Coal Ash Beneficial Use at Mine Sites in Pennsylvania

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ABSTRACT

The beneficial use of coal ash at mine sites in Pennsylvania started in 1986 and is regulated under the state’s Solid Waste Management Act and the accompanying coal ash beneficial use residual waste management regulations. Fluidized bed combustion (FBC) coal ash is the type of ash most frequently beneficially used on Pennsylvania’s mine sites, but significant amounts of coal ash from pulverized coal fired power plants (PC) are also beneficially used for mine reclamation in Pennsylvania and other states. Pennsylvania benefits from several waste coal burning projects where coal refuse piles are burned by FBC power plants, acid mine drainage and sediment pollution from refuse piles are eliminated, and the alkaline coal ash generated is beneficially used for mine reclamation.

Pennsylvania Department of Environmental Protection (DEP) regulations and technical guidances define types of beneficial uses at mines, coal ash analysis parameters and concentration limits, surface and groundwater monitoring requirements, geologic and hydrologic site evaluations, operational parameters, and mine reclamation plans. During the past eighteen years, coal ash has been beneficially used on over 120 permitted mine sites. Consequently, long-term monitoring data of the chemical and physical characteristics of the coal ash, and the groundwater quality are available for many of these sites, documenting the success of the beneficial use program. The sixteen FBC power plants in Pennsylvania have contributed to the reclamation of approximately 3,400 acres of abandoned mine lands, alone, within the past fifteen years.

INTRODUCTION – SCOPE OF COAL ASH BENEFICIAL USE IN PENNSYLVANIA

This paper is a condensed version of a 442 page book entitled “Coal Ash Beneficial Use in Mine Reclamation and Mine Drainage Remediation in Pennsylvania”, that was published by the Pennsylvania DEP and the Pennsylvania State University in 2004. DEP developed a contract with the Materials Research Institute (MRI) at Penn State to conduct a series of rigorous scientific studies of three waste demonstration permit sites in the Anthracite Region of Pennsylvania. It was out of the collaboration between the MRI and DEP that the concept for this book originated. The initial intent was to produce a publication that presented the results of the demonstration projects. From there the scope broadened to include the results from other active
and abandoned mine sites where coal ash has been beneficially used in Pennsylvania. One reason for broadening the scope of this publication is that the beneficial use of coal ash on mine sites has become somewhat controversial on a national level. That controversy has been fed, in part, by the misreporting and partial reporting of information and data, some of which have been from sites in Pennsylvania. Thus, it became even more important to present the facts and the science behind the beneficial use of coal ash in Pennsylvania.

Since commercial coal mining began in Pennsylvania prior to 1800 (Dodge & Edmunds, 2003), the Commonwealth’s miners have extracted approximately 16.3 billion tons of coal from the Anthracite and Bituminous Coal Fields combined (PA DEP, 2002). Prior to the enactment of the federal Surface Mining Control and Reclamation Act (SMCRA) in August 1977 and the PA Surface Mining Conservation and Reclamation Act in 1971, laws and regulations governing surface mining and the surface effects of underground mining, were largely ineffective in achieving reclamation of mined lands. However, much of the vast abandoned mine lands (AML) problem from the pre-1977 mining remains. There are more than 5000 abandoned, unreclaimed mine problem areas encompassing more than 189,000 acres in Pennsylvania, according to the DEP Bureau of Abandoned Mine Reclamation (BAMR). It is estimated that Pennsylvania suffers from up to 3,100 miles of streams degraded by acid mine drainage (AMD) as a result of abandoned mines. AMD is Pennsylvania’s most serious stream pollution problem. The BAMR-estimated price tag to eliminate Pennsylvania’s AML problems is a staggering $14.6 billion.

One approach Pennsylvania has taken to help address the AML problem is to encourage re-mining of abandoned mine lands in settings where technical data show that additional problems are unlikely to occur, and, where in the normal course of re-mining, abandoned mine features will be reclaimed. Waste coal piles represent a significant subset of AML remining sites in Pennsylvania. These sites present both some unique problems and opportunities. The piles are typically toxic to plant life, and thus are barren and highly erosive. The bituminous piles in particular can leach highly concentrated AMD with acidity values in the thousands of mg/L, and which can include, in addition to typical AMD parameters, elevated levels of some trace metals such as arsenic, lead, copper, and chromium. The cost of reclaiming these piles using conventional AML techniques is high, and the extremely poor water quality is often beyond the reach of current passive treatment technology. However, the key to reclamation of many of the piles may be in the fuel-value of the material.

The significant growth in the use of coal ash in mine reclamation in the anthracite and bituminous coal regions of Pennsylvania in the past 20 years is principally due to three regulatory developments: 1) the enactment of the federal Public Utility Regulatory Policies Act (PURPA) in 1978 and related regulations of the Federal Energy Regulatory Commission (FERC), which facilitated the development of the culm burning cogeneration plants, 2) the development of DEP policies and procedures in 1986 authorizing the Bureaus of Mining and Reclamation (BMR) and District Mining Operations (DMO) to issue permits for the use of coal ash in reclaiming active and abandoned mine lands within Surface Mining Permits (SMP) boundaries, pursuant to the Solid Waste Management Act of 1980, and 3) the promulgation of specific regulations for the beneficial use of coal ash in 1992 by the Pennsylvania Environmental Quality Board (25 Pa. Code Sections 287.661 through 287.666). These regulatory enhancements resulted in the construction of 16 waste coal plants in Pennsylvania shown on Figure 2, and the
issuance of 122 permits for coal ash use in mine reclamation by DEP from 1986 through 2004. The permitted coal ash placement sites are shown on Figure 1.

The cogeneration plant concept is perfectly suited to Pennsylvania because these facilities remove abandoned coal refuse banks, mix the culm with limestone in their circulating fluidized-bed combustors, producing an alkaline coal ash, and use the coal ash to reclaim abandoned pits and other AML features. Therefore, multiple environmental benefits accrue from the removal of unsightly, acid-producing culm banks, the backfilling of AML features and the reduction of acid mine drainage pollution. In addition, social and economic benefits result from jobs related to the production of electrical power and by-product usage of steam (e.g. growing hydroponic flowers and tomatoes) in areas with a depressed economy. The cogeneration plants would be impossible without the development of the circulating fluidized bed boilers. PURPA created the business opportunity, and the circulating fluidized bed technology made it possible to burn the waste coal material. The new combustion technology was also capable of emissions control that enabled these combustion units to meet the most stringent of the emissions regulations mandated by the Clean Air Act of 1970.

There have been sixteen fluidized bed combustion (FBC) power plants constructed in Pennsylvania in the past seventeen years. The locations of these plants are shown on Figure 2. The Kimberly Clark FBC plant is an industrial site-power plant, and the remaining plants are all

Figure 1. Location of coal ash beneficial use mine sites in PA.
commercial power producers. Some are also cogeneration facilities in that they supply heat to one or more customers. (An FBC power plant is also considered a cogeneration project if it markets at least five percent of its steam to a thermal energy user.) The Archbald power plant was decommissioned in June 1997, and the Reliant Energy Seward FBC power plant started operating in the spring of 2004, so there currently are 15 FBC plants operating in Pennsylvania. Fifteen of the sixteen FBC plants range in size from 18 megawatts to 107 megawatts, however the most recent FBC plant (Seward) to come on line is 520 megawatts.

Figure 2. Distribution of the 16 FBC power plants in Pennsylvania.

In Pennsylvania, there are 21 pulverized coal-fired (PC) electric generating power plants ranging in size from 100 megawatt (Mw) to 2700 Mw. The locations of the power plants are shown in Figure 3. These PC power plants burn about 45 million tons of coal annually, resulting in the production of about 5 million tons of coal ash (Bidden, personal communication, 2004). Pulverized coal-fired plants produce much less ash per ton of fuel burned than do waste coal plants because waste coal contains much more noncombustible (inorganic mineral) material, and because the FBC process includes the addition of lime into the boiler.

Each year Pennsylvania’s power plants presently generate approximately ten million tons of coal ash, with about half coming from traditional plants and half coming from FBC plants. Currently, the FBC plants consume an average of 7,500,000 tons of coal refuse annually. However, with
the addition of Reliant Energy Seward’s FBC power plant, another 4,000,000 tons of coal refuse will be burned yearly, which is about a 50% increase to 11,500,000 tons per year. The FBC power plants in Pennsylvania, collectively have burned more than 88,551,000 tons of refuse up through 2002, the last full year for which figures are currently available. The FBC industry in Pennsylvania has generated over 58,188,000 tons of ash between 1988 and 2002.

In 2002, about 6.4 million tons of ash were beneficially used on mine sites, of which about 5 million tons were FBC ash. Of the approximate 5,000,000 tons of conventional coal ash produced that year in Pennsylvania, only a little over 1,000,000 tons or twenty percent was used beneficially. However, opportunities do exist for the beneficial use of traditional PC ash on mine sites, where the ash has appropriate chemical and physical properties.

The sixteen FBC power plants in Pennsylvania have contributed to the reclamation of approximately 3,400 acres of abandoned mine lands within the past fifteen years. See Figure 4 for the annual number of acres reclaimed by the ten anthracite FBC power plants and the six bituminous FBC power plants as of the end of 2002. In the Anthracite Region, where the abandoned mine pits are significantly deeper than in the Bituminous Region, the number of acres of abandoned mine acres reclaimed is less, but the depth of the pits are greater.

Figure 3. Distribution of 21 conventional PC coal-fired power plants in Pennsylvania.
Figure 4. Acres of abandoned mine lands reclaimed by FBC plants in the Anthracite and Bituminous Regions.

