FINDINGS OF THE WVDEP AND OSMRE SCR-15 "PHASE I" STUDY ON THE UNDERGROUND INJECTION OF COAL SLURRY[1]

Andrew Nick Schaer[2]

Abstract. The state of West Virginia Senate Continuing Resolution-15 authorized a comprehensive two-phase study on the potential effects of underground injection of coal slurry on the environment (Phase 1) and human health (Phase 2). A team whose members include personnel from West Virginia Department of Environmental Protection's DMR (Division of Mining and Reclamation) and Division of Water and Waste Management (DWWM), the West Virginia Department of Health and Human Resources-Bureau of Public Health, and Office of Surface Mining Reclamation and Enforcement are conducting the first phase of the study.

An analysis of the chemical composition of coal slurry, including an inventory of organic and inorganic constituents, was conducted at six locations across the State. With input from the environmental and industry groups, six sites were selected from the 13 active coal slurry injection sites in the state. The study sites included are: Southern Minerals, Panther LLC, Marfork Coal Company, Power Mountain, Loadout LLC, and Coresco, LLC.

A detailed hydrogeologic evaluation of the migration of coal slurry and its constituents from injection wells into the ground and surface waters was conducted at four of the six sites. The assessment sites include the coal preparation facilities where the underground injection of coal slurry took place. The sites are Southern Minerals, Panther LLC, Loadout LLC and Power Mountain. All four assessment sites are located in the southern coal fields and have mines which are considered below or mostly below-drainage (mines workings are located below surface drainage features). Water samples collected from surrounding surface and ground water were analyzed for over 170 organic and inorganic chemical constituents. All the sites sampled reflect a "snapshot" of the site-specific hydrologic conditions that surround the slurry injection sites.

Additional Key Words: Slurry, UIC, Hydrogeology

---

[1] Paper was presented at the 2010 National Meeting of the American Society of Mining and Reclamation, Pittsburgh, PA ***Bridging Reclamation, Science and the Community*** June 5 - 11, 2010. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2]Andrew Schaer is a Geologist with the West Virginia Department of Environmental Protection, Charleston, WV 25304

Proceedings America Society of Mining and Reclamation, 2010 pp 914-939
DOI: 10.21000/JASMR10010914

http://dx.doi.org/10.21000JASMR10010914

Introduction

Preparation plants use physical and chemical processes to remove impurities from coal. Slurry is the fine-grain wet portion of the impurities removed from the coal. Most modern plants use the addition of various chemicals to aid in this separation. According to WVDEP figures, approximately eighty-five percent of the coal slurry produced in West Virginia is disposed in surface structures, such as slurry impoundments and slurry cells. This report investigates the fifteen percent of coal slurry produced by preparation plants in West Virginia that is injected underground.

Underground injection involves the placement of coal slurry in abandoned underground mine voids. Slurry is gravity fed into the underground mine via a network of slurry pipelines and injection wells. Under most conditions, the solid portion of slurry settles to the bottom of the mine void, while the liquid portion migrates.

In May of 2009 the West Virginia Department of Environmental Protection (WVDEP) released the findings of Phase I of the "SCR-15" West Virginia legislative report on the environmental impacts of the underground injection of coal slurry. The completed Phase I SCR-15 study can be found at the WVDEP website.

http://www.dep.wv.gov/dmr/studies%20and%20investigations/Documents/Slurry%20UIC%20Investigation.pdf

The finding detailed here are just a small part of the much larger report presented there. The second part of SCR-15 is being conducted by the West Virginia Division of Health and Human Resources, who have contracted West Virginia University. SCR-15 Phase II will concentrate on the human health aspects of the underground injection of coal slurry along with an ecosystem analysis. This study is still in progress and can be tracked at it official website maintained by WVU at http://www.coalslurry.net/.

This study was conducted in response to concerns expressed by citizens and environmental organizations about potentially acute and chronic environmental impacts resulting from the underground injection of coal preparation plant slurry, the West Virginia Legislature mandated that a comprehensive study of the issue be conducted. The mandate, Senate Concurrent Resolution 15, or SCR-15, required:

1) An analysis of the chemical composition of coal slurry;

2) A hydrogeologic study of the migration of coal slurry into surface and/or groundwater;

3) An analysis of the effects of the coal slurry and its constituent contaminants on human health;

4) A study of the effects of coal slurry and its constituent contaminants on public health;

5) An environmental assessment of the effects on surface water and aquatic ecosystems;

6) Any other considerations that the Department of Environmental Protection and the Bureau for Public Health deem to be important.

A team comprised of personnel from the WVDEP, the WVDHHR, and OSMRE was selected to conduct the study. The first phase of which was completed in March 2009. The results of this phase, which assessed the chemical and environmental effects of underground slurry injection, will provide background data for the WVDHHR to complete the remainder of the requirements, specifically those involving human health.

Tasks and Objectives

The tasks of this first phase of the SCR-15 study, Items 1), 2), and 5), were addressed as follows:

1) An analysis of the chemical composition of coal slurry, including an inventory of organic and inorganic constituents was conducted at six sampling locations across the state. Solid and liquid components of the slurry were analyzed for more than 170 chemical constituents.

2) A hydrogeologic evaluation of the migration of coal slurry and its constituents into the surface and groundwater was conducted at four (4) mining sites.

5) An environmental assessment of the effects on surface water by direct and indirect migration of the injected slurry was performed. Additionally, a comparison of surface water quality upstream and downstream of the surface emplacement of coal slurry was conducted.

Criteria for Individual Sample Site Locations

Sample sites were selected by consensus of the SCR-15 study team with input from citizens and environmental groups concerned about the coal slurry issue. Locations are shown in Fig. 1.

Southern Minerals

The first site to be chosen was Southern Minerals in McDowell County, the oldest continually active injection site in the state. Underground injection has occurred there for well over 30 years, which means the mine pool has had more time to accrue impacts to its water quality. If any chemical reactions take place over a long period of time, they would most likely be found at Southern Minerals. More importantly, two large public water supplies draw from areas of the flooded mines near the injection points. If water quality were degraded by slurry injection, this is where the impact to human health could be the most direct and on the largest scale.

Loadout

The second site was chosen on the basis of optimum scientific suitability; this was Loadout, LLC in Boone County. Loadout was chosen because it is the only site in the state where no other mining activity occurred in the watershed prior to slurry injection. Therefore, pre-injection baseline surface and groundwater quality could be analyzed that showed no impacts from slurry or any other large scale mining. Furthermore, significant parts of the watershed are still un-affected by mining and could be used as a reasonable baseline comparison.

Panther

The Panther, LLC site in Kanawha County was chosen because several area residents and environmental groups had brought water quality concerns to the attention of the study team. However, after sampling had begun at Panther, it was discovered that no suitable groundwater monitoring was available. Because of this shortcoming, the SCR-15 group elected to study an additional hydrology site.

