

# DISPOSING OF COAL COMBUSTION RESIDUES IN INACTIVE SURFACE MINES: EFFECTS ON WATER QUALITY<sup>1</sup>

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**Abstract:** The disposal of coal combustion residues (CCR) in surface and underground coal mines can provide a stable, low-maintenance alternative to landfills, benefitting the mining and electric power industries. The material may be able to improve water quality at acid generating abandoned or reclaimed coal mine sites. Most combustion residues are alkaline, and their addition to the subsurface environment could raise the pH, limiting the propagation of pyrite oxidizing bacteria and reducing the rate of acid generation. Many of these CCR are also pozzolanic, capable of forming cementitious grouts. Grouts injected into the buried spoil may decrease its permeability and porosity, diverting water away from the pyritic material. Both mechanisms, alkaline addition and water diversion, are capable of reducing the amount of acid produced at the disposal site. The U.S. Bureau of Mines is cooperating in a test of subsurface injection of CCR into a reclaimed surface mine. Initially, a mixture of fly ash, lime, and acid mine drainage (AMD) sludge was injected. Lime was the source of calcium for the formation of the pozzolanic grout. Changes in water quality parameters (pH, acidity, anions, and trace metals) in water samples from wells and seeps indicate a small but significant improvement after CCR injection. Changes in the concentration of heavy metals in the water flowing across the site were apparently influenced by the presence of flyash.

## Introduction

Approximately 80% of the coal produced in the United States is used for electric power generation, and 10% to 15% of this amount is recovered as coal combustion residues (CCR). Since 1988, CCR have been produced at the rate of more than 100 million tons per year, including 60% fly ash, 16% bottom ash, 4.5% boiler slag, and 18% flue gas desulfurization sludge. The increased consumption of low-sulfur coal and the use of clean coal technologies are expected to increase the amount of CCR produced to 250 million tons by the year 2000 (Chugh 1992). Over the next 20 years, while coal use in some markets is expected to decline, demand for coal for electricity is projected to increase by more than 50% (Rose 1991, Alpert 1991).

CCR are generally classified as residual wastes to be placed in landfills. Several States currently permit or are developing regulations for disposal in surface or underground coal mines as a beneficial use. Fly ash is an alkaline material that has pozzolanic properties (Pozzolan: a finely divided silicious material that in the presence of moisture will chemically react with alkali and alkaline earth hydroxides at ordinary temperatures to form cementitious compounds). If it is placed with acid-producing mine spoil, either during or after reclamation, alkaline addition and water diversion may reduce the rate of acid formation at these coal mine sites. The U.S. Bureau of Mines is evaluating the effect of CCR injection on the discharge of acid mine drainage (AMD) at a reclaimed surface mine. In this study, a pozzolanic grout prepared from fly ash, AMD sludge, lime, and treated water was injected over a 12-month period into an experimental section of a reclaimed surface mine that continues to produce AMD. The alkaline grout if injected directly into areas of acid-producing mine spoil may reduce the permeability and porosity of the backfill, diverting ground water away from acid producing material. The mixture can also encapsulate acid-producing material, reducing potential exposure to air and water. Adding alkaline material to the subsurface environment may neutralize acidic groundwater. Both mechanisms, water diversion and alkaline addition, should decrease the rate of acid-producing reactions and inhibit bacterial activity.

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There are several types of CCR's. Fly ash is the type that was used at this site. It is generated from the burning of powdered coal and is noncombustible material swept through the furnace with hot flue gases. It ranges in size from 5 to 100 microns in diameter. Its physical properties are similar to those of volcanic ash; its chemical properties are similar to clay. Fly ash is produced from conventional power plants and from fluidized-bed combustion (FBC) plants. Fly ash from conventional U.S. power plants typically has a pH between 6.5 and 9.0 and contains less than 1% calcium (Paul et al. 1992). The FBC plants burn a mixture of low-Btu coal or coal refuse and limestone, producing an ash that is high in calcium oxide (>50%). Both materials are considered non-hazardous under the standards of the Toxicity Characteristic Leaching Procedure (TCLP), as defined by the U.S. Environmental Protection Agency (Federal Register 1990).