REGULATORY FRAMEWORK FOR COAL ASH PLACEMENT AT MINE SITES

Coal ash is defined in Pennsylvania’s Solid Waste Management Act (SWMA) as fly ash, bottom ash, or boiler slag resulting from the combustion of coal. The beneficial use of coal ash in Pennsylvania is regulated under the SWMA, the Surface Mining Conservation and Reclamation Act, the Coal Refuse Disposal Act, the Clean Streams Law, and the Air Quality Control Act.

Beneficial use of coal ash was authorized under the 1986 amendment to the SWMA, which authorized the beneficial use of coal ash for mine site reclamation along with other beneficial uses. Prior to 1986, DEP required a waste disposal permit for the use of coal ash at mine sites. In 1992, the residual waste management regulations were amended in accordance with SWMA to regulate the beneficial use of coal ash at mine sites (under 25 Pa. Code Sections 287.661 to 287.666). The regulations were further revised in 1997 in regard to water monitoring, volumes of ash that may be used at mine sites, and certification guidelines for ash. In addition, the DEP developed a Memorandum of Understanding between its waste and mining programs and three technical guidance documents to further coordinate and manage the beneficial use of coal ash on both active and abandoned mine sites.
Pennsylvania currently defines the following four uses of coal ash on active mine sites as beneficial uses: 1) alkaline addition; 2) low permeability material; 3) soil substitute or additive; 4) placement. Alkaline addition takes advantage of the potential for some coal ashes to generate alkaline leachate and is used to offset the potential for on-site materials to generate acid mine drainage. According to Pennsylvania’s current guidelines, to qualify for use as an alkaline addition agent the ash should have a neutralization potential (NP) of at least 100 parts per thousand and a pH of between 7.0 and 12.5. Using ash as a low permeability material usually entails sealing or encapsulating materials on site that have the potential to produce acid mine drainage. For use as a low permeability material on a mine site an ash should have pozzolonic characteristics and should be capable of achieving permeability equal to or less than $1.0 \times 10^{-6}$ cm/sec under laboratory conditions. As a soil supplement, alkaline coal ash is used as a liming agent and also to improve the physical characteristics of the soil or soil substitute being used as site cover, as described in more detail in Strock and Stehouwer (2004). In some re-mining settings soil is not readily available, especially on coal refuse reprocessing operations, and coal ash can be used to enhance the characteristics of other on-site material to produce an acceptable growth medium. The soil/ash mixture must result in a pH between 6.5 and 8.0 to be considered suitable, and the amount of ash used must otherwise be commensurate with the need to establish a growth medium. The term “ash placement” involves the use of coal ash on a mine site to backfill pits or re-contour refuse piles on re-mining sites. The pH of the coal ash must be in the range of 7.0 to 12.5 at the generator’s site for placement approval. In practice, coal ash use on a mine site typically fulfills more than one of the above beneficial use criteria. For example, coal ash being returned to a refuse reprocessing site may serve as an alkaline addition agent, an encapsulating agent (capping), as a soil additive, and for re-contouring.

Beneficial use of coal ash on a surface mine site can be requested as part of an original permit application or as a permit amendment. Either way, public notice and public participation are an integral part of the review process for all beneficial uses of coal ash on mine sites. The application for use of coal ash on a mine site must include a detailed operational plan, which includes: identification of the ash source(s); a certification from the ash generator(s); amount of ash to be used; purposes(s) of ash utilization; operational details of how the ash is to be handled and incorporated into the site; a demonstration that the ash is chemically and physically suitable for the proposed use; documentation of the hydrogeology of the ash-use area; and a monitoring program, including background data collection, designed to show any influence of ash use on surface and groundwater quality.

An application for use of coal ash on mine sites must include chemical analyses of the ash proposed for use. Analyses are performed on a dry-weight basis for pH plus sixteen metals. A SPLP (Synthetic Precipitation Leach Procedure) leachate analysis is required for pH, sulfate, chloride, plus seventeen metals. Coal ash must meet the maximum acceptable leachate limits for contaminants, based on the minimum requirements for an acceptable waste at a Pennsylvania Class III residual waste landfill. Periodic (typically biannual) re-certification and/or monitoring of the ash quality are required as long as the ash is being used on the mine site. The ash shipped from most power plants usually includes proportions of both fly ash and bottom ash, and analyses are provided of both or the mixture to be beneficially used. When the proposed use of ash on a site is as a soil supplement or additive, the applicant must also provide a soil analysis for pH, PCB’s, arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium,
and zinc so that potential plant up-take levels may be considered as part of the permitting process.

Groundwater monitoring is required for all ash applications on mine sites, except for sites where the only application is as a soil amendment. The volume of ash used on soil application sites is so small as to negate the need for water monitoring. For all other applications of coal ash on mine sites, groundwater monitoring is required before, during and after ash placement on the site. Monitoring points are chosen so as to best show the effects, if any, of ash placement on the site. On many sites, especially re-mining sites, directly downgradient groundwater seeps, springs and discharges may provide the most representative monitoring points for the site. The monitoring program should include monitoring wells, where existing groundwater discharge points are inadequate in number or character to fully monitor the site. Upgradient wells, while they may not need to be as numerous as the downgradient points are important, especially in an area where potential upgradient influences on water quality, such as other mine sites are present. In some upland or minepool settings, upgradient groundwater monitoring is not possible. For most mine sites, Pennsylvania requires a minimum of six monthly background samples for each monitoring point, and ash monitoring points are no exception. The ash monitoring points must be sampled for a suite of standard mine drainage parameters plus aluminum, arsenic, cadmium, calcium, chloride, chromium, copper, lead, magnesium, mercury, nickel, potassium, selenium, sodium, and zinc. During operations, monitoring must be done, at a minimum, quarterly for the mine drainage parameters and annually for the additional metals and chloride. More frequent monitoring is required on some sites. Once the site is completed, monitoring continues until the site is judged stable. Coal ash generally must be placed no closer than within eight feet of the top of the regional groundwater table. However, this requirement may be waived under the regulations if DEP approves the placement as part of a demonstration project.

The beneficial use of coal ash for mine reclamation is addressed in Sections 287.663-664 and subject to the requirements outlined in Table 1, Coal Ash Special Conditions. Coal ash may be beneficially used at active coal mine sites and abandoned mine sites to improve water quality or prevent degradation. In addition, coal ash is capable of eliminating public health and safety hazards at mine sites. Basically, the ash must be placed in approved areas, spread and compacted in two-foot lifts, covered with four feet of suitable material and graded to a 3% minimum final slope.

PHYSICAL PROPERTIES OF COAL ASH AT MINE PLACEMENT SITES

Earthen materials are widely variable in physical and chemical properties and “in-place” strata conditions. Soil engineering methods have been developed that can be applied to coal ash as shown by decades of academic evaluation and practical experience. For purposes of engineering, uniformly placed coal ash can be considered as an artificial “soil” type that is usually more uniform than a natural soil layer. Engineering methods to determine particle size distributions generally classify a soil or coal ash by the percentages of particles that can pass through standardized sieve opening sizes via comparison to a USDA Soil Triangle Classification Chart. Coal ash generally contains approximately 60 to 70 percent silt, and 30 to 40 percent sand size particles depending on the characteristics of the fuel burned by the plant. The coal ash classification is normally that of a silt loam.
Table 1. Key Items of Coal Ash Special Conditions used in DEP Permits.

<table>
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<th>KEY ITEMS OF COAL ASH SPECIAL CONDITIONS</th>
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<tr>
<td>• Grade the disposal area to create a stable base.</td>
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<td>• Keep the coal ash disposal area free of standing, running, or impounded water at all times.</td>
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<td>• All coal ash must be within the acceptable moisture content range in order to achieve a minimum compaction of 90% of the maximum dry density.</td>
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<tr>
<td>• Coal ash is not to be deposited within eight feet of any coal outcrop, vein or seam, pit floor, high wall, low wall or highest regional groundwater elevation.</td>
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<tr>
<td>• Complete chemical analysis and leachate analysis of the coal ash shall be conducted on a semiannual basis.</td>
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<tr>
<td>• Modified Proctor or Standard Proctor tests of each separate source of coal ash to be disposed shall be conducted on a semiannual basis, to determine the optimum moisture content and the acceptable moisture range needed to achieve a minimum compaction of 90% of the maximum dry density as determined by the Modified Proctor Test or 95% of the maximum dry density as determined by the Standard Proctor Test.</td>
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<tr>
<td>• Approved monitoring points shall be analyzed on a quarterly basis for Coal Ash Groundwater Quality Parameters.</td>
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<td>• The final cover layer on the coal ash disposal area shall be a minimum of four feet.</td>
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<tr>
<td>• Field density tests (minimum of one test per acre of active coal ash disposal areas) shall be conducted to insure that proper field compaction is being achieved within the disposal area.</td>
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<tr>
<td>• All coal ash conveyed or hauled to the coal ash disposal area must be spread and compacted in lifts of two feet or less.</td>
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In coal ash monofills at both conventional ash disposal sites and demonstration ash sites, nationally recognized engineering standard tests are conducted and data is gathered. From this, an estimate of the ash’s strength or bearing capacity can be made. The coal ash strength and bearing capacity sets the upper limit on potential building types, and other future uses. A laboratory Proctor Density Test must be conducted on the coal ash (either standard or most commonly the modified version). From this test, the theoretical Maximum Dry Density and the Optimum Moisture Content can be determined. Figure 5 illustrates a laboratory compaction test adapted from Bowles (1970).

DEP requires that field compaction results achieve 90 percent of this laboratory maximum density of 107.5 pcf, in this example. By projecting a line through the curve at this point it is seen that, the acceptable moisture range needed in order to achieve the required compaction in the field is between 12.5 and 17.3 percent for the example in Figure 5. Therefore, the moisture
content of the ash can be adjusted in order to place it on site within this moisture range. These numbers can then be used to ensure that the material is brought to the placement site at a moisture content which will allow adequate on-site compaction. In short, the test method usually shows a narrow range of density and optimum moisture for coal ash that has the desired engineering qualities for the proposed usage of the material, however the results can be different for fly ash and bottom ash.

