EFFECTS OF STORM RUNOFF ON ACID-BASE ACCOUNTING OF MINE DRAINAGE[1]

by

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Abstract. Pre-reclamation conditions were documented at an abandoned mine site in an upland area at the headwaters of a small perennial stream in southwestern Indiana. Stream discharge and chemistry were monitored from April to October 1995, in an effort to assess the total acid-base budget of outflows from the site. The chemistry of three lakes, a shallow aquifer, and flooded mine voids was also monitored. During the period of monitoring, thirty-five rainfall-runoff events occurred, producing a total storm discharge of approximately 6.12×10^7 L. Baseflow during the monitoring period was approximately 1.10×10^8 L and was characterized by water chemistry that was similar to that of a spring that issued from the flooded mine voids. Analysis of the discharge and chemistry associated with an isolated thunderstorm revealed fluctuations in acidity that were not congruent with fluctuations in the total discharge hydrograph. For example, acidity increased rapidly during the initial phase of hydrograph rise, but dropped significantly as the storm hydrograph peaked. A second, more subdued, rise in acidity occurred during a second rain pulse, and the acidity gradually decreased to pre-storm levels during hydrograph recession. The trends are interpreted to reflect different sources of storm runoff associated with various components of the total discharge hydrograph. Preliminary calculations indicate that the total quantity of acidity that is discharged during stormflow is about eight times higher than that which is discharged during a comparable period under baseflow conditions. While the lower acid concentrations generated during storm events are ecologically favorable, the increase in total quantities of acidity can have implications for the buffering capacities of receiving water bodies.

Additional Key Words: Acid-base Budget, Abandoned Mine Land Reclamation

Introduction

As part of a study to document the effects of reclamation on the hydrology and acid-base budget of an abandoned mine site in southwestern Indiana, streamflow and water chemistry were monitored at the outlet of the watershed that drains the affected area. While monitoring during the pre-reclamation phase, chemical trends were observed that indicate a fairly complex relationship between storm runoff and chemistry that may have implications for evaluating acid-base budgets of areas experiencing acid mine drainage. The purpose of this paper is to describe the monitoring program and to present data that were collected during an isolated storm event, along with a preliminary interpretation of the results that combine concepts of hydrograph separation with those of acid-drainage generation.

Field Site and Data Collection

Background

The Indiana Department of Natural Resources, Division of Reclamation, commenced operations on a pilot program in January, 1995, to use post-combustion coal byproducts (CCB) and fixated scrubber sludge (FSS) as fill and capping materials in reclaiming a small abandoned coal mine in southwestern Indiana. The site was chosen for both its close proximity to the Indianapolis Power and Light Petersburg Generating Station, the source for the CCB and FSS materials, and its physical complexities, facilitating the use of these materials in several different reclamation applications.

In an effort to ascertain the effectiveness of CCB and FSS materials in abandoned mine reclamation, a monitoring program was initiated to catalog the hydrologic and chemical trends in the surface water flowing from the site, as well as in localized groundwater systems during each phase of reclamation. This part of the project was contracted to the Indiana Geological Survey (IGS), Environmental Section, which began its montoring program in March, 1995.

Location

The reclamation site is located in Section 22, T. 2S., R. 7W., Pike County, Indiana (Figure 1). The site is situated in an upland portion of the Patoka River watershed and is drained by a series of ephemeral channels and a