### Site Description

The experimental site is a 14.5-ha (36-acre) reclaimed strip mine in Greene County, PA. Mining ceased in 1981 after partial removal of the Waynesburg coal seam (Ackman, et al, 1993). A buried highwall was left along the eastern boundary of the site. The overburden associated with this coal seam consisted of a sandstone and thin carbonaceous shale, both pyritic. Acid-base accounting at 13 postmining monitoring wells indicated a net acid-producing potential (NAP) of 4 to 44 mt of calcium carbonate (CaCO<sub>3</sub>) equivalency per 908 mt of material. Drill cuttings from seven wells across the experimental portion of the site had an average NAP of 20 mt of CaCO<sub>3</sub> per 908 mt of material. The buried spoil ranges between 5 and 15 m, averaging about 10 m, under 2 m or less of vegetated cover.

After reclamation, AMD discharged at an initial rate of 0.19 L/s; the rate has increased to 1.9 L/s (30 gpm) (Harshbarger, 1991). Currently, water treatment includes seepage collection, lime neutralization, aeration, and a series of sludge settling and polishing ponds. Ground water flows from east to west across the site. The flow path is inferred from the relative locations of the buried highwall and seep, geophysical investigations, and drilling.

Sixty-three wells were drilled on the reclaimed mine; 34 of these are located on the 1.2-ha (3-acre) experimental section. Twelve are monitoring wells, and the remainder are injection wells (fig. 1). Well A (1010)<sup>3</sup> is located at the edge of the site outside the mined area to the east of the experimental section. It is considered indicative of background water quality. Well C (1030) is near the buried highwall, where ground water enters the previously mined area. The primary discharge point, Seep A (1001), is also outside the experimental area and drains most of the reclaimed mine, including sections that were unaffected by grout injection.

### Procedures

Fly ash was loaded into a 3.8-m<sup>3</sup> (5-yd<sup>3</sup>) steel bin using a small front-end loader, then fed into a 5.1-m<sup>3</sup> (1,350 gal) steel mixing tank. Water from the AMD treatment system and AMD sludge and/or lime waste (which consists of about 30% unused lime) were pumped into the mixing tank. Turbulence created by the feed streams and a 20-hp submersible slurry pump mixed the grout. The grout was pumped through a flexible 7.62-cm hose to the cased injection wells. The maximum distance was about 150 m across the surface. Grout was pumped into the injection wells until refusal, at a maximum pumping pressure of 3.5 kg/cm<sup>2</sup> (50 psi).

Grout was injected intermittently between July 1992, and June 1993, (table 1). Fly ash (50 m<sup>3</sup>) from a conventional power plant was injected into 12 holes to the west of the experimental section between July and October 1992. Between October 1992 and May 1993, 54 m<sup>3</sup> of fly ash from another conventional source was injected into 12 holes on the western half of the experimental section. In May and June 1993, 67 m<sup>3</sup> of ash from a third conventional power plant was injected into 7 holes around Well 11 (1111). On a volume basis, fly ash constituted an average 5.6% of the injected grout.

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<sup>3</sup>Four digit numbers in parenthesis refer to location codes on figure 1.