![Laboratory Proctor Density Test](image)

**Figure 5.** Typical display of compaction test data.

The maximum dry density is that point where there is little potential for additional compaction. Therefore, long-term settlement of the coal ash is minimized if the coal ash is already near or at maximum density. An analysis of the maximum density, optimum moisture content, and field compaction test results for fly/bottom ash for four different ashes over time (Figs. 6a to 6c) indicates the maximum dry density varies from approximately 70 lbs/cu.ft. to 105 lbs/cu.ft. (mean value of 85 pcf), and the optimum moisture content varies from approximately 16% to 38%, (mean value of 25%). Field compaction tests reveal that compaction percentages are almost always 90% or higher (Fig. 6c). Other engineering properties can often then be correlated to the same maximum range of dry density, compaction and optimum moisture due to the uniformity of the coal ash materials.

After the ash is spread and compacted, field density tests can be performed with a nuclear densometer or other test method to determine or verify that the ash fill is meeting the 90% requirement. Results of these tests are summarized in a report from a certified testing laboratory. Analysis of the field density tests taken at conventional ash disposal sites has shown that their compaction consistently meets 90% or greater of the modified proctor densities with minimal compactive effort (i.e. dozers, trucks, etc.), without the need for the usual steel drum, rubber tire, or sheeps foot roller equipment. The use of this extra equipment and labor are not routinely needed to achieve the required compaction and density for most sites. There may be some sites, however where compaction equipment may be needed.
Figure 6(a). Plot of Maximum Dry Density.

Figure 6(b). Plot of Optimum Moisture Content.

Figure 6(c). Field compaction tests of ash from various ash sources.
Occasionally direct readings are taken with a hand held pocket penetrometer (Sowers and Sowers, 1970), which gives a rough estimate of the bearing capacity of the material at the surface (e.g. in tons/square foot). This type of testing is primarily useful as a spot check for the surface layer of the placed ash. It must be supplemented with the Troxler nuclear moisture density gauge or other test methods giving results that are accurate for below the exposed surface of the coal ash. At the demonstration permit sites described in the last section of this paper, the soil penetrometer results consistently met or exceeded 3.0 tons/square foot (tsf) and commonly “maxed out” on the penetrometer gauge at 5.0 tsf, which more than satisfies the accepted minimum standard of 2.0 tsf listed in the permit. The physical properties of coal ash and engineering practices of coal ash placement at mine sites in Pennsylvania are described in more detail in Owen et al. (2004).

Finally, in some cases, and for the demonstration permit sites, Soil Boring Tests are performed which utilize a split-spoon for sampling at depth intervals (usually 5 feet) and Standard Penetration Tests (U.S. Department of the Interior, Bureau of Reclamation, 1974) are performed at these same intervals which measure the number of times (i.e. the blow count) it takes to drive the spoon through a specified vertical interval with a standard weight hammer and drop distance on the drill rig (i.e. the “blow”), (ASTM Standard Penetration Test – ASTM D 1586-2003). From these numbers, the engineer can use technical literature (Tschebotarioff, 1974) in order to estimate the “in-place” bearing capacity of the material at depth, and can make recommendations as to design of footing foundations for structures. Available data from other test methods were compared to the penetrometer test results, and appear to support the high bearing capacities. The penetration results on the soil boring logs showed a sufficient value of “Blows/Foot” to adequately support a spread footing foundation at a design parameter of 2.0 tsf.

In summary, the ash fills, whether at conventional or demonstration sites are more than suitable for construction purposes for residential or commercial buildings, roads, and most other engineering applications, with perhaps the exception of “super-structures” such as heavy bridges or tall buildings, but even these uses could be investigated on a case by case basis. Ash has been utilized in other cases either with or without additives, such as Portland cement or cement kiln dust, in a slurry form to fill in mine voids, narrow crop falls, etc. where equipment access is a problem. Flowable fill is produced by mixing fly ash and a small amount of cement, hydrated lime or other binder material with water to a flowable consistency. Flowable fill is virtually self-leveling with the consistency of pancake batter. DEP has found these types of ash grout cement uses to be successful and continues to look at other possible uses within the same realm.

CHEMICAL CHARACTERISTICS OF COAL ASH, LEACHATE, AND GROUNDWATER QUALITY AT MINE SITES

The physical and chemical properties of coal ash are monitored and evaluated by DEP through permitting and inspection activities at coal ash placement sites. The general chemical monitoring requirements for the solid ash samples, SPLP leachate, and groundwater samples are described in the preceeding section of this paper on the regulatory framework and in the book chapter by
Dalberto et al. (2004). The purpose of this section is to use site-specific data from an anthracite case study described in Hornberger et al. (2004) to illustrate the relationships among the chemical parameters in the solid ash, SPLP leachate and groundwater monitoring points. Groundwater monitoring associated with coal ash placement at anthracite mine sites generally depends upon an understanding of the minepool hydrology. Almost all of the refuse bank reprocessing and strip mine sites overlie abandoned underground mines, and these individual collieries have minepools with gravity discharges, or are hydrologically interconnected to other minepools and downgradient discharge points.

The large B-D Mining coal refuse reprocessing and coal ash placement site is located in Mahanoy and West Mahanoy Townships and Gilberton Borough in Schuylkill County. The SMP #54850202 is for a total of 1,590 acres, including 809 acres of coal refuse removal and 175 acres of coal ash placement areas. This SMP was issued in December 1985 as a repermitting operation that encompassed five previous surface mining permits. The permit boundary and active and abandoned mine features are shown on Figure 7. This site consists of a large area of abandoned mine lands containing extensive waste coal (refuse material) and coal silt deposits that are consumed in the Gilberton Power Cogeneration Plant. While the ash placement site overlies a single abandoned underground mine (Boston Run Colliery), the SMP overlies a total of 8 abandoned collieries, and the Gilberton Shaft minepool monitoring point within the SMP receives mine drainage from at least 11 upgradient collieries and interconnected minepools. This case study site was selected because it represents a large volume coal ash placement area within a large-scale refuse reprocessing operation with a complex groundwater monitoring scenario.

Figure 7. Map of B-D Mining site showing permit boundary, ash placement areas and monitoring locations.
Before describing the monitoring points and monitoring data, it is useful to put the B-D Mining site in perspective with the other coal mining and ash placement activities in the watershed. The 1,590 acre B-D Mining SMP shown on Figure 7 is adjacent to the 3,038 acre Reading Anthracite Co. Ellengowan SMP located to the northeast. That Reading Anthracite SMP contains the Schuylkill Energy Resources (SER) cogeneration plant and its large coal refuse bank fuel supply, plus the Shen Penn and Knickerbocker pits, and the Ellengowan silt dam coal ash site within the SMP boundaries. Thus, there are three significant coal ash placement sites in the area as shown in Figure 7, the Knickerbocker pit to the north, the Ellengowan silt dam in the middle, and the B-D ash placement site to the south of the other two. The entire area underlying these two large surface mining pits is a series of interconnected abandoned underground mines. Surface mining activities within this area consisted of numerous small pits, several large open pit mines including the Shen Penn and Knickerbocker pits, and extensive coal refuse disposal and refuse reprocessing operations. Annual records of refuse consumption and ash production from the Gilberton Power and SER cogeneration plants, show that more than 22 million tons of coal refuse have been removed from the permit areas, and more than 15 million tons of coal ash have been beneficially used from 1988 to 2002. All of these mining and ash placement areas drain to the Gilberton Shaft and ultimately the Packer V discharge at Girardville, shown on Figure 7.

The coal ash material placed within permit areas shown on Figure 7 has been regularly monitored and tested since 1988 for solid ash bulk chemistry and leachate analyses in accordance with the DEP’s Module 25 requirements, and monitoring has shown that the solid ash and leachate parameters are consistently within allowable limits. Table 2 shows the chemical analyses for the solid ash expressed in milligrams per kilogram (i.e. parts per million) for the ash from the SER plant. The bottom half of the table shows the leachate concentrations from the Synthetic Precipitation Leachate Procedure (SPLP) test, expressed in milligrams per liter (i.e. parts per million), for the ash samples shown in the top half of the table. The samples included in the table are representative samples of the 25 samples contained in the permit file resulting from the semiannual testing requirements. The samples selected for inclusion in Table 2 represent the range in concentrations, the medians, the range in time, or sampling events when bottom ash or fly ash were separately tested. The writers determined that to include all available analyses in these tables would make them too voluminous for inclusion in the body of this paper; plus, all of this data is public file information within the permit files. However, the concentration plots of the ash, leachate and monitoring data in Figure 8 and 9 show the entire range and median values of all of the data within the permit files. Another table in Hornberger et al. (2004) shows the chemical analyses for the solid ash and SPLP leachate from the Gilberton Power Plant in the same format as Table 2.

The elements in the columns of Table 2 are arrayed in the approximate order of their abundance in the solid ash samples. The major elements, aluminum, iron and potassium shown in the table are present in the range of thousands to tens of thousands of mg/kg. Other major elements in coal, coal refuse and overburden rock minerals (e.g. calcium, magnesium, sodium and silica) are not included in the table, because they are not routinely required in the Module 25 list of analytes; but they are known to be present in these approximate ranges (i.e. thousands of mg/kg) from other analyses discussed in Scheetz et al. (1997) and other sources. Barium is relatively abundant in the hundreds of mg/kg range, followed by manganese, chromium, copper, zinc, nickel, boron, molybdenum and arsenic, generally in the tens of mg/kg range. Finally, the
elements of selenium, cobalt, mercury, cadmium and silver are generally present in the range of a few mg/kg to trace quantities of a few hundredths of a mg/kg.

Table 2. Chemical analyses of SER coal ash and SPLP leachate. (0.00 values = below detection limit).