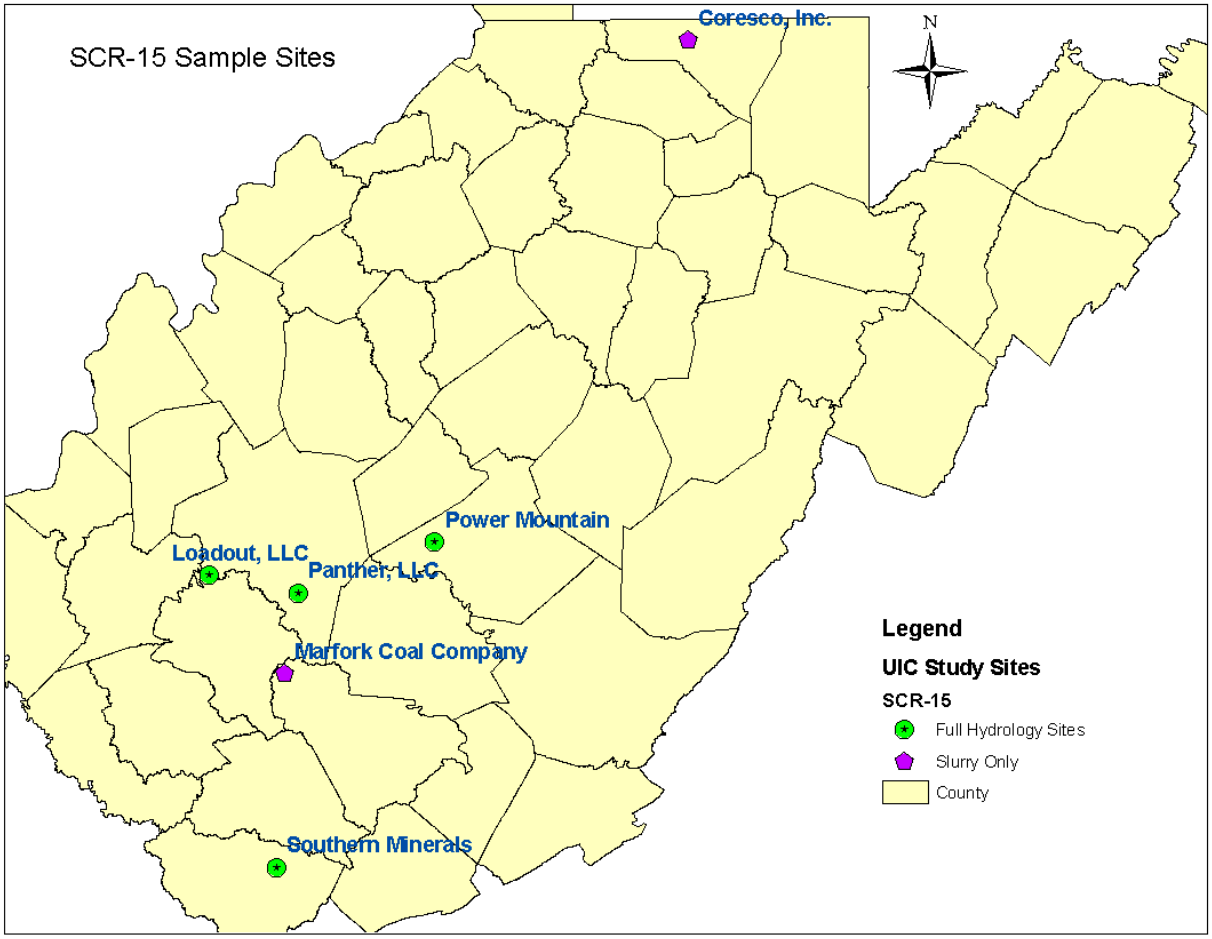

Figure 1-1: SCR-15 Sample Sites.

<u>Power Mountain</u>

The fourth site chosen was Power Mountain in Nicholas County. It, too, was recommended for study by citizens and environmental groups. Power Mountain had engaged in slurry injection for decades, nearly as long as Southern Minerals. Also, there are several domestic wells in the vicinity of Power Mountain and some of the well users had reported water quality problems to local environmental groups.

Study of the Power Mountain site is complicated; of all the sites considered for sampling, this area is the most heavily disturbed by mining activity, past and present. Because of the scale of surface mining, deep mining, refuse disposal, and slurry emplacement at Power Mountain, this site would be expected to exhibit the greatest overall mining water-quality footprint.

Slurry-Only Sites

Lastly, two slurry-only sample sites were chosen. The slurry only sample sites were chosen so the variability of slurry constituents from a broader set of locations could be assessed. One, Coresco, Inc. in Monongalia County, was selected because it was the only slurry injection site in the high-sulfur northern coal fields and, therefore, was essential for assessing variability of slurry across the state. Additionally, Coresco was the only preparation plant that used no chemicals in its process. The other slurry-only site was Marfork in Raleigh County, which did not use slurry injection.

Methods and Laboratory Analysis

Parameter Selection

Prior to conducting field sampling activities, team members met and discussed the various parameters that would be evaluated at each site. A parameter listing for sampling coal, coal slurry, and surface and ground water was agreed upon by the team after several meetings in May 2007. The sample parameter listing is set forth in Appendix II-I of the online report. The listing contains more than 175 organic and inorganic parameters and the tests that the team recommended be evaluated for each site.

Both inorganic and organic parameters were analyzed for all samples collected at the sites. The requirement that both organic and inorganic constituents of the coal slurry be determined was outlined in the Senate Concurrent Resolution that mandated the study and determined its objectives. Additionally, the study team deemed these parameters necessary for the health and environmental assessment also required by the Resolution.

Most of the organic and inorganic parameters were chosen from an established list used for general health and environmental assessments. Many of these parameters have known health risks with established standards. Additionally, other parameters were chosen based on previous environmental and health studies related to coal slurry and chemicals used at coal preparation plants.

Sampling Protocol

Team members took samples at the six study sites for testing. The samples were collected between July 2007 and July 2008.

The sampling protocol set forth in Appendix II-N was followed for all water and coal slurry sampling. These included using latex gloves and plastic sheeting to prevent contamination of the samples and sampling equipment; collecting samples in clean and appropriate containers; using distilled water to rinse sampling and field instruments; using trip blanks; using chemical preservatives, when necessary, and keeping samples chilled to 4 C°; photographing the sampling sessions; and completing and filing the chain-of-custody for each sample.

Coal Slurry Characterization

A comprehensive hydrologic assessment for each of the four sample sites is contained in Appendix I-A through D.

Information on coal slurry constituents is essential in understanding the potential impacts of coal slurry on the environment and to the public health. An accurate characterization of the slurry is necessary to determine the type and amount of constituents that may be released into the environment, in addition to its chemical stability under various conditions. Determining the water quality of the leachate and or liquid phase of the slurry once placed into the abandoned underground mine and the resultant water quality of the mine pool is essential in protecting the surrounding ground and surface waters.

A sampling program was designed and implemented to provide site specific and regional data on the coal slurry. The coal slurry samples represent the coal slurry produced at the preparation plant at the time of the sampling event and may not represent current or previous injectate. The program was designed to: a) provide essential data on the chemical composition of the solid and liquid phase of the slurry and the associated coal; b) provide comparisons and contrasts regarding coal quality, site locations and preparation plant processes; and c) determine if there exists a unique constituent that could be used to identify coal slurry impacts; i.e., a "tracer" to follow the migration of the slurry from the injection site into the surrounding hydrologic regime.

Six sample sets were collected at six different coal preparation plants located throughout the State. A sample of coal slurry and run-of-mine coal located at the preparation plant where injection activities occurred were collected and analyzed for a suite of organic and inorganic constituents. The liquid phase of the sample was separated at the lab through settling of the solids and decanting of the liquid. The solid and liquid portions (phases) of the slurry were then analyzed separately. To further understand the composition of the slurry, a solid coal and a simulated coal leachate was also analyzed. The coal was crushed to a size similar to that of the slurry, mixed with deionized water, and tumbled for a period of 24 hours to produce a simulated coal leachate.

The following table provides a description of the sampling points.

Table 1 WEST VIRGINIA COALSLURRY INJECTION STUDY – COAL SLURRY CHARACTERIZATION SAMPLING SITES

Preparation Plant / Site Location	Slurry and Coal Sample Designations	Presently Injecting	Coal Seam Represented by Samples
Southern Minerals (SM)	SM-Slurry	Yes	Fire Creek
Panther, LLC (PL)	PL-Slurry, PL-Slurry	No	Eagle
Loadout, LLC (LL)	LL- Slurry, LL-Coal	No	Eagle
Power Mountain (PM)	PM-Slurry, PM-Slurry	Yes	Several*
Coresco (CL)	CL-Slurry, CL-Coal	Yes	Redstone
Marfork (MF)	MF-Slurry, MF-Coal	No	No. 2 Gas

*Coalburg, Stockton, Five Block, Winifrede

Coal slurry was collected at each preparation plant thickener, and ranged from 10 to 50 percent solids. Both the liquid and the solid phase of the slurry was analyzed for approximately 175 constituents. The raw coal was collected from a coal stockpile at the preparation plant before cleaning. The coal should represent the material or particles that remain in the coal slurry after processing. However, due to the large and varied operations at some of the preparation plants, the coal may not represent the exact coal particles remaining in the slurry, nor does it necessarily represent the same coal seam where injection occurs. It does, however, represent coal from the surrounding area and provides data on the composition and relative constituents found in area coal. This is useful for comparisons with the constituents found in coal slurry.

The coal slurry characterization phase of this study focused on the chemical constituents composing coal slurry. Physical parameters (particle distribution, permeability, density, viscosity, etc.) were not tested on individual samples. General information on the coal slurry's physical characterization was taken from documents associated with the individual coal slurry injection sites and published information.

As noted earlier, the liquid and solid phases of the slurry were sampled separately. Summary and comparison tables have been completed, in addition to column plots, to help illustrate the data. An index of the tables and plots is shown below.

