CHAPTER 8. THE KNICKERBOCKER DEMONSTRATION PROJECT

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8.1 OBJECTIVE

The objective of the Knickerbocker wet-to-dry demonstration was to establish the technology and economics of placement of ash via a water/solids slurry without impacting the environment in an inverse manner.

8.2 DESCRIPTION OF THE KNICKERBOCKER SITE

The Knickerbocker demonstration represented a wet-to-dry mine pit placement strategy not previously used in eastern ash handling. This method of moving mine tailings is used in metal mines in the western US and is proven to be efficient and very cost competitive. The Knickerbocker project was implemented in 1997 and completed in 2002 with the placement of approximately 4 million cubic yards of ash and the recovery of a stripping pit reclaimed back to its approximate original contour. The Knickerbocker Slurry Pit demonstration permit was issued to Reading Anthracite Company on the 21st July 1998 as DEP Waste Demonstration Permit # 301301 for a project area of 44 acres.

8.2.1 Local Geology

The Knickerbocker Pit is contained within the Knickerbocker Basin, part of the northeast-trending synclinorium in the eastern side of the Western Middle Anthracite Field. Description of the Western Middle Anthracite Field is contained in the previous chapter describing the Ellengowan and Shen Penn demonstration projects (section 7.2.1).   Figure 7.2 shows the lithologic section through the Knickerbocker Basin.   The Knickerbocker Pit is approximately one half-mile east of the Shen Penn Pit. The structural and lithological context is essentially the same. In the Knickerbocker Basin, the axial plane of the fold dips north at depth and south nearer to the surface (see Fig. 7.3). The geologic description is contained in Kehn and Wagner's 1955 "Geology of Anthracite in the Eastern Part of the Shenandoah Quadrangle, Pennsylvania."

The stripping operation and the former mining operations are located geologically in a series of coal basins, the Shenandoah, Ellengowan, Yatesville, and Middle Mahanoy, of the Western Middle Anthracite Field. The property of the Reading Anthracite Company in this area is bounded on the east by mining operations on lands controlled by Lehigh Valley Coal Company, on the north by lands controlled by the Cox and Girard Estates on the North Mahanoy Mountain, and on the south by the Reading Anthracite Company, Blaschak Coal Company and Read Realty Company properties and the Mahanoy anticlines and on the west by property controlled by the Girard Estate and Sheafer Estate. The property owned by Reading Anthracite Company in the overall area consists of ten tracts of land totaling 2300 acres. It extends a distance from its eastern boundary to the western boundary of 18,000 feet and from north to south approximately 6000 feet. It is in this overall area they operated deep mine operations at Mahanoy City, North Mahanoy, Knickerbocker and Turkey Run Collieries.   Deep mine

operations were discontinued between 1932 and 1954. These deep mine operations were and are all interconnected underground on various levels and are all presently flooded.

Deep mining at these operations involved the mining in the Little Buck Mountain, Buck Mountain, Seven Foot, Skidmore, the Top, Middle and Bottom Splits of the Mammoth, the Holmes, Little Primrose, Primrose, Orchard, Little Orchard, Diamond, Tracy and Little Tracy Veins on both the North and South Dips of the various basins and anticlines in the area.

Mining at these deep mine operations began via water level drifts in the various veins about 1850. In subsequent years, as mining progressed, slopes were sunk from the surface on both North and South Dip measures of the various basins and later shafts were sunk at various locations with depths of 300 to 1000 feet. In some instances, underground slopes were sunk and developed coal reserves below sea level. The entire superficial acreage involved in mining at these former operations of Reading Anthracite Company comprised approximately 2300 acres.

During the operating years of these collieries, mining extended to the east on lands of Lehigh Valley Coal Company as far east as Delano, approximately 4 miles, where collieries were developed via water level drifts, slopes and shafts beginning in 1850 and continuing until 1960. Some of these collieries were the Primrose, Copley, Springdale, Malvean, Mayersville, Trenton and West Lehigh. These operations are all interconnected by underground mining and are all flooded. The water enters the property of Reading Anthracite Company on its eastern extremity at the Springdale Shaft, West Lehigh Colliery.

During the same period of time, mining operations were developed westward of Reading Anthracite Company's property on lands of the Girard Estate and Sheafer Estate, beginning development via Water Level Tunnels, slopes and shafts starting around 1850 and continuing until 1961. The collieries were William Penn, Packer Nos. 2, 3 and 4, Weston, Girard Mammoth, Packer No. 5, and Hammond. The operations had their western terminus in the vicinity of Girardville Borough. All of these mining operations are interconnected underground in the various veins and are all flooded.

All of the mining operations, beginning at Delano and Lehigh Valley Coal Company property, continuing through Reading Anthracite Company property and thoughout the Girard Estate and Sheafer Estate property, mined the same veins of coal from the Little Buck to the Tracy Veins. It is noted here that stripping operations have been conducted on some of these properties as far back as 1880. With the discontinuance of mining and pumping facilities in the 1950's and 1960's at collieries in the overall area, the operating collieries assumed high pumping loads because all of these operations were interconnected at various levels in the entire area. In 1961, with the abandonment of Packer No. 5, the last operating colliery, the impounded mine water rose to the surface in the vicinity of the eastern end of Girardville Borough at a location within a few feet of Mahanoy Creek at its junction with Shenandoah Creek in an area known as Connerton Village. This impounded mine water flowed to the surface through a backfilled Holmes Vein stripping pit, formerly a Packer No. 5 Colliery operation and through strata cracks caused by deep mine operations. In August 1963, it was estimated that the flow was 15,840,000 gallons per day from all of these abandoned operations. In June 1966, the flow was estimated at 21,600,000 gallons per day. The quantity of water is subject to fluctuations due to precipitation

in the area. The area drained by this discharge is estimated at 11 miles in an east to west direction by 4000 to 6000 feet in width representing approximately 8000 acres. There are two major streams which drain most of this area, Mahanoy Creek paralleling the southern boundary from Delano to Girardville and the Shenandoah Creek with headwaters north of Shenandoah Borough which joins Mahanoy Creek at Girardville.

