THE WESTERN MARYLAND COAL COMBUSTION BY-PRODUCTS/ACID MINE DRAINAGE INITIATIVE THE WINDING RIDGE DEMONSTRATION PROJECT

by

Leonard Rafalko[1] and Paul Petzrick[2]

Abstract. The Maryland Department of Natural Resources Power Plant Research Program (PPRP) and the Maryland Department of the Environment Bureau of Mines (MDE) have undertaken the Western Maryland Coal Combustion By-Products (CCB)/Acid Mine Drainage (AMD) Initiative, which is a joint effort with private industry to demonstrate the beneficial application of alkaline CCBs to create flowable grouts to prevent the formation of AMD. The Initiative is a key component of Maryland's overall ash utilization program to promote and expand the beneficial use of all CCBS. Ultimately, the Initiative is targeting AMD abatement from significant AMD sources in the State, such as the Kempton Mine and Three Forks Run complexes. The Winding Ridge Project is the Initiative's first demonstration of this technology. The Frazee Mine (a small "kitchen" mine), in Garrett County, Maryland, was selected for the demonstration.

The CCB grout mixing and mine injection phase was performed in October and November 1996. This phase demonstrated the engineering feasibility and logistics of using 100 percent CCBs and acid mine water to create a grout, which was injected into the Frazee Mine. Approximately 5,600 cubic yards of CCB grout were injected into the mine under both dry and submerged conditions. Observations from borehole camera logging indicated that the grout was capable of flowing at least 100 feet along the mine pavement.

Laboratory tests of hardened grout core samples recovered from the mine showed unconfined compressive strengths of over 1,000 pounds per square inch (psi) (28-day strength tests were over 300 psi) and permeabilities of about 10-7 centimeters per second. These observations indicate that the use of CCBs as a grout for mine sealing is a promising technical option for the large-scale beneficial application of these materials. Currently, postinjection water quality monitoring is being performed to better evaluate the long-term effects on the mine discharge. In addition, future work will evaluate the economic feasibility of this technology.

Additional Key Words: Coal Combustion By-Products, Acid Mine Drainage, Fluidized Bed Combustion, Flue Gas Desulfurization

Introduction

The Maryland Department of Natural Resources (DNR) Power Plant Research Program (PPRP) and the Maryland Department of the Environment (MDE) have undertaken the Western Maryland Coal Combustion By-Products (CCBs)/Acid Mine Drainage (AMD) Initiative, which is a joint effort with private industry to develop permanent solutions to AMD. AMD plagues about 450 miles of waterways in western Maryland, including many within the Chesapeake Bay watershed.

The Initiative is a multi-year project that commenced in April 1995. The Initiative's goal is to demonstrate the beneficial application of alkaline CCBs generated by clean coal technologies, such as fluidized bed combustion (FBC) and flue gas desulfurization (FGD), to prevent the formation of AMD from abandoned, underground coal mines. The Initiative is based on the concept that grout prepared using FBC and FGD by-products, which otherwise would be landfilled, can be injected into underground mines to prevent the formation of AMD by sealing mine surfaces from exposure to oxygen and water. Ultimately, the Initiative is targeting AMD abatement from significant AMD

[1]Leonard Rafalko is a Project Manager for Environmental Resources Management (ERM), Annapolis, MD, 21401.
[2]Paul Petzrick is a Project Manager for the Maryland Department of Natural Resources Power Plant Research Program, Annapolis, MD, 21401.

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sources in the State, such as the Kempton Mine and Three Forks Run complexes.

The Winding Ridge Project is the Initiative's first demonstration of this technology. The Frazee Mine, located atop of Winding Ridge in Garrett County, Maryland (Figure 1), was determined by MDE to be the most suitable location for this first project. The Frazee Mine is a small, hand-dug, abandoned, underground coal mine that was used to mine coal from the Upper Freeport seam from the 1930s to circa 1960. The Winding Ridge Project consists of six phases:

1. *Phase I - Frazee Mine Characterization:* The principal objectives of Phase I were to develop a mine map, determine mine hydrology, establish baseline water quality conditions, and identify the regulatory permitting requirements.

2. *Phase II - Characterization and Procurement of Alkaline CCBs for Mine Injection:* The principal objective of Phase 11 was to determine the optimal grout formulation.

3. *Phase III - Design of Underground Injection Program:* Phase 1lI prepared the final engineering design and technical specifications.

4. *Phase IV - Injection of Alkaline CCBs: CCB* based grout was injected into the Frazee Mine in October and November 1996.

5. *Phase V - Post-Injection Monitoring:* The physical and chemical characteristics of mine discharge and in-situ grout are being monitored following injection and curing in the mine.

6 *Phase VI - Mineback for In-Situ Grout Inspection:* A mineback phase will be considered to expose the injected, hardened grout for detailed examination.

Purpose

The purpose of this paper is two-fold:

1. Summarize the means and methods of the grout injection phase (Phase IV) of the Winding Ridge Project; and

2. Present the results of post-injection monitoring through the last quarterly sampling event (i.e., September 1997), which is almost one full year after grout injection.

Physiographic Setting, of the Frazee Mine

The Frazee Mine is located in the Casselman River Basin of the Appalachian Plateau physiographic province, about one mile east of Friendsville, Maryland (Figure 1). Relative to the Frazee Mine openings, the nearest surface water is Bear Creek, which is located in the Youghiogheny Watershed and about 2,000 feet downhill from the Frazee Mine. AMD from the Frazee Mine does not enter Bear Creek via overland flow.

The geology in this area consists of folded Pennsylvanian, Mississippian, and Devonian-age sedimentary rocks. Upper Freeport coal (Pennsylvanian age) was mined at the Frazee Mine. Stratigraphically, the Upper Freeport coal seam is situated at the top of the Allegheny formation, and is one of five principal coal seams mined in Maryland. The sulfur content measured in Upper Freeport coal samples from the project site ranges from 1.0% to 3.5%. Other characteristics of the coal include an ash content between 10% and 13%, volatile matter of approximately 23%, and a heat content between 12,700 and 13,000 Btu per pound.

Frazee Mine Geometry

A mine map for the Frazee Mine does not exist. Therefore, various techniques were used to investigate the mine configuration including interviews with a former miner, drilling 80 exploratory boreholes, and borehole camera logging. The information obtained from these investigations was integrated to interpret the mine configuration, which was used as an engineering design basis for grout injection into the Frazee Mine.

