2001 International Ash Utilization Symposium, Center for Applied Energy Research, University of Kentucky, Paper #54. Copyright is held by the Authors.

http://www.flyash.info

Water Quality at the Roberts-Dawson Coal Mine Three Years After Placement of Flue Gas Desulfurization By-Product

P. Taerakul, M. Lamminen, H.W. Walker, and E. Whitlatch

Department of Civil and Environmental Engineering and Geodetic Science, The Ohio State University, 470 Hitchcock Hall, 2070 Neil Avenue, Columbus, OH 43210

KEYWORDS: Acid Mine Drainage, Flue Gas Desulfurization By-Product, Coal Combustion By-Product

ABSTRACT

The removal of sulfur oxides following the combustion of coal results in over 20 million metric tons of flue gas desulfurization (FGD) by-product every year. Because coal-fired power plants are typically located close to coal mines, there is increasing interest in the placement of FGD by-product in deep mine environments for the purpose of FGD by-product disposal and acid mine drainage reduction. In this research, we examine water quality at an underground coal mine following the injection of FGD by-product. Between September 30, 1997 and January 17, 1998 approximately 23,000 cubic yards of FGD grout was injected into the down-dip portions of the Roberts-Dawson mine. Immediately following grouting, increases in acidity, iron, aluminum, calcium and sulfur in mine drainage waters were observed at the main seeps exiting the mine. Three years after placement of FGD by-product, however, concentrations of these and other constituents at the main seep of the Roberts Dawson mine were near levels observed prior to FGD by-product injection. These results suggest that placement of FGD by-product in deep mines does not have deleterious, long-term impacts on water quality, but further research is needed to develop effective approaches for using FGD by-product to improve the quality of mine drainage waters.

INTRODUCTION

In 1998, approximately 22.7×10^6 metric tons of FGD by-product were produced in the United States, with roughly 90% going to landfills[1]. In order to reduce the volume of FGD by-product entering landfills, there is increasing interest in the utilization and/or disposal of FGD by-product at abandoned mine lands (AMLs). Coal mine areas are especially attractive for this purpose because they are often located near coal-fired power plants that produce FGD by-product. Effective re-use of FGD by-product at these sites reduces land requirements for FGD by-product disposal and may aid in subsidence control and the reduction of acid mine drainage (AMD).

Previous studies have shown FGD by-product can be used effectively at surface mine sites for the reclamation of areas containing mine-spoil[2,3,4,5]. For example, Stehouwer et al. showed that FGD by-product could be utilized to raise the pH of acidic mine-spoil and enhance re-vegetation of Kentucky 31 tall fescue[4]. In fact, increased plant yield was observed upon application of FGD by-product, which was attributed to a decrease in soluble aluminum and its associated toxicity. The levels of As, Cd, Cr, and Se in plant tissue also decreased upon FGD by-product amendment and boron toxicity was not observed, providing further support for the effective and environmentally sound utilization of FGD by-product at these sites.

The large-scale placement of FGD by-product in abandoned deep mines is currently being considered. In fact, a number of full-scale acid mine drainage abatement projects utilizing FGD by-product have recently been carried out, including projects at the Frazee Mine, in Garrett County, Maryland[6] and the Broken Aro mine located near Coshocton in southeastern Ohio[7]. Previously, we reported on changes in surface and groundwater quality at the Roberts Dawson mine one year after injection of an FGD by-product grout[8,9]. FGD by-product was injected into the down-dip portions of the Roberts-Dawson mine in an attempt to seal major seeps exiting the mine and to coat exposed pyritic surfaces. Immediately following grout injection, increases in acidity, iron, aluminum, sulfur, and calcium were observed at surface and groundwater locations impacted by the grouting operations. Following this initial flush of elements, however, the concentrations of most constituents began to decrease.

In this paper, we examine the impact of FGD by-product on water quality at the Roberts-Dawson mine three years after placement of FGD by-product. Surface water and groundwater quality monitoring was carried at the Roberts-Dawson site both before and after grouting operations. Surface water samples were collected monthly from 14 sites and groundwater samples were collected at over thirty groundwater wells. In this paper, water quality data for the two main seeps exiting the Roberts Dawson mine (surface water sites 3 and 5) will be discussed. Details on grout mineralogy and weathering[9,10,11] as well as the influence of FGD by-product on groundwater flow and transport[12,13] can be found elsewhere.

