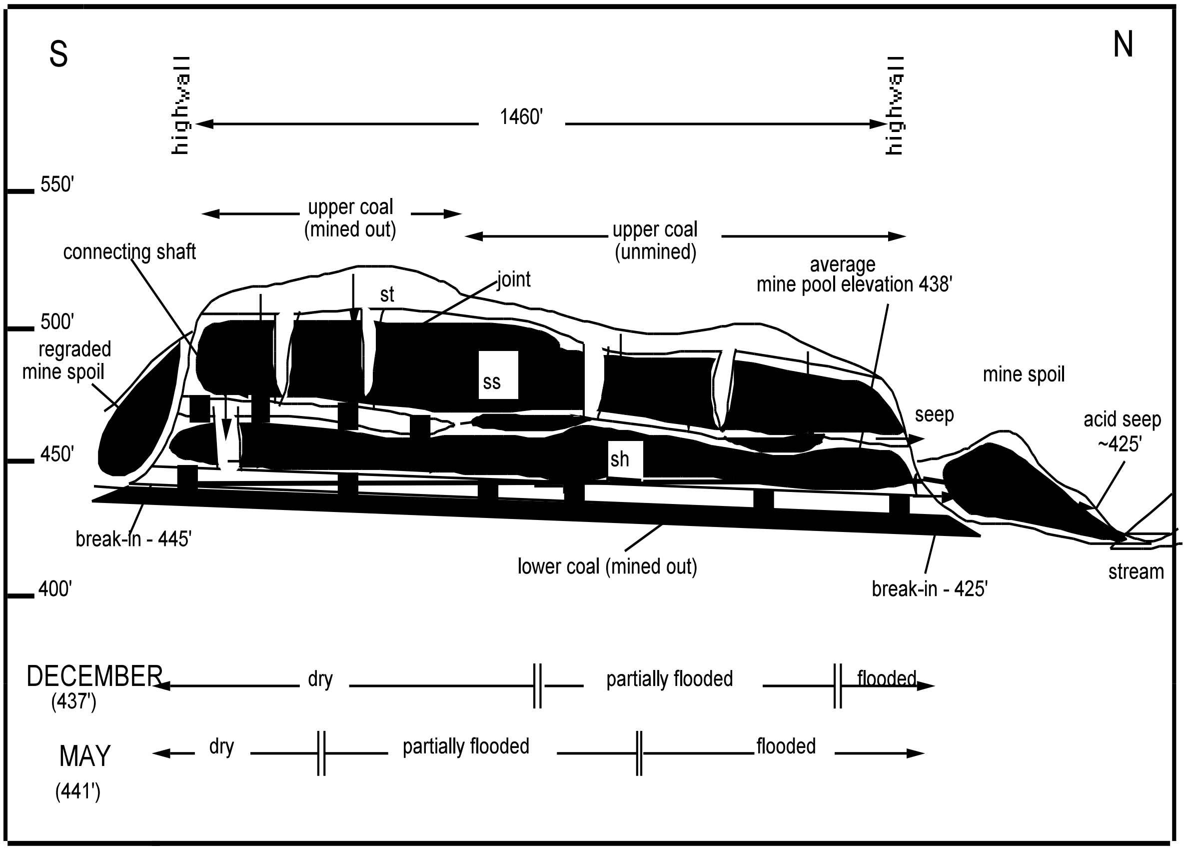


FIG. 2: S - N Cross Section through the "horseshoe" showing general stratigraphy, inferred infiltration flowpaths, mine workings, and seasonal variations in mine pool elevation.

This paper presents the results of a preliminary, 9-month monitoring program in 1997-1998 designed to establish baseline environmental conditions at the site. The focus here is on the physical, hydrologic and geochemical characteristics of the mine pool and its role in generating AMD. The investigation is to be resumed in 2002 on a longer term basis.

Methods

In order to adequately characterize the site, it was first necessary to establish overall mine geometry and extent. This was no easy task, since existing maps of the three relevant underground mines are incomplete and somewhat confusing. The extent of mining had to be inferred from production figures on record at the Illinois Office of Mines and Minerals. Based on known mine plans, extraction ratios, coal crop lines and property boundaries, the general location of mine boundaries could be inferred. The results indicate approximately 18 ha of the "horseshoe" were originally undermined. The 12 ha remaining after stripping operations are considered to be fully interconnected, an inference confirmed by the well data. Still older underground works, with no mine map or other information, are known to be present along the west edge of the site. Whether these works contribute to the mine pool is unknown. The hydrologic data for the site suggest their contribution is minor, if any.