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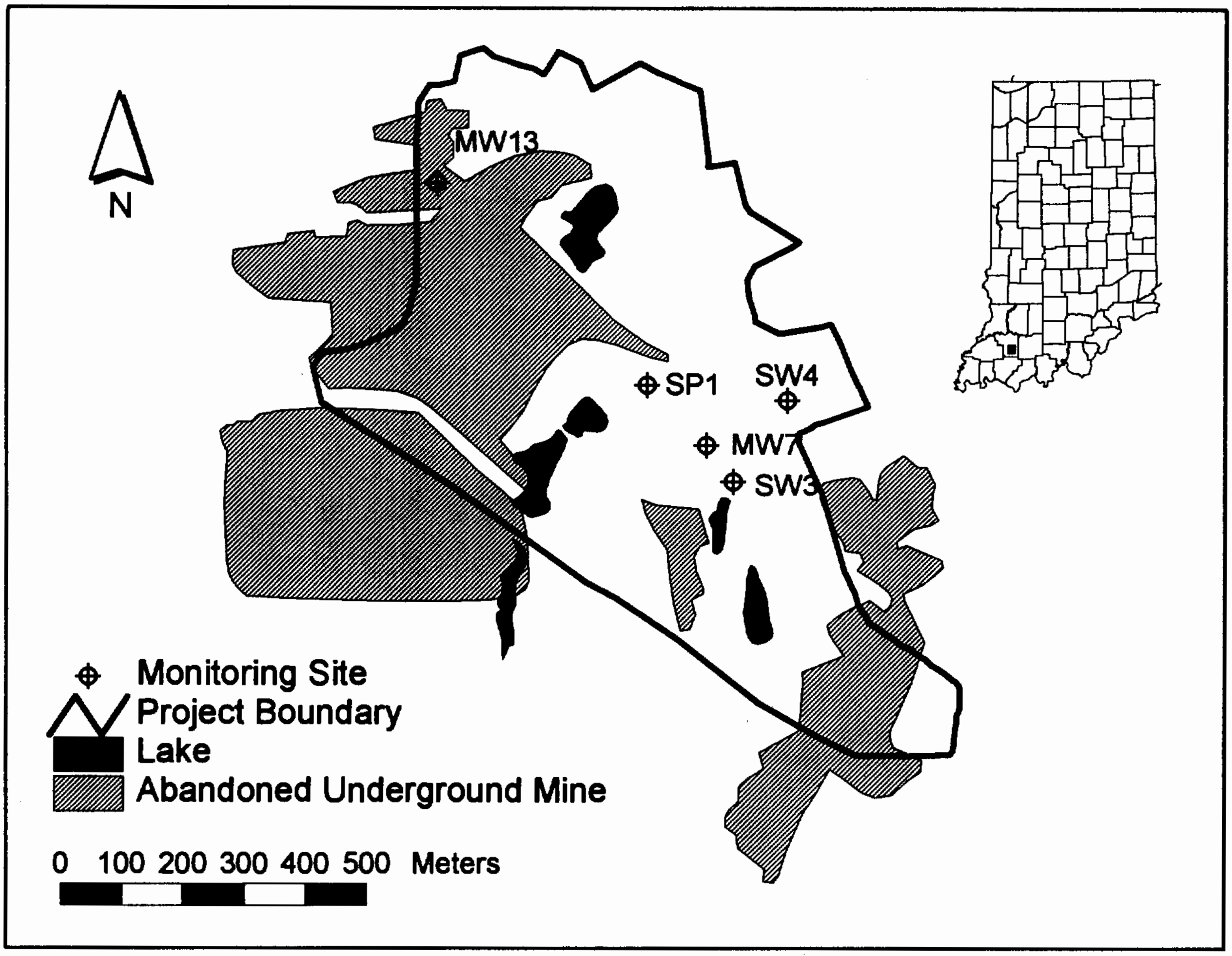

Figure 1. Location of study area and monitoring sites.