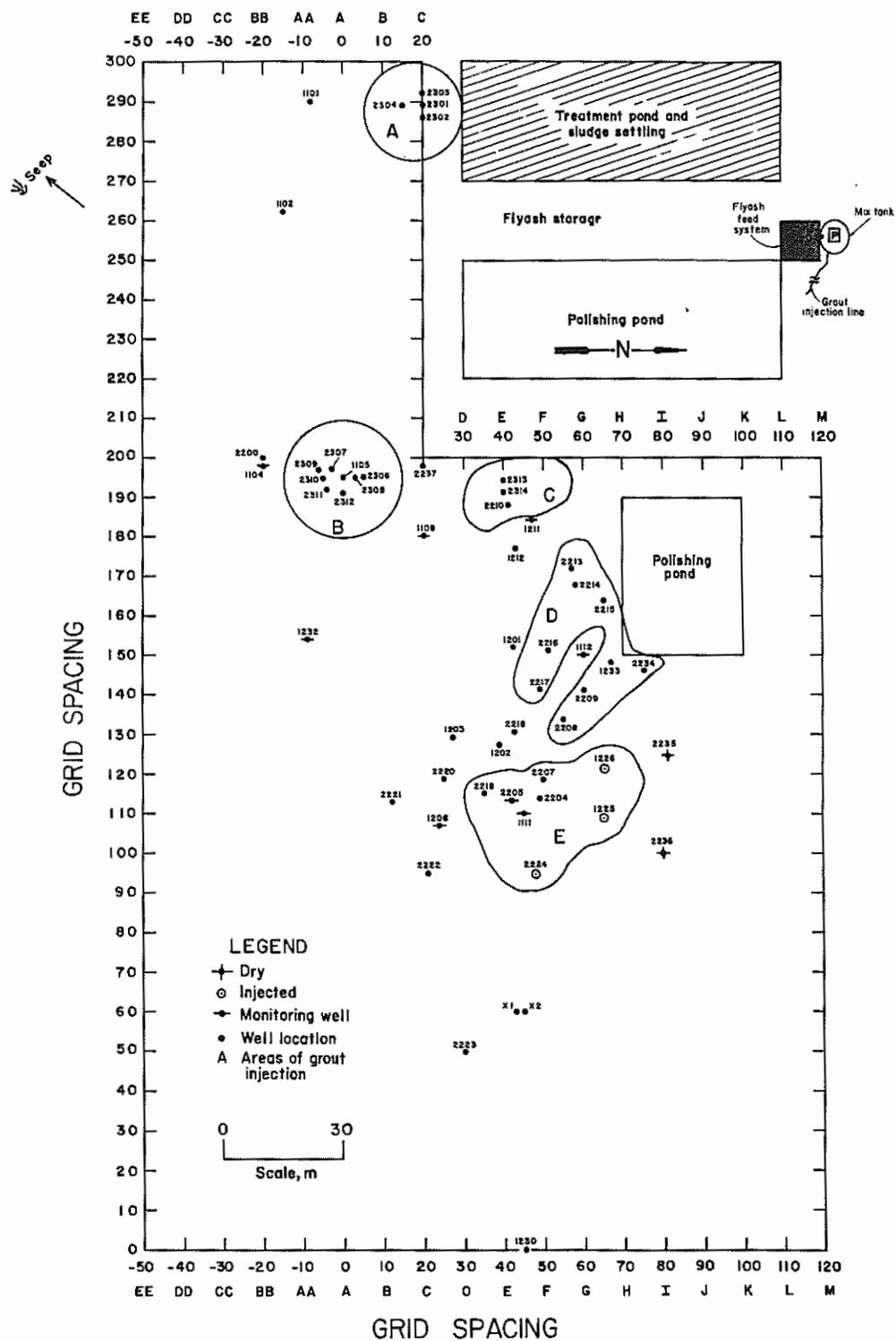


Figure 1. Well locations on map of experimental section of reclaimed strip mine.

Table 1. Fly ash injection at Bognanni Site.

Injection area <sup>1</sup>	Date	Number of wells	Fly ash, m <sup>3</sup>	Fly ash source	Number of injection days
A .....	Aug 1992	1	13.6	F	4
A .....	Sept 1992	3	11.9	F	2
B .....	Sept 1992	6	22.2	F	2
B .....	Oct 1992	2	2.5	H	1
C .....	Oct 1992	3	24.9	H	2
D .....	Nov 1992	3	22.2	H	2
D .....	May 1993	7	5.7	H	2
E .....	May 1993	6	36.3	G	4
E .....	June 1993	2	31.1	G	2

<sup>1</sup>Refer to figure 1.

### Results

Water samples were collected during a 1-year period prior to injection from several wells and from the central seep (1001). Because of their location across the site, the data for Well C (1030), Well 8 (1108), Well 11 (1111), and Well 12 (1112) and for Seep A (1001) are considered representative of changes in water quality. Table 2 lists water quality data for Well A (1010), which is located outside the mined area and is considered indicative of the ground water entering the site. Prior to grouting, the pH of the water decreased across the site (fig. 2). After grouting, the average pH at monitoring wells increased. During the active period the pH at Well C (1030) was decreasing (fig. 3). Although the average pH at the seep showed little variation, the data points were slightly higher after grouting. After injection of the fly ash grout, the total acidity decreased at the monitoring wells and at the seep. Similar trends were observed for ferrous iron, total iron, aluminum and sulfate (table 3).

Based on a comparison of parametric and nonparametric tests of significance, on standard normal scores and the frequency distribution, almost all values for the pregrouting and postgrouting water quality data for this site are found to be normally distributed. To test if there is a significant difference between water quality parameters measured before and after grouting, a one-tailed t-test was computed for the variables listed in table 2. The test evaluates the differences between two data sets (before and after fly ash injection) based on their respective means and their standard deviations (Zar 1984). The level of acceptance or rejection was established at  $p \leq 0.05$  (table 4). The decrease in total acidity and total iron was significant at Well 8, Well 11, and Well 12 and at Seep A. Although the sulfate concentration decreased at these monitoring points, the change was significant only at Well 11, Well 12, and Seep A. The increase in the concentration of calcium and magnesium, significant at Well 8, Well 11 and Seep A, is probably due to the presence of these elements in the grout.