<table>
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<tr>
<th>SAMPLE</th>
<th>pH</th>
<th>Al</th>
<th>Fe</th>
<th>K</th>
<th>Ba</th>
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<td>Combined Fly and Bottom Ash</td>
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<td>34</td>
<td>19</td>
<td>12</td>
<td>11</td>
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<td>23150</td>
<td>16170</td>
<td>163</td>
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<td>28</td>
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<td>24500</td>
<td>10600</td>
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<tr>
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<td>13000</td>
<td>8360</td>
<td>121</td>
<td>50</td>
<td>16</td>
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<td>42</td>
<td>1.2</td>
<td>0.02</td>
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<tr>
<td>1/10/90</td>
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<td>4.30</td>
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<td>0.56</td>
<td>0.00</td>
<td>0.12</td>
<td>0.17</td>
<td>0.00</td>
<td>0.40</td>
<td>0.42</td>
<td>0.63</td>
<td>0.00</td>
<td>0.00</td>
<td>0.30</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Chemical analyses of SER coal ash and SPLP leachate. (0.00 values = below detection limit).

| SAMPLE       | pH  | Al  | Fe  | K   | Ba  | Mn  | Cr  | Cu  | Zn  | Ni  | B   | Pb  | Mo  | As  | Se  | Co  | Hg  | Cd  | Ag  |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Combined Fly and Bottom Ash |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 4/30/91      | 5.4  | 5.12 | 0.20 | 0.27 | 0.27 | 0.00 | 0.00 | 0.07 | 0.18 | 0.18 | 0.09 | 0.05 | 0.01 | 0.12 | 0.00 | 0.00 | 0.00 |     |
| 12/7/92      | 5.4  | 9.88 | 0.04 | 0.00 | 0.40 | 0.00 | 0.00 | 0.14 | 0.08 | 0.37 | 0.00 | 0.23 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10/28/98     | 10.1 | 1.72 | 0.00 | 0.00 | 0.24 | 0.03 | 0.08 | 0.02 | 0.00 | 0.04 | 0.00 | 0.12 | 0.15 | 0.01 | 0.08 | 0.00 | 0.00 | 0.01 |
| 11/3/99      | 8.8  | 2.85 | 0.12 | 0.00 | 0.02 | 0.07 | 0.03 | 0.00 | 0.00 | 0.20 | 0.22 | 0.00 | 0.45 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 |
| 11/10/00     | 10.3 | 1.67 | 0.03 | 0.10 | 0.07 | 0.05 | 0.02 | 0.01 | 0.04 | 0.20 | 0.10 | 0.10 | 0.01 | 0.01 | 0.00 | 0.02 | 0.00 |     |
| 4/17/02      | 10.2 | 1.64 | 0.02 | 0.03 | 0.01 | 0.01 | 0.01 | 0.06 | 0.01 | 0.07 | 0.05 | 0.01 | 0.04 | 0.01 | 0.00 | 0.01 |     |     |
| Bottom       | 5.00 | 13.82 | 4.26 | 0.00 | 0.56 | 0.00 | 0.12 | 0.17 | 0.00 | 0.40 | 0.42 | 0.63 | 0.00 | 0.00 | 0.00 | 0.30 | 0.04 |     |
| Conditioned Fly | 5.10 | 14.38 | 4.30 | 0.00 | 0.56 | 0.00 | 0.10 | 0.21 | 0.00 | 0.44 | 0.54 | 0.00 | 0.00 | 0.00 | 0.32 | 0.03 |     |

While some of these elements are not abundant in the solid ash or the SPLP leachate, they are included in Table 2, and are routinely required in the Module 25 analyses because they are elements of concern in the federal RCRA program (i.e. As, Ba, Cd, Cr, Pb, Hg, Se, Ag). The leachate concentrations of all of these major, minor and trace elements in the bottom half of the table can easily be compared to the solid ash analyses, and it is evident that the relative abundance of certain elements in the solid ash is not matched by their relative abundance in the leachate. For example, aluminum and potassium are more concentrated in the leachate than iron, and barium concentrations in the leachate are no higher than manganese or zinc. In the 15 columns from barium to silver, none of the leachate concentrations are greater than 1.0 mg/L. The analyses for some of these elements that are shown as 0.00 in Table 2 were reported that way in the monitoring data submitted to DEP, but actually should be expressed as less than a specified analytical detection limit for that element.

The ranges of concentrations of constituents in the solid ash samples from the Schuylkill Energy Resources FBC plant are shown in Figure 8. All of the 25 solid ash analyses for the SER power plant were used in computing the range and median for these data sets. The bold vertical lines express the range of concentrations and the bold horizontal lines represent the median values in these frequency distribution diagrams. These figures are graphed on a log scale because the range of concentrations of elements in the coal ash extends over 7 orders of magnitude for this
coal ash source, and the patterns of variations for all these elements can then be viewed simultaneously as an “ash fingerprint” or chemical signature for that ash. These data plots are essentially simplified box plots, following the concepts developed by Tukey (1977) and McGill et al. (1978) for comparing batches of data, and used in the statistical analysis of mine drainage data by Griffiths et al. (2001), Fox et al. (2001), Smith et al. (2004), and Brady et al. (1998). If these diagrams were truly box plots, the interquartile range of the data would be contained in a box. While the boxes are very useful in evaluating the shape of the frequency distribution of the data and in comparing large data sets, it was determined that the boxes were not essential in these diagrams.

**Figure 8.** Ranges and medians of elements in SER coal ash. (all parameters except pH and NP are expressed as mg/kg).

Similar diagrams were constructed to evaluate the patterns of variation for several analytes of concern (i.e. aluminum, iron and arsenic) in the solid ash, the SPLP leachate, and an array of groundwater monitoring points, as described in more detail in Hornberger et al. (2004). Figure 9 shows the patterns of variation for iron in the solid ash, the leachate and the downgradient groundwater monitoring points occur over seven orders of magnitude. The three monitoring wells (South BH, MW7, MW8) are located downgradient of the B-D and SER ash sites and they were mostly installed after ash placement commenced and it was determined that these additional monitoring points were needed. Thus, the data from the first few years of monitoring were compared to the data for all of the later years to determine if there were any noteworthy changes. The data from the early years is shown as MW7-e, for example, and the later years as MW7-1. The median iron concentrations in the solid ash are similar at 19,995.5 mg/kg for the
Gilberton Power ash and 15,750 mg/kg for the SER ash. The SPLP leachate medians for iron are both relatively low at 0.16 mg/L for Gilberton and 0.07 mg/L for SER. The three downgradient monitoring wells had interesting differences between median iron concentrations. MW007 had no significant change between the first 3 years of data and the remaining 6 years, because the median for the early years (MW7-e) is 66.7 mg/L and the median for the later years (MW7-l) is 69.5 mg/L. The median iron concentrations in the South BH and MW008 on Figure 9 show very substantial differences between the early and later years of monitoring. The first 2 years of data for the South BH downgradient of the SER ash site have a median of 168.5 mg/L (n=14), compared to the median for the later 14 years of 22.6 mg/L (n=80). The first 2 years of data for MW008 downgradient of the Gilberton ash site have a median of 121.5 mg/L, compared to the median for the later 5 years of 9.65 mg/L. The Gilberton Shaft pumped minepool discharge point is the key downgradient groundwater monitoring point for both coal ash placement sites and the median iron concentration for the first 4 years of monitoring is 55.83 mg/L (for 24 samples from 1986 to 1990), while the median for the last 12 years is 43.92 mg/L (for 49 samples from 1991 to 2003). The Packer V minepool overflow point further downgradient has a median iron of 18.5 mg/L. The conclusion that can be made for the entire data set of iron values shown on Figure 9 is that although more than 15 million tons of coal ash were placed in the drainage basin with high concentrations of iron in the solid ash samples, the median iron concentration at the downgradient Gilberton Shaft monitoring point decreased by 12 mg/L, and the median iron concentrations in two monitoring wells immediately downgradient of the two coal ash placement areas decreased by an order of magnitude (i.e. from >160 mg/L to <25 mg/L in South BH, and from >120 to <10 mg/L in MW008).

The median aluminum concentrations in the Gilberton Power and SER ash samples were 31,608 and 23,150 mg/kg respectively, while the medians of the SPLP leachate from these ash samples were both 2.2 mg/L, and the median aluminum concentrations for the Gilberton Shaft and Packer V downgradient groundwater monitoring points were both less than 1.0 mg/L. The median arsenic concentrations in the Gilberton Power and SER solid ash samples were 11.6 and 12.17 mg/kg respectively, the medians of the SPLP leachate were 0.02 mg/L or less, and the medians of all groundwater monitoring points were less than 0.01 mg/L. Additional diagrams and data for aluminum and arsenic are shown in Hornberger et al. (2004).

The anthracite minepool interconnections are described above to provide illustrations of the potential difficulties and complexities of developing realistic groundwater monitoring plans for some anthracite surface mine and coal ash placement sites. The simplified residual-waste monitoring concept of an upgradient monitoring well to document ambient groundwater quality of the aquifer, and one or more downgradient monitoring wells to detect and capture any groundwater pollution emanating from the site, is not applicable to many anthracite mine sites. Thus, the configuration of voids within the underground mine workings (i.e. gangways, cross-cut rock tunnels, slopes, shafts, etc.) is evaluated to select potential upgradient and downgradient monitoring well locations and the presence of breaches in barrier pillars is considered in determining groundwater (minepool) flow patterns.
CONVENTIONAL ASH PLACEMENT PRACTICES IN THE BITUMINOUS AND ANTHRACITE REGIONS

Bituminous Coal Region
Beneficial use of coal ash on bituminous coal mine sites in Pennsylvania is not a new concept and has been practiced for at least 15 years. Abandoned coal refuse piles, large and small, dot the landscape of Pennsylvania’s bituminous coal region. Coal refuse (also known as gob) is the nonmarketable material that was removed from mines along with the coal. Many of the piles occur near old mine mouths or cleaning plants; most, but not all, are associated with deep mines. Surface mined coal that was cleaned prior to being marketed also contributed to some piles. The aboveground piles typically are toxic to any colonizing vegetation and are highly erosive. Often the refuse was deposited in the lowland areas, below mine entries or cleaning facilities, frequently on stream banks, and sometimes directly in the stream channel. Even decades after refuse placement, each significant precipitation event washes fresh refuse onto adjacent properties and into streams. Most coal refuse contains relatively high percentages of sulfur and, therefore, leaches severe quality AMD. Because the oxidation of pyrite is exothermic, some refuse piles catch fire and burn for decades, adding air pollution to the list of problems they create for the small mining communities that often exist next to them.

