

# Cost Optimization for Mine Void Stabilization Projects: A Deep Mine Case Study

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## ABSTRACT

With increasingly sprawling communities encroaching upon underground abandoned mine lands, economic costs due to the risk of building over mine voids include lost business opportunities for real estate development and associated jobs, and stunted economic development. For a candidate site in western Maryland, an adaptable, economical and environmentally friendly means of restoring underground mines to productive use is presented with detailed optimized cost components.

Underlain by mine voids, a business incubator park is considered for the prototypical site in the study area. By using Coal Combustion by-Product (CCP) grout in lieu of conventional Portland cement, a cost savings of several million dollars for a grout volume of 150,000 cubic yards is demonstrated. Proportionally lower project costs are associated with the use of progressively higher CCP grout volumes. The specified CCP mix consists of 100 percent Fluidized Bed Combustion (FBC) ash in a 70:30 fly to bed ash ratio which results in an environmentally benign material with excellent structural and engineering properties that are similar to conventional cement.

Based on the study, the primary categories of cost for mine void stabilization are:

- Engineering Services;
- Site Preparation and Restoration;
- CCP Materials, Supply and Transportation; and
- On Site Grouting Operations.

On-Site Grouting Operations account for approximately 83 percent of the overall project cost with construction labor for this component comprising approximately 54 percent of the overall project cost. Therefore, the construction labor costs for the CCP grouting contractor are anticipated to be a key cost control component.

## INTRODUCTION

The site chosen for the analyses, the Allegany Business Center (ABC) Site consists of approximately 60 acres of undeveloped, wooded land on the southwestern portion of the Frostburg State University (FSU) campus in Allegany County, Maryland (Figure 1). Allegany County plans to develop the Site as an incubator park for small technology related businesses. Like much of Western Maryland, however, the ABC Site is underlain by mine voids, in this case from two abandoned coal mines. To mitigate land surface subsidence due to settlement into mine voids, the voids may be filled with various materials to provide structural support.

Conventional mine void stabilization techniques<sup>1</sup> involving the injection of Portland cement (conventional) grout to backfill and stabilize the mine voids are often expensive due to the cost of cement and associated material. As an alternative, Coal Combustion by-Products (CCPs) can be obtained for minimal cost from nearby power plants and used as a conventional grout substitute. CCPs are coal ash by-products continually produced by coal fired power plants in and around the region.

CCP grout has properties similar to conventional grout, is environmentally benign, and costs approximately 25 to 65 percent less to use than conventional grouts with cost savings depending on the grout volume. The more CCP grout utilized, the greater the cost savings due to the minimal cost of materials. These characteristics make CCP grout ideal for applications where large grout volumes are required, (such as mine void stabilization), and substantial project cost reductions are desired.

This report builds upon the previous success experienced by PPRP to demonstrate the beneficial use of CCPs to mitigate subsidence and acid mine drainage (AMD) from abandoned underground coal mines. An initial demonstration project was undertaken during 1995 at the Frazee Mine in Winding Ridge, MD.<sup>2</sup> by injecting a 100 percent CCP grout into deep mine voids to mitigate AMD. PPRP also sponsored the injection of a 100 percent CCP grout into fractured bedrock to create a barrier for reducing groundwater flow into the Kempton Man Shaft which accessed Kempton Mine No. 42 located in Western Maryland.<sup>3</sup>

Accordingly, the Maryland Department of Natural Resources Power Plant Research Program (PPRP) has undertaken a cost optimization study to assist interested parties in evaluating the use of CCP grout as an environmentally safe and cost-effective alternative to mitigate potential land surface subsidence. The ABC Site was selected as a model for this project due to the proximity to AES Warrior Run, a 180 megawatt coal fired power plant, the mine voids underlying the site, and the redevelopment potential of associated real estate parcels.

## PHYSICAL SETTING

The ABC Site lies within the Georges Creek Basin of Western Maryland, roughly between Big Savage Mountain and Dans Mountain Wildlife Management Area. The

basin is about 5 miles wide by 21 miles long with 75 percent of the basin in Allegany County and the remaining portion in Garrett County, WV. The basin contains extensive areas of abandoned underground mine lands (Figure 2).