Ten monitoring wells were installed in the upland and fringe area around the seeps. One upland borehole encountered unmapped but inferred mine voids, increasing confidence that the inferred mine boundaries are reasonable. Water levels in the wells were measured weekly to establish (1) whether the three mines are hydrologically interconnected, and (2) the minepool response to precipitation events. Two weirs were built to measure total runoff from the site, one of which was equipped with a continuous recorder. About 3 weeks of runoff data were lost in May, 1998 when the recorder malfunctioned. Mine pool geochemistry sampling included Eh, pH, total acidity, calcium, magnesium, iron (ferric and ferrous), aluminum, sulfate and total dissolved solids. Samples were collected at low (133.1 m), intermediate (133.9 m), and high (134.3 m) pool elevations. Since only three sampling periods were available, the geochemical data have no statistical validity and are suggestive only. More extensive sampling is planned for the coming year.

Mine Pool Hydrology

Table 1 contains information about the lower mine works volume and hydrologic conditions. The lower mine works occupy a volume of ~150,000 m^3 of which roughly two-thirds % is void space. During the 9 month period of investigation, water levels in all but three of the wells were within 0.1 m of one another. The three exceptions were (1) MW # 2A which is completed in spoil and reflects head loss in the spoil, (2) MW#6 which is completed in backstowed spoil completely filling the mine void, and (3) MW#8 which was at the updip edge of the "horseshoe" and therefore dry. Water level fluctuations were identical in each of the wells completed within the pool, indicating hydraulic interconnection within the lower works (Fig. 3).

The weir data were used, in conjunction with precipitation records, to establish a general water budget for the mine pool watershed (Table 1 and Fig. 4). Weir hydrographs indicate that about 60% of total precipitation is present as total runoff, with 35% infiltrating to the mine pool and emerging at the seeps as baseflow. This infiltration rate is a relatively high percentage of total runoff, but is reasonable considering the high fracture permeability of the capping sandstone. Much of the remaining runoff is from interflow at the base of the sandstone, appearing as a large non-AMD seep at the northern highwall. This seep appears to be active for up to one week following a major precipitation event. The baseflow component, derived entirely from the acid seeps, is a relatively constant ~150 m^3/d (38,000 gpd), even during dry periods.

As shown in Figures 3 and 4, water levels in the lower works can be correlated with precipitation only on a seasonal basis, with lag times of several days to a few weeks following precipitation events. This lag may be influenced by (1) the thick, relatively impermeable shale unit separating the permeable sandstone from the lower seam where the upper seam is not present or not mined, and (2) the upper seam mined-out area in the up-dip part of the “horseshoe”, which would receive rapid infiltration but would have to partially fill before overflowing down the connecting shaft(s). Under this scenario, only precipitation events above a certain magnitude would have a rapid effect on mine pool volume.

The seasonally (climate) controlled water level fluctuations in the mine pool have important implications for mine pool geochemistry. During low water in December, an estimated 42,000 m^3 of water is present in the lower works, or 28% of its total volume. During high water in May, about 80,000 m^3 is present, or 52% of total volume. Thus, almost 25% of the exposed, chemically reactive surface of the lower works is subjected to annual wetting - drying cycles (Fig. 2). The actual exposed surface area is probably much larger due to roof falls and rubble accumulation on the mine floor. At an average baseflow rate of 150 m^3/d (38,000 gpd), the computed residence time for mine pool water is between 0.8 and 1.5 years (Table 1).

Mine Pool Geochemistry

Water quality samples were taken at 7 wells, the 2 weirs, and the 2 largest seeps at low (133.1 m, 436.7 ft.), intermediate (133.9 m, 439.3 ft.), and high (134.3 m, 440.6 ft.) mine pool water elevations. The data were used to ascertain (1) AMD concentration differences, if any, in a downgradient direction for each sampling date, and (2) AMD concentration changes through time as a function of mine pool elevation.