The subsurface hydrology is described in section 7.2.3. The flow path is one of movement between the large interconnected minepools from Shen Penn, Shenandoah City, through Knickerbocker and Maple Hill. The water flows from the west from Shen Penn out of the abandoned mine workings from the Kehley Run Colliery to the Shenandoah City Colliery to Knickerbocker. From there, the water turns south, traveling through barrier pillar breaches to the Maple Hill Colliery and turning to the west. The ultimate discharge point for this system is suspected to be the Packer 5 outfall. The Packer 5 discharge flows to Shenandoah Creek. See figure 7.5 for the map of the flow path.

8.2.2   Mining History

The initial coal removal operation began in 1965 with the issuance of the Knickerbocker Stripping permit No. M-112A. An estimate of approximately 560,000 net raw tons of coal was recovered from former deep and strip mining operations on the site at a rate of 500 tons per day. The operations consisted of the extension of old stripping pits existing in the Bottom, Middle and Top Splits of the Mammoth Vein, the Holmes, Little Primrose, Primrose, Orchard, Diamond and Big and Little Tracy Veins. The various veins have a strike North 75° East and have dips to the North and South from 30° to 80°. Figure 8.1 is a cross section mine map which run N-S through the demonstration site showing individual stripping sections. In all cases, the recoverable coal was from that remaining in the pillars left from previous deep mine operations and the stripping operations are all above the body of the impounded mine water.
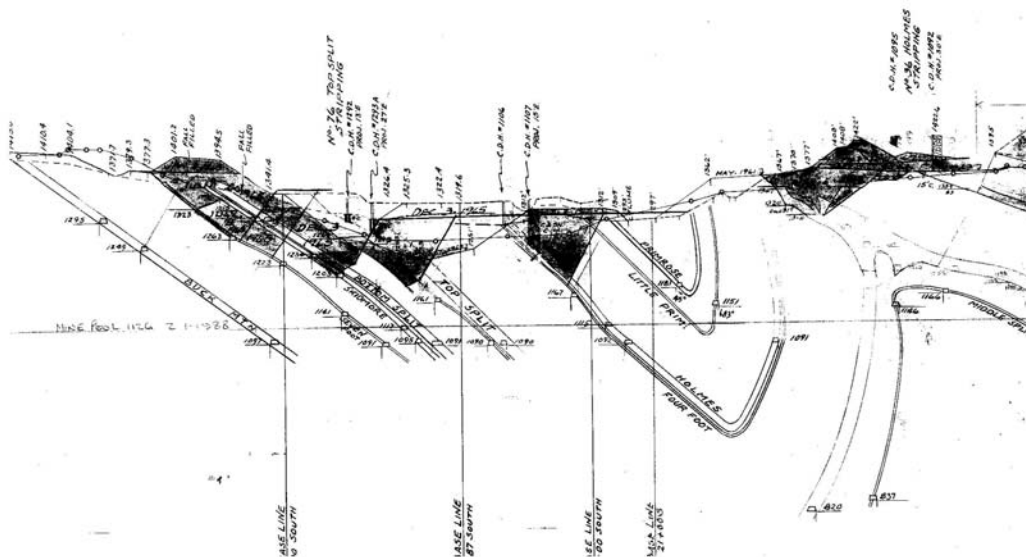

Figure 8.1. Cross-section through the Knickerbocker Pit (34+00).

The stripping operation was developed from east to west on the various veins where recoverable coal was assumed to be present. The overall length of the combined stripping pits in the various veins was approximately 3600 feet, with widths from 400 to 1800 feet. The elevation of the surface over the stripping operations ranged from 1300 feet to 1450 feet. The normal elevation of the impounded mine water in the flooded underground mine workings of Reading Anthracite Company's property is at 1060 feet msl before it overflows through penetrated barrier pillars to the west into the Packer No. 2,3 and 4 operations. All pits reached a depth of 150 or more feet. The overall area stripped was 173 acres.

Raw coal removed from the stripping location was transported by truck approximately three quarters of a mile to the adjacent Reading Anthracite Company's Maple Hill Cleaning Plant where the raw coal was pre-cleaned by removing the extraneous rock and the pre-cleaned product transported by rail to the company's new St. Nicholas Breaker and Fine Coal Plant approximately 55 rail miles away. The extraneous vein material removed in the course of pre-cleaning at Maple Hill Cleaning Plant was returned to the stripping pits where it was covered by backfilling operations.

There are no surface streams involved within the Knickerbocker stripping operation. All drainage is in the form of precipitation falling directly into the pits and flows by gravity into the existing minepool.

8.3 ASH PLACEMENT

8.3.1 Source of Ash

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. 8.2). 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.

The ash slurry system began operation in September of 1998, with an average monthly deposition rate of approximately 52,000 tons of dry ash. Based on an ash density of 90 pounds per cubic foot, the estimated volume of the Knickerbocker Pit was initially 2,400,000 cubic yards.