The Ebensburg Power Company Revloc site is located directly east of the village of Revloc and south of highway US 422 in Cambria County, Pennsylvania. The South Branch of Blacklick Creek, a tributary of the Conemaugh River, bisects the pile as shown on Figure 10. The South Branch supports a native brook trout population directly upstream of the Revloc pile, but has been virtually devoid of aquatic life below the pile for decades. Refuse in the pile is from the
Bethlehem Mines Corporation Mine 32 Lower Kittanning deep mine that operated during the middle decades of the twentieth century. The refuse was placed in a lowland area where an unnamed tributary entered the South Branch; the refuse actually dammed the South Branch, producing a pond on the upstream side of the pile. Ebensburg Power Company obtained separate mining permits on the northern and southern sections of the Revloc pile, which are separated by the South Branch. The company permitted the larger northern pile under SMP #11880201 (Revloc 1), which DEP issued in 1989. Revloc 1 contained approximately 3.8 million tons of coal refuse spread over approximately 56 acres. In 1997, the company obtained SMP #11960202 (Revloc 2), which included 0.7 million tons of coal refuse.

![Aerial photo circa 1988 showing the Revloc sites and key associated monitoring reports. The photo was obtained from the permit application for Revloc 1.](image)

**Figure 10.** Aerial photo circa 1988 showing the Revloc sites and key associated monitoring reports. The photo was obtained from the permit application for Revloc 1.

Ebensburg Power Company began removing refuse from the Revloc 1 site at the end of 1990 and began bringing ash back to the site in very early 1991, when its 50-megawatt fluidized bed cogeneration facility, located in Ebensburg, PA, went online. Mining began on the northern end of the site adjacent to Route 422 and has advanced toward the southwest on multiple working faces. The company activated the Revloc 2 site in the fall of 1997; excavation on Revloc 2 began on the eastern side of the pile, in the area known to be burning. Thus, the fire was extinguished early in the operations to end that source of air pollution and to preserve the useable fuel in the pile. The company operates the two piles concurrently as fuel needs warrant.

Because the Revloc 1 site has been active for ten years, there is a large body of data available from the site. (The approximate locations of the monitoring points discussed herein are shown on Figure 10). Well MW-1 is a downgradient well, located just off the south-central edge of pile
and between the pile and the South Branch. MW-2 is located along the western side of the pile, between the pile and the village of Revloc, and is located upgradient of the site. Well 3 is located along the north central edge of the pile, between the pile and US Route 422, and MW-3 is located transverse to the direction of groundwater flow. The shallow groundwater flow direction at the site is from the northwest toward the southeast, from an upland recharge area in and to the north of the village of Revloc toward the discharge area at the South Branch.

Figure 11 is a photograph of the Revloc 1 site taken from the Revloc 2 site looking toward the village of Revloc to the northwest. The lighter green area in the center of the photo is recently planted area, while the darker green area on the right side of the photo is area that has been planted for at least two years. The dark area on the left of the photo is an area awaiting soil and vegetation. The refuse in the foreground is a yet-to-be-reclaimed area on the Revloc 2 site, and the small tree line at the base of the reclaimed pile marks the location of the South Branch.

Data from MW-1, and other monitoring points from the Revloc site are discussed herein and in Kania and Tarantino (2004). Figure 12 displays the historical results for acidity, iron and sulfate, three of the parameters most commonly elevated in mine drainage. The data show that groundwater downgradient of the pile was, not surprisingly, severely degraded by acid mine drainage prior to the Ebensburg Power Company operation. The data show a steady trend of declining concentrations for acidity, iron and sulfate throughout the monitoring period. The decline appears to have begun prior to initiation of Ebensburg Power Company’s operations in early 1991. The site had been disturbed by another operation approximately 10 years before Ebensburg Power Company permitted the site; it is possible that some of the earlier declines in
concentrations are due to the natural attenuation of the results of that earlier disturbance of the pile. The data for MW-1 also show that specific conductance, aluminum, zinc and TDS have declined at MW-1 during the monitoring period, which is consistent with the decline in mine drainage parameters.

When the median values of the early years of monitoring data are compared to the median values of the recent data, significant pollutant load reductions to the South Branch Blacklick Creek are evident. Sampling Point SP-1 is located on the South Branch below the Revloc 1 and Revloc 2 sites. This point is influenced by the direct discharges and groundwater baseflow from the piles into the stream. Table 3 compares the data in terms of median values collected from SP-1 prior to 1992 (N=14) to the 14 most recent samples at the time of this writing. The reductions in aluminum, acidity and sulfate at SP-1 are evident when the background data medians are compared to the most recent data medians. The data from SP-1 show the improvement to date in terms of mine drainage pollution in the South Branch that has resulted directly from the Ebensburg Power Company operations at the two Revloc sites. Note especially the reduction in aluminum and acidity concentrations along with the increase in pH. During times of low flow, the stream still experiences spikes in pollutant concentrations, but that condition should only improve as re-mining and reclamation continues.

Table 3. Comparison of background median flow and mine drainage pollutant concentrations at SP-1, the monitoring point on the South Branch directly downstream of the Revloc 1 and 2 sites.

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<th>Flow (gpm)</th>
<th>pH (su)</th>
<th>Acidity (mg/L)</th>
<th>Iron (mg/L)</th>
<th>Mn (mg/L)</th>
<th>Al (mg/L)</th>
<th>Sulfate (mg/L)</th>
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Figure 12. Graph of acidity, sulfate and iron at MW-1.
The use of FBC ash in the re-mining and reclamation of two large refuse piles at Revloc, PA has resulted in a large reduction in pollution load from site discharges and in a substantial improvement in downstream quality on the South Branch Blacklick Creek. Both flows and concentrations of pollutants have declined at the largest discharge points. Remining and reclamation are ongoing at these sites, and further water quality improvements are expected. Monitoring data show no significant negative impacts to downgradient water quality from the use of FBC ash on the sites.

Two additional bituminous surface mine sites are described in Kania and Tarantino (2004), but the water quality results related to the beneficial use of coal ash are less significant than the Revloc site. At the Laurel Land Development, Inc. McDermott site in Cambria County, the use of FBC ash as an alkaline addition agent was unsuccessful in preventing mine drainage formation. Water quality data indicate that the large quantity of ash placed in the backfill may be neutralizing some AMD, but has not prevented the formation of AMD, and has not generated net alkaline water. Several downgradient monitoring points have been degraded with AMD at the McDermott site. While operational complications, such as an intermittent ash supply, stockpiling of ash before incorporation into the backfill, and delayed and incomplete site reclamation may have contributed to the site problems, they likely are not the sole cause of the problems. At the Abel-Dreshman site in Clarion County, the use of FBC ash in the reclamation of an abandoned surface mine resulted in an improvement in downgradient water quality. The use of ash appears to have increased the net alkalinity of downgradient monitoring points, increased the pH, and decreased metal concentrations. Net alkalinity appears to have declined recently, but remains above pre-ash placement levels. The coal ash did not cause groundwater pollution or degradation in either of these two cases, but the results were not as favorable as the Revloc site.

Anthracite Coal Region
The spatial distribution of permitted beneficial use coal ash sites in the Anthracite Region is closely related to several key aspects of the mining history of the region. Underground mining accounted for most of the coal production prior to 1950, and surface mine production increased steadily from the 1920’s and surpassed deep mining by around 1950. Underground mining in the Anthracite Region started out small in the late 1700’s, but by 1850, there were 1000-foot deep shafts and extensive lateral development of gangways and rock tunnels in numerous collieries of the anthracite coal fields. Historical accounts of this early mine development in the region are found in Miller and Sharpless (1985) and Wallace (1981). The Department of Mines and Mineral Industries of the Commonwealth of Pennsylvania produced annual reports of coal production from 1870 to 1972, and its successors, the Pennsylvania Department of Environmental Resources and the Pennsylvania Department of Environmental Protection, produced these statistical reports from 1972 to the present. Those reports state that anthracite production peaked in 1917, at 100,445,299 tons.

In addition to the extensive network of colliery development features underground, the effects of all of this anthracite mining on the landscape of the anthracite region included thousands of large coal refuse (or culm) banks, and many thousands of mine subsidence features. By the 1940’s
advances in the development of large surface mining equipment, and the demand for anthracite related to World War II industrial development efforts, facilitated the development of large open-pit surface mines several hundred feet deep. Many of these large open-pit mines and thousands of smaller surface mine pits were abandoned prior to the enactment of laws requiring surface mine reclamation.