Near Cumberland, MD, the AES Warrior Run power plant is approximately 15 miles driving distance from Frostburg and would be the source of CCPs used for mine void stabilization. Westernport, which is the source of coal for the AES Warrior Run power plant and the current destination for the resulting CCP, is located in the southern portion of the Georges Creek Basin. The distance from AES Warrior Run to Westernport is about 30 miles. The roundtrip distance from AES Warrior Run to the ABC Site is 30 miles less than the roundtrip to Westernport.

## MINE GEOMETRY

The largest section of coal-bearing rocks in Maryland occurs in the Georges Creek Basin. The economically important coal seams in the basin include the Pittsburgh, Sewickley (Redstone) and Waynesburg formations. Most of the early coal mining activity in Maryland took place in the Georges Creek Basin, primarily targeting the Pittsburgh coal seam. As a result, thousands of acres in the region are underlain by mine voids including the City of Frostburg, FSU and the ABC Site.

Beneath the ABC Site, only the Redstone and the Pittsburgh coal seams have been mined. These mines are dry with no known incidence of flooded voids or tunnels, or firedamp (methane). The mine tunnels for the Redstone seam (Figure 3) are approximately 4 to 7 feet high. Tunnels for the Pittsburgh seam (Figure 4) are at least 8 to 12 feet high. The dip of the coal seams is generally towards the southeast with an average slope of approximately 5 to 7 percent. The mine floor is expected to approximate the slope of the coal seams.

Based on the mine maps, the total estimated area of Redstone mine tunnels within the ABC Site boundary is four acres (excluding coal pillars), with a void volume of approximately 116,000 cubic yards (yd<sup>3</sup>). Within the ABC area, the total estimated tunnel area for the Pittsburgh mine is 18 acres with a void volume of 292,000 yd<sup>3</sup>. In the area of the ABC Site, boreholes indicate that portions of the Redstone mine are filled with mine gob, collapsed mine roof rock, and mine debris that has collapsed or washed into the mine. The Pittsburgh mine tunnels beneath the Appalachian Laboratory adjacent to the ABC Site, have been characterized as being partially collapsed.<sup>4</sup> Therefore, the actual mine void (and grout) volumes are anticipated to be substantially lower than the above volumes calculated from the mine maps. Actual void volumes are likely to be closer to the volume per area calculated based on the Appalachian Laboratory grouting project as discussed below.

Adjacent to the ABC Site (Figures 3 and 4), the Appalachian Laboratory grouting project was completed in 1997 using conventional grout to stabilize the Redstone and Pittsburgh mine workings prior to construction.<sup>5</sup> The mines beneath the Appalachian Laboratory were stabilized by injecting approximately 1,920 yd<sup>3</sup> of grout into the mine

voids through a total of 371 boreholes over an area of about 1.43 acres.<sup>4</sup> Of the 371 boreholes, 166 were completed across the shallow and the deep mine horizons. Approximately 450 yd<sup>3</sup> of grout was injected into the Pittsburgh mine through 166 borings. The shallow Redstone mine was stabilized with injection of 1,470 yd<sup>3</sup> of grout injected through 371 boreholes. The average borehole depth into the Redstone and Pittsburgh mines was 67 ft and 112 ft, respectively.

The equivalent grout volume injected per area of site footprint for the Appalachian Laboratory is approximately 0.85 ft<sup>3</sup> per square foot of site area. Using this estimate over the 60 acres of the ABC Site, the injected volume required for Redstone and Pittsburgh mine void stabilization would be approximately 100,000 yd<sup>3</sup>. The actual grout volume required for mine void stabilization may vary from this estimate based on the condition of the mine voids encountered during field investigations. For the purposes of the cost optimization study in this report, a volume of 150,000 yd<sup>3</sup> of CCP grout was assumed to be required for mine void stabilization at the ABC Site.

## COAL COMBUSTION BY-PRODUCTS AND GROUT FORMULATION

### CCP Characteristics

AES-Warrior Run uses a fluidized bed combustion (FBC) "clean coal" technology. Finely ground limestone are fed into the combustion chamber and intimately mixed with combustion air by forcing air into the chamber from the bottom. The forced air enters the combustion chamber at a speed great enough to suspend the coal and limestone particles, causing them to act as a fluid. The heat in the combustion chamber causes the limestone to decompose to an oxide that captures the sulfur dioxide produced from burning the coal. FBC units can remove more than 95 percent of the sulfur that would normally be produced from burning coal.

The resulting combined ash is a pozzolan: a silica, alumina, and calcium based material which, in the presence of water, will chemically combine with the free lime from the slurry spray and produce a cementitious material with excellent structural and engineering properties.