SITE DESCRIPTION

The Roberts-Dawson mine is located on the border of Coshocton and Muskingum counties, in central-eastern Ohio. Figure 1 shows the known mine voids at the Roberts-Dawson site. There was also a significant area of unmapped mine voids on the southern portion of the site. There are two major seeps that discharge AMD at the Roberts-Dawson mine. These sites are numbered 3 and 5 in Figure 1. Site 5 drained from the mapped portion of the mine voids while site 3 drained the unmapped portion of the mine. These two seeps, however, were not hydraulically isolated. Both seeps discharged into an adjacent receiving stream, which flowed into a collection pond, and then discharged through a culvert to Wills Creek Reservoir.

Two grout mixes were used at the Roberts-Dawson site, both produced by adding water to FGD by-product material from the Conesville coal-fired power plant. A higher strength grout was used to seal the main seeps of the Roberts-Dawson mine, while a

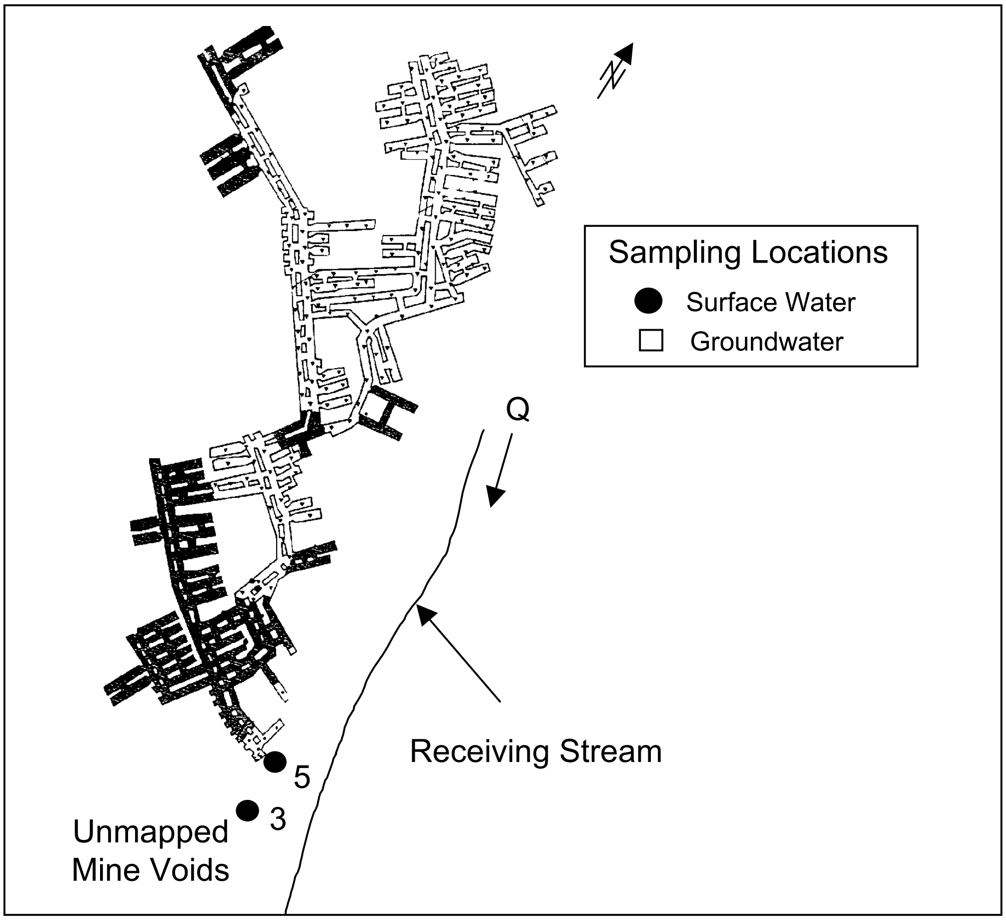

Figure 1. Known mine voids and sampling locations at the Roberts Dawson mine site. Shaded regions indicate mine voids where high strength grout were placed while unshaded regions are areas where lower strength grout was used.

more fluid and lower strength mix was used to coat the mine voids[14]. Both FGD grouts were a 1.25:1 mixture of fly ash and dewatered scrubber sludge with an additional 5% lime (CaO). Elemental analysis indicated that the grout consisted primarily of calcium, silicon, iron, sulfur, and aluminum[10,11]. Other minor elements were also present including antimony, arsenic, barium, beryllium, boron, carbon, chromium, cadmium, copper, lead, manganese, nickel, potassium, sodium, selenium, strontium, and zinc. FGD grout was injected into the down-dip portions of the Roberts-Dawson mine between October 1997 and January 1998.