8.3.2   CKD Test Cells

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 cement kiln dust (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. The sub-study of placement of cogeneration derived ash and cement kiln dust (CKD) mixture into the Knickerbocker Pit began

on February 3, 2000. 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. A front end loader was used to transfer the CKD into the hopper for mixing with the fly ash slurry at the outlet end of the delivery line, which was then piped into the test cells. The four test cells were at the northwest end of the Knickerbocker Pit. They were carved from ash originally slurried into the pit over the past 2 years. The cells can be seen in the foreground of the demonstration pit in Figure 8.2. The first cell measured 180'x180'x10' and was designed to remain undecanted. The three others were approximately 100'x100'x10'. 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 (Fig. 8.3).

test cells in the Knickerbocker Pit

Figure 8.2. Aerial photograph of the Schuylkill Energy plant and the Knickerbocker Pit.

As the mixture flowed into each cell, the heavier particles would settle out and form a delta-type deposit, with standing water covering the farthest ¾ of the cell (Figs. 8.3 and 8.4). Cells 1 and 2 were filled on the 3rd to 5th of February 2000 and cells 3 and 4 were filled the 15th to 17th of February 2000. Because the pump was not working properly, cells 1 and 2 stood for

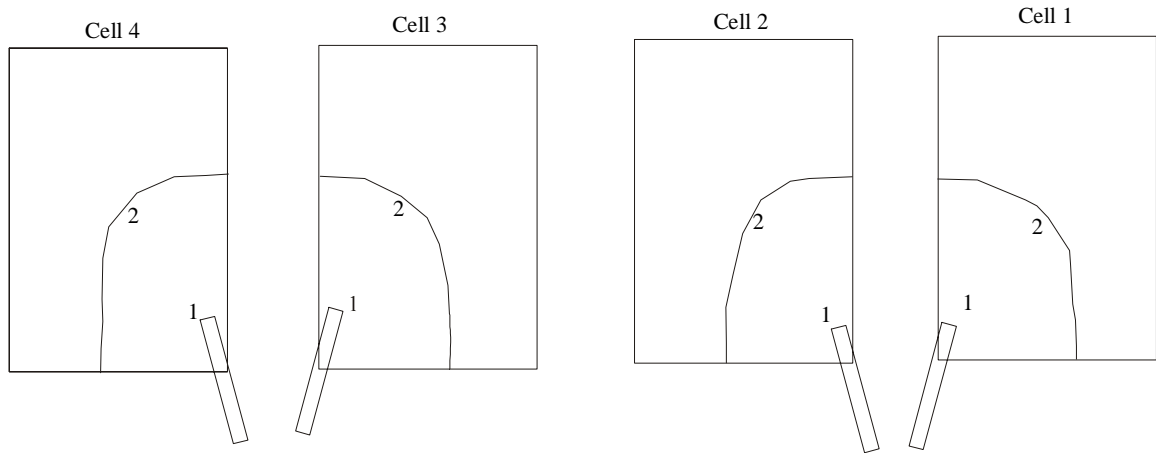approximately 12 days and cells 3 and 4 contained water for approximately 20 days before they were pumped.

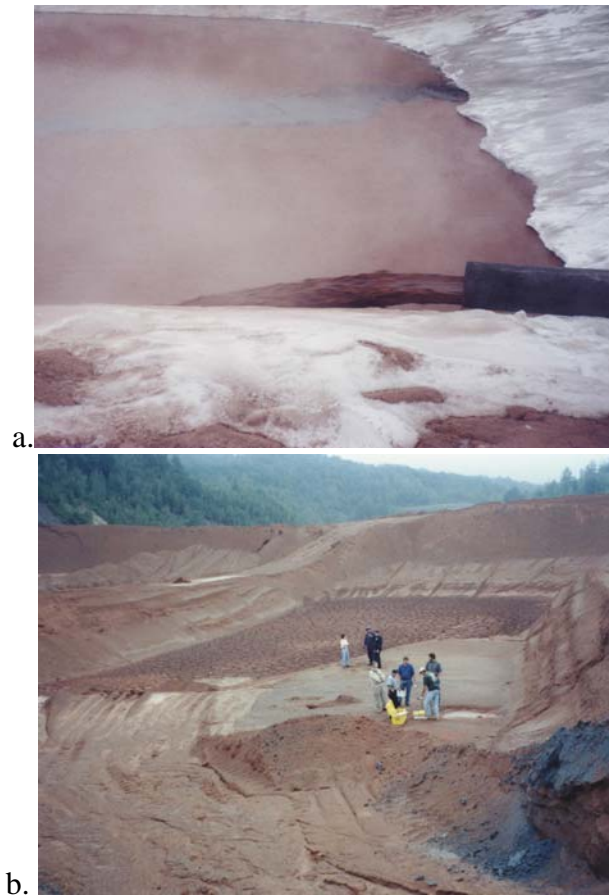**Figure 8.3.** Schematic of cells and locations of sampling.

Figure 8.4. a) Inlet pipe to cell 1, February 2000. b) Locations of borings in cell 2, the first group of people is near the inlet pipe location, and the farther group is at the boring location

closer to the center of the cell. Delta formation is evident, with mudcracks in the remainder of the cell.

Water and sediment samples were collected when each cell was 1/3 full, 2/3 full, and completely filled. Soil borings 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. In August, 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 have been performed on the ash/CKD mixture from the Knickerbocker test cells in addition to blow count and densitometer measurements.

8.4   RESULTS

8.4.1 Ash Properties

8.4.1.1 Density analysis

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 mining equipment could immediately drive (Fig. 8.5). Semi-annual characterization of the proctor densities of the ash and size distributions are reported in Appendix 8.A. These data show that compaction of the ash was routinely above 90% with enough structural strength to support wheeled vehicles.