TABLE SC-A	Coal & Slurry Solid Phase Organic Chemistry (>ND)
TABLE SC-B	Coal & Slurry Liquid Phase Organic Chemistry (>ND)
TABLE SC-CI	Coal & Slurry Solid Phase Inorganic Chemistry – Metals
TABLE SC-CII	Coal & Slurry Solid Phase Inorganic Chemistry – General Chemistry
FIGURE SC-1	Metal Percentages in Solid Coal Slurry – Part 1
FIGURE SC-2	Metal Percentages in Solid Coal Slurry – Part 2
FIGURE SC-3	Metal Concentrations in Slurry Liquid – Part 1
FIGURE SC-4	Metal Concentrations in Slurry Liquid – Part 2
TABLE SC-DI	Coal & Slurry Liquid Phase Inorganic Chemistry - Metals
TABLE SC-DII	Coal & Slurry Liquid Phase Inorganic Chemistry – General Chemistry

The concentrations and constituents found in the solid phase were evaluated to determine the composition of the material; the evaluation of the solid phase does not take into consideration the mobility or availability of the constituents in the environment, whereas the liquid phase provides data on those constituents that have been dissolved in water and may be mobilized in the environment.

<u>Organic Chemistry for Coal and Slurry Solid Phase</u> – Table SC-A shows the organic compounds which were detected in the six sets of samples. The table illustrates the similarity of the coal seam and slurry in composition. The majority of the organic compounds detected were from a

group of compounds called PAHs (Polycyclic Aromatic Hydrocarbons). These organic compounds are associated with coal, fuels, gas, oils and tars. They can occur naturally, or as a result of pollutants and are ubiquitous in the environment. As shown in the Table SC-A, most of the compounds detected in the coal are also detected in the slurry. Those compounds that were detected in the slurry samples, but not in the paired coal sample are acetone, chloromethane, ethylbenzene, n-propylbenzene, butylbenzene, naphthalene, n-nitrosodiphenylamine, and pyrene. For slurry samples that did not have a paired coal sample, the other coal samples were used for comparison purposes. Of these compounds, only butylbenzene was shown to be in the coal slurry at the Panther, LLC. This can be attributed to several factors which are outlined in the individual report for Panther, LLC in Appendix I-C. Unfortunately, the type of testing performed cannot identify the exact source of these compounds because a more comprehensive set of data is necessary to identify the sources. If future studies are performed, a review of organic compound ratios from potential sources and the samples in question may be useful.

Organic Chemistry of the Liquid Phase of the Slurry – Table SC-B shows the organic compounds that were detected in the liquid phase of the slurry and the simulated leachate of the coal for all sample sites. As illustrated in the referenced table, only three compounds were detected in the liquid phase of the slurry that were not detected in the coal leachate, specifically: naphthalene, phenanthrene and 2-butanone.

Naphthalene and phenanthrene are common PAHs and were detected in the liquid phase of the slurry at Loadout, LLC. The exact source of the compounds has not been determined, however, the compound 2-butanone which was measured in a slurry sample from the Panther, LLC site was determined to be associated with the coal preparation process. The organic compound found in the liquid phase of the slurry determined to be from the slurry process was 2-butanone, although an additional compound (1-butanol) classified as a Tentatively Identified Compound (TIC), which supports this conclusion, can be found in the individual Panther, LLC report set forth in Appendix I-C.

Note: REIC Labs, which provided the lab analyses for all samples taken in support of this assessement, confirmed that the concentrations reported for the semi-volatile organic compound, bis(2-ethylhexyl)phthalate were lab artifacts and not associated with the samples taken from the various sites. This means that the compound is present throughout the laboratory environment and can be detected in some samples.

The organic characterization data did not reveal a universal conservative (stable in the environment) tracer that could be used in future environmental assessments relative to slurry impacts.

<u>Inorganic Chemistry of the Solid Phase of the Slurry</u> – Tables SC-CI and SC-CII summarize the inorganic chemistry of the solid phase of the slurry and the coal for all samples. The main constituents of concern for human health and the environment are the heavy metals which have been converted into percentages and transferred onto two individual plots, Figures SC-1 and SC-2. The plots illustrate the relative concentrations of the metals within each sample and at the separate sites.

For all sample sites, iron, sodium, aluminum, and calcium made up the greatest portion of the slurry solids. Although the percentages varied for the individual sites, iron was the greatest percentage found at all sites, except Loadout, which had Na in the greatest proportion. There were no concentrations of Ag, cyanide, or Th found in the samples, and most samples had no detectable concentrations of Se and Sb, with the exception of Coresco and Southern Minerals.

All of the samples from all of the sites were alkaline with varying concentrations of chloride and sulfate values. The greatest sulfate concentration was found at Coresco and the lowest was at Southern Minerals. This may be a direct reflection of the sulfur content of the coal.

<u>Inorganic Chemistry of the Liquid Phase of the Slurry</u> – Tables SC-DI and SC-DII summarize the inorganic chemistry of the liquid phase of the slurry and coal. The dissolved metal concentration can come from a variety of sources. They may have been released from the slurry solids and/or the chemical additives used at the plant. They may also have been in the water used at the preparation plant. Dissolved metal concentrations account for the metals in solution and are appropriate when evaluating the liquid phase of the slurry. The dissolved constituents represent the most mobile in the environment depending on site specific conditions. Mine conditions, such as the amount and variability of saturation and chemical characteristics such as pH and redox (reduction and oxidation) conditions significantly affect the solubility of the constituents. In addition, other chemical conditions will affect the adsorption and precipitation of these constituents.

In all the liquid slurry samples from all the sites, Na concentrations were the greatest; ranging from 58.8 mg/L to 272.0 mg/L. Calcium, Mg and K were the next three highest ranking concentrations for all samples. Sulfate concentrations were highest in the slurry liquid phase for all samples at all sites, except for Panther where chloride was the most dominant constituent.

Relative to the heavy metals, no concentrations were reported for Cd and Hg. Silver and Ti were only reported at the detection level for the samples at Power Mountain. It is interesting to note that neither of these metals had concentrations reported in the solid sample at Power Mountain. Of the other metals analyzed, Al, Ba, Mn and Mo all had notable concentrations.

A review of the inorganic data did not reveal a universal conservative tracer that could be used in future studies. In fact, the predominant constituents found in the solid and the liquid phases are the same as those found in coal and coal mining impacted waters.

Using the Federal Primary Drinking Water Standards for comparison, three dissolved metal concentrations exceeded the standards in slurry liquid samples at selected sites. Antimony levels exceeded the standard of (0.006 mg/L) in the sample at Panther, Southern Minerals and Coresco (0.0104, 0.0220 and 0.0069), respectively. Arsenic levels exceeded the standard of (0.010 mg/L) in the sample at Panther (0.012mg/l), as did lead, which exceeded the standard of (0.015mg/l) at 0.0762 mg/L. Panther is not currently injecting.

TABLE SC-A Coal & Slurry Solid Phase Organic Chemistry (> Non-Detect)