The nine anthracite region FBC plants account for 38.14 million tons of the coal ash beneficially used for abandoned mine reclamation described in a previous section of this paper (see Figure 4). The coal ash placement sites associated with these 9 FBC plants represent the greatest volume of coal ash and the largest acreage of abandoned mine land reclamation with coal ash in the anthracite region. However, many of the 51 permits issued by the Pottsville District Office were for the use of coal ash from pulverized coal power plants in Pennsylvania and other states, which is transported to the anthracite region by truck and rail for use in the reclamation of active and abandoned pits on these surface mining permits. Many of the yellow dots on Figure 1 represent coal ash placement mine sites that are not located at or near a FBC plant. Several case study sites of conventional ash placement in the Anthracite Region are described in Hornberger et al. (2004) and Menghini et al. (2005, this volume). Figure 13 shows the Westwood FBC plant under construction in 1985 and the large coal refuse pile adjacent to Interstate 81 in Schuylkill County. Figure 14 shows the Westwood site in 2003 after the large coal refuse pile was removed and consumed in the FBC plant, and a significant amount of coal ash was placed on site.

Figure 13. Westwood FBC plant near Tremont in Southern Anthracite Field (1985).
Some anthracite coal ash sites exhibit a distinct effect upon minepool chemistry (e.g. reduction in acidity/increased alkalinity) at downgradient minepool discharge sites; for other coal ash sites any effects are more subtle. The following characteristics of the coal ash placement site and the minepool system are believed to determine the magnitude of any water quality effects: the size of the minepool drainage area, the flow volume of the minepool discharge, the size of the coal ash placement area and ash volume (a 10 acre ash site may not produce a detectable change in the typical minepool discharge, but a 100 acre site might), the ratio of the coal ash site acreage to the minepool drainage area acreage, the thickness and permeability of the coal ash deposit, the bulk chemistry and mineralogy of the coal ash deposit, the acidity to alkalinity ratio in the minepool, the geologic structure underlying the surface mine coal ash site and the associated minepool, and the configuration of underground mine development features.

Three possible interpretive scenarios emerge from interactions of the coal ash site and minepool characteristics listed above: (a) significant improvement in water quality parameters at minepool monitoring points from beneficial use of coal ash in mine reclamation, (b) no significant change in minepool chemistry associated with the coal ash, and (c) a significant degradation in minepool chemistry and pollution loading at downgradient mine pool discharge locations attributable to the coal ash placement. Fortunately, for the interests of the coal mining/electrical power production industry, the environmental regulatory agencies, and the environmental/citizens groups, none of the type (c) environmental damage scenarios have been found in more than 15 years of compliance monitoring and inspections of anthracite ash sites by DEP staff. The Westwood site and the Mount Carmel cogeneration site (described in Hornberger et al. (2004) and Menghini et al. (2005, this volume) exhibit significant improvement
in alkalinity (type (a) behavior) at downgradient minepool monitoring points (see Fig. 15), presumably due to a relatively small ratio of minepool drainage area size to coal ash placement area acreage, bulk chemistry of the FBC ash, and favorable geologic structure and underground mine development features, to convey groundwater flow from the coal ash site to the minepool monitoring points. Figure 15 shows that the alkalinity in the downgradient monitoring well increased significantly after the start of ash placement, while the upgradient monitoring well was essentially unchanged. The Wheelabrator site described in Menghini et al. (2005), and the B-D/SER sites exhibit the type (b), no significant change, behavior in varying degrees, for a variety of known and unknown reasons. However, when hundreds of acres of abandoned mine lands on these sites are reclaimed (at no cost to the government or taxpayers) with millions of tons of FBC coal ash that contains large amounts (tens of thousands of mg/kg) of aluminum and iron, and there is no discernable degradation of downgradient minepool discharge points with these metals or other analytes of concern, the overall project still represents a significant environmental benefit. For example, the Wheelabrator cogen site has reclaimed 123 acres of abandoned mine lands and the Mount Carmel cogen site has reclaimed 209 acres. Several sites discussed in Hornberger et al. (2004) and Menghini et al. (2005) showed no significant change in groundwater/minepool water quality, despite extensive ash placement and land reclamation – although these sites significantly reduced infiltration to the minepool, and thus should represent a reduction in the flow and thereby the pollution load of acidity, iron and other metals in these high volume minepool discharges. The groundwater monitoring data for some of the case study sites and the hydrologic budget discussion below demonstrate that the “high and dry” concept of placing relatively dry (optimum moisture content) coal ash into a relatively dry mine environment is working well.

![Figure 15. Alkalinity in upgradient and downgradient monitoring wells at the Westwood FBC power plant site.](image-url)
The purpose of this hydrologic budget discussion is to briefly evaluate the effects of coal ash placement in abandoned surface mine reclamation as a component in the post-reclamation hydrologic budget. The Wheelabrator case study site described in Menghini et al. (2005) and Hornberger et al. (2004) is selected for this purpose because it is near Hazleton, and the surface water/groundwater relationships are very similar to the hydrologic budget components in Ballaron (1999) for the pre-reclamation site conditions. The site description documents that there was very little surface runoff from the permit area because the tributary to Mill Creek entering the eastern end of the permit, goes subsurface to the minepool, and most of the permit area was covered by extensive abandoned surface mine pits and spoil piles prior to remining and coal ash placement by Wheelabrator. Using the values from Ballaron (1999) to evaluate the before-remining conditions of a 10 acre phase of the Wheelabrator permit area, the annual precipitation of 48.5 inches falling on that 10 acres equals 13.2 million gallons, the surface runoff would be 0.94 million gallons, and the evapotranspiration would be 3.5 million gallons. Therefore the amount of water infiltrating to the minepool from that unreclaimed 10 acre phase would be 8.76 million gallons. In the post-reclamation hydrologic budget for the Wheelabrator 10 acre site area with the presumed annual precipitation of 48.5 inches (13.2 million gallons); the surface runoff term in the hydrologic budget equation would be 9.7 inches (2.64 million gallons) and the evapotranspiration would be 20 inches (5.44 million gallons) with the remainder in groundwater runoff/minepool discharge of 18.8 inches (5.12 million gallons). Total reduction in mine recharge was 3.64 million gallons per year. Given the assumption that recharge to the minepool equals discharge, the flow of the Morea/New Boston minepool discharge at the downgradient monitoring point should decrease by about 41.6 percent, after the entire site is reclaimed.

There may be some zones of saturation within the backfilled mine spoil or the coal ash deposit (i.e. groundwater storage), but the minepool is the regional groundwater table of the area, and pursuant to the residual waste regulations and permit conditions, the coal ash must be at least 8 feet above the regional groundwater level (i.e. the “high and dry” concept). A cross-section through the relatively shallow abandoned pits (40 ft depth) on the Wheelabrator site would show a lens-shaped compacted ash deposit of about 20 to 25 feet thickness, with an estimated permeability in the range of $10^{-5}$ to $10^{-6}$ cm/sec groundwater flow, surrounded by more coarse mine spoil (bottom, side and top cover material), with an estimated permeability in the range of $10^{-1}$ to $10^{-3}$ cm/sec. These permeability estimates for the mine spoil are based upon summary statistics of hydraulic conductivity (K values) reported in Hawkins (2004) and related data in Hawkins (1998) and Hawkins and Aljoe (1991). Thus, most of the groundwater flow from the point of recharge to the minepool should be under unsaturated conditions, and given the permeability contrast between the compacted ash lenses/layers and the surrounding mine spoil, most of the infiltrating groundwater should run off of the upper ash surface or flow around the ash deposit (with mine spoil permeability 2 to 6 orders of magnitude greater than compacted ash) before entering the minepool flow system. Nevertheless, some groundwater will flow through the coal ash deposit, with a substantial residence time, and discharge to the minepool.

From the hydrologic budget calculations described above, a rough estimate is made here, that of 5.12 million gallons of recharge in the 10-acre reclaimed area, less than 0.5 million gallons per year would flow out of the ash deposit with a high alkalinity concentration. However that high alkalinity groundwater flow component would commingle with the many millions of gallons of
groundwater in the minepool, and would result in a modest acidity reduction in the downgradient groundwater monitoring point, rather than a significant alkalinity increase in the minepool discharge. The purpose of this discussion has been to document that the “high and dry” coal ash placement concept is apparently working well on mine sites like the Wheelabrator site, although alkalinity benefits may not be maximized with this method of ash placement.

INNOVATIVE COAL ASH PLACEMENT METHODS (DEMONSTRATION PROJECT SITES) IN THE ANTHRACITE REGION

Pennsylvania’s residual waste regulations include the requirement that any waste, which is placed on a site, must be a minimum of 8 feet above the regional groundwater table and 4 feet above any perched water table. The regulations concerning waste demonstration permits enable DEP to issue permits that deviate from these required separation distances (among other things), providing that the demonstration project is a justifiable evaluation of alternative methods of solid waste management, and that an economic and technical analysis of benefits is considered as well as potential environmental effects. Under requirements of 25 Pa. Code Sections 287.501-287.506, waste management permit applications have been approved as Waste Management Demonstration Permits which may allow the demonstration of new or unique technologies for the processing or disposal of residual waste at permitted facilities.

Three such demonstration project permits have been issued in the Anthracite Region of Pennsylvania as alternatives to the conventional coal ash beneficial use requirements of placing relatively dry (optimum moisture content) ash in a relatively dry mine environment. One project is for the placement of high-density ash/water slurry into standing mine water (wet-to-wet placement) in the Shen Penn Demonstration Project. The second is for placement of a high-density ash/water slurry into a dry mine pit (wet-to-dry placement) in the Knickerbocker Demonstration Project. The third is for dry ash placement into standing mine water (dry-to-wet placement), the Big Gorilla Demonstration Project. If DEP determines that these demonstration facilities adequately achieved their objectives and satisfactorily protected public health, safety, welfare, and the environment, the agency subsequently may revise the regulations to allow the use of the new or unique technologies where the characteristics and potential interactions of the specific coal ash, specific mine water chemistry and mine site (i.e. configuration, geology, hydrology) are all favorable.