### CCP Handling Considerations for Construction Crews

The equipment required for handling, mixing, and pumping the CCP grout is similar to equipment typically used for conventional concrete and grouts. Where pumping is required, the pump should be robust and may be of the positive displacement type. CCPs are non-hazardous materials that are handled in much the same way as other industrial minerals such as Portland cement, clay, or calcium carbonate that have the potential for creating nuisance dusts. Because of their fine particulate nature, precautions against the creation of fugitive dust will be required on the project work site. CCP grout would be injected into mine voids in much the same way as conventional concrete has been used for several past and current projects in the region surrounding the project site.

## CCP Grout Formulations for the Site

CCP for the prototypical project will be obtained from the AES Warrior Run power plant and consist of 100 percent FBC fly ash and bottom ash products. Based on past studies of Warrior Run CCPs, the dry ratio of fly ash to bed ash should be 70:30.<sup>6</sup> Depending on the desired flow characteristics of the grout, the percentage solid component of the mix may vary from 60 to 70 percent (Table 1). However, for planning purposes, a solid to water by weight ratio of 65:35 should be assumed. Cured CCP grout is environmentally benign<sup>2</sup> with compressive strengths increasing over time, in much the same manner as Portland cement. Typical strengths at 28 days are in the range of 300 to 500 pounds per square inch (psi) or higher.

**Table 1. Mix Proportions for a 70:30 Bottom Ash (BA) to Fly Ash (FA) Dry Solid Ratio for AES Warrior Run**

SOLID COMPONENT	DRY SOLID PROPORTIONS (%)		GROUT MIX PROPORTIONS (Wt %)			
	BA	FA	BA	FA	Water	W/ Ratio
Cw						
70.0	70	30	49.0	21.0	30.0	0.43
65.0	70	30	45.5	19.5	35.0	0.54
60.0	70	30	42.0	18.0	40.0	0.67

SOLID COMPONENT	VOLUME PROPORTIONS (L per 100 Kg)				GROUT YIELD VOLUMES	
	BA	FA	Water	(L / 100 Kg)	(L / ton)	(cu yd / ton)
Cw						
70.0	18.22	8.08	30.00	56.29	510.68	0.668
65.0	16.91	7.50	35.00	59.41	539.00	0.705
60.0	15.61	6.92	40.00	62.54	567.32	0.742

SOLID COMPONENT	MIX PROPORTIONS (per cu yd)				TOTALS (lb / cu yd)	
	BA (lb)	FA (lb)	Water (lb)	Water (gals)	Dry Mix	Grout
Cw						
70.0	1467	629	898	107.9	2096	2994
65.0	1291	553	993	119.2	1844	2837
60.0	1132	485	1078	129.5	1617	2695

SOLID COMP. (Cw)	CCP DRY		WATER		GROUT	
	lbs/cu yd	tons/cu yd	lbs/cu yd	gals/cu yd	lbs/cu yd	tons/cu yd
65.0	1844	0.92	993	119.2	2837	1.42

Potential Yield for Cw = 65					
	100,000 tons per year BA/ FA				
Requires:	12,959,194	gals of water per year			
Produces:	108,696	cu yd of grout per year			

**Cw** =  $\frac{\text{Wt of solids ( BA+ FA) in mix} \times 100}{\text{Wt of total mix ( BA+ FA+water)}}$

**w/fbc** =  $\frac{\text{Wt of water in mix}}{\text{Wt of CCP in mix}}$

**w/Cm** =  $\frac{\text{Wt of water in mix}}{\text{Wt of cementitious materials ( BA+ FA) in mix}}$

**BA** = Bed Ash, **FA** = Fly Ash, **Wt**: Weight in pounds

## CONCEPTUAL ENGINEERING PLAN

The conceptual engineering plan presented below identifies specific activities envisioned, their associated costs and cost assumptions where appropriate. The conceptual plan serves as the basis for the detailed engineering plan. The detailed plan will be the vehicle for securing all permits, engineering, materials, equipment, and labor

necessary to inject an estimated 150,000 yd<sup>3</sup> of grout into the mine voids that underlie the ABC Site. This injection volume equates to approximately 140,000 tons of CCPs. The tasks and activities required for mine void stabilization are applicable to grout injection using either CCP or conventional grout.