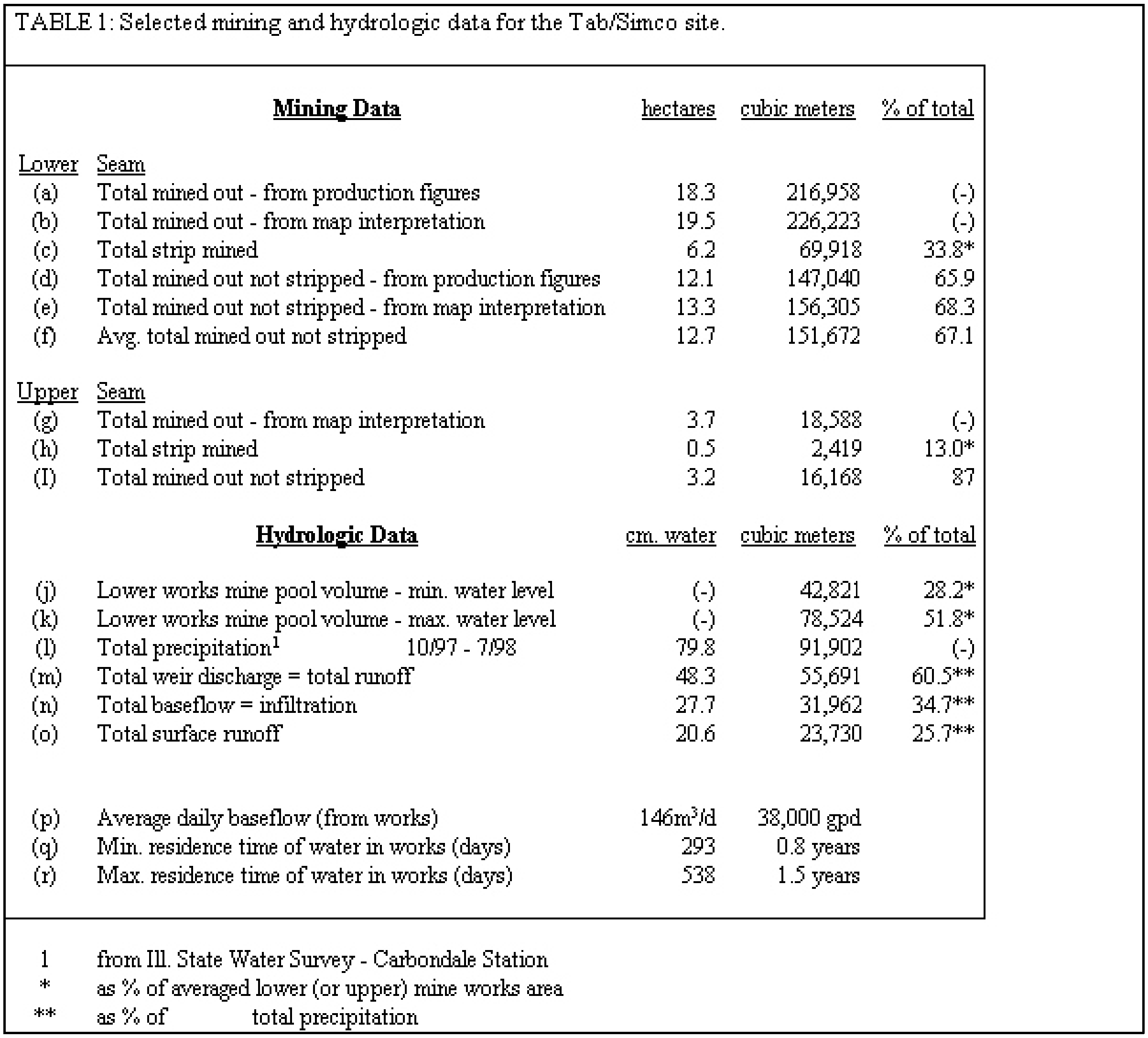


TABLE 1: Selected mining and hydrologic data for the Tab/Simco site.