The mine consists of two main tunnels (or adits), which are referred to as the lower and an upper tunnel (relative to elevation). These tunnels are connected by an unknown number of crosscuts (Figure 2). The adits entered the hillside to mine the Upper Freeport coal seam, which is approximately 3 feet thick. The land surface above the tunnels is an open field, which facilitates access to the mine void from the surface.

The lower tunnel was started first and mined updip (northeast) approximately 1,500 feet. The upper tunnel was mined updip approximately 1,000 feet. The tunnels are about 3 feet in height, with several areas of collapse, and about 16 feet wide. The cross cuts between the tunnels were probably used to drain the upper mine, and to provide ventilation and possible escape routes.

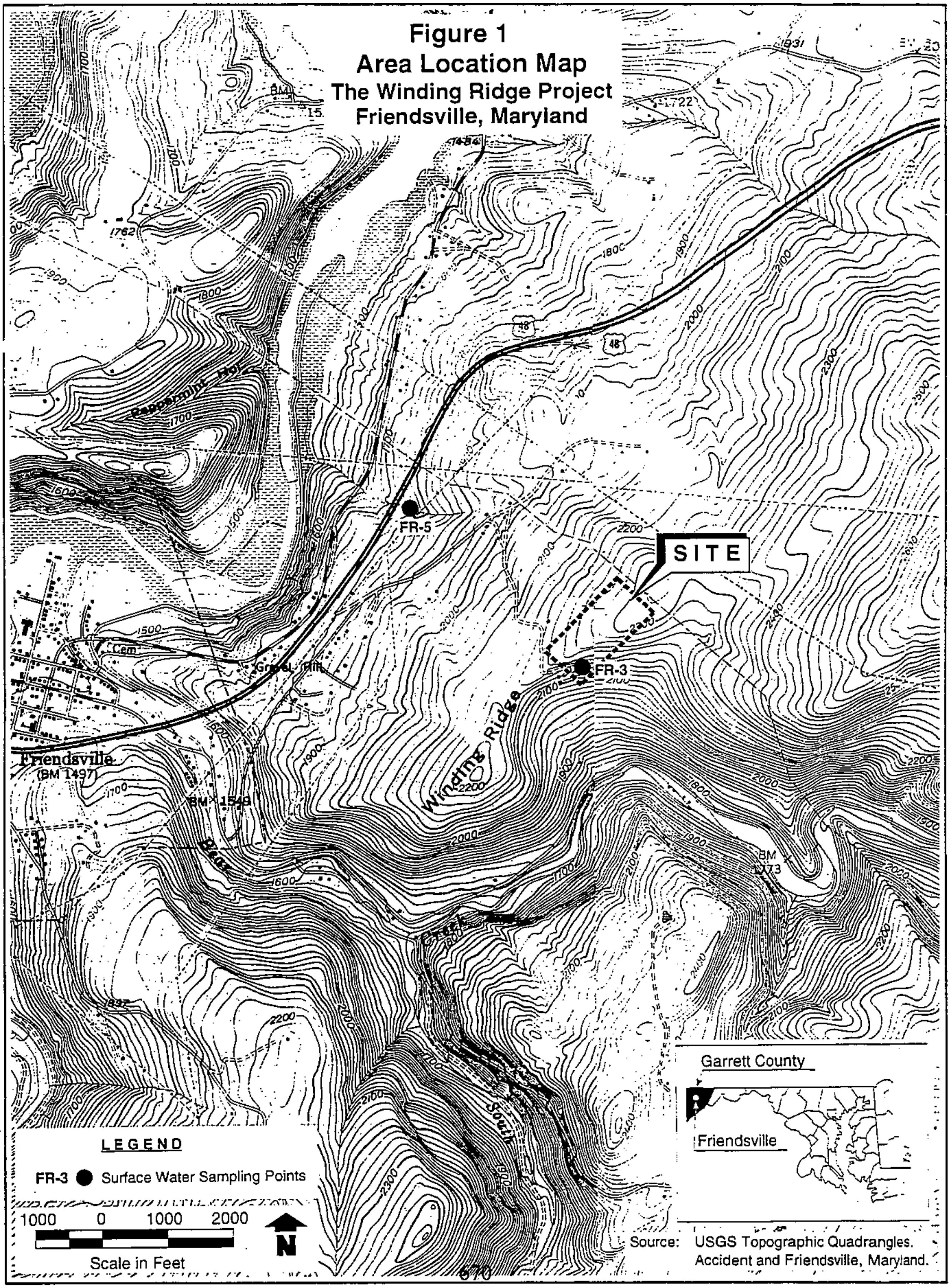

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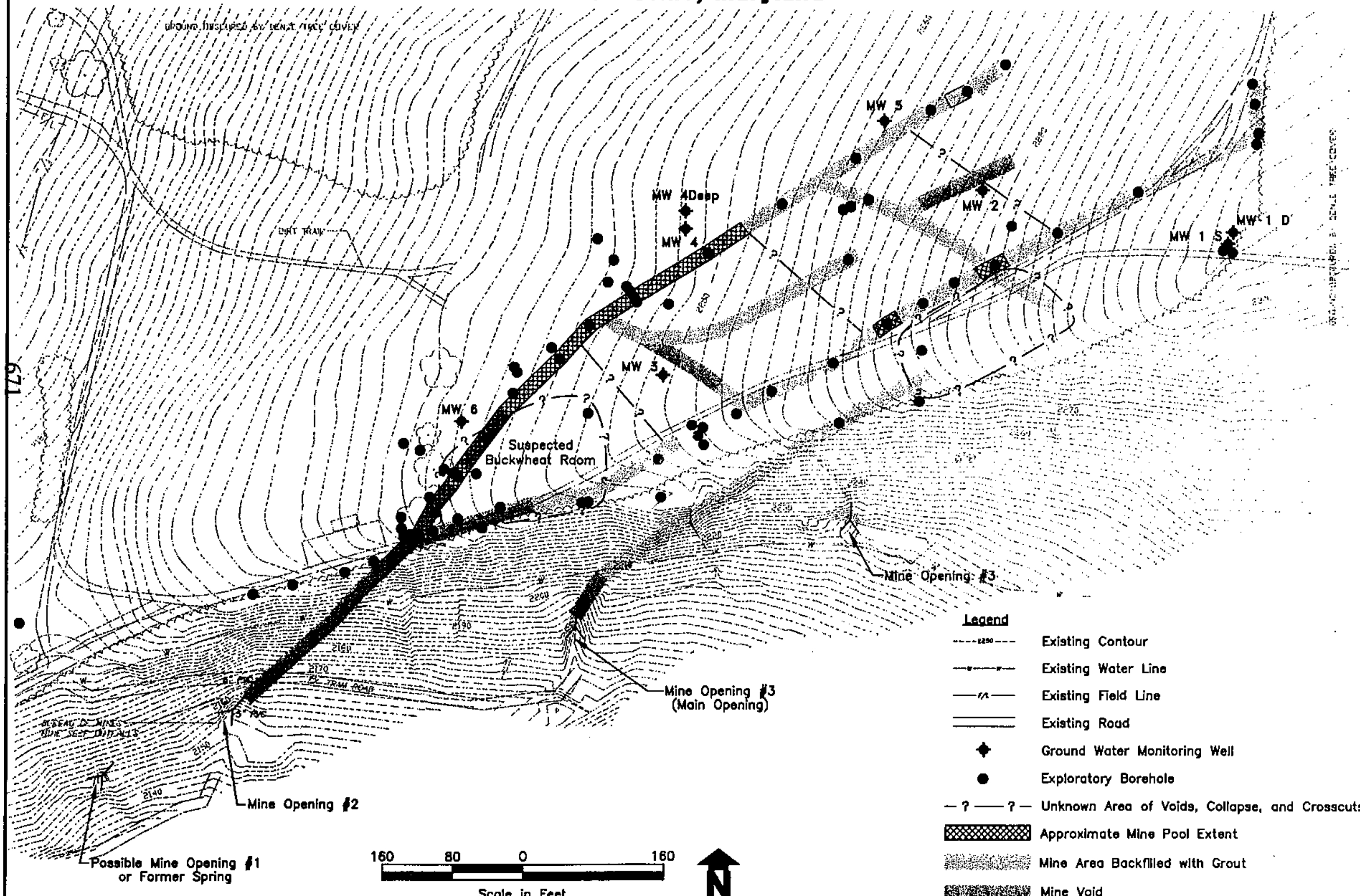
Figure 2
Detailed Site Location Map
Winding Ridge Project
Friendsville, Maryland