The four primary categories of cost for the engineering plan are:

- Engineering Services;
- Site Preparation and Restoration;
- CCP Materials, Supply and Transportation; and
- On Site Grouting Operations.

Engineering Services encompasses all costs associated with project management, design, quality assurance, and resident engineering labor. Because these costs may vary somewhat with each contractor, Engineering Services was isolated as a separate cost item in the cost optimization analyses. The activities associated with the Engineering Services category include:

- Permit Approvals;
- The Grout Plan, Mix Design and Reports;
- Drawings and Instrumentation Plan;
- Construction Costs and Schedule Estimate;
- Bid Document Preparation and Contractor Procurement;
- Risk Analysis;
- On-Site Management and Inspections; and
- Pre-Construction Activities.

## Engineering

In the engineering plan, activities such as Permit Approvals consist entirely of engineering labor and professional services while in other activities, labor and services are a portion of the total cost. The total estimated cost for Engineering Services is approximately \$193,000 which includes those activities and costs described below.

### *Permit Approvals*

This activity would identify the permits and approvals needed to implement the proposed project. The activities are anticipated to include:

- Identifying and obtaining the required local, state, and federal permits. This activity would include an erosion and sediment control (ESC) plan, grading plan, underground injection control (UIC) permit, well permits and an air permit. It is assumed that there would be no basis or need for water treatment or a National Pollutant Discharge Elimination System (NPDES) permit; and

- Preparing the project-specific Health and Safety Plan (HASP). The HASP would require, at a minimum, documentation and oversight to ensure that all contractors and subcontractors comply with the applicable federal, state, and local health and safety regulations to create a safe working environment during project implementation and execution.

Although a formal survey has not been done, there appear to be no wetlands in the proposed project area based on available maps and information. Therefore, a wetlands assessment should not be necessary as part of the permitting process.

- Total Estimated Cost: \$21,000

### *Grout Plan*

The Grout Plan would identify the process, methods, equipment, schedule and engineer's cost estimate to implement the grouting project. The following major activities are included:

- Review and/or refine the estimate of materials, power and water needed to implement the project. Approximately 140,000 tons of bottom ash and fly ash from AES Warrior Run would be used for the project, requiring approximately 20 million gallons of water (which includes 10 percent for potable use and equipment cleaning). Power consumption during grouting operations is estimated to be approximately 230,500 kilowatt-hours (kWh);
- Review the existing mine plans, and identify data gaps. Boreholes drilled during the design phase of the project to verify the mine geometry would also be used for grout injection;
- Optimize and test the grout mix formula to be injected into the mine void. As stated above, the CCP grout would consist of an anticipated solids content of 65 percent, with a 70:30 ratio of FBC fly ash to bottom ash, respectively;
- Quality control and analyses measures for grout including daily summaries of the quantity of grout injected, materials used, and production of periodic test cylinders for strength testing. Daily progress charts for tonnage of grout injected; and
- Selection of the equipment and associated parts necessary for grouting operations including pumps, fittings, hoses, and grout delivery methods would also be considered.

Total Estimated Cost: \$85,000

### *Drawings and Instrumentation*

This activity would develop all the necessary design, engineering and planning drawings required for the cost optimization activities as well as developing testing protocols for ensuring grout consistency and quality during grouting operations.

Total Estimated Cost: \$29,000

#### *Construction Costs and Schedule Estimate*

This activity includes cost and schedule estimates for all construction associated components. These components include grout plant set up/removal, site operations, installing erosion and sediment control measures as required by the ESC Plan, clearing for site access, and constructing temporary roads and the material storage areas. At the end of the project, the site would be restored as appropriate. Site restoration would include demobilizing all site equipment and materials. The ESC measures will remain in place as they could be used during subsequent re-development activities. In addition, the project schedules, milestones, and activity durations will be planned.

Total Estimated Cost: \$11,000

#### *Bid Documents and Procurement*

This activity will include preparation and packaging of all of the documents necessary to solicit competitive bids from prospective grout injection contractors. The bid package would include the mine maps, the grout plan, bid item list, project specifications, drawings, permits and approvals, ESC Plan, HASP, Construction Quality Assurance Plan (CQAP), and required project schedule milestones. Also included would be an evaluation of the contractor bids based on price and qualification, and assistance in selecting a qualified grouting contractor.