An analysis for trace metals indicated that barium ( $Ba^{++}$ ) was present in the incoming water but decreased across the site and was not detected at the seep (fig. 4). Lead ( $Pb^{++}$ ), chromium ( $Cr^{++}$ ) and copper ( $Cu^{++}$ ) were present in samples from the monitoring wells, but were not detected in water at the seep. Cobalt ( $Co^{++}$ ) and zinc ( $Zn^{++}$ ) (fig. 5) were detected at the monitoring wells and at the seep, but the concentrations at the seep did not exceed drinking water standards.

Table 2. Water quality data - Well A (1010)

Water quality parameters	Sample date: June, 1991	Sample date: June, 1993
pH . . . . .	6.93	7.50
Analysis, mg/L . . . . .		
Alkalinity . . . . .	169	167
Ferrous iron . . . . .	ND	ND
Total iron . . . . .	2.1	.5
Calcium . . . . .	53	57
Magnesium . . . . .	12	13
Aluminum . . . . .	1.8	.4
Manganese . . . . .	.5	.5
Sulfate . . . . .	35	35
Arsenic . . . . .	NA	<0.10
Barium . . . . .	NA	.36
Beryllium . . . . .	NA	<0.01
Cadmium . . . . .	NA	<0.01
Cobalt . . . . .	NA	0.01
Chromium . . . . .	NA	0.01
Copper . . . . .	NA	0.01
Nickel . . . . .	NA	0.03
Lead . . . . .	NA	<0.10
Antimony . . . . .	NA	<0.10
Selenium . . . . .	NA	<0.50
Zinc . . . . .	NA	<0.01

NA Not analyzed.

ND Not detected.

Table 3. Mean water quality values (mg/L) for incoming water Well C (1030), across site (Well 8, Well 11, and Well 12) and at outflow (Seep A) for periods before (B) and after (A) grouting.

	Well C		Well 8		Well 11		Well 12		Seep A	
	B	A	B	A	B	A	B	A	B	A
Acidity . . . . .	-18	22	1407	641	1525	796	1977	614	1735	1200
Ferrous iron . . . . .	6	4	294	128	332	218	131	50	369	241
Total iron . . . . .	9	7	302	207	345	254	149	77	382	251
Calcium . . . . .	44	62	349	566	396	525	443	544	399	460
Magnesium . . . . .	16	25	292	387	467	383	320	325	455	319
Aluminum . . . . .	6	7	134	186	142	137	254	112	177	127
Manganese . . . . .	6	4	251	199	164	151	397	226	249	161
Sulfate . . . . .	9	285	3766	4029	4653	3979	5202	3335	4965	3987

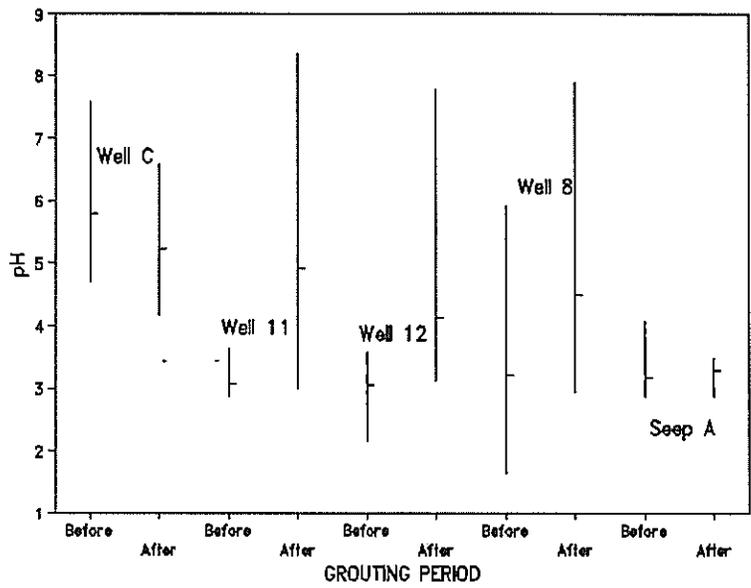


Figure 2. Range (|) and mean (—) values for incoming water (Well C), across site (Well 8, Well 11, Well 12), and at outflow (Seep A) before and after grouting.