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The mine entries are located on the south face of Winding Ridge, in a forested area with moderate to thick underbrush (Figure 2). The soil around both mine openings is stony and has a surface slope close to 40 percent. Four mine openings have been identified; however, AMD only occurs from Mine Opening No. 2:

1. Mine Opening No. I is an aborted entry not apparently connected to the mine;

2. Mine Opening No. 2 is the opening into the lower tunnel and is the point of discharge for the mine;

3. Mine Opening No. 3 is an apparent haulage drift;

4. Mine Opening No. 4 is interpreted to be an air shaft or escape way.

The total mine void originally estimated for the Frazee Mine was about 3,900 cubic yards (cy). However and as is discussed later in this paper, the grout injection phase did not completely backfill the mine even though 5,600 cy of grout were pumped into the mine. These results indicate that the minc configuration is much more complex than originally suggested by our investigation results. This is particularly evident in the southwest area of the mine where a former miner indicated (after injection began) the presence of a large room, designated by the miners as the "buckwheat room."

The project team has performed pilot-scale geophysical surveys of the suspect buckwheat room in an effort to better delineate the mine configuration. Although the results are only preliminary at this time, the results of a ground penetrating radar survey suggests the presence of several previously unknown voids in the area of the suspect buckwheat room.

Mine Geologic and Baseline Hydrogeologic Conditions

Figure 3 shows a cross section of the Frazee Mine through the lower tunnel. The mine overburden consists of sandstone and shale, the thickness of which ranges up to approximately 100 feet along the top of Winding Ridge and tapers to the mine openings. The strike of the Upper Freeport coal at the Frazee Mine was calculated to be N400E based on drilling log information. The dip direction of the seam is N50'W, and the average dip angle is 8'. The mine pavement (i.e., floor of the mine) consists of a dense, dry, low permeability weathered shale and clay that dips to the openings at an angle of about 3' to 7'.

In addition, a rider coal seam (6 to 18 inches thick) overlies the Upper Freeport seam at many locations in the mine. About 3 to 5 feet of shale separate the two coal seams. Acid-base accounting performed on overburden samples indicates that the rider coal seam is the only other potential source of acid producing rock besides the Upper Freeport. The total sulfur content of samples from the rider coal seam was about 1.5% to 4.5%.

The hydrogeologic conditions of Winding Ridge and the Frazee Mine were also investigated as part of the project. Five shallow (i.e., 80 to 100 feet deep) bedrock monitoring wells were installed at upgradient and downgradient locations to monitor the first waterbearing zone commensurate with the elevation of the Frazee Mine. In addition, a deep (i.e., 322 feet deep) bedrock well was installed to monitor regional ground water quality downgradient of the mine.

Water levels collected from these wells indicate that the Frazee Mine occurs in unsaturated bedrock, and that the regional ground water table is approximately 60 feet below the mine pavement. Infiltrating precipitation that is not impounded by the mine pavement and diverted to Mine Opening No. 2 continues to recharge the regional water level.