Total Estimated Cost: \$20,000

#### *Risk Analysis*

A risk analysis would be prepared to identify and quantify any potential risk associated with the project and the appropriate safety and risk mitigation factors to be applied. The risk assessment criteria take into account two basic factors: (1) the existing and anticipated site conditions; and (2) the level of the human exposure to those conditions.

Total Estimated Cost: \$8,000

#### *On-Site Management and Inspection*

On-Site supervision by an experienced representative will be required to oversee site operations, ensure compliance with technical specifications, and health and safety issues related to site setup, grouting operations, and site decommissioning.

Although an engineering task, this activity is integral to, and included with On-Site Grouting Operations. As such, the total estimated cost (\$184,000) for this activity is included with On-Site Grouting Operations and not included in the overall total cost for Engineering Services.

#### *Pre-Construction Activities*

Ensuring and securing the required equipment (e.g., central grout plant parts, grout pumps, truck rentals, tools and materials, etc.) through purchase, rental or lease agreements over the project life will be included in this task. The logistics of transporting equipment for a central grout plant, and heavy equipment for grading, borehole drilling and dust control to and from the site will be developed in this activity. Planning for, and ensuring personnel availability for these activities will also be required.

Total Estimated Cost: \$33,000

#### *CCP Materials and Transportation*

The costs associated with this item are primarily associated with transporting CCPs (i.e., trucking). The cost accounts for the distance between AES Warrior Run and the ABC Site, cost per truck mile, number of truck trips per day, and delivery volume of CCPs necessary to maintain the grout injection schedule. The costs, if any, associated with procuring and transporting CCPs from AES Warrior Run would be nominal since the CCPs represent a material handling and disposal issue for the plant. Notably, the current CCP transportation route is 30 miles further than a roundtrip to the ABC Site.

Total Estimated Cost: \$120,000

#### *Site Preparation and Restoration*

Non-engineering labor for installing erosion and sediment controls, site clearing, access road construction, central stockpile area construction, and site restoration are included in this cost. Heavy equipment costs (i.e., backhoe loader, dump truck, and bulldozer), and construction materials are associated with the total cost of this activity.

Total Estimated Cost: \$20,000

#### *On-Site Grouting Operations*

Grout injection into the mine void would follow the procedures established by the detailed design under the Grout Plan. Grout injection would include the materials and delivery schedule, drilling of boreholes for injection and observation, mixing and injecting. The primary costs under this activity are associated with:

- On-Site supervision by an experienced representative will be required to oversee site mobilization, borehole drilling, mixing plant setup, grout injection, site

demobilization, and ensure compliance with technical specifications and health and safety issues called out for the site setup, grouting operations, and site decommissioning;

- Drilling injection boreholes throughout the site starting at down dip locations, and progressing up dip. Including exploratory boreholes, a total of approximately 150 boreholes, (22,500 linear feet of drilling), is anticipated to be required for grouting. The boreholes would also be used to observe grout flow during injection into the mine void;
- Power and water. Water would be added on site using the municipal supply. Water would be stored as necessary in multiple storage tanks (25,000 gallons capacity) to ensure a steady supply and flow equalization. Power would be provided by connecting to the local power supply; and
- Grout would be mixed using high speed/capacity paddle-type mixers, pug mill or equivalent for batching mortars and grouts. The grout would be injected under pressure through tremie pipes into the mine voids. The target injection rate would be 112 yd<sup>3</sup> per hour and 1,125 yd<sup>3</sup> per ten hour work day. Injection would continue until refusal is reached.

Total Estimated Cost: \$2,243,000

*Cost Analyses Summary*

Excluding contingencies, the total estimated cost for using CCP-based grout to mitigate subsidence on the ABC Site is approximately \$2.7 million with an estimated project time frame of approximately 41 weeks. Although the project consists of 46 labor weeks as summarized below, some tasks such as Drilling and Pre-Investigation will occur concurrently resulting in a project completion time of 41 weeks. The total estimated cost is equivalent to a cost of about \$18 per cubic yard of injected CCP-based grout.

<b>Estimated Project Schedule</b>	<b>Weeks</b>
Site Mobilization	1
Site Preparation & Restoration	6
Pre-Investigation	5
Drilling (33% concurrent with pre-investigation)	7
Grout Injection	27
Demobilization	1
<b>Total Weeks</b>	<b>46</b>
<b>Total Completion Time</b>	<b>41</b>

On-Site Grouting Operations account for about 83 percent of the overall project cost with construction labor for this component comprising approximately 54 percent of the overall project cost. Therefore, the construction labor costs for the grouting contractor are anticipated to be a key cost control component. Elements of the estimates, including

fuel prices and trucking costs, reflect per unit costs estimated during the time of this report.