	Mining Data	hectares	cubic meters	% of total
Lower	Seam			
(a)	Total mined out - from production figures	18.3	216,958	(-)
(b)	Total mined out - from map interpretation	19.5	226,223	(-)
(c)	Total strip mined	6.2	69,918	33.8*
(d)	Total mined out not stripped - from production figures	12.1	147,040	65.9
(e)	Total mined out not stripped - from map interpretation	13.3	156,305	68.3
(f)	Avg. total mined out not stripped	12.7	151,672	67.1
Upper	Seam			
(g)	Total mined out - from map interpretation	3.7	18,588	(-)
(h)	Total strip mined	0.5	2,419	13.0*
(I)	Total mined out not stripped	3.2	16,168	87
	Hydrologic Data	cm. water	cubic meters	% of total
(j)	Lower works mine pool volume - min. water level	(-)	42,821	28.2*
(k)	Lower works mine pool volume - max. water level	(-)	78,524	51.8*
(l)	Total precipitation[1] 10/97 - 7/98	79.8	91,902	(-)
(m)	Total weir discharge = total runoff	48.3	55,691	60.5**
(n)	Total baseflow = infiltration	27.7	31,962	34.7**
(o)	Total surface runoff	20.6	23,730	25.7**
(p)	Average daily baseflow (from works)	146m^3/d	38,000 gpd	
(q)	Min. residence time of water in works (days)	293	0.8 years	
(r)	Max. residence time of water in works (days)	538	1.5 years	

1 from Ill. State Water Survey - Carbondale Station
* as % of averaged lower (or upper) mine works area
** as % of total precipitation

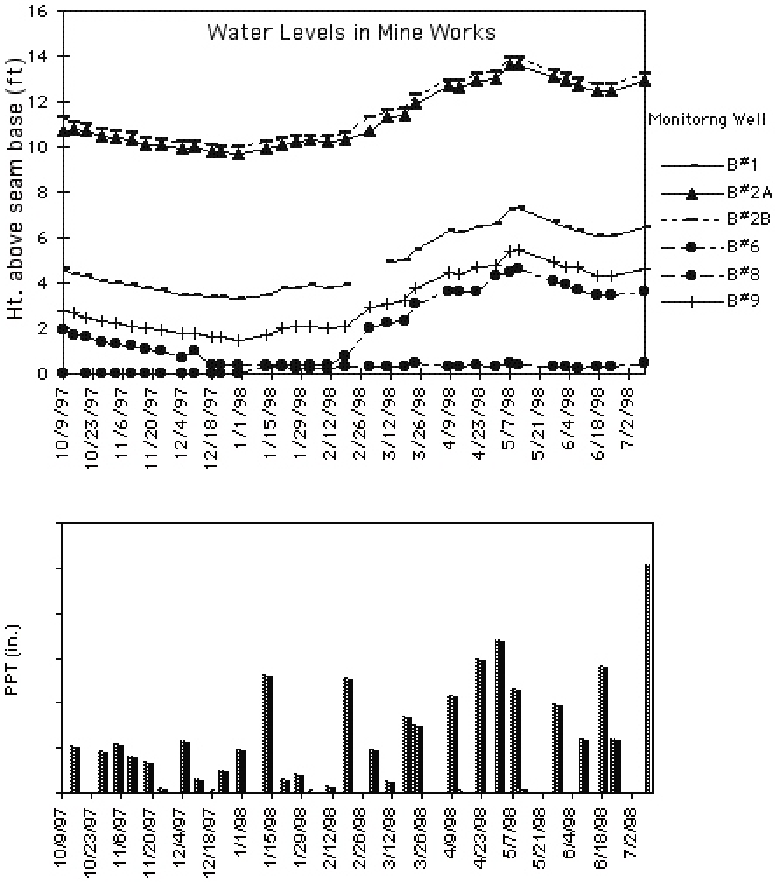


FIG. 3: Relationship between mine pool elevations and precipitation.