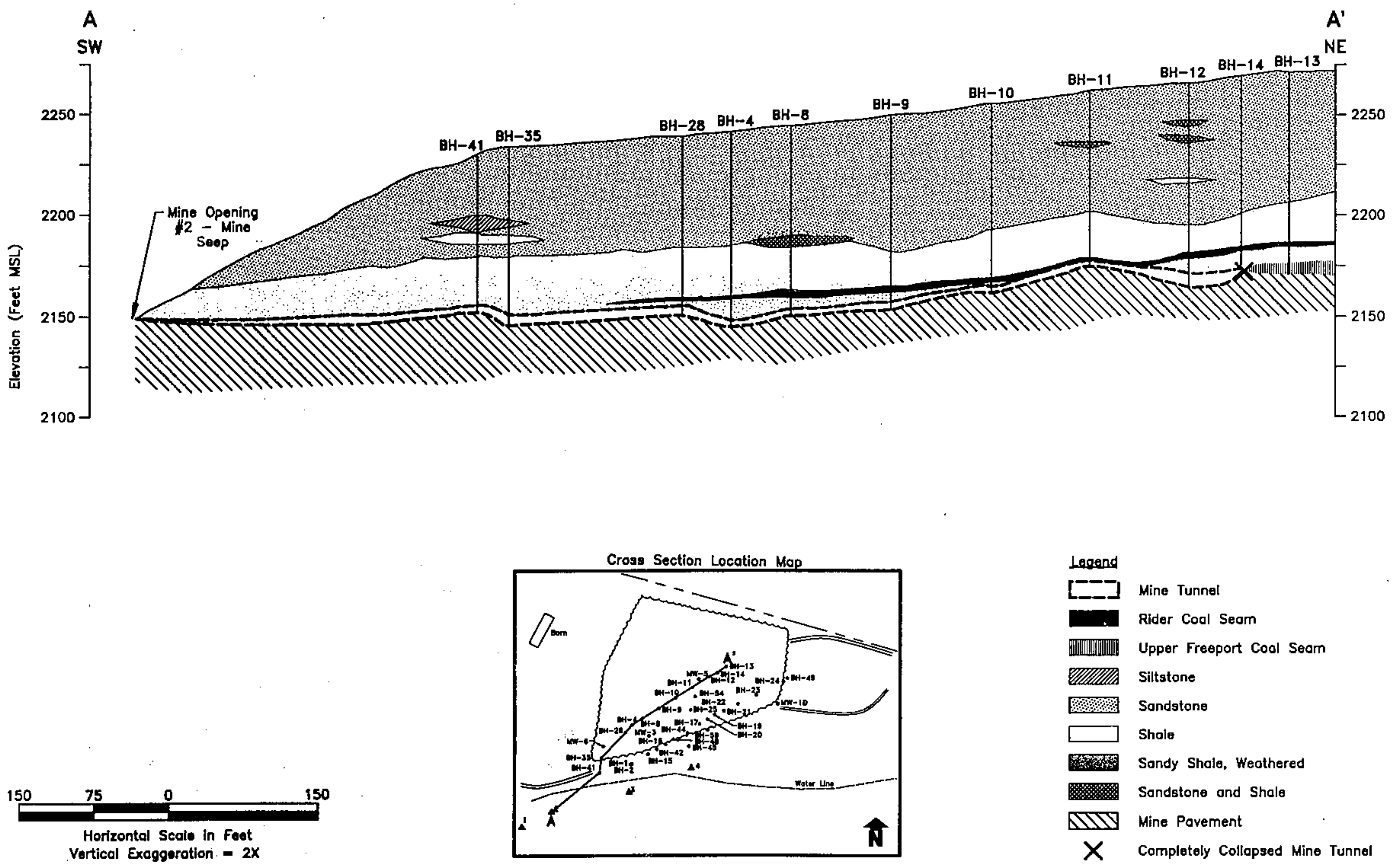
Infiltrating precipitation impounded within the Frazee Mine created a pre-injection mine pool of at least 550,000 gallons. This mine pool resided in the lower tunnel, while the upper tunnel was predominantly dry. Mine water discharge at Mine Opening No. 2 occurs directly from the tunnel and smaller side seeps. Mine discharge flow rates ranged from less than one gallon per minute (gpm) to about 14 gpm. Mine discharge is plotted in Figure 4. Within I 00 feet of Mine Opening No. 2, the water pools and infiltrates into the underlying hillside.

Baseline (i.e., pre-injection) monitoring was performed between September 1995 and September 1996. The monitoring results are summarized below.

1. *Precipitation.* Precipitation data were collected daily from a rain gauge installed in Friendsville. Rain totals averaged 0.9 to 10.8 inches per month (Figure 4).

2. *Mine Discharge.* The discharge water quality was indicative of AMD, with pH values typically less than 3.0, and sulfate [80 to 1,800 milligrams per liter (mg/L)I, total dissolved solids (160 to 2,900 mg/L), and acidity (50 to 2,400 mg/L) concentrations elevated relative to typical ground water quality in the Friendsville area.

Figure 3
Cross Section Through Lower Tunnel
The Winding Ridge Project
Friendsville, Maryland



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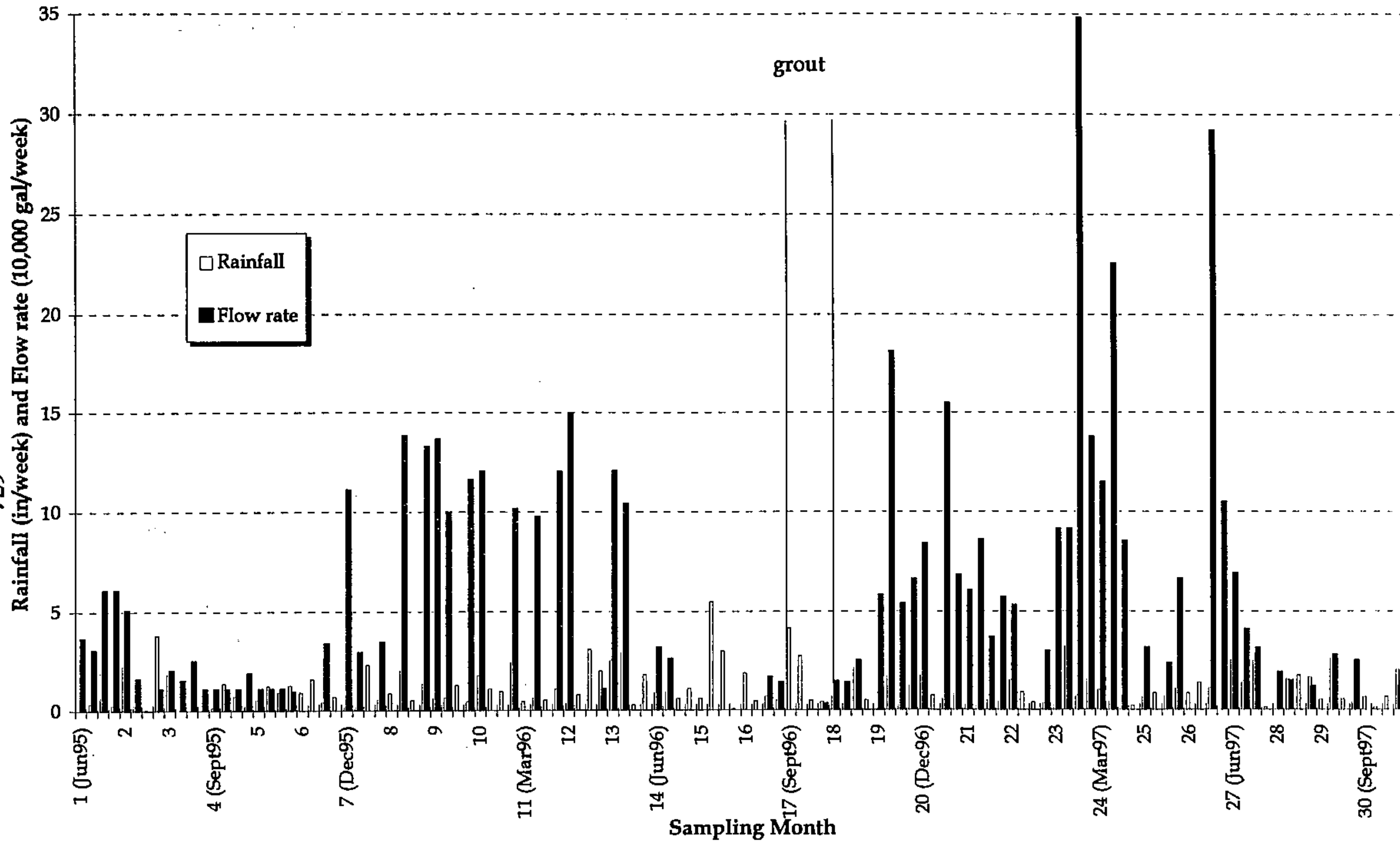