## OPPORTUNITIES FOR FURTHER COST REDUCTION

The rheology of CCP grout may be engineered to maximize grout flow lengths through a given mine tunnel geometry. Given the rheologic characteristics of the grout, the number and spacing of boreholes required for grouting may be optimized to minimize the associated cost of drilling. As an initial means to minimize the number and spacing of boreholes, a generalized Geographical Information System (GIS) model was developed<sup>10</sup> to track (grout) paths down gradient through mine tunnel networks. The model serves to identify and visualize areas that are best suited for grout borehole placement. Knowing the approximate flow lengths of a grout mixture, the model may be used to track directional paths along a given flow length which is otherwise difficult to predict based on a visual inspection of mine floor topography and tunnel geometry. Multiple borehole placement and spacing scenarios can quickly be simulated with the model to optimize drilling costs.

The cost of water required for grout mixing is another area where costs may be reduced. Rather than tapping into and paying for municipal water, the fresh water required for grout mixing may be untreated and used directly from wells, mine pools, streams, rivers or lakes. In addition, the grout consistency proposed for this type of project may be pumped thousands of feet from a centralized mixing plant to the grout boreholes. Therefore, a mixing plant location may be chosen in close proximity to an inexpensive source of water, or close to an area where conditions are most favorable for municipal (e.g., power and water) utility connections. A remote mixing plant also has favorable implications for isolating environmental nuisances (e.g., dust, noise, traffic, etc.) from populated areas, neighborhoods or sensitive areas.

## CCP VERSUS CONVENTIONAL GROUT COST COMPARISON

Costs inherent to any grouting project are associated with materials, equipment and labor. Whether using CCPs or conventional grout, equipment and labor costs are generally similar for a mine void stabilization grouting project. As a by-product of power generation, CCPs may be provided by nearby producers (power plants) at low to negligible cost. The negligible material cost is a key advantage of CCP grout over conventional grout use.

For the ABC Site, the total estimated cost for mine void stabilization using CCP grout is approximately \$2.7 million equivalent to a cost of about \$18 per cubic yard of injected CCP-based grout. Conversely, the use of conventional grout at the site is estimated to cost \$7.35 million, which is equivalent to about \$48 per injected cubic yard of grout. Over the 60 acres of the ABC Site, the equivalent total cost per acre using CCP grout is approximately \$45,000. This cost represents a savings of \$77,500 per acre over the use of conventional grout for mine void stabilization. The cost optimization analysis clearly

demonstrates that mine void stabilization with CCP grout is extremely cost competitive when compared to conventional grout for large grout volumes.

## SUMMARY OF KEY FINDINGS

CCP grouting costs in the study are shown to range from less than \$20 per yd<sup>3</sup> for grout volumes in excess of 100,000 yd<sup>3</sup> to more than \$80 for grout volumes of 10,000 yd<sup>3</sup> and below. For general cost comparison, conventional grouting projects in the vicinity of the ABC Site have been estimated to range from about \$70 to over \$200 per yd<sup>3</sup> for grout volumes under 10,000 yd<sup>3</sup>.<sup>7,8,9</sup> Therefore, at low (10,000 yd<sup>3</sup> and less) grout volumes, grouting project costs are expected to be similar using CCP or conventional grout. The work presented in this study demonstrates that the cost savings associated with CCP grout over conventional grout is approximately 25 to 65 percent depending on the grout volume (Figure 5).

Lime activated CCP grout cures to form an environmentally benign material with excellent structural and engineering properties. With over 6,000 abandoned underground mine lands in the Mid-Atlantic Highlands, mine void stabilization using CCP grout represents a cost effective and environmentally friendly means of restoring significant areas of mine-scarred lands to productive use by beneficially using material that may otherwise be placed unstabilized in landfills. Left unstabilized, CCPs are capable of leaching harmful metals into the hydrologic system. Proper engineering and stabilization eliminates or significantly reduces leached components<sup>11</sup> to below regulatory levels and often, below detectable levels.