Figure 8.5. Truck parked on recently placed ash.

Density measurements in cells 2-4 were made by DEP using a Cs-137 densitometer on July 31, 2000 (Table 8.1). Moisture in the samples ranged from 9.8% to 14.9%. Excess water from slurrying may have seeped through the sediment, evaporated, and/or been incorporated into

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minerals re-hydrating or forming within the sediment. The moisture content of the area away from the inlet pipe (hole 2), as measured in July 2000, consistently increased as CKD content decreased. Conversely, in the area close to where the inlet pipe was located (hole 1), there was a small decrease in the moisture content with decreasing CKD content. This difference may be due to the particle sizes in each location, which would be expected to be different based on the delta-type deposit, extending from the slurry pipe. The gradation in grain size with distance from the pipe is not supported by the grain size distribution measured in the laboratory, where there was no significant difference between samples (Table 8.2). However, packing density most likely plays a role in the increased strength and more consistent blow count values recorded in the center of the cells.

Table 8.1. Troxler nuclear density moisture gauge results collected by DEP, July, 2000.

cell/hole	%CKD, location	dry density (lbs/ft3)	moisture (%)	wet density (lbs/ft3)
2/1	20%, inlet	97.5	10.9	108.2
2/2	20%, center	98.5	9.8	108.1
3/1	10%, inlet	97.1	10.6	107.4
3/2	10%, center	99.2	10.5	109.6
4/1	5%, inlet	102.9	10.3	113.6
4/2	5%, center	95.5	14.9	107.9

Table 8.2. Percent grain size distribution (μm).

Cell	Hole	Depth	>160	160-74	74-45	45-38
2	1	4-6'	85.8	11.5	2.6	0.1
2	2	4-6'	85.3	11.4	3.2	0.1
4	1	4-6'	82.8	13.8	3.3	0.1
4	2	4-6'	79.0	18.4	2.5	0.1
1	2	12-14'	80.6	13.2	5.8	0.4
2	2	12-14'	83.8	10.2	5.6	0.5
3	1	12-14'	83.0	10.6	6.0	0.4
3	2	12-14'	81.6	12.1	5.8	0.5
5	2	12-14'	76.8	15.5	7.3	0.4

Penetrometer values ranged from 0.5 to greater than 5 tons per square foot at different locations in cell 2. The values were not consistent. Below the initial 1 cm of material, the hardness was generally increasing.

8.4.1.2 Split-spoon sampling

The number of blows per 6 inches of depth 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 control borings were drilled in the same fashion, in the portion of the Knickerbocker Pit that does not contain CKD.

In August, there was some indication of hardening (relative to the control boring) in the upper two feet of the borings close to the center of each cell, for all of the test cells. The borings close to the inlet pipe showed no such distinction. In November, a more complete set of blow counts was collected, and trends were more apparent (Fig. 8.6). The data are presented as blow counts per foot and in the appendices are also presented in normalized form relative to cell 4, with 5% wt. CKD addition (Appendix 8.B).
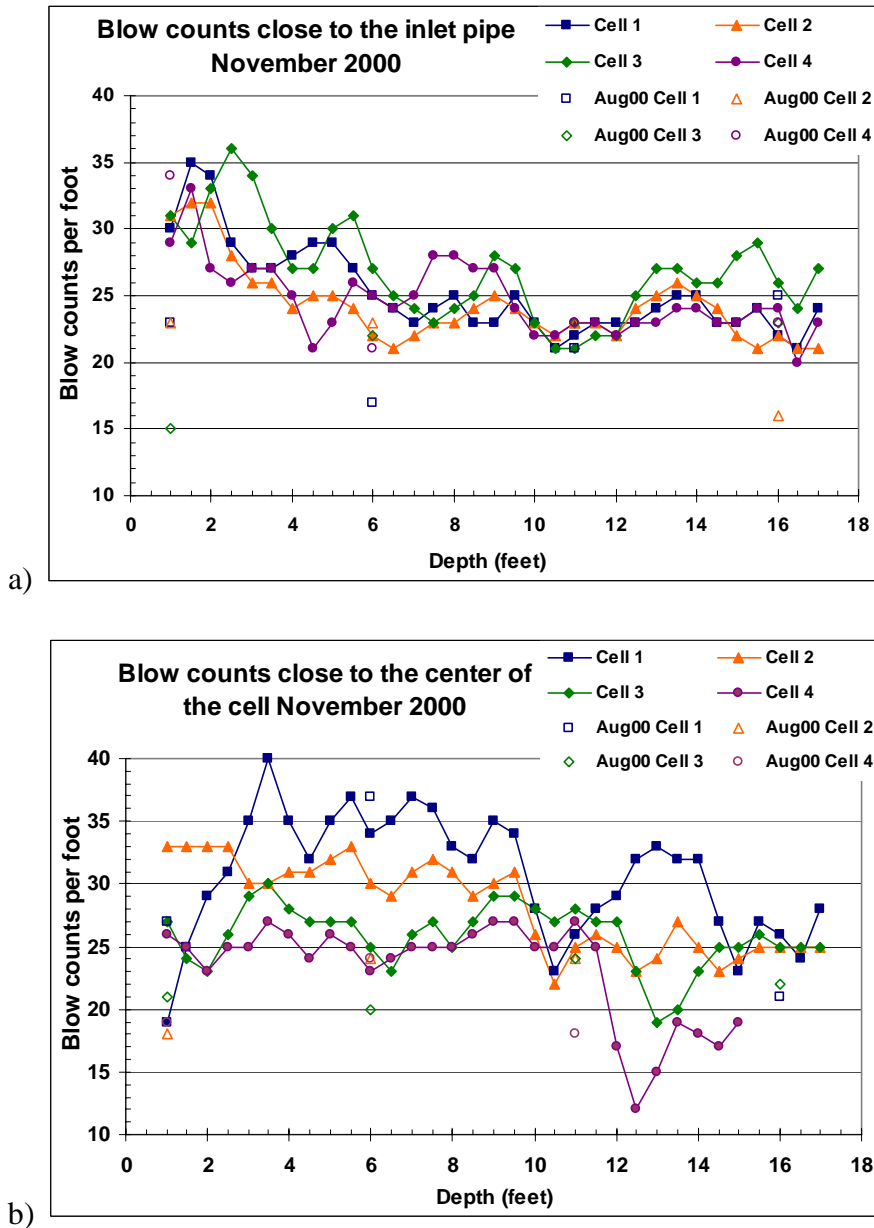