A total of 317 boreholes were drilled to inject the FGD by-product grout into the mine voids and 18,182 m^3 of grout material was injected[14]. The shaded areas in Figure 1 indicate locations where high strength FGD by-product grout was injected into known mine voids in order to seal the main seeps. A lower strength grout, also made of FGD by-product, was injected into the un-shaded regions of the known mine voids to coat pyritic surfaces. FGD by-product was also injected into limited areas of the unmapped portion of the mine.

WATER QUALITY SAMPLING AND ANALYSIS

Surface water samples were collected in 60 mL polypropylene bottles. Flow rates were measured at the time of sample collection using weirs or by the "bucket and stopwatch" technique. Filtered and unfiltered samples for metals analysis were acidified to a 10% (volume/volume) acid concentration using ultra pure nitric acid. Following collection, samples were immediately placed in an iced cooler for transport back to the laboratory.

All samples were analyzed for pH, conductivity, sulfate, arsenic, chloride, alkalinity, metals and other inorganic constituents. A more detailed description of the sampling and analysis techniques can be found elsewhere[15]. pH was measured using an Model 525A pH meter (Thermo Orion, Beverly, MA). Conductivity was measured in the laboratory using a digital conductivity meter (Fisher Scientific, Suwanee, GA). Alkalinity, chloride and sulfate were determined using a Lachat Quickchem AE Autoanalyzer (Milwaukee, WI). Arsenic was determined using a Perkin Elmer Graphite Furnace Atomic Absorption Spectrometer (Norwalk, CT, model 4100XL). Analyses for Al, Ba, Be, B, Cd, Cr, Ca, Co, Cu, Fe, Pb, Li, Mg, Mn, Mo, Ni, P, K, Si, Na, Sr, S, and Zn were carried out using an Inductively Coupled Plasma Optical Emission Spectrometer at the Ohio Agricultural Research and Development Center (OARDC) in Wooster, OH.

RESULTS AND DISCUSSION

Water quality data for surface water site 5, before and after grouting with FGD by-product, are shown in Figure 2. In particular, Figure 2 shows the flow rate and concentrations of acidity, iron, sulfur, calcium and aluminum at site 5 from one year prior to grouting to approximately three years after grouting. The bar in each graph represents the time interval over which grouting with FGD by-product took place. For this particular site, mine drainage emerged from the ground approximately half-way between the main exit of the original seep and the receiving stream following grouting. As a result, the contribution of flow from site 5 to the receiving stream was relatively unchanged after grouting. As can be seen in Figure 2, the flow rate at site 5 ranged from close to zero to approximately 85 gallons per minute, depending on the particular sampling date.

Immediately following grouting, acidity, iron, sulfur, calcium, and aluminum from this new seep at site 5 increased significantly and remained elevated until March or April of 1998. After this time, the levels of acidity, iron, sulfur, and calcium steadily decreased. However, by the end of 2000 the levels of these constituents remained slightly higher than pre-grout conditions. Because flow to the receiving stream was not reduced, the increases in constituent levels following grouting was likely not due to a concentration effect. A notable exception to these trends is the behavior of aluminum following injection of FGD by-product. Although the concentration of aluminum initially increased following grouting, the concentration of this element quickly decreased to levels close to pre-grout conditions.