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Figure 4. Precipitation and Mine Opening No. 2 Flow Rates at Winding Ridge (June 95 through September 97)

3. *Perched Ground Water.* Analytical results are pH 6.0-6.2 standard unit; alkalinity 21-38 mg/L; total dissolved solids 20-34 mg/L: and specific conductivity 52-75 gm hos/cm. These ground water results from on-site wells are similar to residential bedrock supply wells in the Friendsville area that are completed in similar strata.

CCB Grout Formulation

The CCB grout formula was developed by an iterative process that included both laboratory tests of candidate mixes and field adjustments. The grout was optimized for good flowability with minimum bleed and settlement. These properties of grout workability were balanced against the need for sufficient long-term strength for the hardened grout to remain intact. The grout tests were performed using potable spring and acidic mine waters from the site. The CCBs used for the Project were FGD by-product and Class F fly ash from Virginia Power Company's Mt. Storm power plant (Mt. Storm, West Virginia), and FBC by-product from the Morgantown Energy Associates power plant (Morgantown, West Virginia).

The initial step was a laboratory study that evaluated different ratios of CCBs. Two different activators containing free-lime were investigated: fresh, unconditioned FBC by-product, and commercially available quicklime. Using each activator, grout mixes were prepared with FGD byproduct and fly ash. The fly ash provided pozzolan and the FGD by-product (mostly of calcium sulfite and calcium sulfate with no free lime) was used to bulk the grout. The laboratory tested several grout formulae for key engineering parameters, including slump, modified flow, bleed, settlement, and unconfined compressive strength (UCS).

Table 1 summarizes the laboratory study results for measured grout characteristics. The optimal FBC mix determined from this initial laboratory study consisted of 30% FBC with 38% added moisture, and a fly ash/scrubber sludge ratio of 1.2. The optimal quicklime mix consisted of 10% lime and 40% water, and approximately equal parts fly ash and FGD. The tests showed that either FBC or quicklime could be used to optimize a CCB grout for the project with FGD by-product and fly ash. Therefore, a grout mix consisting of FBC, FGD and fly ash was selected for advanced testing because of its relatively low cost compared to the quicklime mixes, and its use of I 00% CCBs.

Once the FBC-based grout mix was selected for the project, the next step was to transition this mix from the laboratory to field conditions. This entailed evaluating the heterogeneity of the FBC by-product to account for "as-delivered" conditions (e.g., free lime and moisture content) once injection started. Consequently, FBC by-product samples were collected from the Stack's Run FBC disposal site near Kingwood, West Virginia, which receives MEA's FBC by-product. The samples represented a range of ages, from freshly generated material to ash that was four weeks old or more. As expected, the testing results indicated a wide range of values depending on the age of the sample: moisture content ranged from <1% to 58%, free lime (measured by the ASTM C25 method) ranged from <1% to 10%, and pH varied between 9.3 and 11.6. Fresher samples generally had higher free lime content and pH, and lower moisture content.

As a result of this testing, the final grout mix design was to be based on the use of fresh FBC that was conditioned at MEA in accordance with routine operations. The mix design consisted of 60% fresh (defined as less than 24 hours old) FBC by-product, 20% FGD by-product, and 20% fly ash. The FBC was conditioned at the plant to contain about 15% moisture, which resulted in about 3% to 5% free lime content. This final design mix yielded 8 inches of spread using ASTM PS 28-95, and a 28-day UCS of 520 pounds per square inch (psi) as determined using ASTM C 39-94.

The final adjustments to the grout mix were performed in the field during injection. Specifically, the moisture content was increased to 57% on a dry weight basis for the design mix ratio of 60/20/20 for FBC, FGD and fly ash. The need to increase the water content to achieve the desired workability of the grout was due to: 1) the full-size mixing equipment, which required greater water to provide efficient and uniform mixing; and 2) our desire to maximize flowability characteristics to facilitate movement of the grout through the mine voids and collapsed material.

In addition to the geotechnical and workability parameters discussed above, the grout was also tested for metals using the Toxicity Characteristic Leaching Procedure (TCLP). The TCLP test for metals was performed on a freshly prepared grout sample with a mix ratio of 30/40/30 for FBC/FGD/fly ash and 38% water. The only two metals that were detected in the leachate were arsenic and barium at levels of 0. 13 and 0. 11 mg/L, respectively. The remaining six TCLP metals were not detected above the method detection limit, and none of the results exceeded their respective regulatory limits for characterization as a hazardous waste.

CCB Grout Injection into the Frazee Mine

CCB grout injection commenced on 30 September 1996 with the mobilization of construction equipment for grout handling, mixing and injection. Full-scale injection began on 7 October 1996 and ended on 8 November 1996. The grout mix consisted of 100% CCBs and virtually 100% mine water pumped from the Frazee Mine. Figure 5 shows the layout of operating areas during injection. Figure 6 shows a schematic of the field operations. More than 5,600 cy of grout were injected into the Frazee Mine, for which the design basis was 3,900 cy.

The CCBs injected into the Frazee Mine consisted of 3,800 tons of FBC ash, and 1,200 tons each of fly ash and FGD by-product. The project used 520,000 gallons of water, consisting of 449,000 gallons of untreated mine water (pH of about 3) and 71,000 gallons of water from the Youghiogheny River. About 471,000 gallons were used for grout mixing, and 49,000 gallons were used for equipment washing.

As shown in Figure 5, the CCBs were stored in separate holding bins prior to mixing. A front-end loader was then used to load the segregated CCBs into a Maxon MC-1-10 mixer at the appropriate proportions by weight. The mix water was incrementally added to the mixer from the water storage tanks. The grout was pumped to the injection boreholes using a Schwing trailer-mounted concrete pump. At the injection boreholes, the grout entered the mine voids by gravity until refusal (i.e., the borehole take terminated).