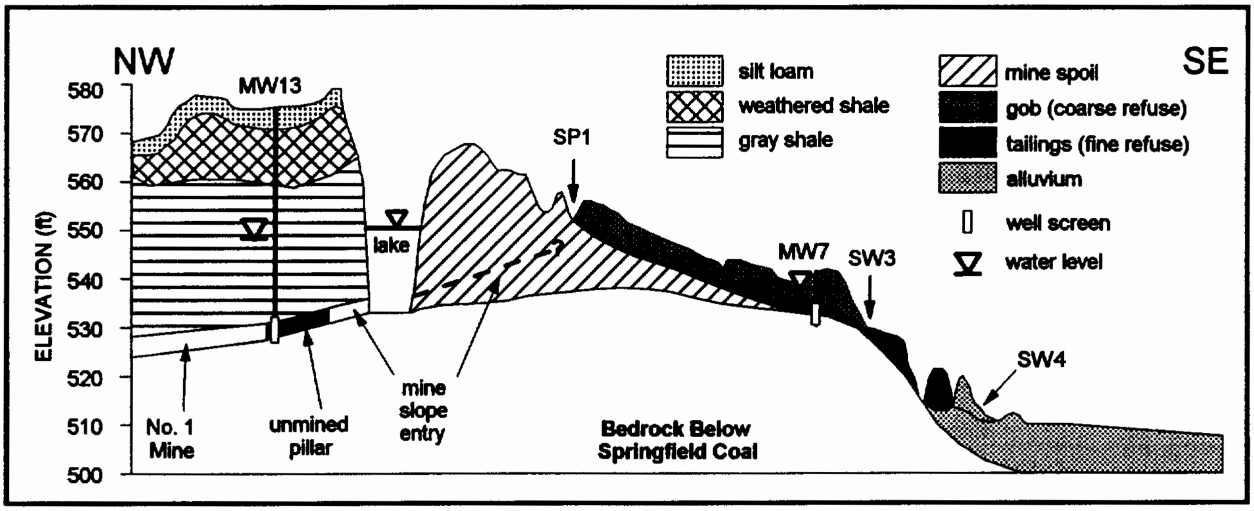

Figure 2. Generalized cross-section through the study area.

perennial trunk stream. The topography of the study site and the surrounding area is heavily disturbed from past surface mining activities that resulted in several exposed highwalls, highwall lakes, and massive deposits of spoil and coal-preparation refuse (Figure 2). The surface-mined areas on site also intersect at least one of three flooded underground mine workings, with hydrologic interactions described by Harper *et al.*, 1996.

The two main source areas for the generation of acidic mine drainage (AMD) on site are the surficial refuse in the central lowland area and the flooded underground mine workings. As shown in the cross-section of Figure 2, the surficial refuse in the central lowland consist of a veneer of pyritic coal-preparation refuse overlying thicker deposits of fine-grained mine refuse (tailings) and overburden spoil. Because a shallow water table lies within the veneer of pyritic refuse, acidity produced from oxidation of pyrite in the overlying unsaturated zone is readily transported out of the refuse and into the trunk stream that drains the lowland. During rainstorms, additional acidity is generated in the central lowland area when overland flow and interflow dissolves the abundant iron-sulfate salts which occur on the refuse surface and capillary pores within the deposit. The flooded underground mine workings, which contain water with a high potential acidity from reduced iron, are also a major source of AMD at the field site. These waters discharge through a spring that developed along a poorly sealed slope entry that is located on the periphery of the central lowland area (Figures 1 and 2).

Data Collection

Data on water chemistry in the coarse refuse of the central lowland area were collected, on a quarterly sampling basis, from a monitoring well (MW7, Figures 1 and 2) that was screened in the shallow unconfined aquifer. Data from the flooded mine workings were collected from a monitoring well (MW13, Figures 1 and 2) that was screened in a small interior pillar. Water samples were also collected from the main spring (SP1, Figures 1 and 2) that discharges from the mine workings, and from a small tributary (SW3, Figures 1 and 2) that drains one of the lakes that formed in a highwall pit. Outflows of water and contaminants were monitored at the station labeled SW4 in Figures 1 and 2. Streamflow was measured using a calibrated 90° V-notch weir fitted with a stilling well that contained an electronic pressure transducer. Rainfall was monitored at the site by a tipping-bucket rain gauge that was connected to the same digital data logger as the pressure transducer. Samples of baseflow were collected at SW4 on the same quarterly basis as the samples from the other sites. In addition, samples of storm discharge were collected at ten-minute intervals by a peristaltic auto-sampler over a four-hour period in August, 1995.