Analyte	Unit	Sample Results											
		Loadlout, LLC		Panther		Southern Mineral		Power Mountain		Cresco		Marfork	
		Slurry Solid	Coal	Slurry Solid	Coal	Slurry Solid	Coal	Slurry Solid	Coal	Slurry Solid	Coal	Slurry Solid	Coal
TPH (Diesel Range)	mg/kg	282	746	144	NA	280	NA	222	927	712	1020	179	535
TPH (Oil Range)	mg/kg	469	525	159	NA	391	NA	382	782	765	740	258	640
Volatile Organic Compounds													
1,2,4-Trimethylbenzene(C9H12)	µg/kg	ND	64.1	216	NA	ND	NA	25.2	398	87.9	86.9	26.7	166
1,3,5-Trimethylbenzene(C9H12)	µg/kg	ND	60.1	76.8	NA	ND	NA	ND	183	35.4	78.6	22.6	94.3
Acetone (C3H7O)	µg/kg	267	ND	ND	NA	ND	NA	ND	ND	ND	398	ND	ND
Acrolein (C3H4O)		ND	ND	ND	NA	ND	NA	ND	ND	ND	356	ND	ND
Benzene(C6H6)	µg/kg	ND	16.6	166	NA	ND	NA	ND	330	ND	ND	ND	ND
Carbon disulfide (CS2)	µg/kg	ND	36.7	ND	NA	ND	NA	ND	ND	ND	ND	ND	ND
Chloromethane(CH3Cl)	µg/kg	ND	ND	ND	NA	ND	NA	ND	ND	ND	ND	ND	ND
Ethylbenzene(C8H10)	µg/kg	ND	24.9	122	NA	ND	NA	ND	139	20.2	ND	ND	24.5
Isopropylbenzene(C9H12)	µg/kg	ND	62.2	30.2	NA	ND	NA	29.9	132	107	162	34.4	100
m,p-Xylene(C8H10)	µg/kg	ND	92.6	585	NA	ND	NA	44.6	976	71.4	44.4	ND	163
Methylene chloride (CH2CL2)	µg/kg	ND	ND	ND	NA	ND	NA	ND	23.2	ND	ND	ND	ND
Naphthalene(C10H8)	µg/kg	ND	ND	259	NA	ND	NA	34.4	99.3	ND	ND	40.4	ND
n-Propylbenzene(C9H12)	µg/kg	ND	ND	45.5	NA	ND	NA	ND	61	22	ND	ND	23.7
o-Xylene(C8H10)	µg/kg	ND	53	284	NA	ND	NA	28.7	473	72.6	66.8	ND	114
Sec-Butylbenzene(C10H14)	µg/kg	ND	ND	8.5	NA	ND	NA	ND	ND	ND	ND	ND	ND
Toluene(C7H8)	µg/kg	27.6	205	1040	NA	ND	NA	51.6	8670	64.3	25.1	ND	178
SemiVolatile Organic Compounds													
2,4-Dimethylphenol(C8H10O)	mg/kg	0.482	1.24	0.167	NA	ND	NA	ND	0.466	ND	ND	ND	0.424
Acenaphthene((C12H10)	mg/kg	0.07	0.227	ND	NA	ND	NA	ND	0.072	ND	ND	ND	0.197
Benzo(a)anthracene(C18H12)	mg/kg	0.136	0.563	0.036	NA	ND	NA	ND	0.127	ND	ND	ND	ND
Benzo(a)pyrene(C20H12)	mg/kg	0.162	0.834	0.07	NA	0.167	NA	0.463	0.329	0.747	0.797	ND	0.231
Benzo(b)fluoranthene(C20H12)	mg/kg	0.176	0.859	0.082	NA	ND	NA	ND	0.261	ND	ND	0.087	0.227
Benzo(g,h,i)perylene(C22H12)	mg/kg	0.513	2.07	0.155	NA	0.092	NA	0.346	0.982	ND	ND	0.098	0.42
Benzo(k)fluoranthene(C20H12)	mg/kg	0.065	0.298	ND	NA	0.191	NA	ND	0.278	ND	ND	ND	0.213
Bis(2-ethylhexyl)phthalate (C24H38O4)	mg/kg	ND	0.239	ND	NA	ND	NA	ND	0.217	ND	ND	ND	0.227
Chrysene(C18H12)	mg/kg	0.198	0.76	0.206	NA	0.528	NA	0.248	1.16	0.73	0.873	0.32	1.1
Dibenzo(a,h)anthracene(C22H14)	mg/kg	0.042	0.251	0.032	NA	ND	NA	ND	0.183	ND	ND	ND	0.132
Fluoranthene(C16H10)	mg/kg	0.119	0.525	0.07	NA	0.078	NA	0.144	0.288	ND	ND	0.096	0.348
Fluorene(C13H10)	mg/kg	0.184	0.675	0.202	NA	0.327	NA	0.180	0.852	0.843	1.14	0.135	1.04
Indeno(1,2,3-cd)pyrene(C22H12)	mg/kg	0.074	0.371	ND	NA	ND	NA	ND	0.175	ND	ND	ND	0.08
m,p-Cresol(C7H8O)	mg/kg	0.21	0.428	0.089	NA	ND	NA	ND	0.175	ND	ND	ND	0.151
Naphthalene(C10H8)	mg/kg	2.69	9.61	1.5	NA	0.069	NA	1.41	7.54	4.1	5.24	0.234	4.8
Nitrobenzene(C6H5NO3)	mg/kg	ND	ND	ND	NA	ND	NA	ND	ND	ND	ND	ND	ND
N-Nitrosodiphenylamine	mg/kg	0.171	ND	ND	NA	ND	NA	ND	ND	ND	ND	ND	ND
o-Cresol(C7H8O)	mg/kg	0.207	0.434	ND	NA	ND	NA	ND	0.224	ND	ND	ND	0.229
Phenanthrene(C14H10)	mg/kg	0.947	3.77	0.903	NA	0.949	NA	1.09	4.99	4.22	6.2	0.604	4.76
Phenol(C7H6O)	mg/kg	0.068	0.087	0.045	NA	ND	NA	ND	0.075	ND	ND	ND	ND
Pyrene(C16H10)	mg/kg	0.225	0.966	0.095	NA	0.136	NA	0.169	0.447	ND	ND	0.121	0.462

ND - Non Detect
NA - Non Analyzed

TABLE SC-B Coal & Slurry Liquid Phase Organic Chemistry (> Non-Detect)

Analyte	Unit	Lab Results											
		Loadlout, LLC		Panther		Southern Mineral		Power Mountain		Coresco		Marfork	
		Slurry Liquid	Coal Leachate	Slurry Liquid	Coal Leachate	Slurry Liquid	Coal Leachate	Slurry Liquid	Coal Leachate	Slurry Liquid	Coal Leachate	Slurry Liquid	Coal Leachate
TPH (Diesel Range)	mg/l	16.6	ND	0.51	ND	ND	NA	0.26	ND	ND	ND	NA	ND
TPH (Oil Range)	mg/l	19.4	ND	ND	ND	ND	NA	ND	ND	ND	ND	NA	ND
Volatile Organic Compounds													
Acetone(C3H7O)	µg/l	7	14.8	16.7	9.9	ND	NA	ND	ND	ND	ND	NA	ND
Benzene(C6H6)	µg/l	ND	ND	1.8	1.6	ND	NA	ND	1.4	ND	ND	NA	ND
2-Butanone	µg/l	ND	ND	68.4	ND	ND	NA	ND	ND	ND	ND	NA	ND
Methylene Chloride	µg/l	1.4	1	ND	ND	ND	NA	ND	ND	ND	ND	NA	ND
Toluene(C7H8)	µg/l	0.6	0.7	2.8	2.1	ND	NA	ND	1.9	ND	ND	NA	0.2
0-Xylene(C8H10)	µg/l	ND	ND	0.6	0.3	ND	NA	ND	0.3	ND	ND	NA	ND
m,p-Xylene(C8H10)	µg/l	ND	ND	0.8	0.4	ND	NA	ND	0.4	ND	ND	NA	ND
SemiVolatile Organic Compounds													
Naphthalene(C10H8)	mg/l	0.0143	ND	ND	ND	ND	NA	ND	ND	ND	ND	NA	ND
Phenanthrene	mg/l	0.0061	ND	ND	ND	ND	NA	ND	ND	ND	ND	NA	ND
Bis(2-ethylhexyl)phthalate		ND	ND	ND	ND	ND	NA	ND	0.0091	ND	ND	NA	0.0108