Shen Penn Demonstration Permit Site
The Shen Penn Pit is located within the town of Shenandoah on the eastern end of town and encompasses approximately 39 water-filled acres with a measured depth of 240 feet. Associated with the pit is an exposed highwall approaching 600 feet. Figure 16 is an aerial overview of the pit and its relationship to the cogeneration facility and the town of Shenandoah. The Shen Penn Pit represents a significant public health and safety problem directly to the city of Shenandoah and surrounding communities because it is often used as a recreational swimming hole and is the site of multiple drowning fatalities. The most recent being an 11-year old boy triggered a renewed interest in eliminating the safety problem with the water-filled pit. The objective of the demonstration was to show that ash could be transported in the form of a slurry and placed in the deep standing waters of the Shen Penn Pit. The significance of the Shen Penn Pit to mineland reclamation in the Commonwealth cannot be over stated. The sheer volume of the pit limits
It is estimated that for just backfilling with rock, the cost would be between $20 and $28 million, comparable to the Pennsylvania Bureau of Abandoned Mine Reclamation’s annual budget. A Waste Management Demonstration Permit (No. 301289) was issued to Reading Anthracite Company on August 6, 1996, that included details on testing and monitoring the physical and chemical properties of the coal ash slurry and its interactions with the mine pool impoundment. Unfortunately, Waste Management Demonstration Permit No. 301289 was never activated, due to the impediment of a $5 per ton coal ash tax imposed by the local school district. Scheetz et al. (2004) describes the small-scale demonstration project completed within the permitted ash placement area on the Ellengowan permit (at the SER cogen site) that was conducted as a precursor to the Shen Penn project, and also provides additional information on the mine pool chemistry and monitoring data relevant to the Shen Penn and Knickerbocker sites.

The Ellengowan demonstration project was a necessary precursor to the three Waste Demonstration Permits in order to develop tangible data on a small scale before embarking on the full-scale demonstration projects. The Ellengowan silt dam was within the approved ash disposal area on the Reading Anthracite surface mining permit, and it contained about 9 ft. of water wherein two ash placement techniques were evaluated: direct dry-to-wet end dumping of ash into the water, and slurry delivered, wet-to-wet placement. Both placement techniques were successful in the shallow water impoundment. Slurry placement of the ash was found to be an adequate approach if the slurry is allowed to flow into shallow standing water in a slow delta-like spreading flow of material.

**Knickerbocker Demonstration Permit Site**

On July 21, 1998, DEP issued Waste Demonstration Permit No. 301301, to Reading Anthracite Co. (RAC) for the 44-acre Knickerbocker pit area within the Ellengowan surface mining permit near the Schuylkill Energy Resources FBC power plant site. The Knickerbocker pit is a dry
abandoned surface mine above the mine pool level, located on the same surface mine permit as the Shen Penn pit to the east along the strike of the syncline, and in West Mahanoy Township (outside of the boundaries of the school district and the ash tax). This permit approval authorized RAC and SER to demonstrate their coal ash slurry concept in a dry pit. It also enabled DEP to obtain scientific and engineering data on a relatively large-scale slurry project, for possible future use into a water-filled pit (i.e. the original wet-to-wet alternative). The results of the Knickerbocker demonstration project, including an evaluation of the effectiveness of the use of various percentages of a cement kiln dust (CKD) admixture as an activator for cementitious behavior of the ash in test cells, are described in Loop et al. (2004 a). The Knickerbocker project was implemented in 1997 with the placement of approximately 4 million cubic yards of ash placed by 2005, and the completion of reclamation back to approximate original contour is anticipated in 2007.

A water/ash slurry consisting of a mixture of 60% (by volume) deep minepool water pumped from the Maple Hill shaft and 40% ash was delivered to the placement site, a distance of approximately 1 km, in a 10 inch diameter high-density polyethylene pipe (Fig. 17). Discharge of the slurry into the pit was controlled so that laminar flow conditions were maintained. As observed in the Ellengowan demonstration, turbulent mixing of the slurry would result in unnecessary turbidity in the transporting water, which could percolate into the minepool or be recycled back to the ash slurrying operation. Neither outcome was desirable. When placed in a manner that allowed the transport water to flow in a slow and laminar fashion, the ash dropped out of suspension rapidly and resulted in a dense, strong compacted fill onto which equipment could immediately drive (Fig. 18). Semi-annual characterization of the proctor densities of the ash and size distributions are reported. These data show that compaction of the ash was routinely above 90% with enough structural strength to support wheeled vehicles.

![Test cells in Knickerbocker pit](image)

**Figure 17.** Aerial photograph of the Schuylkill Energy plant and the Knickerbocker Pit.
A subset of the principal wet-to-dry demonstration was a study intended to evaluate the potential for the enhancement of the mechanical properties of the cogeneration ash by the additions of CKD. CKD, depending upon its storage history, can contribute significant alkalinity to an ash/CKD mixture to enhance the cementitious reactions and/or it can serve as a fine filler to enhance packing within structural fills. Schuylkill Energy slurried both bottom and fly ash approximately 2900 feet to a blending tank beside four test cells. Keystone Cement Company delivered 20 ton truckloads of CKD to the test cell area, which were then stockpiled. The four test cells were at the northwest end of the Knickerbocker Pit. They were carved from ash originally slurried into the pit. The cells can be seen in the foreground of the demonstration pit in Figure 14. Test cells 1 and 2 contained a mix of 20% CKD and 80% ash. Cells 3 and 4 contained 10% and 5% CKD, respectively, with ash as the remainder.

Soil borings and split-spoon samples were collected by the Borings, Soils, and Testing Company of Harrisburg, PA on the four cells in both August and November, 2000. At this time, the necessary blow counts were recorded. Dry density, wet density, and moisture measurements were collected by the DEP with a Troxler nuclear density moisture gauge. Weight bearing capacity measurements were collected with a penetrometer. Wet chemical, fertility, x-ray diffraction (XRD), moisture loss, grain size, and scanning electron microscope (SEM) analyses also have been performed on the ash/CKD mixture from the Knickerbocker test cells as described in Loop et al. (2004 a).

The number of blows per 6 inches of depth from Split-spoon sampling were noted by the Borings, Soils, and Testing Company as they drilled into the test cells and a control area in August and November. In each cell, one boring was drilled close to the inlet pipe location and another drilled toward the center of the cell, but on the ash platform. The mean and standard deviations of the blow count values from cells 1 through 4 are presented in Table 4.
Table 4  Mean and standard deviation data for blow counts per foot recorded at the center of cells 1 – 4 in November 2000.

<table>
<thead>
<tr>
<th></th>
<th>Cell 1</th>
<th>Cell 2</th>
<th>Cell 3</th>
<th>Cell 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>12.07</td>
<td>7.93</td>
<td>4.67</td>
<td>2.87</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.94</td>
<td>1.53</td>
<td>2.29</td>
<td>1.96</td>
</tr>
</tbody>
</table>

The economic benefit to the Commonwealth is that abandoned mine lands are reclaimed at no cost to the Commonwealth. The company benefits due to the reduction of materials handling costs, from the minimal amount of equipment, maintenance and labor requirements.

**Big Gorilla Demonstration Permit Site**

On June 16, 1997, DEP issued Waste Demonstration Permit No. 303104 to Northeastern Power Co. (NEPCO). This project placed optimum moisture content ash into an abandoned water-filled pit known as the Big Gorilla pit, a 16.6 acre area within the 876 acre surface mining permit site at the NEPCO FBC power plant site near the borough of McAdoo. The mine water impoundment in the Big Gorilla pit was 80 feet deep in most places. Cogeneration ash was first placed in contact with the surface mine pool in August 1997, which was entirely filled by 2004. Over 3 million tons of ash were placed from two platforms, and will eventually be brought to pre-mining contour and re-seeded. The Big Gorilla had an estimated volume of approximately 120 million gallons when the water level was at 1570 feet msl. It was approximately 1,400 feet long, 400 feet wide, and about 80 feet deep before ash placement began (Fig. 19a).

The use of trucks and bulldozers in regular placement activities provided the only mechanical compaction of the ash platforms. When driving or walking on the ash, there is no indication of soft areas or water accumulation. (Fig. 19c) NEPCO is required to submit ash samples to undergo a Proctor test (ASTM, 2001) every six months. The results from the Proctor test provide a theoretical maximum density, as well as an optimum moisture content. Also, the DEP Pottsville office staff regularly monitored the density and moisture content of the ash platform using a Troxler nuclear moisture density gauge. Based on both procedures, the density of the ash placed on the platform is consistently 90-100% of the theoretical maximum. The weight bearing capacity is measured in the field with a penetrometer by DEP, and is routinely over 69 MPa (5 tons per square foot).

The data evaluated in the Big Gorilla demonstration project as described in more detail in Loop et al. (2004 b) and Scheetz (2005, this volume) suggest that the presence of free lime (Ca(OH)₂) is necessary for placement of ash in standing mine water. Lime serves to immobilize labile heavy metals but more importantly, it is the activator that initiates chemical reactions among the fly ash phases. These hydration reactions not only contribute to the immobilization of metals but also to the development of cementitious chemical reactions that will influence the development of favorable mechanical and physical properties of the ash. As the hydration reactions mature with time, the resulting microstructure of the mass will continue to develop leading to a decrease in permeability to external fluids. Lime from the ash in contact with the pit waters will result in an elevated pH, the driving factor in the chemical reactions. The aluminosilicate structures of
the glass or meta-clay phases are activated by elevated pH values to initiate the hydration reactions which begin to dissolve their structures. The presence of aluminum and silica in solution in the presence of calcium results in the precipitation of tobermorite (a fiberous mineral that acts like the glue in Portland cement).