The average daily injection rate was about 220 cy over a 10-hour injection work day (additional time was needed daily for set up and take down). Hourly injection rates ranged from about 20 cy to as much as 60 cy. The higher hourly injection rates could not be sustained due to equipment sizing, workability of the CCBS, and injection pipe setup. However, we are confident that the equipment can be sized for scale-up projects to attain sustained grout injections of at least 60 cy/hour.

The Winding Ridge Project demonstrated the engineering feasibility and logistics of using 100% CCBs and acid mine water to create a grout that can be used to backfill underground coal mines. The CCB grout was injected into the mine under both dry and submerged conditions, and exhibited flow characteristics very similar to that of flowable fill. Although direct measurements of grout flow in the mine tunnels were not practicable, observations from borehole camera logging indicated that the grout was capable of flowing at least 100 feet along the mine pavement. Another indication of the good fluidity and workability of the grout is that the Schwing concrete pump pushed the grout a maximum distance of 850 feet over a 60-foot vertical rise during a sustained time period of several hours.

Unconfined compressive strength tests performed in the laboratory on grout samples collected during injection showed that significant gains in strength occur from 7-days of curing to 28-days. Seven-day strength tests ranged from about 30 to 77 psi. Casts from the same grout samples showed 28-day strengths ranging from 245 psi to 520 psi.

During injection, it became evident that the Frazee Mine was more complex than determined during the mine characterization phase (Phase 1), even though a former miner was interviewed and 80 boreholes were drilled. The onset of winter limited additional drilling to 17 boreholes during injection, eight of which were used to inject grout. Without a mine map, however, the percentage of total mine void sealed by injection is indeterminate. Because an unknown volume of void space remains in the Frazee Mine, AMD continues to flow as of January 1998.

Post-Injection Monitoring Results A Preliminary Assessment

In-Situ Grout Sampling and Results

In September 1998, nearly one year after grout injection was completed, nine coreholes were drilled at the Frazee Mine. The objective was to collect grout core samples from the mine to evaluate weathering processes that had occurred to the grout in the mine environment. The corehole locations targeted injection boreholes in both the wet and dry parts of the mine. Grout core samples were submitted for laboratory testing of density, permeability (hydraulic conductivity) and unconfined compressive strength.

Grout was encountered at five of the coreholes, from which samples were submitted for laboratory testing. The fact that grout was not detected in the other four coreholes attests to the complexity of the mine geometry (even though, for example, the coreholes were drilled within five feet of injection boreholes).

In general, the grout cores were in very good shape, and had little evidence of in situ weathering caused by the mine environment. The grout cores showed good contact with the mine roof and pavement.

Figure 5
CCB Staging Area
Winding Ridge Project
Friendsville, Maryland

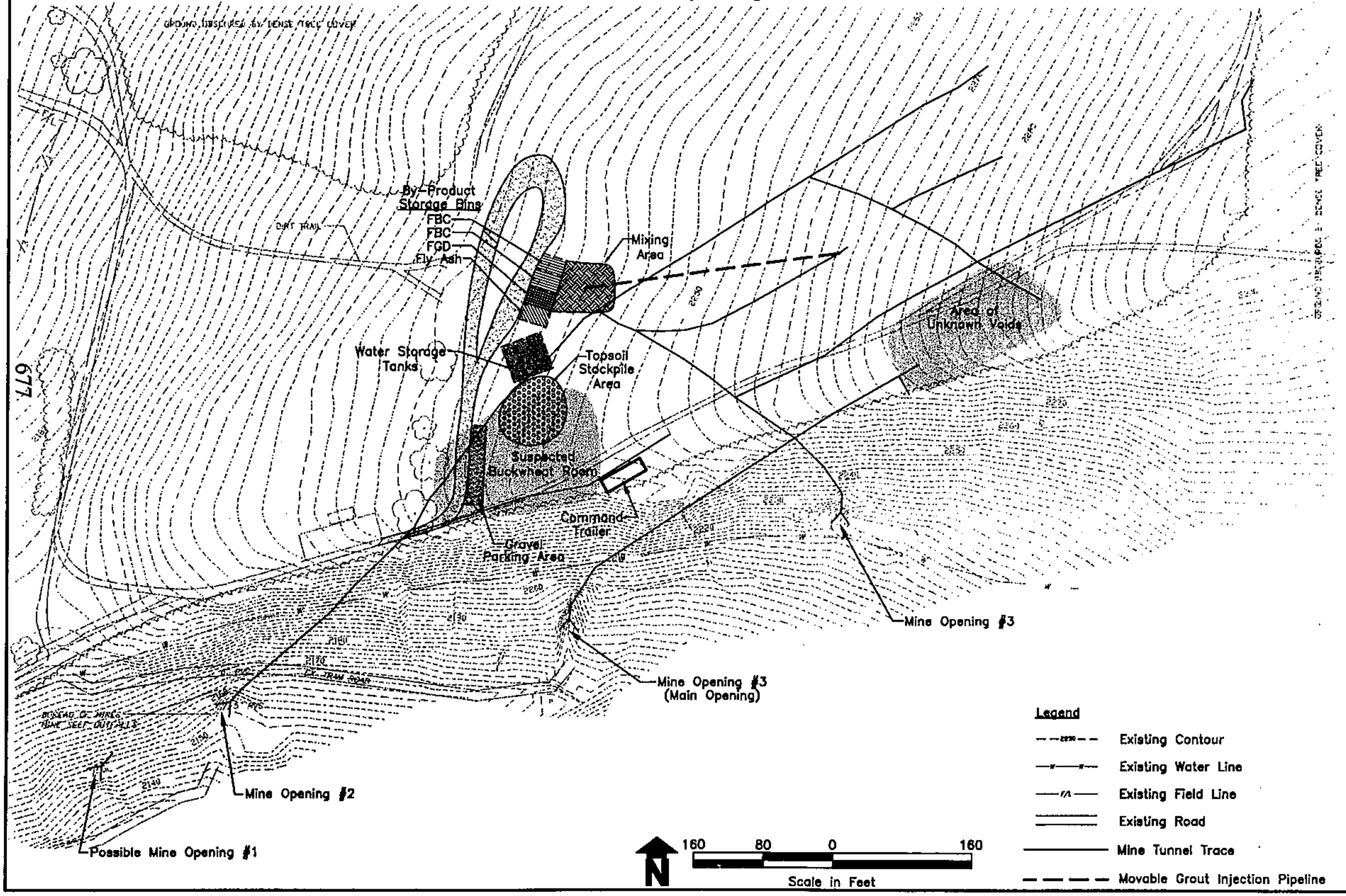
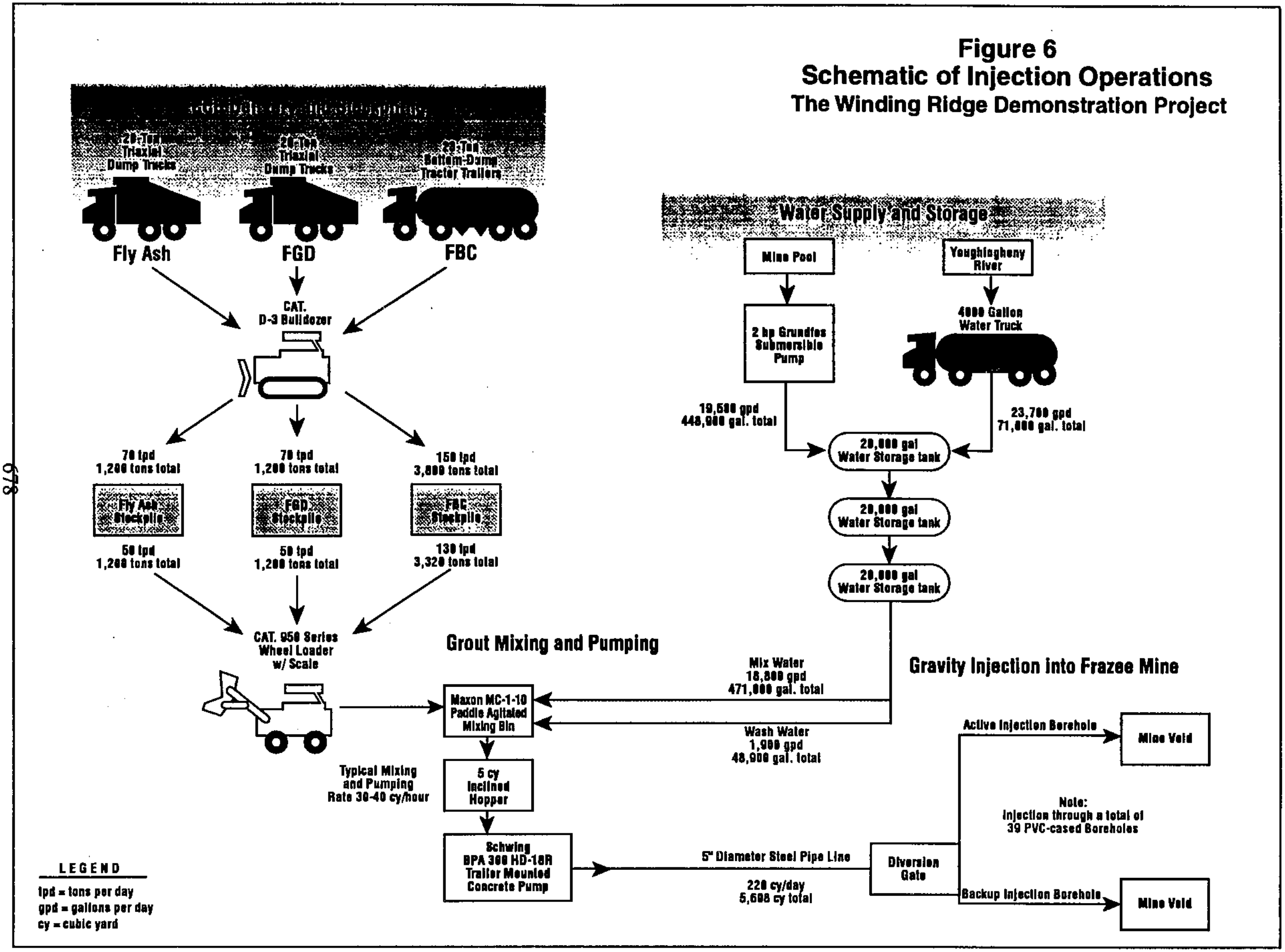