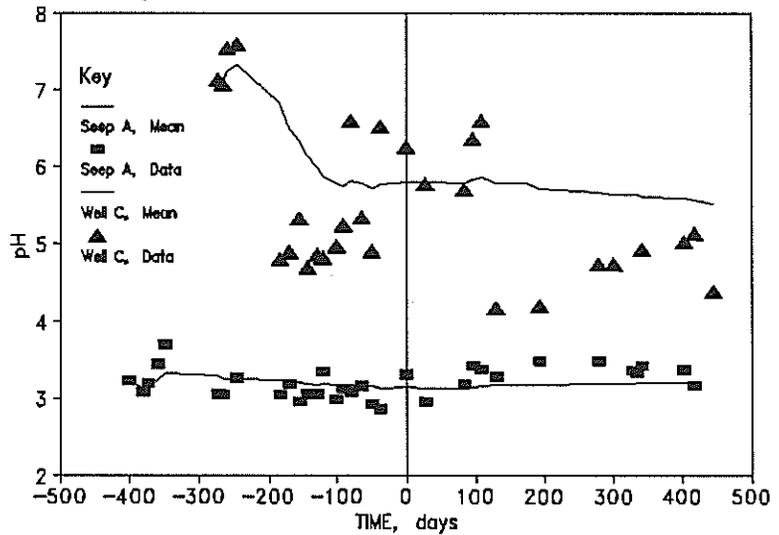


Figure 3. Variation in pH with time at highwall (Well C) and at outflow (Seep A) with time.

Table 4. t-test of significance<sup>1</sup> for water quality variables before and after grouting.

Well	pH	Acidity	Ferrous iron	Total iron	Calcium	Magnesium	Aluminum	Manganese	Sulfate
Well 8	0.0031	0.032	0.000	0.015	0.001	0.007	0.118	0.410	0.110
Well 11	.017	.003	.002	.02	.047	.024	.289	.002	.010
Well 12	.065	.000	.065	.015	.180	.390	.000	.387	.000
Seep A	.080	.002	.000	.000	.005	.000	.002	.000	.000

Values  $\leq .05$  indicate significant difference between samples collected before and after grouting.

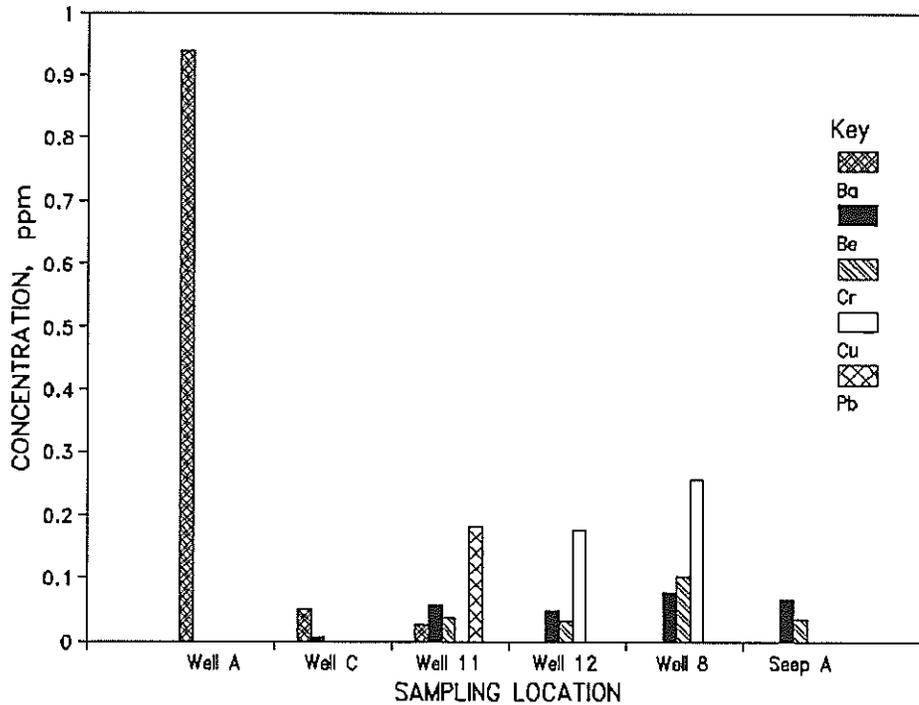


Figure 4. Concentration of five heavy metals in incoming water (Well C), across site (Well 8, Well 11, Well 12), and at outflow (Seep A) after grouting (day 402).