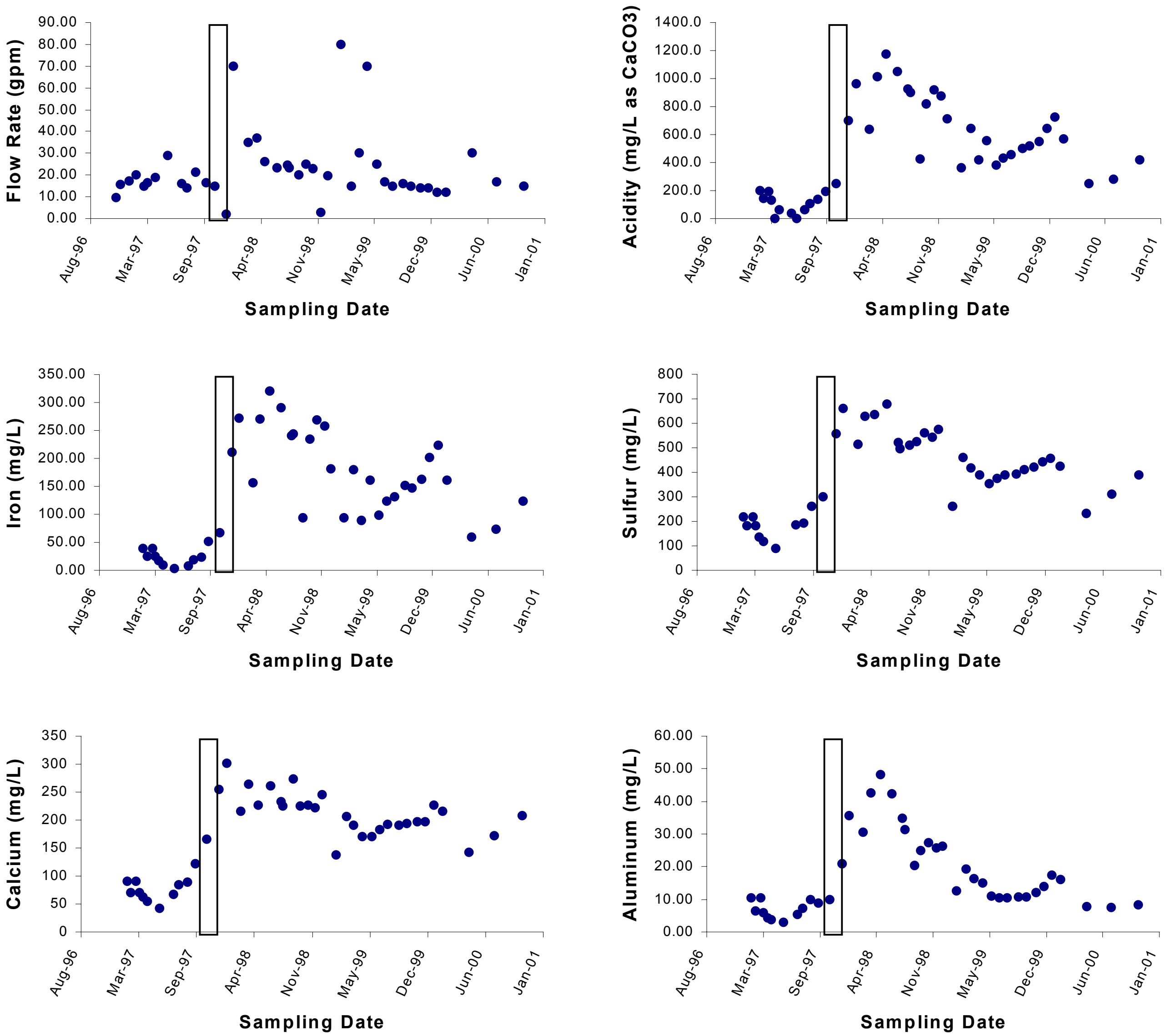

Figure 2. Flow rate and water quality at surface water site 5 before and after grouting with FGD by-product

Table 1 shows data for other water quality constituents at site 5 before and after grouting. As can be seen, the pH initially increased after grouting but has since decreased to levels slightly lower than those observed prior to the grouting operations. A number of constituents demonstrated behavior similar to acidity, iron, calcium and sulfur, as shown in Figure 1; i.e., a peak in concentration shortly after grouting followed by a steady decrease to levels slightly above pregrout conditions. This trend was observed for conductivity, boron, lithium, manganese, strontium, and zinc. The concentration of barium, beryllium, cobalt, magnesium and silicon peaked after grouting, but eventually reached levels similar to those observed prior to grouting operations. The concentrations of lead, molybdenum, and nickel also peaked after grouting. However, the concentration of these elements reached levels lower than pregrout conditions. The concentrations of arsenic, cadmium and chromium did not peak after

Table 1. Concentrations of various constituents at surface water site 5 for selected sampling dates before and after FGD grout injection. Concentrations are in mg/L unless otherwise noted.