a)

b)

Figure 8.6. Blow count plots for samples taken in November 2000.

The number of blows needed to penetrate every half foot of ash/CKD was recorded through the proposed 10 feet of the test cells and into the cell floors, which was non-augmented ash. Two points were sampled in each test cell, one at a distance mid-way across the cell from

the injection point and one located at the injection point. The results of sampling at the injection point show blow count values that less clearly differentiate between the varying CKD loading, however, an increase in blows per foot above the background (as recorded below 10 feet) is observed for all cells. In fact, the initial two feet of the sample exhibits a resistance to penetration nearly 40% larger than background.

At sample point 2, from a depth of approximately 3 to 10 feet, there is a systematic effect of CKD content observed, generally grading from highest blow count with highest CKD loading to the lowest blow count with the lowest loading. In this set of samples, an increase in blow counts of approximately 15% was observed. The continuation of the pattern of blow counts versus CKD loading continues into the base of each cell, which suggests bias in the data collection methodology. Why this pattern is sometimes apparent at a depth of 17 feet is of interest, since the cells were only approximately 10 feet in depth. This differentiation could be due to an alteration in the underlying material with infiltration of fine particles from the ash/CKD slurry. The mean and standard deviations of the blow count values from cells 1 through 4 are presented in Table 8.3.

Table 8.3. Mean and standard deviation data for blow counts per foot recorded at the center of cells 1 – 4 in November 2000.

	Cell 1	Cell 2	Cell 3	Cell 4
Mean	12.07	7.93	4.67	2.87
Standard Deviation	1.94	1.53	2.29	1.96

The borings close to the inlet pipe locations for each of the cells show very different results. The most significant finding is the large increase in hardness in the initial 0-2 feet of material. This was followed by a moderate increase in hardness, and below 10 feet, no significant change in hardness relative to the cell containing no CKD. The results from the borings close to the inlet pipe were not differentiated with respect to the CKD composition, yet in the shallow depths the material was distinctly more difficult to penetrate than that containing no CKD. This indicates that the hardening reactions are aided by <5% of the CKD material. In comparison, the reactions taking place closer to the center of the test cells seem more dependent on the CKD content.

One way to assess the concentration of CKD in the cells is to analyze the ash for calcium oxide (Fig. 8.7). Ash was collected when cells were 1/3 filled, 2/3 filled, and filled. The full bulk analysis of these ash portions are presented in Appendix 8.D. In Figure 8.7, it is apparent that the calcium oxide concentrations are not consistent with depth or with what is expected for each cell. This suggests that greater consideration of the ability to form a consistent product be undertaken in the future. The variation in bulk chemistry of the fly and bottom ash, as well as the CKD, used in the study should be closely monitored in order to do a mass balance on the material and better understand the processes taking place.

8.4.1.3. Wet chemical analysis and leaching

Semi-annual fly ash bulk analyses and leach data are contained in Appendix 8.C. This is a routine test required by the Pennsylvania's Module 25. Data may be compared to those given in Chapter 9 for the NEPCO facility.

Water and sediment samples collected in February 2000 from the filling of the test cells underwent wet chemical analysis. Sediment samples were collected from recently placed ash three times during the filling of each cell. Water samples were collected at the same time from water at the edge of the ash bank. All aqueous samples were filtered with 0.20μm disposable filters and the samples were analyzed at the Materials Characterization Laboratory at The Pennsylvania State University (PSU). Sediment samples underwent microwave digestion with a combination of HCl and HF. Major and minor cations were analyzed by DC plasma emission spectroscopy and trace metals by atomic absorption graphite furnace. Anions were analyzed with an ion chromatograph. Appendix 8.D contains complete results from the chemical analysis performed by MRI.
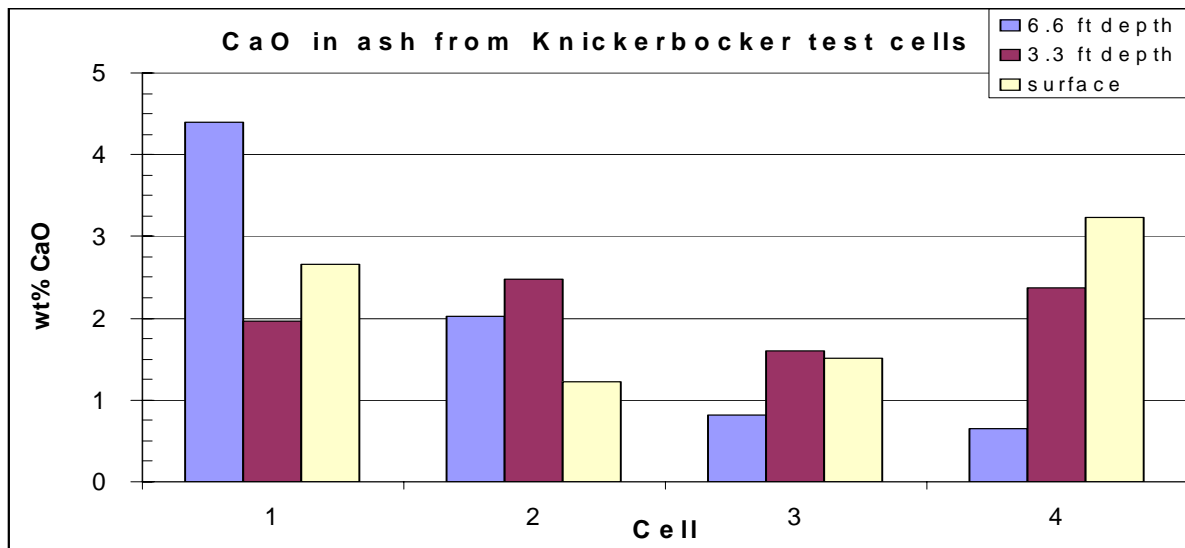