ND - Non Detect
NA - Non Analyzed

TABLE SC-CI Coal Slurry Solid Phase Inorganic Chemistry

Metals	Unit	Lab Results											
		Loadlout, LLC		Panther		Southern Minerals		Power Mountain		Coresco		Marfork	
		LL- Coal (Raw)	LL-Slurry Solid	Coal (Raw)	Slurry Solid	SM- Coal (Raw)	SM- Slurry Solid	PM- Coal (Raw)	PM- Slurry Solid	CL- Coal (Raw)	CL- Slurry Solid	MF- Coal (Raw)	Slurry
Aluminum	mg/kg	1170	36.1	NA	3600	NA	1910	8740	1040	1820	1420	8720	3130
Antimony	mg/kg	ND	ND	NA	ND	NA	0.55	ND	ND	ND	ND	ND	ND
Arsenic	mg/kg	1.56	ND	NA	ND	NA	1.2	4.34	2.11	10.6	4.63	159	ND
Barium	mg/kg	19.9	0.638	NA	52.3	NA	99.2	137	170	34.9	38.9	152	304
Beryllium	mg/kg	0.544	ND	NA	0.385	NA	0.425	1.29	0.289	1.4	0.525	NA	NA
Cadmium	mg/kg	0.0692	ND	NA	0.0809	NA	N/D	0.577	0.149	0.312	0.145	0.445	0.123
Calcium	mg/kg	453	84.1	NA	1220	NA	424	1640	371	2540	3940	951	719
Chromium	mg/kg	5.98	ND	NA	4.82	NA	2.77	14.3	4.33	10.7	7.47	13.9	5.55
Cobalt	mg/kg	3.80	ND	NA	2.31	NA	1.99	13.8	3.02	6.34	3.66	11.2	3.81
Copper	mg/kg	9.88	ND	NA	7.54	NA	4.59	25.7	6.16	10.5	7.98	27.4	10.8
Iron	mg/kg	1480	29.7	NA	6080	NA	2060	33800	9890	19900	8160	28200	7000
Lead	mg/kg	5.67	ND	NA	4.79	NA	2.95	16.7	4.89	8.06	4.09	16.2	5.86
Magnesium	mg/kg	382	26.2	NA	908	NA	620	3150	324	704	584	2680	1260
Manganese	mg/kg	13.5	0.498	NA	51.9	NA	22.5	570	34.3	85.7	48.7	183	72.9
Mercury	mg/kg	0.052	ND	NA	ND	NA	ND	0.044	0.112	0.158	0.034	0.254	ND
Molybdenum	mg/kg	0.610	ND	NA	ND	NA	0.395	0.56	0.408	0.765	0.876	1.62	ND
Nickel	mg/kg	6.80	ND	NA	5.06	NA	4.34	22.10	6.10	11.1	7.93	21.5	7.68
Potassium	mg/kg	451	43.3	NA	1210	NA	931	2160	422	555	381	2180	1280
Selenium	mg/kg	1.96	ND	NA	ND	NA	ND	ND	ND	ND	0.617	1.17	ND
Silicon	mg/kg	77.5	32.3	NA	46.3	NA	453	342	250	174	70.8	321	317
Silver	mg/kg	ND	ND	NA	ND	NA	N/D	ND	ND	ND	ND	ND	ND
Sodium	mg/kg	48.1	217	NA	754	NA	44.3	588	85.7	415	394	593	315
Strontium	mg/kg	13.4	1.57	NA	13.6	NA	16.8	68.9	14.4	84.6	84.0	61.4	34.6
Thallium	mg/kg	ND	ND	NA	ND	NA	ND	ND	ND	ND	ND	ND	ND
Vanadium	mg/kg	7.93	ND	NA	6.61	NA	3.14	13.2	25.6	16.5	11	16.8	8.22
Zinc	mg/kg	16.5	2.7	NA	17.4	NA	8.6	68.9	10.3	23.9	20.3	49.1	18.7

ND - Non Detect
NA - Non Analyzed

TABLE SCII Coal Slurry Solid Phase Inorganic Chemistry

General Chemistry	Unit	Loadlout, LLC		Panther		Southern Mineral		Power Mountain		Coresco		Marfork	
		LL-Coal (Raw)	LL-Slurry Solid	Coal (Raw)	Slurry Solid	SM-Coal (Raw)	SM- Slurry Solid	PM- Coal (Raw)	PM- Slurry Solid	CL- Coal (Raw)	CL- Slurry Solid	MF- Coal (Raw)	MF- Slurry Solid
Nitrogen, Nitrate	mg/kg	ND	N/D	NA	ND	NA	ND	ND	4.10	3000	2390	ND	ND
Nitrogen, Nitrite	mg/kg	ND	N/D	NA	9.06	NA	ND	ND	ND	304	251	ND	ND
Chloride	mg/kg	306	118	NA	554	NA	ND	26.10	130.00	265	173	31	173
Cyanide	mg/kg	ND	ND	NA	ND	NA	ND	ND	ND	ND	ND	ND	ND
Fluoride	mg/kg	ND	N/D	NA	1.86	NA	ND	ND	5.10	35	90	2.54	ND
Sulfate	mg/kg	577	690	NA	144	NA	9.35	26.8	798.00	36100	18500	260	191
Nitrogen, Ammonia	mg/kg	31.9	33.6	NA	33.6	NA	ND	68.3	20	6.7	ND	57.1	25.8
Acidity, Total	mg/kg	ND	ND	NA	ND	NA	11.40	ND	ND	N/A	N/A	N/A	N/A
Alkalinity, Bicarbonate	mg/kg	652	1710	NA	ND	NA	449.00	787.0	352.0	1700	4820	ND	843
Alkalinity, Carbonate	mg/kg	7.7	86.1	NA	ND	NA	2.30	77.4	ND	358	521	ND	5.7
Alkalinity, Total	mg/kg	660	1790	NA	1390	NA	451.00	865.0	352.0	2060	5350	594	848
pH	SU	8.10	8.73	NA	9.44	NA	7.63	9.02	7.35	9.35	9.06	9.2	7.86

Lab Results

ND - Non Detect

NA - Non Analyzed

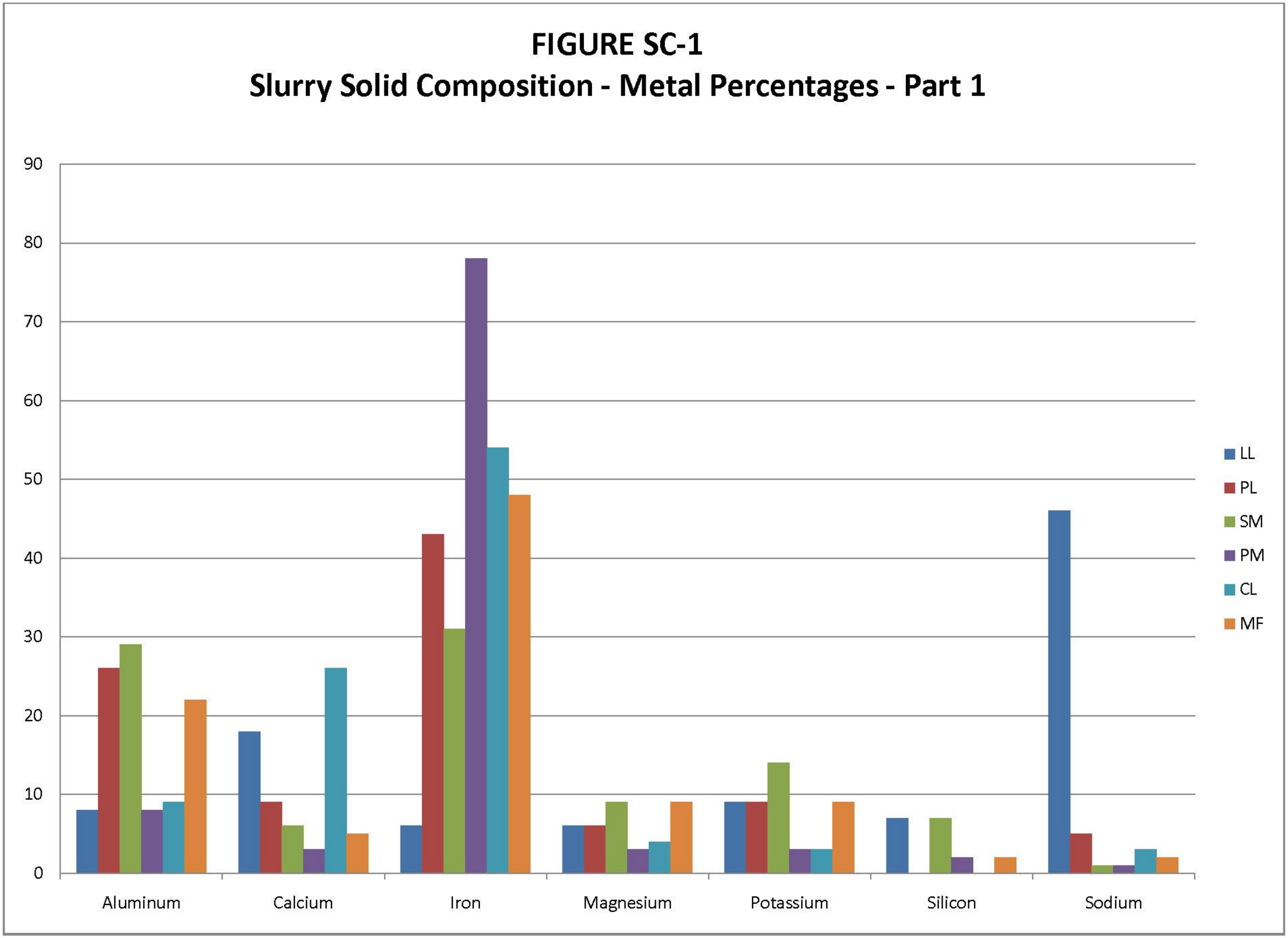
FIGURE SC-1
Slurry Solid Composition - Metal Percentages - Part 1
90
80
70
60
50
40
30
20
10
0
Aluminum
Calcium
Iron
Magnesium
Potassium
Silicon
Sodium
LL
PL
SM
PM
CL
MF