	Before Grouting	**After Grouting**			
Constituent	3/13/97	1/10/98	9/20/98	6/24/99	4/27/00
Flow Rate (gpm)	16	70	25	17	30
pH (pH units)	3.30	3.69	3.19	3.22	3.09
Acidity (mg/L as $CaCO_3$)	129	960	817	428	251
Conductivity (μS/cm)	806	nd[1]	2400	1825	1618
As (μg/L)	32	47	4	1	nd
Al	6.0	35.5	24.8	10.4	7.87
Ba	0.002	0.017	0.005	0.010	0.004
Be	0.002	0.011	0.003	nd	0.003
B	0.13	1.20	0.16	0.17	0.22
Cd	0.001	nd	0.005	nd	nd
Cr	0.002	nd	nd	nd	nd
Ca	70	302	226	183	142
Co	0.024	0.210	0.115	0.050	0.028
Cu	0.002	nd	nd	nd	nd
Fe (dissolved)	24.9	271.8	235.1	123.4	59.2
Fe (total)	25.0	276.5	---	100.3	---
Pb	0.020	0.174	0.031	nd	nd
Li	0.06	0.26	0.26	0.17	0.15
Mg	42	139	100	66	44
Mn (dissolved)	1.8	11.8	8.0	5.1	3.7
Mn (total)	1.9	12.2	---	5.1	---
Mo	0.011	0.030	nd	nd	nd
Ni	0.06	0.41	0.40	0.17	nd
Si	11.4	22.7	13.6	6.1	13.2
Na	9.5	16.0	21.6	21.4	19.7
Sr	0.23	0.79	0.54	0.46	0.37
S	181	659	525	374	234
Zn	0.12	0.50	0.51	0.22	0.17

“nd” not detected
“---“ not determined

grouting, but have decreased to below pregrout conditions. Sodium behaved differently than most other elements with the concentration increasing after grouting and remaining at an elevated level.

Flow rate and water quality data for surface water site 3 are shown in Figure 3. Initially, the flow of mine drainage waters from this seep was reduced by the grouting program. However, in March of 1998 water began to flow from this location through a sandstone