Figure 6
Schematic of Injection Operations
The Winding Ridge Demonstration Project



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In some cores, it was evident that shale from the collapsed mine roof was entrained by the grout flow during grout injection. Nonetheless, these cores showed no detrimental effects during curing from the entrained collapse material.

Table 2 summarizes the results of the geotechnical tests performed on the grout core samples. The measured permeabilities range from 6.02 x 10-8 to 1.89 x 10-6 cm/sec. Regarding the unconfined compressive strength measurements, with the exception of the grout core from CH-1, all strengths were measured above 1,100 pounds per square inch (psi). The grout core sample from CH-1 had an unconfined compressive strength of 560 psi. These results show that in some cases strengths have doubled compared to the 28-day strength tests on samples collected during injection. As a point of reference, flowable fill (consisting of 5 percent Portland cement and 95 percent fly ash) has a strength of about 100 psi, and can be hand dug with a shovel.

Mine Discharge Monitoring

AMD continues to flow from the mine. As stated before, unknown void remains and provides areas for pooling of infiltrating rainwater. Water levels from piezometers installed in the mine tunnels as part of post-injection monitoring show that the mine pool has not been bifurcated. New side seeps locations have been observed at Mine Opening No. 2 suggesting that the injection phase diverted the mine discharge flow path. Post-injection discharge flow rates are comparable to pre-injection flows (Figure 4).

During and immediately after injection, the pH of the mine discharge fluctuated within the historically observed range of values (i.e., about a pH of 3) but the last several sampling rounds show a slowly climbing trend of increased pH (Figure 7). Since peaking during injection, concentrations of sulfate and aluminum have returned to at least pre-injection levels (about 500 to 1,700 mg/L and 20 to 90 mg/L, respectively) (Figure 7).

Of most significance is the calcium concentration in the discharge water. Pre-injection water quality data showed that calcium concentrations were negligible (Figure 7). However, post-injection calcium levels remain elevated, ranging from about 150 to 500 mg/L. The most likely source of calcium is the dissolution of calcium sulfite from the FGD admixture, with a possible contribution of calcium sulfate from the FBC ash. The persistent elevated calcium concentrations suggest that, to some extent, the grout is dissolving in the acidic mine environment.

Summary of Significant Findings

The Winding Ridge Project has demonstrated that CCBs can be used beneficially to form a grout that can be injected into and backfill an abandoned, underground coal mine. To date, our key findings include the following:

1. Power plants were capable of providing conditioned CCBs without any changes to plant operation;

2. An effective grout can be produced with 100% CCBs and mine water;

3. CCB grout can be mixed, handled and injected using conventional concrete mixing equipment;

4. Compressive strengths are adequate for mitigating subsidence;

5. It is of paramount importance to know the mine configuration and conditions of mine collapse; and

6. Soluble minerals in the CCBs (such as calcium sulfite in the FGD) used for grout preparation are susceptible to dissolution in the mine environment.