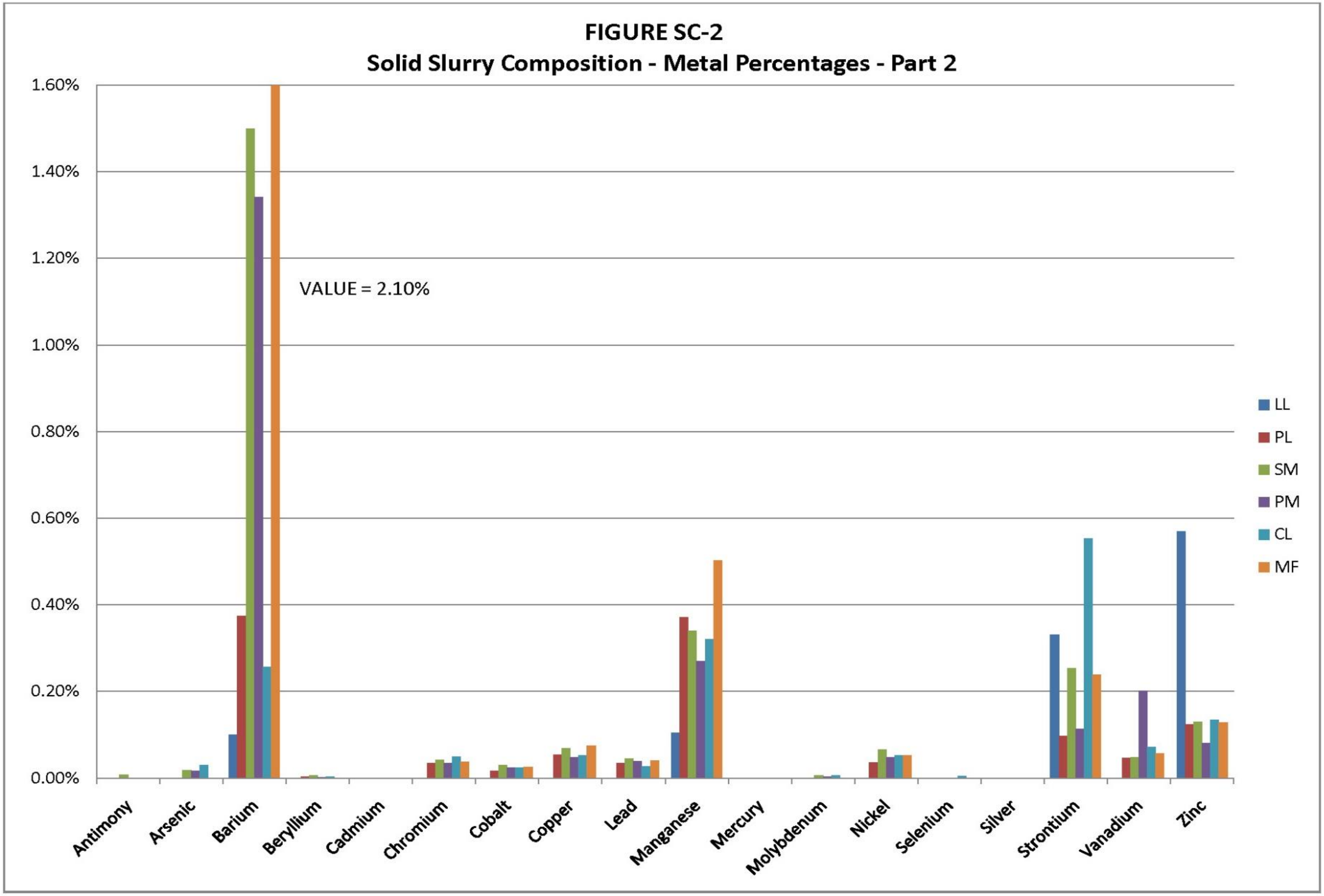
FIGURE SC-2
Solid Slurry Composition - Metal Percentages - Part 2
1.60%
1.40%
1.20%
1.00%
0.80%
0.60%
0.40%
0.20%
0.00%
VALUE = 2.10%
LL
PL
SM
PM
CL
MF
Antimony
Arsenic
Barium
Beryllium
Cadmium
Chromium
Cobalt
Copper
Lead
Manganese
Mercury
Molybdenum
Nickel
Selenium
Silver
Strontium
Vanadium
Zinc

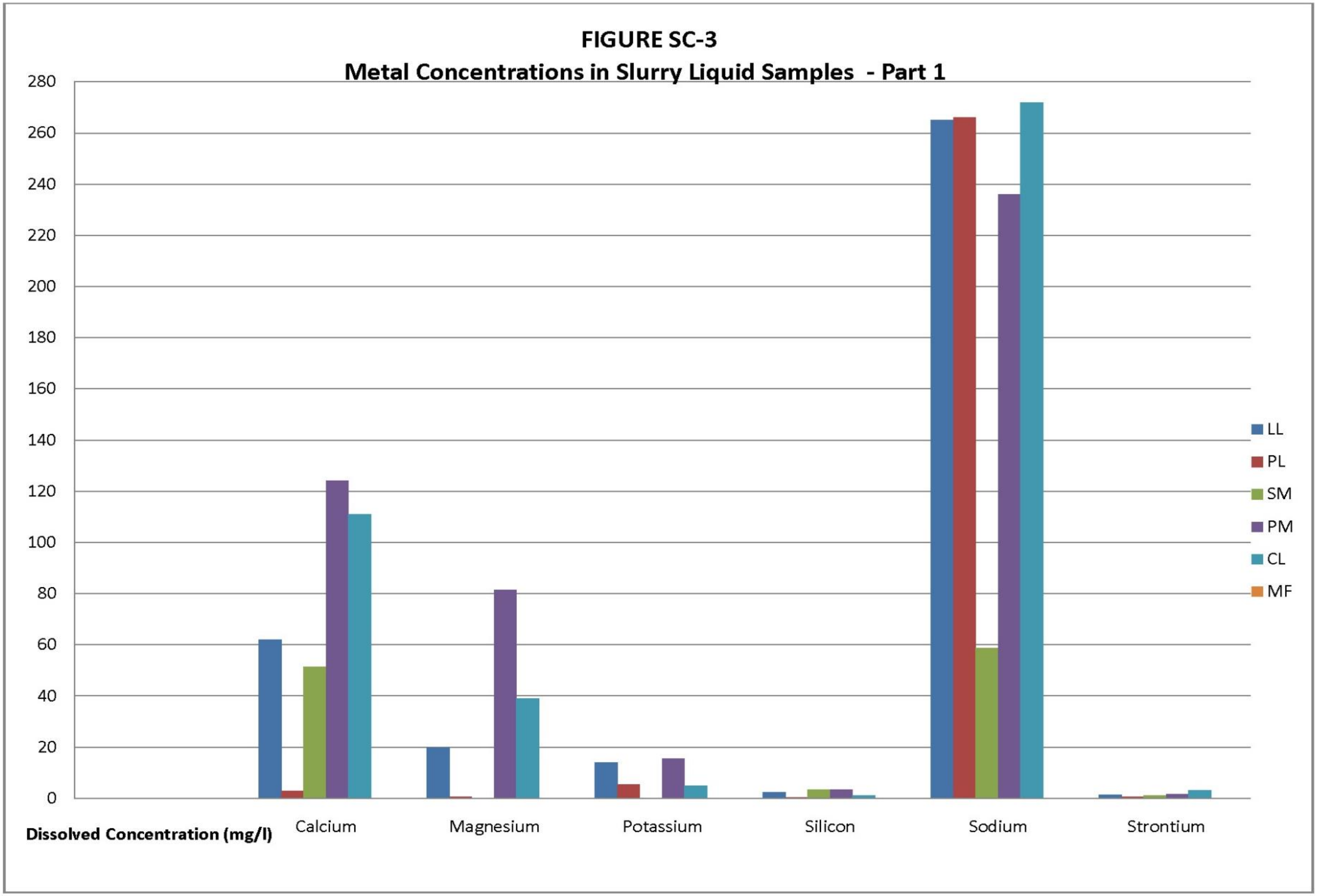
FIGURE SC-3
Metal Concentrations in Slurry Liquid Samples - Part 1
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
Dissolved Concentration (mg/l)
Calcium
Magnesium
Potassium
Silicon
Sodium
Strontium
LL
PL
SM
PM
CL
MF