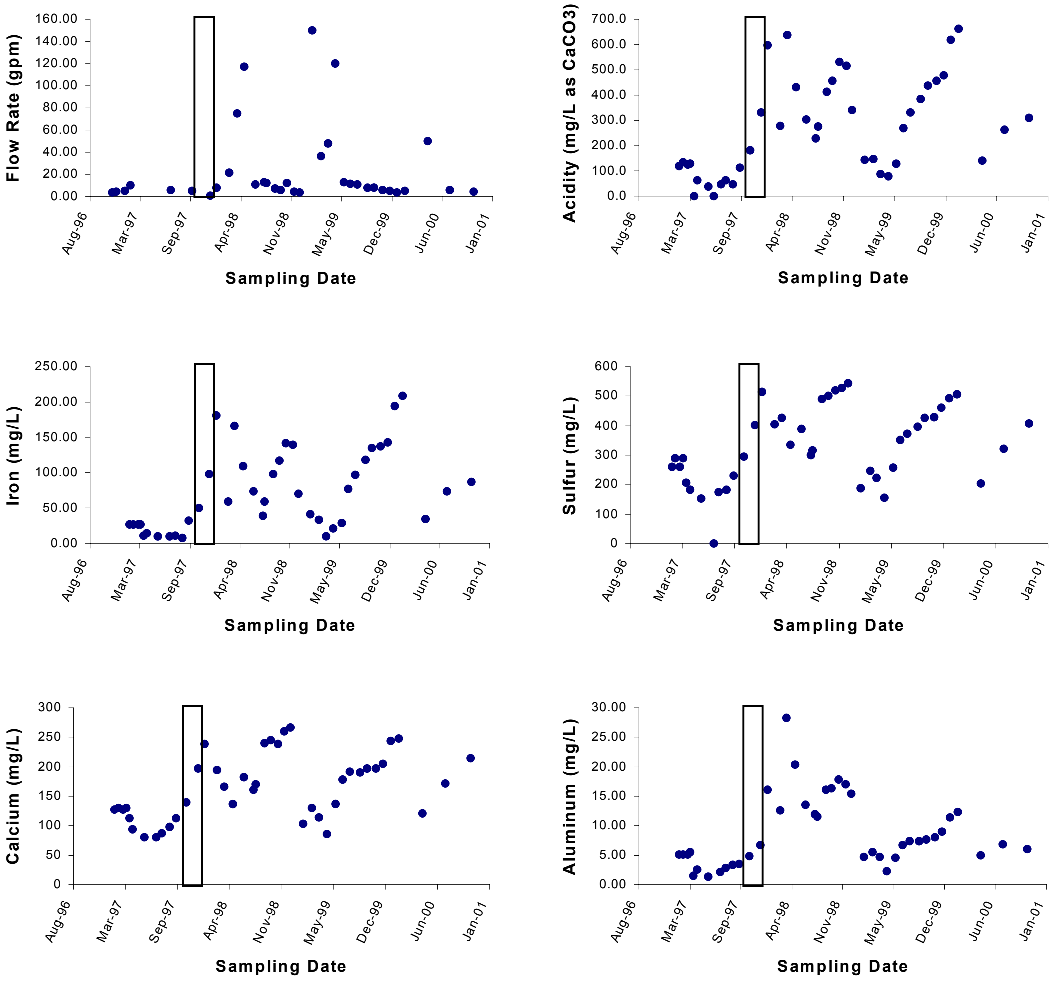

Figure 3. Flow rate and water quality at surface water site 3 before and after grouting with FGD by-product.

layer located on top of the seal. As a result, flow at site 3 remained highly seasonal with flow rates ranging from zero to close to 150 gpm. The levels of acidity, iron, sulfur, calcium, and aluminum at site 3 increased significantly following grouting, similar to trends observed for surface water site 5. However, the levels of these constituents continue to be highly seasonal, unlike site 5 in which water quality has improved since grouting. In fact, the concentrations of acidity, iron, sulfur and calcium measured at site 3 at the end of 1999 were as high as values observed immediately following grouting operations. Levels of these constituents at the end of 2000 were decreased compared to 1999, but still remained elevated compared to pregrout conditions.

A number of factors may be responsible for the different behavior observed for surface water sites 3 and 5. For example, samples at site 5 were collected midway between the mine opening the receiving creek, and therefore, traveled a significant distance within the subsurface. Interaction with the soil could perhaps reduce the amplitude of seasonal variation in various parameters. The mine voids adjacent to site 5 were also more heavily grouted as compared to site 3. Site 3 largely drained the unmapped portion of the site. Although an attempt was made to inject grout in this location, and unknown nature of the mine voids made grout injection difficult.

Another factor that may explain the behavior of surface water sites 3 and 5 is the differences in flow during 1999. Both seeps had relatively low flow rates (less than 17 gpm) for all sampling trips carried out in the latter part (June through December) of 1999. However, the flow from site 3 was significantly lower during this time period than the flow from site 5. At site 5 the flow varied from approximately 12-17 gpm, while the flow rate at site 3 varied from 3-12 gpm, with most values being closer to 3 gpm. Perhaps these lower flow conditions, and the fact that drainage emerged from site 3 at the top of the grout seal, resulted in long residence times in the mine voids, and subsequently higher concentrations of acidity, iron, sulfur, calcium, and aluminum.

CONCLUSIONS

The injection of FGD by-product into the Roberts Dawson coal mine resulted in significant changes in surface water quality. Initially after grouting, the concentrations of many elements, including iron, calcium, and sulfur significantly increased. After this initial flush of elements, however, the concentrations of most constituents approached levels observed prior to grouting operations. Although there were short-term negative impacts on water quality, no major long term impacts on water quality were observed at site 5, the main seep draining the area of the mine voids most heavily grouted. While placement of FGD by-product in mine drainage environments may not have long term deleterious impacts, better approaches are needed for the effective utilization of FGD by-product for the reduction of acid mine drainage.