Figure 8.7. CaO concentration in test cells.

Of all the sediment and water analyses collected during the placement of the ash/CKD mixture, 9 samples of water exceeded the drinking water limits for fluoride, and all 12 water samples exceed the drinking water limits for sulfate (Table 8.4). The drinking water limits were not exceeded for any other analytes in the solid or water samples. Because the PA Module 25 limits that are applicable to mine waste, none of the samples exceed the Module 25 limits for sulfate. The pH values of the ash/CKD mixture were between 11.8 and 13.1, probably due to CaO in both the ash and the CKD.

Table 8.4. Range of concentrations in sediment (using the SPLP test) and in water from the Knickerbocker test cells, February 2000. For comparison, the maximum contaminant levels (MCL) for drinking water as of 2002 are given.

	water (mg/L)	sediment (mg/L)	MCL (mg/L)
Cations			
Ag	<0.02-0.09	<0.02-0.06	0.1*
Al	0.44-1.50	0.89-2.75	0.05 to 0.2*
As	<0.005-0.05	<0.005-0.01	0.01
B	0.19-0.27	<0.02-0.05	
Ba	0.24-0.46	<0.02-0.05	2
Be	<0.02	<0.02	0.004
Ca	760-1300	64-155	
Cd	<0.005	<0.005	0.005
Co	<0.02	<0.02-0.06	
Cr	<0.02	<0.02-0.04	0.1
Cu	<0.02-0.03	<0.02	1*
Fe	<0.02	<0.02-0.04	0.3*
Hg	<0.002	<0.002	0.002
K	295-1950	6.6-80	
Mg	0.05-0.14	0.03-0.18	
Mn	<0.02	<0.02	0.05*
Mo	<0.02	<0.02-0.06	
Na	110-330	2.87-11.6	
Ni	<0.02	<0.02	
Pb	0.01	0.01	0.015
Sb	<0.005-0.01	<0.005-0.01	
Se	0.01-0.02	<0.005	0.05
Si	4.2-8.2	5.5-11.9	
Sr	4.0-22.1	0.48-1.03	
Ti	<0.01	0.02-0.1	
Tl	<0.005	<0.005	0.002
V	<0.02	<0.02-0.05	
Zn	<0.02	<0.02	5*
Anions			
Br	2.3-12.6	<0.01-0.53	
Cl	52-230	0.28-9.0	250*
F	3.1-6.3	0.40-0.56	2*
NO2	<0.05	<0.01	1
NO3	19.2-32	0.03-0.12	10
PO4	0.2-0.3	<0.01	
SO4	1350-3100	61-270	250*

* = secondary drinking water standard

By weight, the ash is mostly composed of SiO_2, Al_2O_3, CaO, Fe_2O_3, K_2O, SO_3, TiO_2, MgO, Na_2O and water (Table 8.5). The authors expect that the bulk chemical composition of the

ash and CKD used should be relatively consistent with time. The raw data show that CaO can vary significantly with depth in the cells (Appendix 8.D). For example, in cell 4 at the 3.3 foot, 6.7 foot, and 10 foot intervals, CaO concentrations were 0.65, 2.37, and 3.23% wt., respectively. The other cells do not show the same consistent variation of CaO with depth, but also show less variability. The variation in CaO with depth indicates that the mixing of the ash and CKD in the test cells was not as consistent as would be desired, and in another application, these procedures should be improved. The bulk chemical inconsistencies within the cells most likely cloud the blow count results, tying them less directly to the proposed percentages of CKD within each cell.

Table 8.5. Average bulk chemical concentrations from the four test cells.

Wt %	Cell 1	Cell 2	Cell 3	Cell 4
Al_2O_3	13.9	12.5	13.5	11.3
CaO	3.01	1.90	1.31	2.08
Fe_2O_3	2.57	2.18	2.63	2.47
K_2O	2.36	1.98	2.35	2.22
MgO	0.52	0.38	0.34	0.28
Na_2O	0.28	0.25	0.27	0.27
SiO_2	45.3	49.3	51.7	50.3
TiO_2	0.90	1.25	1.01	0.95
SO_3	1.17	0.90	0.87	0.92
H_2O	30.1	28.4	25.4	28.3

Based on geochemical modeling using PHREEQC, a thermodynamic equilibrium model developed by the U.S. Geological Survey (Parkhurst, 1995), the solutions in each of the cells were found to be supersaturated with respect to calcium-containing minerals such as aragonite, calcite, dolomite, hydroxyapatite, and fluorite (Appendix 8.E). The solutions are also supersaturated with respect to barite and some clay minerals. Because PHREEQC does not incorporate kinetic factors, not all of the named minerals would be expected to precipitate (e.g. dolomite). Calcite, however, will almost certainly form in this environment with time.