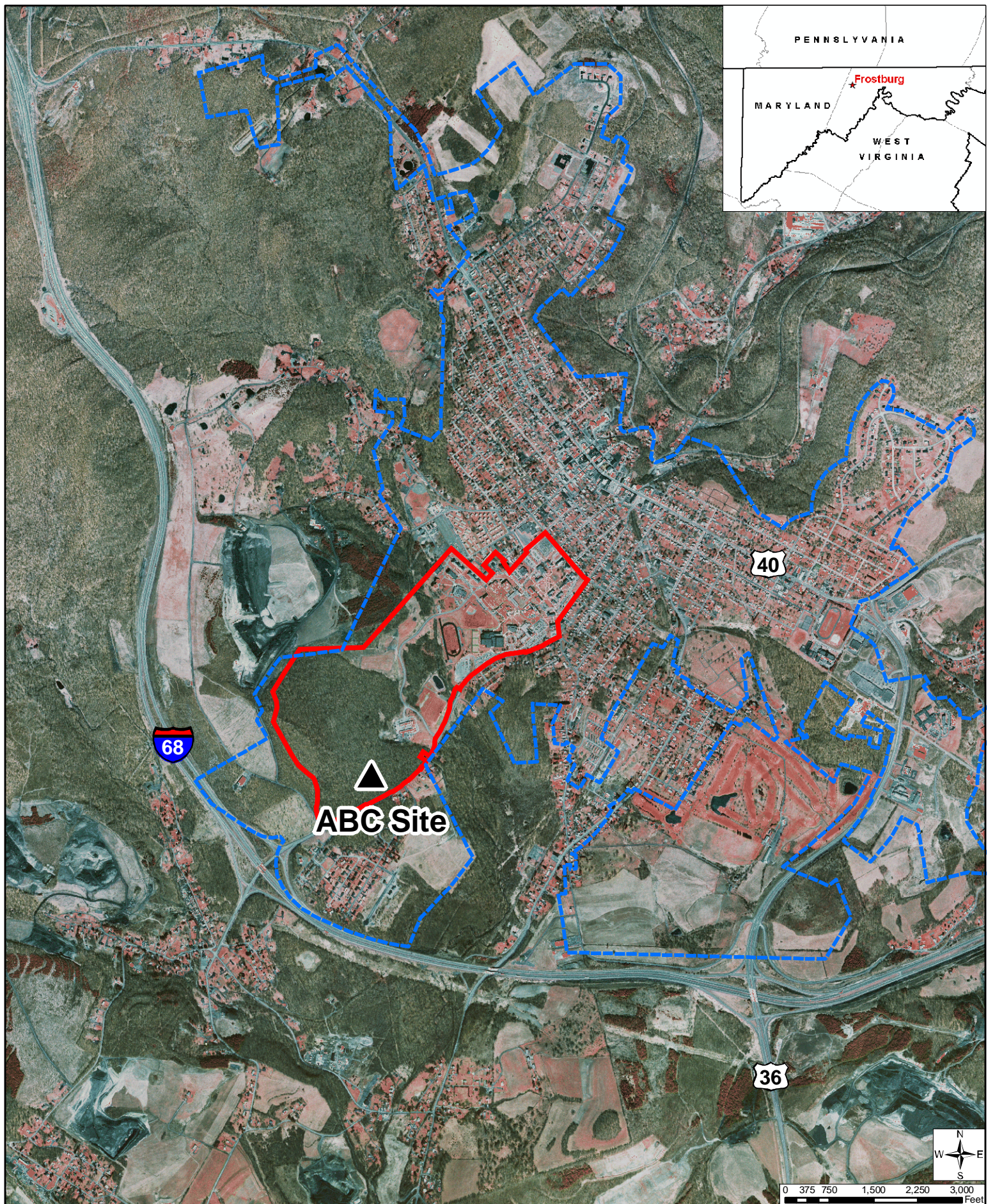
PPRP research and pilot projects demonstrate that lime activated CCP grout is a viable cost-effective substitute for conventional grout in mine void stabilization applications. With the existing infrastructure in place, this proven technology is readily applicable to Western Maryland and the surrounding region of the Mid-Atlantic Highlands. Although the ABC Site was used as a prototypical model, the modular cost estimates provided in this study may be easily adapted to similar sites throughout the region.

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# FIGURES





-  Frostburg State University Property Boundary
-  Frostburg City Property Boundary

Figure 1. Location Map for ABC Site.