ACKNOWLEDGMENT

This project was funded in part by the Ohio Coal Development Office, Ohio Department of Development, under OCDO Grant No. D-95-17 and the Ohio Environmental Protection Agency. Additional support was provided by American Electric Power, Ohio Department of Natural Resources, US Department of Energy, Dravo Lime Company, Office of Surface Mines, Corp of Engineers, US Environmental Protection Agency, and The Ohio State University. Partial salary support was provided by OSU/OARDC. The authors would also like to thank Dr. Sam Traina and Doug Beak in the School of Natural Resources, Kevin Jewell at OARDC, Wooster, and Jim Wood, formerly in the Department of Geological Sciences, all at Ohio State University, for their assistance in sampling and analysis.

REFERENCES

[1] Stewart, B. R. and Kalyoncu, R. S. Proc. International Ash Utilization Symposium, 1999, Lexington, KY, October 18-20.

[2] Dick, W. R., Stehouwer, R.C., Bigham, J. and Lal, R. Proc. International Land Reclamation and Mine Drainage Conference, 1994, Pittsburgh, Pennsylvania, April 24-29, pp. 129-138.

[3] Stehouwer, R. C., Sutton, P., Fowler, R. K and Dick, W. A. *J. Environ. Quality*, 1995 **24**, pp. 165-174.

[4] Stehouwer, R. C., Sutton, P., Fowler, R. K. and Dick, W. A. J*. Environ. Quality* 1995, **24**, pp. 861-869.

[5] Hao, Y. L., Dick, W. A., Stehouwer, R. C. and Bigham, J. M. Inhibition of acid production in coal refuse amended with calcium sulfite and calcium sulfate-containing FGD. Phase II Technical Report, 1998, Ohio Agricultural Research and Development Center. Wooster, Ohio.

[6] Refalko, L., Petzrick, P. Proc. International Ash Utilization Symposium, 1999, KY, October 18-20.

[7] Rudisell, M. T., Stuart, B. J., Novak, G., Payne, H. and Togni. C. S. *Fuel*, 2001, **80**, pp. 837-843.

[8] Lamminen, M., Wood, J., Walker, H. and Chin. Y.-P. Proc. International Ash Utilization Symposium, 1999, Lexington, KY, October 18-20.

[9] Lamminen, M., Wood, J., Walker, H., Chin, Y.-P., He, Y. and Traina, S. *J. Environ. Quality*, 2001, **30**, pp. 1371-1381.

[10] Laperche, V. and Traina, S. J. *J. Environ. Quality*, 1999, **28**, pp.1733-1741.

[11] Laperche, V., and Traina, S. J. Injection of FGD grout to mitigate acid mine drainage at the Roberts-Dawson underground coal mine, Coshocton and Muskingum Counties, Ohio. Volume 7: Grout weathering and chemical characterization. Final Technical Report. 1999. Ohio Coal Development Office, Columbus, Ohio.

[12] Hammer, M. J. and Bair, E. S. Injection of FGD grout to mitigate acid mine drainage at the Roberts-Dawson underground coal mine, Coshocton and Muskingum Counties, Ohio. Volume 2: Site Geology and Hydrogeology. Final Technical Report. 1999. Ohio Coal Development Office, Columbus, Ohio.

[13] Metheny, M. A. and Bair, E. S. Injection of FGD grout to mitigate acid mine drainage at the Roberts-Dawson underground coal mine, Coshocton and Muskingum Counties, Ohio. Volume 8: Contaminant transport model. Final Technical Report. 2000, Ohio Coal Development Office, Columbus, Ohio.

[14] Damian, M.T., and Mafi. S. Injection of FGD grout to mitigate acid mine drainage at the Roberts-Dawson underground coal mine, Coshocton and Muskingum Counties, Ohio. Volume 5: Grouting Operations. Final Technical Report, 1999. Ohio Coal Development Office, Columbus, Ohio.

[15] Walker, H. W., Wood, J. T., Lamminen, M., Y.-P. Chin, and Whitlatch E. E. Injection of FGD grout to mitigate acid mine drainage at the Roberts-Dawson underground coal mine, Coshocton and Muskingum counties, Ohio, Volume 6: Groundwater and surface water quality, Final Report ,1999, Ohio Coal Development Office, Department of Development, Columbus Ohio.