Samples from monitoring wells were obtained by bailing and surface waters were grab-sampled. Two liters of water were obtained from each station and transported (within 15 minutes) to a temporary field laboratory for analysis of certain unstable chemical constituents and properties. These included temperature, pH, Eh, SpC and alkalinity (if needed). The remaining portion of the water sample was then acidified with HNO_3 and kept on ice to preserve its chemical properties until further analysis could be done in the laboratory. All water samples were analyzed in the laboratories of the Geochemistry Section of the Indiana Geological Survey.

Results

Background Chemistry

Selected water chemistry data, for quarterly samplings conducted in April, June, and August, 1995, are presented in Table 1. The data are presented as averages and the data for SW4 correspond to baseflow conditions. Based on the tabulated data, groundwater in the central lowland area (MW7, Table 1) is by far the most concentrated source of on-site AMD. The concentrations of acidity in MW7 are at least an order of magnitude greater than the concentrations at the other monitoring stations. Total dissolved solids in the groundwater of the central lowland is also much higher than elsewhere on the site and consists primarily of iron and sulfate. A comparison of the water chemistry data from SW4 with the data from MW7 and SP1 indicates that the trunk stream's baseflow chemistry is a mixture of waters from the two main source areas. The mean acidity in the trunk stream (SW4) is roughly twice as large as that of the spring, but it is also much smaller than the acidity of groundwater in the coarse refuse. A similar pattern of difference can be observed for the ion concentrations at the three sites (Table 1). Therefore, it may be concluded that although the trunk stream is receiving inflow from both source areas during periods of baseflow, with the spring being the dominant source.

Streamflow

The discharge at station SW4 for the pre-reclamation phase was measured continuously from April to October, 1995, during which time thirty-five rainfall-runoff events were detected and measured. Over this seven-month period, total storm-event discharge was calculated to be approximately 6.12 x 10^7 L, contrasted with a total baseflow of approximately 1.10 x 10^8 L.

On the evening of August 9, 1995, an isolated thunderstorm of moderate intensity was measured and sampled. Baseflow prior to the storm was about 15 L/s.

Table 1. Calculated average baseline chemistry for monitoring stations.

Station ID	SpC	pH	Acidity mg/L	SO4 mg/L	Total Fe mg/L	Fe2 mg/L	TDS mg/L
MW7	26,290	1.46	7,050	15,250	5,250	4,750	29,000
MW13	854	6.40	130	93	3	1	685
SP1	1,974	4.00	190	1,450	82	73	2,150
SW3	3,625	2.74	510	2,750	135	36	4,300
SW4	3,190	2.91	520	2,400	190	148	3,700

Table 2. August 9, 1995 storm sample chemistry.

Time on Aug. 9	SpC	pH	Acidity mg/L	SO4 mg/L	Total Fe mg/L	Fe^2 mg/L	TDS mg/L
19:30	2,190	2.71	830	2,000			
19:40	2,000	2.58	1,100				
19:50	1,388	2.77	500	1,000	87	22	1,300
20:00	1,534	2.76	500				
20:10	1,927	2.75	600				
20:20	1,697	2.73	630				
20:30	1,745	2.69	670				
20:40	1,791	2.68	750				
20:50	1,892	2.64	850	1,400	190	42	1,900
21:00	1,688	2.70	660				
21:10	1,628	2.74	610	1,200	130		1,600
21:20	1,756	2.73	660				
21:30	1,803	2.69	710				
21:40	1,755	2.69	700				
21:50	1,804	2.7	700				
22:00	1,797	2.71	690				
22:10	1,830	2.72	720				
22:20	1,882	2.7	730				
22:30	1,922	2.7	730				
22:40	1,863	2.71	730				
22:50	2,040	2.72	720				
23:00	1,976	2.72	760				
23:10	2,255	2.74	790	1,600	190		2,200
23:20	2,250	2.75	760				

Rainfall began at 18:15 hours and continued at a low intensity until approximately 19:15, when intensity increased. Peak intensity was 1.25 cm of rainfall occurring between 19:30 to 19:45, subsiding steadily thereafter with the exception of a minor rain pulse from 20:30 to 21:00 (Figure 3). In the four-hour period between 18:15 to 23:15, total storm rainfall was 2.57 cm. Calculations of total storm discharge were made by integrating the discharge hydrograph and subtracting the contribution of baseflow at its pre-storm rate. Total storm-related discharge was calculated to be 2.187 x 10^6 L, which is equivalent to total storm runoff of approximately 2.33 cm.