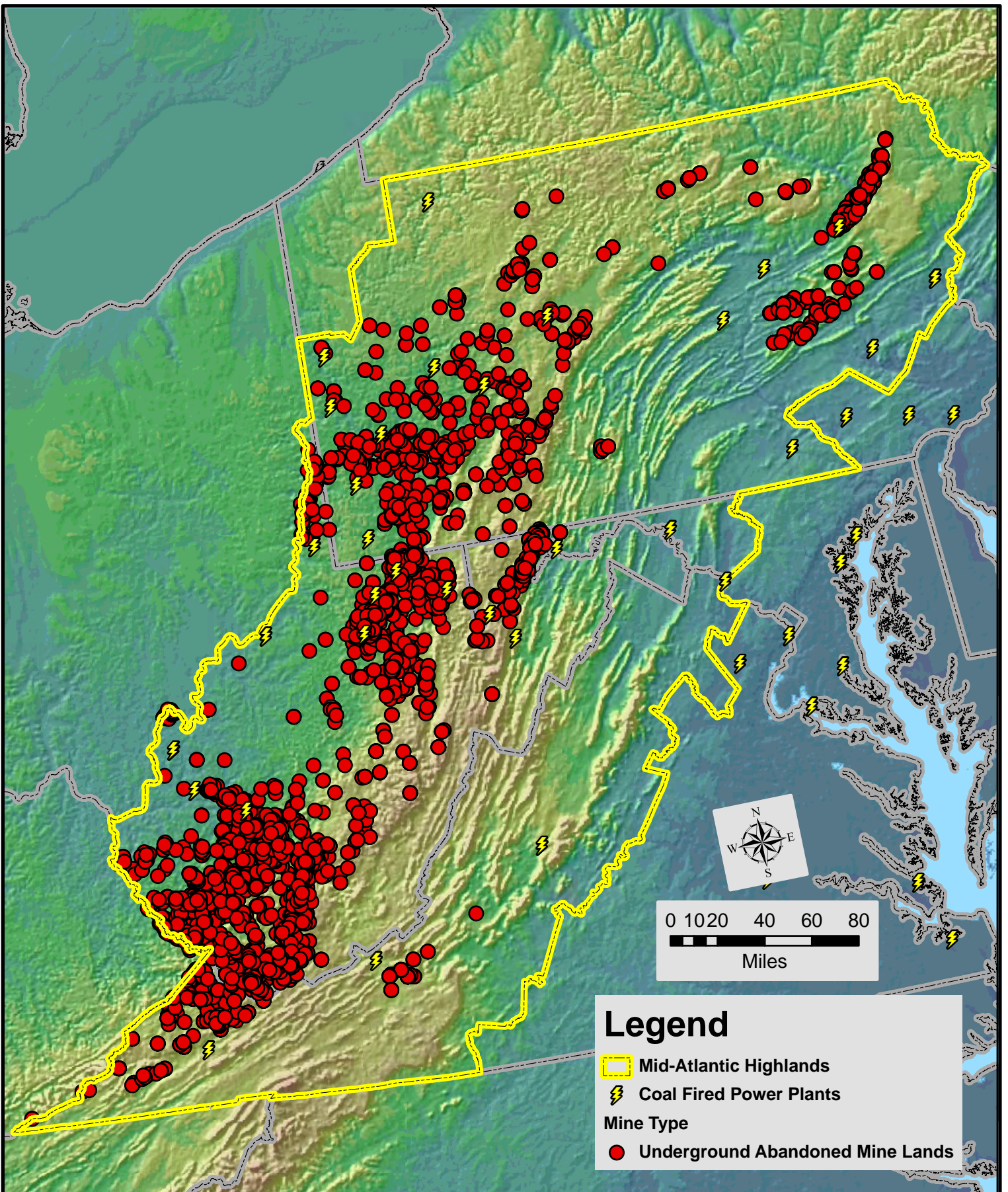


Figure 2. Overview of Abandoned Underground Mine Lands in Western Maryland and the Surrounding Region.



- ABC Site Boundary
- Mine Pillars Removed\*
- Mine Pillars
- Mine Perimeter

Figure 3. Redstone Coal Seam Mine Map

Air Photo Date: 2005



- ABC Site Boundary
- Mine Pillars\*
- Mine Perimete

Figure 4. Pittsburgh Coal Seam Mine Map

**Figure 5. Cost Comparison Between CCP and Conventional Grouting Projects.**