Future Courses of Action

Post-injection water quality monitoring will continue through 1998. In addition, grout core samples will be submitted for further testing to better understand the geochemical reactions that are taking place within the mine environment. Grout core samples will be submitted for bulk chemical analysis, sulfur and iron speciation, scanning electron microscopy, and x-ray powder diffraction.

In addition to the grout testing, the project team will be moving forward with the use of geophysical surveys to determine if the mine configuration can be refined. Surveys that have been performed to date include ground penetrating radar, dipole-dipole resistivity, terrain conductivity, gradiometer, and very low frequency. At the time of this paper preparation, the results from these surveys were preliminary and not available for inclusion herein.

Table 1 ***Winding Ridge Grout Formulation***

Parameter	Initial Laboratory Study FBC-Based	Initial Laboratory Study Lime-Based(b)	FBC-Based Grout Mixes (c)	During Injection
FBC/FGD/fly ash ratio (a)	30/32/38	NA	60/20/20	60/20/20
Lime/FGD/fly ash ratio	NA	10/40/50	NA	NA
Target Water Content (%)	38	40	47	46 - 57
Slump (in)	8.5 - 9.0	8.1 - 8.2	NM	7 - 8
Spread (in)	NM	NM	8	6.5 - 9.5
Bleed (%)	0.9 - 1.8	1.0	NM	NM
Unconfined Compressive Strength (psi)				
7-day	294 - 319	192 - 213	142	30 - 77
28-day	711 - 735	1,095-1,134	520	245 - 560

(a) Expressed as percentages of total solids by weight. (b) Not carried forward into subsequent testing. (c) Second iteration of laboratory testing after selecting the FBC as the free lime component of the grout. NM - Not measured; NA - Not applicable.

Table 2 ***Summary of Grout Core Geotechnical Testing, The Winding Ridge Project***

COREHOLE	SAMPLE DEPTH (FEET AND INCHES)	PERMEABILITY (CM/SEC)	STRENGTH (PSI)	DRY DENSITY (PCF)
CH-1	84'4" - 85'8"	1.89×10^{-6}	560	70.6
CH-3	71'8" - 72'10"	2.58×10^{-7}	1208/1128	76.8
CH-3	73'3" - 74'1"	2.58×10^{-7}	Not tested	71.7
CH-6	83'2" - 84'5"	1.29×10^{-7}	1339	80.4
CH-9	85' - 87'1"	6.02×10^{-8}	1417	75.4

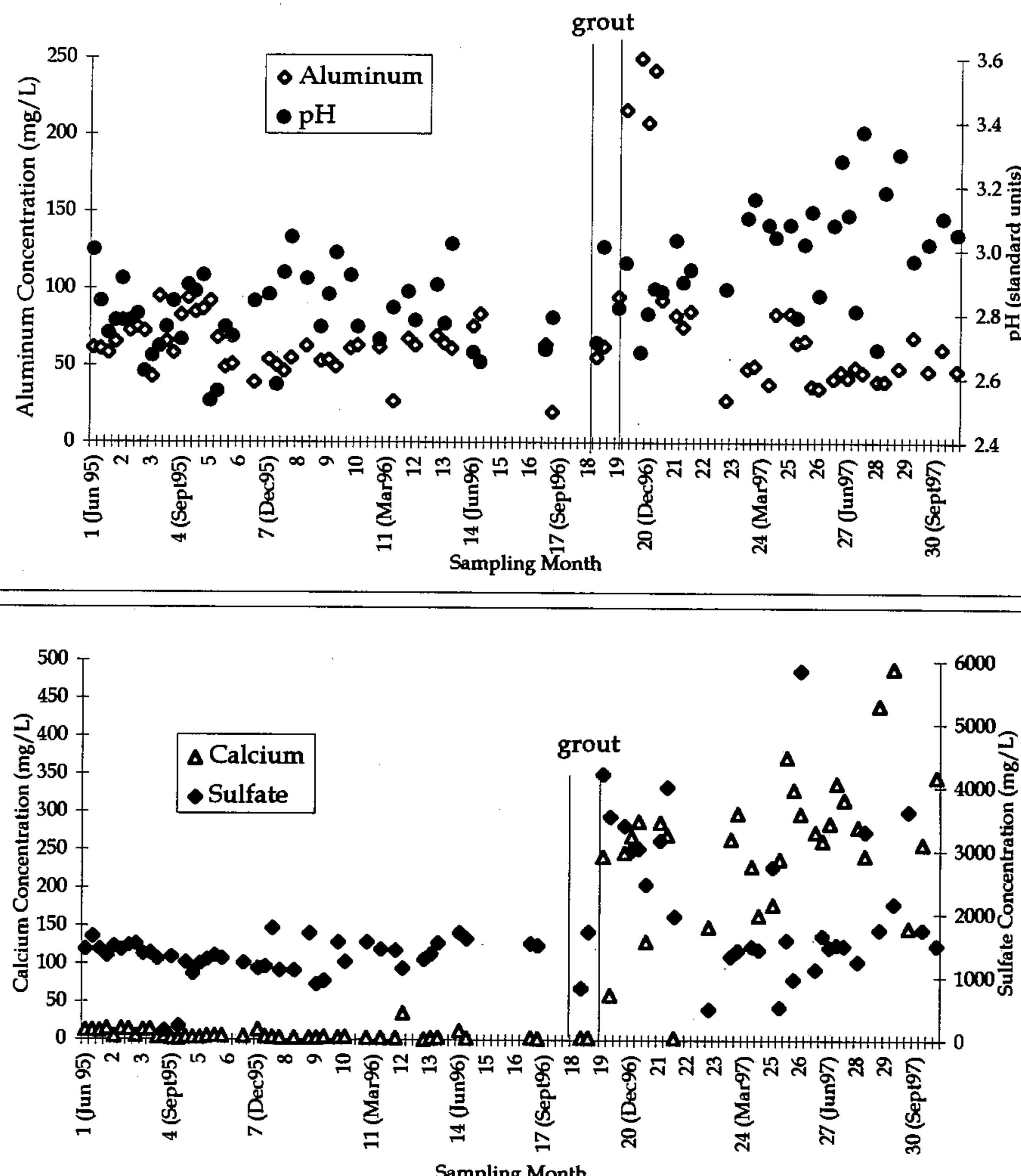

Figure 7. Selected Post-Injection Monitoring Water Quality Results, The Winding Ridge Project