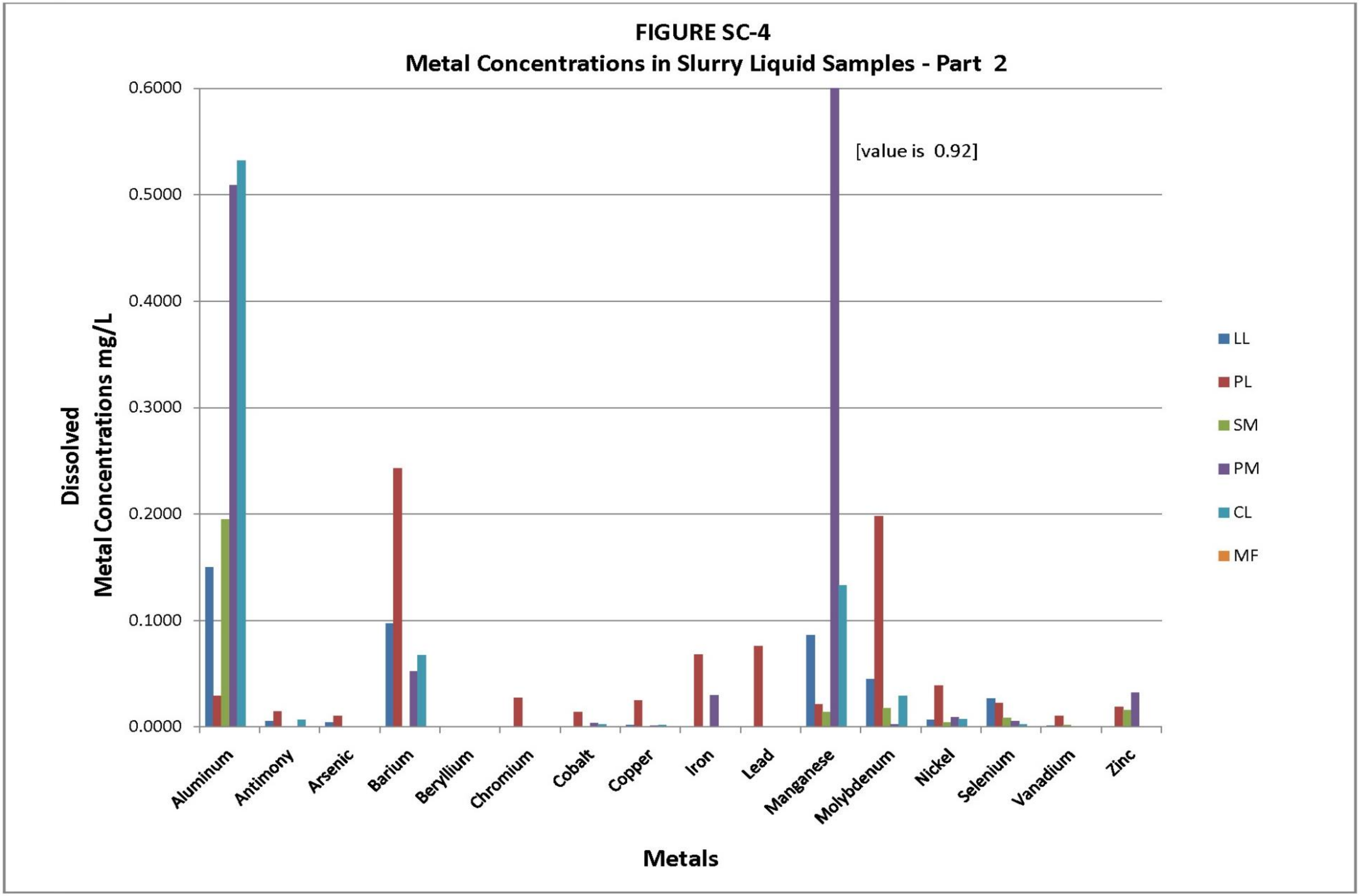

FIGURE SC-4
Metal Concentrations in Slurry Liquid Samples - Part 2
Dissolved
Metal Concentrations mg/L
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
[value is 0.92]
Aluminum
Antimony
Arsenic
Barium
Beryllium
Chromium
Cobalt
Copper
Iron
Lead
Manganese
Molybdenum
Nickel
Selenium
Vanadium
Zinc
Metals
LL
PL
SM
PM
CL
MF

TABLE SC-DI Coal Slurry Liquid Phase Inorganic Chemistry

Dissolved & Total Metals Analyses Results	Unit	Lab Results																	
		Loadlout, LLC			Panther			Southern Mineral			Power Mountain			Coresco			Marfork		
		LL- Slurry Liquid		LL- Coal Leachate	PL- Slurry (Liquid)		PL- Coal Leachate	SM- Slurry Liquid		SM- Coal Leachate	PM- Slurry Liquid		PM- Coal Leachate	CL- Slurry Liquid		CL- Coal Leachate	MF- Slurry Liquid	MF- Coal Leachate	
		Dissolved	Total	Dissolved	Dissolved	Total	Dissolved	Dissolved	Total	NA	Dissolved	Total	Dissolved	Dissolved	Total	Dissolved	Dissolved/Total	Dissolved	Total
Aluminum	mg/L	0.1500	2.37	0.0540	0.029	0.046	0.398	0.1950	0.651	NA	0.509	0.564	0.214	0.532	0.644	0.356	NA	0.146	1.190
Antimony	mg/L	0.0057	0.0059	0.0019	0.0146	0.016	0.0012	0.0220	0.0215	NA	0.0004	0.0005	0.0018	0.0069	0.0071	0.0005	NA	0.0015	0.0011
Arsenic	mg/L	0.0042	0.0047	0.0041	0.0104	0.0113	0.012	0.0039	0.0043	NA	ND	ND	0.0141	ND	ND	0.0019	NA	0.0198	0.246
Barium	mg/L	0.0974	0.133	0.0055	0.243	0.269	0.0129	0.0809	0.114	NA	0.0523	0.0634	0.0079	0.0677	0.0713	0.0047	NA	0.0227	0.695
Beryllium	mg/L	ND	ND	ND	ND	ND	ND	0.0002	0.0004	NA	ND	ND	ND	ND	ND	ND	NA	ND	0.002
Cadmium	mg/L	ND	ND	ND	ND	0.0011	ND	ND	ND	NA	ND	ND	ND	ND	ND	ND	NA	ND	ND
Calcium	mg/L	62.10	63.7	2.42	2.83	3.51	0.464	51.4000	51.7	NA	124.000	123.000	0.552	111	115	4.820	NA	0.2840	1.260
Chromium	mg/L	ND	ND	0.0013	0.0272	0.0342	ND	0.0013	0.0016	NA	ND	ND	ND	ND	ND	ND	NA	ND	0.0054
Cobalt	mg/L	ND	0.0016	ND	0.0142	0.0161	ND	0.0021	0.0024	NA	0.0037	0.0039	ND	0.0027	0.0029	ND	NA	ND	0.0067
Copper	mg/L	0.0016	0.0034	ND	0.0248	0.0278	ND	0.0012	0.0018	NA	0.0015	0.0016	ND	0.0021	0.0021	ND	NA	ND	0.0248
Iron	mg/L	ND	0.828	ND	0.068	0.089	ND	ND	0.91	NA	0.030	0.195	0.038	ND	0.174	0.022	NA	0.050	13.200
Lead	mg/L	ND	0.0016	ND	0.0762	0.0775	ND	ND	0.0008	NA	ND	0.0004	0.0004	ND	ND	ND	NA	0.0003	0.2170
Magnesium	mg/L	19.8	20.6	0.705	0.591	0.771	ND	20.8	21	NA	81.40	82.20	ND	38.90	40.00	0.29	NA	ND	2.21
Manganese	mg/L	0.0860	0.097	ND	0.021	0.028	ND	0.0141	0.0177	NA	0.921	0.921	ND	0.133	0.138	ND	NA	0.001	0.142
Mercury	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	NA	ND	ND	ND	ND	ND	ND	NA	ND	ND
Molybdenum	mg/L	0.0447	0.0466	0.0090	0.198	0.217	ND	0.0176	0.0178	NA	0.0023	0.0024	0.0035	0.0290	0.0297	0.0020	NA	0.0029	0.0021
Nickel	mg/L	0.0067	0.0073	ND	0.0386	0.0432	ND	0.0043	0.0052	NA	0.0092	0.0096	ND	0.0073	0.0074	ND	NA	ND	0.0110
Potassium	mg/L	13.9	14.3	5.02	5.38	7.05	1.23	6.90	7.07	NA	15.50	15.50	0.380	5.01	5.16	1.080	NA	0.321	0.925
Selenium	mg/L	0.0268	0.0278	0.0195	0.0224	0.0255	0.0087	0.0082	0.0082	NA	0.0057	0.0059	0.0082	0.0024	0.0024	0.0019	NA	0.0043	0.0040
Silicon	mg/L	2.3	8.54	11.1	0.346	0.358	0.384	3.3	3.76	NA	3.27	5.31	7.59	1.14	3.91	0.43	NA	13.20	71.00
Silver	mg/L	ND	ND	0.0005	ND	ND	ND	ND	ND	NA	0.0006	0.0006	ND	ND	ND	ND	NA	ND	ND
Sodium	mg/L	265	267	4.88	266	341	10.1	58.8	55.5	NA	236.0	237.0	75.5	272.0	279.0	12.6	NA	48.1	6.7
Strontium	mg/L	1.44	1.4700	0.0159	0.571	0.632	0.0222	1.16	1.1700	NA	1.630	1.740	0.0043	3.19	3.270	0.16	NA	0.115	0.135
Thallium	mg/L	0.0003	0.0004	ND	ND	ND	ND	ND	0.0002	NA	0.0002	0.0003	ND	ND	0.0002	ND	NA	0.0002	0.0004
Vanadium	mg/L	0.0013	0.0025	0.0044	0.0103	0.0131	0.007	0.0018	0.0021	NA	ND	ND	0.0052	ND	ND	0.0015	NA	0.0031	ND
Zinc	mg/L	ND	0.008	0.008	0.019	0.014	ND	0.016	0.027	NA	0.032	0.041	ND	ND	ND	0.003	NA	ND	0.038