The ascending limb of the storm-discharge hydrograph began to rise between 19:15 and 19:30. Peak discharge achieved a maximum value of 668 L/s at 20:00, with a 15-minute lag between the centroid of discharge and the centroid of rainfall. The descending limb asymptotically subsided to pre-storm baseflow value in the following five hours, with one slight increase at 21:00 corresponding to the rain pulse at 20:45 (Figure 3).

Storm Runoff Chemistry

Relationships between storm discharge and acidity in samples of stream flow are shown in the upper graph of Figure 3. The autosampler at SW4 was triggered by low-intensity rains that preceded the rise of the hydrograph. Consequently, the first sample is considered to be representative of pre-storm baseflow conditions. The samples of streamflow, which were collected at ten-minute intervals throughout the entire storm, were analyzed for pH, SpC, Eh, and acidity. Complete analyses were done on selected samples at a later date to determine concentrations of major ions and trace metals.

As shown in Figure 3, acidity increased rapidly (from 750 to 1100 mg/L) during the initial phase of the hydrograph's rise and dropped significantly (to 500 mg/L) as the hydrograph peaked. There was a second, more subdued, rise in acidity (to 850 mg/L) that occurred during the hydrograph's recession. This was followed by another decline in acidity (to 610 mg/L) that occurred prior to a gradual return to the pre-storm concentration of 750 mg/L. Note that the secondary rise and decline were associated with a secondary pulse of rainfall (Figure 3). A total of about 1.429 x 10^6 g of acidity were discharged during the storm event.

Discussion and Conclusion

The discharge of the trunk stream at baseflow conditions was determined to be comprised primarily of runoff from seeps and springs that drain the flooded underground mine at the study area. Other contributors are thought to be inflow from the shallow aquifer in the coarse refuse deposit on the central lowland, and to a lesser extent, runoff from surface-water sites in the southeastern quadrant of the site.

The chemical trends over the course of the storm event were interpreted as follows. The immediate increase in acidity was thought to be caused from the initial flushing of secondary pyritic surface salts by Hortonian overland flow across the coarse refuse and in ephemeral channels. The significant drop in acidity at peak flow was interpreted as the dilution of overland flow after the supply of surface salts had been depleted. The second, more subdued rise in acidity after the slight increase in rainfall is interpreted as the influx of acidic interflow from the shallow aquifer in the coarse refuse deposit as the storm progressed. The gradual rise in acidity at the end of the storm was interpreted as dilution, as runoff (both surface and subsurface) from the coarse refuse subsided and outflow from the underground mine workings again became the primary source of streamflow.

Preliminary calculations indicate that total acidity discharged during the storm was about eight times higher than that from baseflow over a comparable length of time. High-flow storm events are generally viewed as ecologically favorable due to increased dilution. The results of this study, however, underscore the importance of evaluating the consequences that the increased quantities of acidity during storms may have on the buffering capacities of receiving bodies. We contend that acid-base budgeting of reclamation sites -- which is the most direct and accurate basis of site assessment -- should include the separate effects of baseflow and stormflow conditions.