The high pH and alkalinity also results in a large amount of meta-clay undergoing pozzolanic reactions with the formation of hydrous calcium silicate phases. Thermodynamic modeling described in Loop et al. (2004 b) has confirmed the existence of 14Å tobermorite. This phase is the crystalline equivalent of C-S-H, the glue in Portland cement. In Portland cement, calcium-silicate-hydrate (C-S-H) forms as an amorphous hydration product of both di- and tri-calcium silicate. It is the morphology of this phase that imparts the mechanical properties that are attributed to concrete. Although the thermodynamic calculations have been conducted for a phase that contains no aluminum, C-S-H that forms under real world cement hydration conditions always contains a finite amount of aluminum substitution that is at the maximum solubility limits (Barnes and Scheetz, 1989). In the ash fill, clays in the culm and coal are thermally altered to the point where the clays give off their water and dehydroxylate. It is the
reaction of these meta-clays with Ca at elevated pH that forms C-S-H, as described in more
detail in Scheetz et al. (2005, this volume).

SEM characterization of placed ash has visually confirmed the development of the mineral
ettringite. Ettringite is an important component of the alteration of the ash since it has been
demonstrated thermodynamically that it is not only responsible for limiting control of the
solubility of aluminum in the mine-pit lake waters at high pH, but it is also an important
component in the cementitious reactions that are taking place within the ash fill and an important
control for arsenic sequestration. The observation that ettringite formation limited the solubility
of aluminum in the pit waters suggests that the sulfate content of the pit water/ash mass is also an
important controlling component.

In summary, the Big Gorilla demonstration project described in Loop et al. (2004 b) and Scheetz
(2005, this volume), is the Waste Demonstration Permit issued to evaluate alternative ash
placement technology of placing relatively dry (optimum moisture content) ash into a water-
filled abandoned surface mine pit (i.e. dry-to-wet placement). Early in the process of filling the
pit with FBC ash from the NEPCO power plant, two significant findings were recognized: a) the
pH of the 80 ft. deep mine water impoundment had changed from a background water quality of
pH 3.6 to a pH of approximately 11, homogeneously throughout the impoundment, due to the
unreacted calcium hydroxide in the FBC ash, and b) the physical properties of the completed ash
terrace, resulting from the placement technique of end-dumping the ash into the standing water,
had adequate stability and bearing capacity to support heavy equipment, meet the DEP
compaction requirements, and allow an orderly advancement of the dumping face from east to
west, without causing turbidity in the western portion of the impoundment. Detailed scientific
research produced three additional significant conclusions: c) the pore water chemistry within the
completed coal ash fill closely resembles the chemistry of pore water solutions in conventional
Portland cement (i.e. C-S-H) and concrete products, d) the mineral ettringite has formed and is
abundant in the completed ash fill, which is an important component in the cement formulation
process, and e) the relatively high sulfate concentrations of the mine pool chemistry were
necessary to promote the formation of the ettringite, and then the ettringite provides an additional
environmental benefit by sequestering heavy metals.

Sharp Mountain Demonstration Agreement Site
The Sharp Mountain cropfall abatement project in the city of Pottsville is an innovative project
using coal ash and other materials to create a cementitious grout mixture for filling dangerous
subsidence (cropfalls) that are prevalent in the Southern and Western Middle Anthracite Coal
Fields of Pennsylvania. The purpose of the project was to conduct a demonstration (in
cooperation MRI) to employ new technology to reclaim the cropfall mine subsidence features
that were previously filled and re-subsided and to develop a strategy that could be implemented
on other cropfalls adjacent to the project area. Due to the complex nature of cropfall features
described below, a structural plug was created using a grout mixture to form a cement-like plug
to bridge a void. The beneficial use of FBC coal ash as the major component in the grout cement
mixture, and pulverized coal PC power plant ash as the bulk fill material for more extensive
backfilling of the cropfalls is an excellent example of solving a significant public health and
safety problem, as well as associated environmental problems. The beneficial use of coal ash
and cement kiln dust in this mine subsidence abatement project was authorized by an Agreement
executed by DEP and the City of Pottsville pursuant to 25 PA Code Section 287.665b(6). Various mixtures of FBC ash and Portland cement or CKD were evaluated to determine their relative strengths, bearing capacities, and cost-effectiveness. As the project advanced the cement grout mixtures using CKD were unable to meet the compressive strengths in the laboratory tests and the CKD was replaced with Portland Cement.

The result of the surface outcrop of coal falling into the abandoned underground mine voids below is known as a cropfall. Cropfalls are dramatic features that often occur with little warning, resulting in deep narrow voids with near vertical walls. Many of the cropfalls occur as result of the work of “bootleg miners” who operated after the major collieries closed, or by geological and climatological processes over a number of years that weaken the support until it fails abruptly. This type of cropfall feature frequently develops in the spring of the year, following freeze-thaw cycles, and can be very dramatic, considering that the gaping hole may extend downdip as much as 900 feet depth, or deeper, depending on how many lifts were mined and whether the chain pillars between the lifts were robbed during retreat mining. The magnitude of the extensive underground mine void system connected to the cropfall feature may make the abatement of the subsidence with coal ash or any other material problematic, as described in Koury et al. (2004). In the years following the initial dramatic collapse of a cropfall, rock and soil materials gradually fall into the gaping hole and develop a weak or strong bridging system. This represents a mitigating factor in developing subsidence abatement plans (or may fool the unsuspecting hiker of lurking dangers beneath the rock and soil bridging material).

Figure 20. An aerial view of cropfalls on Sharp Mountain in the city of Pottsville.
The City of Pottsville lies on the northern exposure of Sharp Mountain along the southern boundary of the Southern Anthracite Coal Field. Although cropfalls occur throughout the Southern & Western Middle Coal fields, the cropfalls in Pottsville area are unique in that they are very close to residential areas. Cropfall features have existed on Sharp Mountain in Pottsville and are shown on maps of the Sherman Coal Company as early as 1925 and many of them have been dormant since that time and they appear stable with overgrown vegetation. In the 1990’s however several areas that extend over 1,000 linear feet began to collapse significantly. The subsidences have continually occurred and expanded causing an imminent danger to the safety of the public. There are 4 distinct continuous lines of subsidence that are dramatic and unstable, as seen in Figure 20. The active subsidences are within 300 feet of residences, including a community baseball field, swimming pool and cemetery. There are many challenges to addressing the cropfalls in Pottsville in that the only established access to the mountain is through residential areas and the fact that since they are a collapse, there is no available on-site material available to use as fill. The demonstration project addressed cropfalls in a 2.5 acre area. The project area shown in Figure 21 consists of Pit A East and Pit A West. The area referred to as Pit A originally subsided in 1999, was backfilled with dirt and rock in 2000, and re-subsided in 2001. Pit A consisted of 2 subsidences which were separated by a vertical support pillar of coal that remained intact, as displayed in Figure 21b. In order to install the structural plug, the subsidences were further excavated and prepared. Approximately 2,250 cubic yards of material were removed from Pit A to locate solid competent rock adjacent to the subsided coal vein.

The method of backfilling in Pit A was to develop a structural wedge so if the false bottom of the pit would fail, the wedge would become lodged and would not undergo catastrophic failure. Concrete panels were placed on the floor of the excavated pit in both the eastern and western portion of Pit A. The purpose of the concrete panels was to retard the flow of the grout until it had time to cure and to create an additional structural member of the plug. The concrete panels were originally manufactured to be used as sound barriers along major highways. The panels were flawed or damaged and they were donated by Schuylkill Products, Inc. a nearby concrete fabrication operation. In the eastern portion of Pit A an inverted steel truss was fabricated to act as a structural support member that spanned the void and was wedged into the competent solid rock on the north and south end of the pit (Fig. 21b). The self leveling cementitious grout mixture, not unlike controlled low strength flowable fills, was then placed in the eastern portion of Pit A covering the steel member. The grout mixture of FBC ash, approximately 9% Portland cement, and water was blended at Quandel Concrete, Minersville and imported to the site in cement mixers (Fig. 21b). The consistency of the grout mixture allowed it to flow throughout the east pit and it hardened relatively quickly allowing the vehicles to travel on the grout mixture (Fig. 21c).

The west side of Pit A was prepared similarly in that reject concrete panels were placed in the floor of the pit. Instead of the fabricated steel trusses, recycled reinforcement bar (rebar) was imported from Glasgow, Inc. to form a wire mat in the grout mixture for structural support (Fig. 21c). The rebar was loosely packed and it allowed the grout to flow through it. The grout was placed and leveled with the eastern portion of Pit A covering the steel member. The grout mixture of FBC ash, approximately 9% Portland cement, and water was blended at Quandel Concrete, Minersville and imported to the site in cement mixers (Fig. 21b). The consistency of the grout mixture allowed it to flow throughout the east pit and it hardened relatively quickly allowing the vehicles to travel on the grout mixture (Fig. 21c).
(Fig. 21d). As with the Northampton FBC ash, PPL donated the PC ash and delivered it to the site. Once the area was backfilled and graded to the adjacent contours, topsoil was added and the area was vegetated, Figure 21d.

![Figure 21(a). Cropfall resubsidence.](image1)

![21(b). Grout mixture poured on steel truss.](image2)

![21(c). FBC ash grout mixture pour with rebar.](image3)

![21(d). Cropfall reclamation completed.](image4)

The cropfall type of mine subsidence features present a significant challenge in abandoned mine reclamation efforts because of the general lack of adjacent backfill materials. Conventional backfill materials, or concrete, have resubsided shortly after completion of previous reclamation projects. The Sharp Mountain cropfall project is an innovative approach to abating the mine subsidence problems, utilizing FBC ash in formulating ash cement grout mixtures, and using PC ash as a bulk fill material.

CONCLUSIONS

This paper has presented descriptions of a variety of permit and project sites in Pennsylvania where coal ash has been beneficially used in mine reclamation and mine drainage remediation. Most of these sites have been clear success stories: abandoned mine lands and their associated
safety and environmental hazards have been reclaimed at no cost to the taxpayer; water quality has been improved; a waste material has been recycled to a useful end rather than being landfilled. None of these sites represent environmental damage groundwater pollution cases attributable to the coal ash quality.

REFERENCES