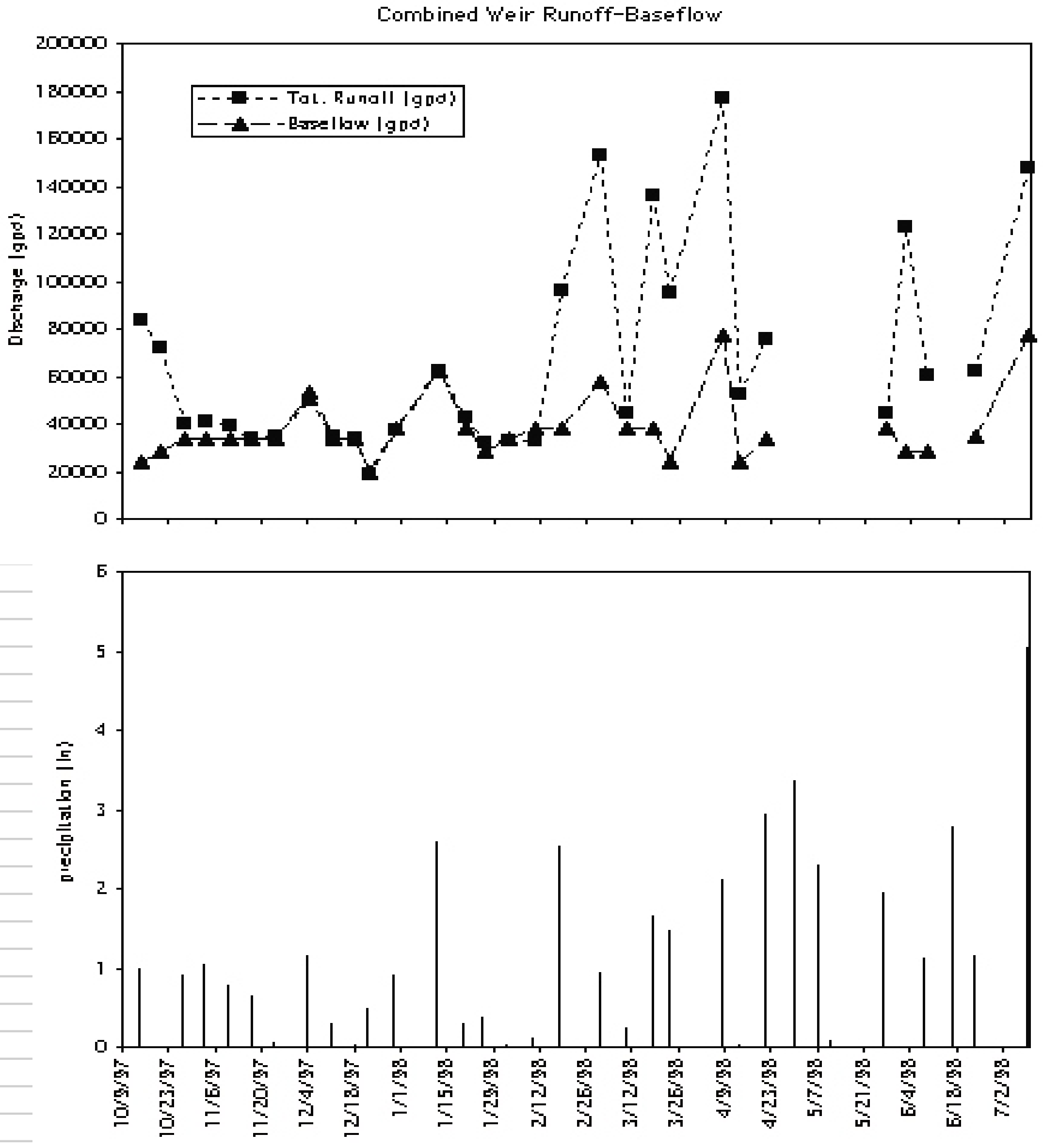


FIG. 4: Combined weir discharge vs precipitation ation

Downgradient concentration changes are shown in Figure 5. For each of the 3 sampling times, concentrations of AMD as expressed by total acidity, dissolved aluminum, iron, calcium, magnesium and sulfate, are relatively consistent throughout the sampled mine pool. Inter-well differences, though not large, are retained for each of the 3 sampling times. Each graph shows a slightly higher AMD concentration in the up-gradient well, with a decrease downgradient within the pool. Concentrations rise slightly again within the spoil and at the seeps. The data suggest that (1) there is significant mixing within the mine pool, and (2) small differences in AMD concentration are site specific and not climatically controlled (Fig. 5).

Between 80 and 95% of the dissolved iron in the mine pool samples is in the ferric, or oxidized, state, with no downgradient change in this ratio. Infiltrating water to the lower mine works from the upper and/or direct infiltration is either sufficiently oxygenated to convert iron to the ferric state, or microbial activity is oxidizing Fe^{++} along the infiltration flowpaths. Measured Eh values in the mine pool are between +0.25 v and +0.55 v.