### Summary

Although the amount of fly ash injected was small and the volume of subsurface area it could have affected is a relatively small portion of the 14.5 ha site, the fly ash grout produced a measurable change in the acidity at the seep and the monitoring wells. Statistically significant changes in the concentration of metal ions and sulfate were also observed at the seep. There was no significant change in the pH at the seep, and the observed reductions in Fe and Mn were not sufficient to meet discharge standards. The release of heavy metals from the fly ash can be inferred from the concentrations in the monitoring wells. It should be noted, however, that the concentrations observed to date do not represent a hazard to surface or ground water.

Some improvement in water quality may be transient, due to the highly alkaline water (pH > 10) associated with the grout. The alkaline water could have created a plume of alkalinity that passed through the site as the solid portion of the grout was deposited in the spoil. If it is assumed that the grout followed the path of least resistance, its effect should coincide with the ground water movement. Increases in alkalinity observed at several of the wells may be related to this effect (fig. 6). Observed decreases in pollution levels

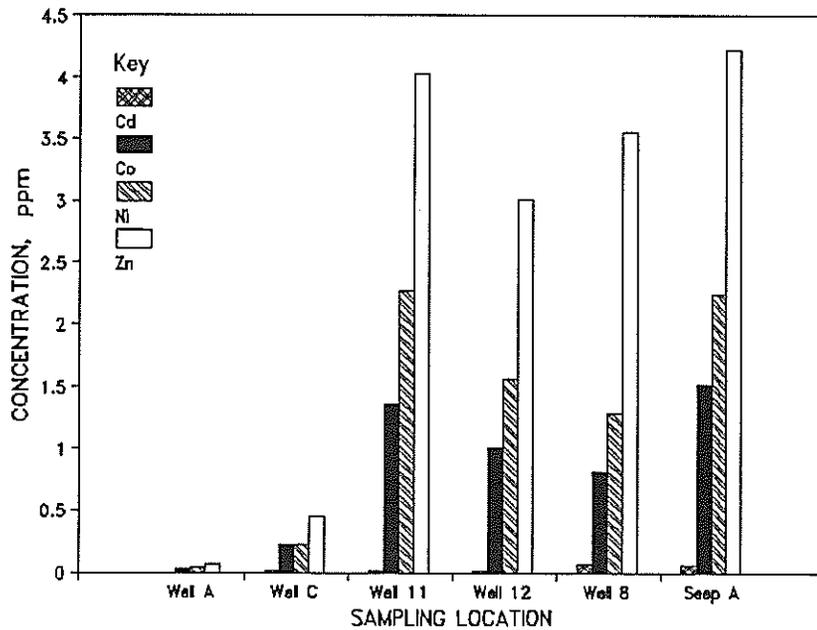


Figure 5. Concentration of four heavy metals in incoming water (Well C), across site (Well 8, Well 11, Well 12), and at outflow (Seep A) after grouting (day 402).

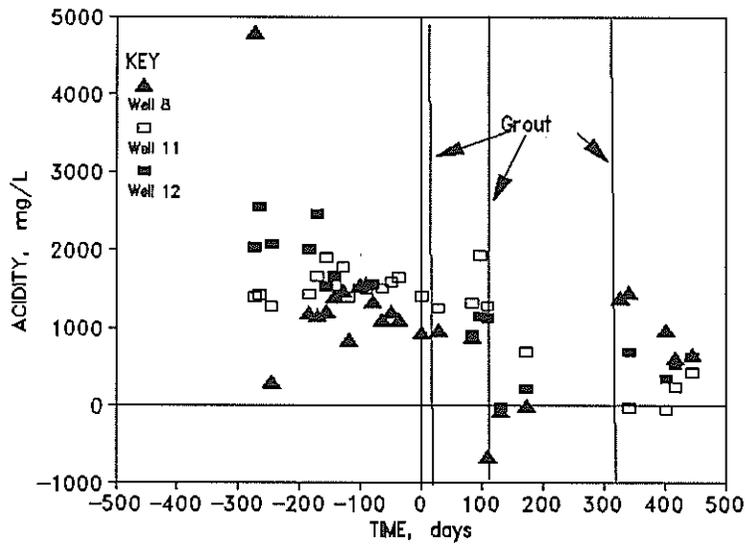


Figure 6. Variation in acidity at monitoring wells for pre and postgrouting periods.

may be due to encapsulation or armoring of pyritic material and/or to reduced permeability and porosity of the backfill material. Continued monitoring (>1 year) at the site is planned to determine if CCR injection produces long-term improvement in water quality.

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