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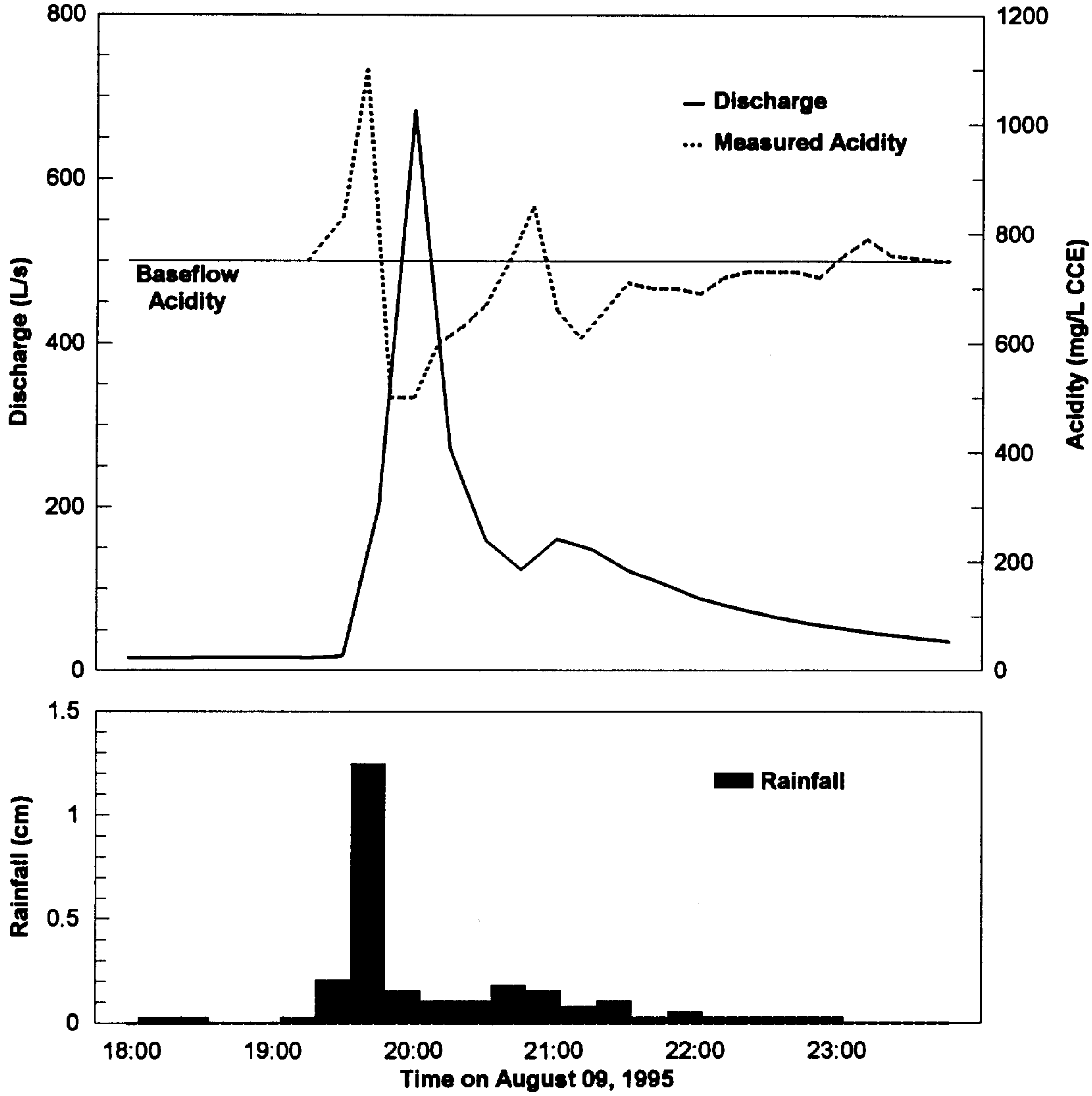

Figure 3. Upper: Hydrograph of stream discharge (left scale) associated with an isolated storm that occurred on August 9, 1995. Measured acidity (right scale; CCE is an abbreviation for "$CaCO_3$ equivalent") of streamflow samples are also plotted. The thin horizontal line corresponds to acidity measured prior to the rise of the hydrograph. Lower: Hyetograph of rainfall associated with the storm.