Figure 6 presents ion concentration values for mine pool, spoil, and seep samples at three different pool elevations. Note the scale differences for log ion concentration values on this graph. The data, despite their previously mentioned limitations, indicate two important trends. The first is the uniformity of response of each ionic constituent to mine pool elevation changes at all sample sites. For example, SO_4^{-2} concentrations increase by about one-half order of magnitude at all 11 sites, including spoil and seeps, between low and intermediate water elevations. The changes are most pronounced between the low and intermediate water stages, probably because ~two thirds of the total water volume change occurs between these stages. Causative conditions within the mine works governing ion concentration changes must therefore be operative throughout the works, rather than localized along certain flow paths.

The second trend involves the differing responses to mine pool volume changes among the 8 measured parameters. Specifically, a rise in mine pool elevation/volume is attended by (1) moderate decrease in total acidity, iron, aluminum, and TDS, (2) increase in pH of ~0.5 pH unit, (3) sharp increase in SO_4^{-2} concentration, (4) little or no change in Ca^{++} and Mg^{++} concentration.

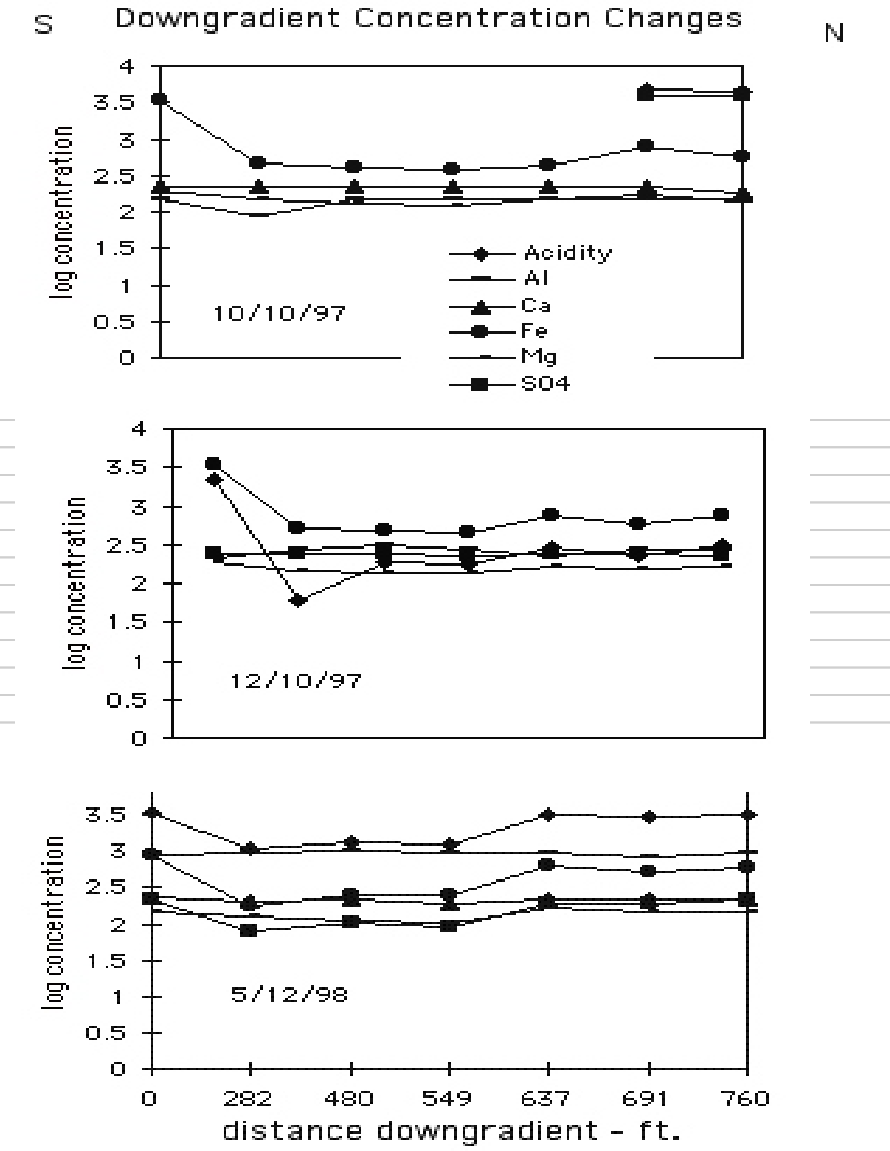


FIGURE 5: Downgradient ion concentration changes for 3 sampling times.