8.4.1.4 Moisture loss

The moisture loss values for November 2000 samples at 4-6 feet and 12-14 feet depth almost all fall within 11-15% (Table 8.6). The exceptions are cell 4, hole 2 at a 12-14 foot depth, which had a large amount of black material (most likely from CKD addition) with, consequently a low moisture loss value (7.99%), and cell 4, hole 1 at a 4-6 foot depth, which had an anomalously high moisture loss value. Cell 5 samples had higher moisture loss values (15-17%) and there was no noticeable difference between the 12-14 foot and 4-6 foot sections in the cells. Thus, the moisture loss tests were not found to be very useful in determining the effects of ash/CKD placement.

8.4.1.5 X-ray diffraction

X-ray diffraction patterns collected from ash/CKD mixtures from all of the cells were consistent with respect to time, depth, percent CKD, and location with in the cell (Appendix 8.F). They were all primarily composed of quartz. Peaks at 4.49A, 2.59A, 9.64A, and 3.31A indicate that the second mineral is a muscovite or a type of clay. For some samples, a calcite peak at

3.02A is found. The XRD patterns show that between February and November 2000, no other mineral phases were formed at concentrations greater than 5% within the ash/CKD mixture. Ettringite may have been forming at lower concentrations.

Table 8.6. Test cell moisture loss values of samples collected November 2000.

Cell	Hole	Depth (ft)	Crucible mass (g)	Cruc+ wet ash (g)	Cruc+ dry ash (g)	Δ ash
1	2	12/14	31.696	50.16	47.94	12.02%
2	2	12/14	17.011	28.556	27.26	11.23%
3	2	12/14	23.243	34.001	32.6	13.02%
4	2	12/14	16.728	30.283	29.2	7.99%
3	1	12/14	16.67	28.294	26.66	14.06%
4	1	12/14	17.214	30.757	28.92	13.56%
2	2	4/6	25.252	35.38	33.93	14.32%
4	2	4/6	22.175	33.587	32.2	12.15%
2	1	4/6	15.894	26.885	25.46	12.97%
4	1	4/6	28.871	40.595	37.87	23.24%
5	1	4/6	18.194	33.713	31.06	17.10%
5	2	12/14	16.708	28.062	26.26	15.87%

* - major portions of CKD in sample 4-2 12/14'

8.4.1.6 Scanning electron microscopy (SEM)

SEM images were generated for samples from cell 1 hole 2 at depths of 0-2 feet, 8-10 feet, and 16-18 feet, in addition to images collected from cell 5 hole 2 at depths of 0-2 feet and 58-60 feet. The grains observed were approximately 100-300μm in diameter. Each lower magnification (80x-250x) image showed rounded, non-spherical grains, with smaller grains on the surface. Higher magnification images (3000x-3500x) identified angular material mixed with rod-like shapes, an indication of the growth of cementitious phases, in all the samples. The ash and ash/CKD material looked similar at all levels of magnification, with no discernable additional crystal growth. Figure 8.8 shows the SEM images from cell 1 hole 2 at 8-10 feet depth.