Simple dilution cannot fully explain these trends. A similar response to infiltration increases has been observed at the nearby Palzo surface mine site (Smith and others, 2001). The literature on AMD generation contains other examples of this trend (Rose and Cravotta, 1998).

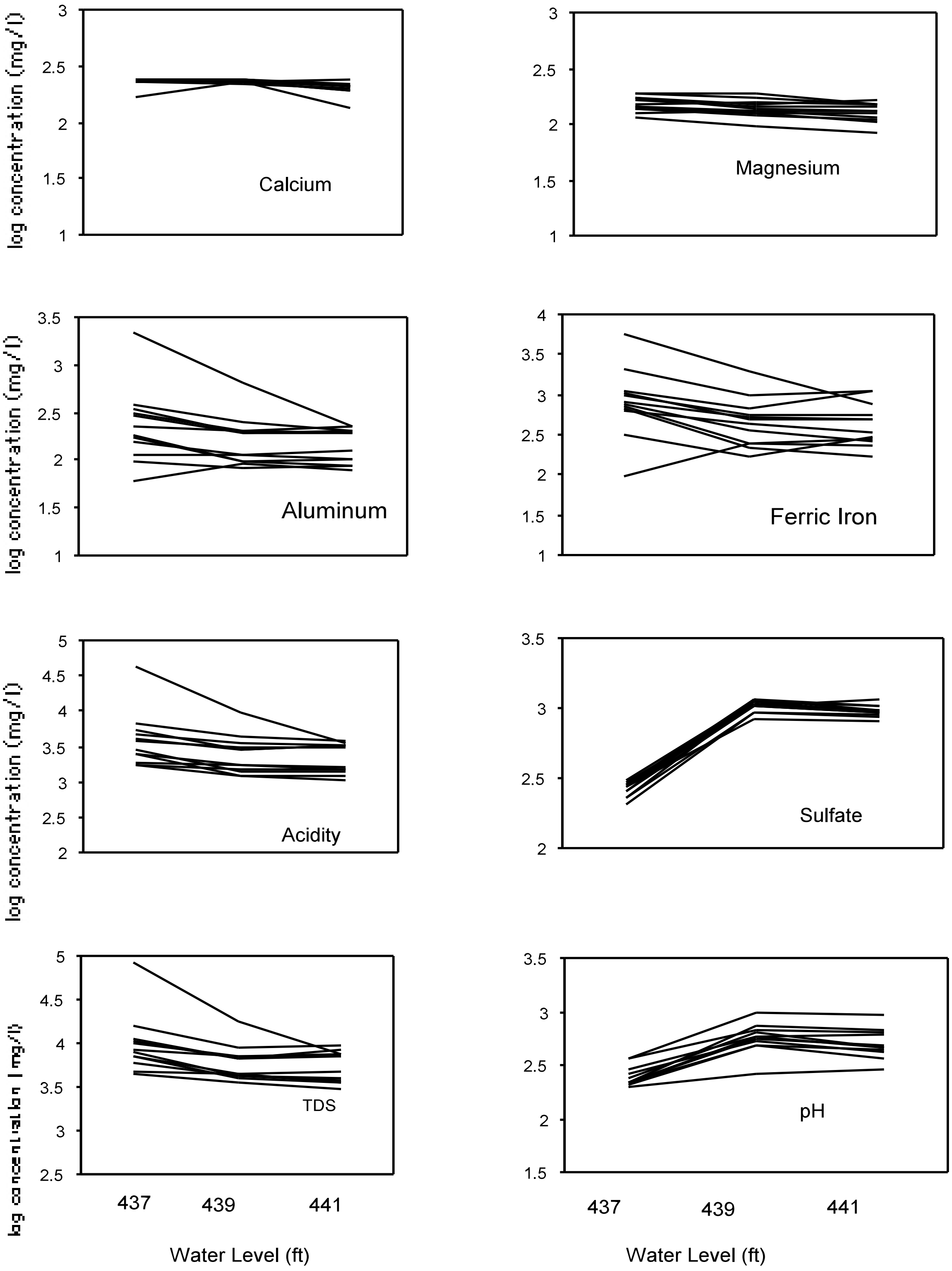


FIG. 6: Selected ion concentrations at three different mine pool elevations

Discussion

The superposition and vertical interconnection of upper and lower mine works at the Tab-Simco site dictate, to an extent, the flowpaths of infiltrating water. Infiltration into the upper works through the vertically jointed and fractured capping sandstone is assumed to be relatively high. Where the upper coal is cut out or not mined, infiltration is considered to be low volume and slow, since much of it appears as one or more large, persistent seeps at the sandstone - shale contact along the north highwall. The geochemical evidence suggests that AMD is being generated in the upper works before it flows down to the mine pool in the lower works. This may explain why upgradient wells in the mine pool have slightly higher acidity, aluminum and iron, and lower pH, than downgradient wells. The downgradient wells, in addition to receiving AMD from the upper works, would have a small non-AMD source of infiltration from the overlying shale.

The climate-controlled geochemical changes within the mine pool are similar to those observed at some other sites (Aljoe, 1994; Erickson et al, 1982; Rose and Cravotta, 1998). Recent investigations have emphasized the role of acid sulfate salts in generating "stored acidity" in underground mine works and mine waste piles (Nordstrom, 1982; Alpers et al, 1994; Cravotta, 1994). These metastable and highly soluble salts may be precipitated by AMD evaporation under very low pH conditions (pH < ~ 2.5) such as exist during low water periods in the Tab-Simco mine pool (fig. 6). Published Eh - pH diagrams for the Fe - S - O - H - K system (Rose and Cravotta, 1998) at ionic concentrations found during the mine pool's low water stage indicate that AMD entering the pool near its upgradient end is within or near the stability fields of one or more acid sulfate salts. Deposits of a yellowish, poorly crystalline material thought to be jarosite ($KFe_3(OH)_6(SO_4)_2$) form ~ horizontal surface rinds on cobbles at the site downslope from the seeps. A white band of similar poor crystallinity but undetermined composition is usually found above the yellow rind. These zoned rinds disappear during inundation events, but re-form later.

Climatically controlled cycles of precipitation (falling water) and solution (rising water) of these salts can produce characteristic "slugs" of highly acidic AMD (Cravotta, 1994). At the Tab-Simco site, high mine pool elevations result in large increases in SO_4^{-2}, but without attendant lowering of pH and increases in acidity, iron and aluminum, as would be expected by simple dissolution of the salts. The Eh - pH diagrams indicate that the observed pH rise (~2.3 to ~2.9) would be sufficient to oxidize/hydrolize some of the iron and aluminum to produce insoluble hydrous oxides, which would build up on the mine floor. The orange - reddish color of unfiltered mine pool samples suggests that this process is active within the mine pool. The rise in pH needed to sustain this transition would have to be sufficient to compensate for H^+ acidity released by the oxidation/hydrolysis reactions.

While the more chemically reactive (in this environment) ions respond strongly to mine pool volume changes, this is not the case with Ca^{++} and Mg^{++}, which maintain relatively constant concentrations. These ionic constituents are derived primarily from weathering of the 0 to 5 m thick mantle of glacial drift capping the upland. Their abundance in the mine pool would therefore be a function of carbonate leaching and precipitation infiltration rates, neither of which are affected by mine pool elevation changes.

Conclusion

Unique hydrologic conditions at the Tab-Simco site have created an underground mine pool which responds volumetrically and chemically to seasonal, climate-controlled changes in infiltration. An understanding of the annual timetable of wetting and drying of the mine floor and walls, with its attendant controls on AMD generation, could be used to design an appropriate reclamation plan. To that end, the preliminary results discussed above need to be corroborated, or rejected, by a full sampling program. At this site, there is insufficient available space to construct an adequate passive treatment system. A more feasible alternative would be some kind of in-mine treatment system using alkaline materials. Perhaps the alkalinity could be delivered pneumatically to both upper and lower mine works during the low water season, so as to coat reactive surfaces and neutralize “stored acidity” as water levels rise.

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