8.4.1.7 Fertility analysis

Samples of the ash/CKD mixtures from each of the four cells were sent for fertility analysis at the Agricultural Analytical Services Laboratory at PSU. The pH values for the solid samples (9.5-9.9) are much too high to support crops (Appendix 8.G). In every case the pH, and in two of the cells (2 and 4) the potash (K_2O), was deemed excessive. Phosphate levels decreased significantly with increasing cell number, from 225 lb/A, an optimum level, to 5 lbs/A, which is considered low for soil nutrients. Magnesium levels were high in every cell. Because the predominant feel is gritty and one cannot form a ball from the ash/CKD mixture, it has a sandy texture, as determined by the McRae finger assessment method (McRae, 1988).
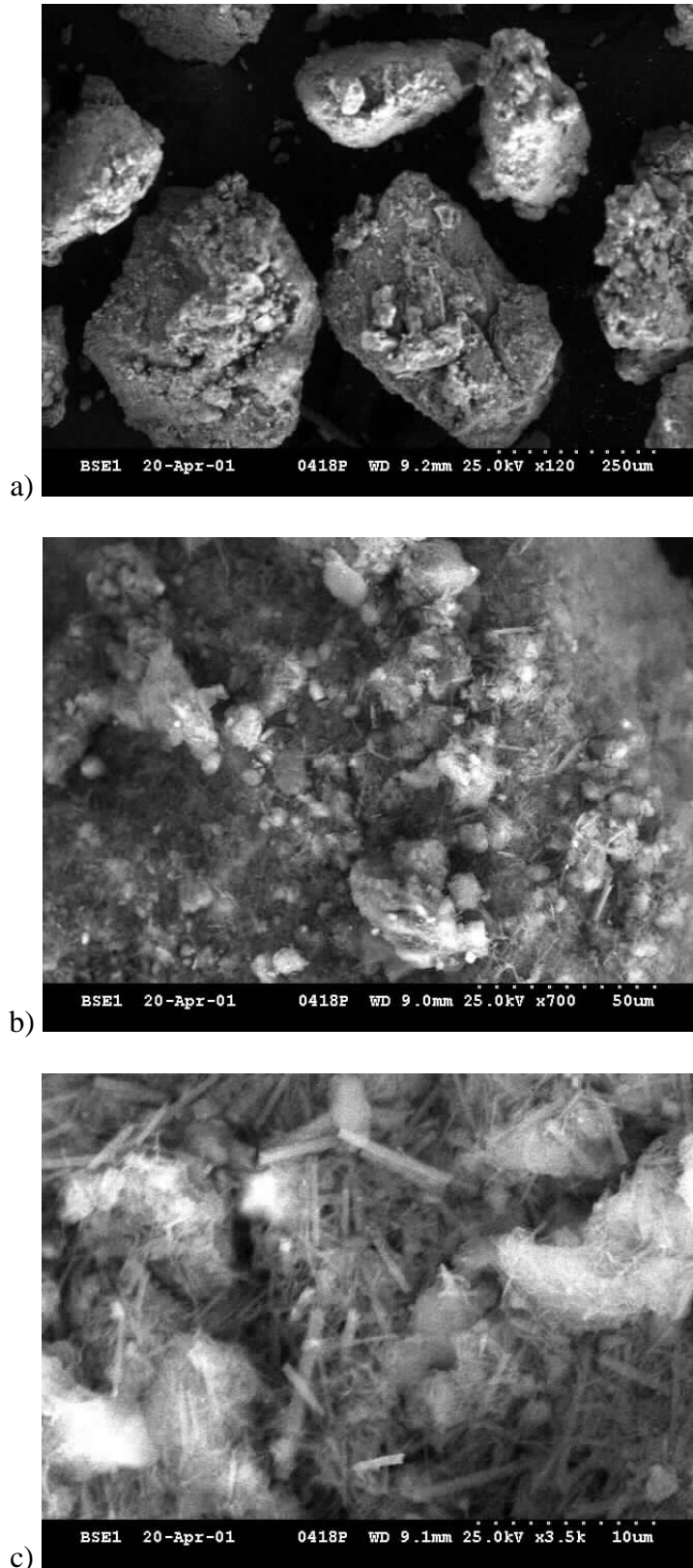
a)

b)

c)

Figure 8.8 SEM images from cell 1-2 at 8-10 feet depth and a magnification of a) 120μm, b) 700μm, and c) 3500μm.

In order to support plants, the ash/CKD mixture would have to be mixed with a material to decrease the pH value and to keep the ash and CKD from hardening. The most obvious option would be to use compost. In Pennsylvania, after reclamation using ash is complete, the area is covered with 4 feet of clean fill, and then revegetated. This would be an appropriate method for revegetating above the ash/CKD mixture as well.

8.4.2 Groundwater Monitoring

The deposition of 52,000 cubic yards of ash per month was also accompanied by approximately 83,000 cubic yards of acid water from the minepool or approximately 18.5 million gallons of water per month. A portion of the water was retained in the ash as pore fluid or consumed in the hydration reactions. The excess water either percolated into the minepool or was recycled back to the power plant and reused.

To monitor the potential impact of the demonstration on the minepool waters, one up gradient well and four down gradient wells were installed to monitor the demonstration. One of the down gradient wells, the Packer V, was selected at the Packer V Mine discharge to represent a regional drainage profile for the entire coal field discharge (see section 7.2.3). These data are summarized in Appendix 8.H. The data show no significant trends, either increasing or decreasing.

8.5 CONCLUSIONS

The remediation approach described above has both environmental and economical benefits. The surface and ground water systems were not adversely affected, and the abandoned mine lands can be reclaimed and will no longer pose a public safety problem. The surface water that enters into the minepool system during the remediation operations may experience an increase in pH due to the chemistry of the ash, thus potentially impacting the microbial activity within the deep mine, and the pH conditions of the minepool discharge. Since the pipeline is a fully enclosed wet system, the potential for spillage and dusting are virtually eliminated, as opposed to the conveyor belt or truck transport alternatives, which require the moisture content to be substantially less. In addition, vehicle emissions are eliminated. Additional environmental benefits include the establishment of vegetation, support of wildlife, and prevention of surface waters entering the minepool.

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 maintenance and labor requirements. Previous disposal costs of utilizing truck transport were calculated at $2.50 to $3.00 per ton, and $1.11 per ton for the conveyor system. The slurry system costs are approximately $0.06 per ton, representing an enormous 97.6% cost saving, in 2003 dollars.

Use of CKD as a material to augment the mechanical properties of an ash/water slurry does appear to make a beneficial contribution to material strength. However, both mixing techniques and initial solids characterization need to be improved in further studies. More efficient mixing of the ash/CKD slurry may contribute to greater uniformity in results between

the cell inlet and center. Some cementitious behavior was observed in the placed ash/CKD slurry but the authors feel that it was insufficient to contribute to the observed gain in mechanical properties; rather it is believed that the presence of CKD contributed by enhancing the packing efficiencies of the slurry, specifically in the area farther from the pipe outlet. Long-term development of cementitious binding minerals is strongly suggested in the SEM observations of this study. The bearing strengths and compaction of the slurry (both with and without amendment) appear to be adequate for structural fill applications. The water that was used as a vehicle to transport the ash contained metals concentrations below any regulatory limit, however, sulfate and occasionally fluoride exceed drinking water standards, although sulfate did not exceed reclamation standards. It is clear from this study that the ash is not a fertile substrate for plant growth directly, based on the high lime content (and pH). For vegetative growth, the surface would either need to have soils added or the surface layer of placed ash amended specifically for plant growth.