ND - Non Detect
NA - Non Analyzed

TABLE SC-DII Coal Slurry Liquid Phase Inorganic Chemistry

General Chemistry	Unit	Lab Results											
		Loadlout, LLC		Panther		Southern Mineral		Power Mountain		Coresco		Marfork	
		LL- Slurry Liquid	LL- Coal Leachate	PL- Slurry Liquid	PL- Coal Leachate	SM- Slurry Liquid	SM- Coal Leachate	PM- Slurry Liquid	PM- Coal Leachate	CL- Slurry Liquid	CL- Coal Leachate	MF- Slurry Liquid	MF- Coal Leachate
Nitrogen, Nitrate	mg/l	1.85	0.07	0.59	0.03	0.45	NA	3.45	ND	0.83	ND	NA	ND
Nitrogen, Nitrite	mg/l	0.35	0.17	ND	ND	2.32	NA	ND	0.14	0.16	ND	NA	0.10
Chloride	mg/l	84.80	1.45	423.00	7.12	0.18	NA	77.10	1.71	32.80	0.60	NA	1.43
Fluoride	mg/l	ND	0.55	1.53	0.51	8.39	NA	0.56	0.42	ND	ND	NA	0.31
Sulfate	mg/l	849.00	7.40	261.00	2.60	157.00	NA	853.00	3.44	1110.00	14.00	NA	4.55
Nitrogen, Ammonia	mg/l	1.27	0.34	1.96	0.44	0.18	NA	1.16	0.35	0.72	0.14	NA	0.10
Cyanide, Total	mg/l	ND	ND	ND	ND	ND	NA	ND	ND	ND	ND	NA	ND
Specific Conductivity	µmh/cm	1840	57.20	5000.00	170.00	702.00	NA	2110	100	2030	116	NA	86.7
Total Dissolved Solids	mg/l	933.00	21.00	2540.00	87.00	423.00	NA	1470	21	1340	51	NA	15.0
Total Suspended Solids	mg/l	191.00	1.00	74.00	6.00	5440.00	NA	9	1	22	1	NA	1
Acidity, Total	mg/l	6.90	ND	ND	ND	6.80	NA	8.7	ND	5.4	ND	NA	ND
Alkalinity, Bicarbonate	mg/l	102.00	25.50	412.00	42.00	180.00	NA	146.0	34.3	143.0	32.1	NA	23.2
Alkalinity, Carbonate	mg/l	ND	6.00	7.10	14.30	1.40	NA	ND	10.0	ND	6.8	NA	6.0
Alkalinity, Total	mg/l	103.00	32.70	420.00	58.20	181.00	NA	147.0	45.8	144.0	40.0	NA	30.6
pH	SU	7.88	9.40	8.26	9.56	7.93	NA	7.75	9.49	7.71	9.35	NA	9.44

ND - Non Detect
NA - Non Analyzed

Findings and Conclusions

The review team chose six underground injection control permits to evaluate. Four were reviewed as part of a hydrologic assessment and an additional two were evaluated for only slurry constituents. The team then gathered slurry, water, and coal samples to evaluate 175 parameters, most of which are not routinely tested as part of a mining operation. This hydrologic assessment aspect of the SCR-15 study was not included here but can be found online as previously detailed.

No universal tracer was found to indicate the presence of coal slurry as distinguished from other mining activities on surface and groundwater. Slurry is similar to coal in its composition. Because manufacturers of the products often do not identify proprietary chemical compositions, there is insufficient information on the chemicals used in the coal preparation process. It is recommended that all chemicals used in the coal preparation process be fully detailed for operations that are permitted to inject slurry.

Despite the fact that the mines studied were below or partially below drainage, several of the mines had documented artesian flow – or internal pressure pushing slurry to the surface. A below-drainage mine is one where the coal seam is lower than the surface drainage feature. Many of these mine pools are pumped to control mine pool elevations. For these reasons, all mine pools that receive coal slurry must be closely monitored.

All of the deep mines evaluated in this study are below or partially below drainage. The majority of the mine workings are located below surface drainage with the exception of entries located at the up-dip end of the mines. Conceptually, waters associated with the deep mine workings below drainage are less likely to impact surrounding groundwater due to the low permeability of the strata surrounding the mine pools. Therefore, it is less likely for slurry and its constituents located in the deep mine pools to impact the surrounding groundwater. Based on available data found in the complete SCR-15 report, this study can neither confirm nor disprove this statement.

Most sites lacked adequate background data on mine pools and groundwater monitoring. All proposed slurry injection sites should be required to conduct detailed baseline monitoring. All existing slurry injection sites and sites permitted for injection in the future should be required to conduct detailed groundwater monitoring throughout the life of the permit.

Samples taken downgradient in a mine pool where slurry injection occurred showed no physical evidence of the migration of slurry solids. In addition, samples taken from two adjacent mine pools showed no physical evidence for the migration of slurry solids.

Two of the four sites showed the effects of injectate on the mine pools. Certain constituents, such as alkalinity, Total Dissolved Solids, sulfates, and some organics, had migrated from the slurry into the mine pool that received the injection. Migration of slurry chemical constituents from the mine pool to the surrounding surface water was not confirmed. It is recommended that all slurry injection sites conduct baseline sampling then monitor all water wells in use within one half mile of the mine pool that receives injectate throughout the injection process.

None of the four sites exhibited water quality impacts to surface waters due solely to slurry injection at the time of sampling.

Two public water supplies draw water from the same mine receiving slurry injection. The finished consumable water from both public water systems met EPA Primary Drinking Water Standards at the time of the sampling event.

In summary, no adverse effects to surrounding surface and ground waters due to slurry injection were observed from the samples taken. Pending the full implementation of all recommendations proposed in this study, the WVDEP is imposing a moratorium on the approval of the injection of coal slurry into mine voids in which coal slurry injection has not previously been approved under the modern era program (since 1999).

Bibliography

2006 Edition of the Drinking Water Standards and Health Advisories, EPA 822-R-06-013, Office of Water, United States Environmental Protection Agency, Washington, DC.

Alliance Consulting, *Underground Injection Plan Modification*, Coal Clean Corporation No. 1 Plant Appalachian Eagle Mine, Dry Branch, Kanawha County, West Virginia, MSHA ID No. 46-05437, 2001.

Aljoe, William and Hawkins, Jay, *Neutralization of Acidic Discharges from Abandoned Underground Coal Mines by Alkaline Injection*, U.S. Bureau of Mines Report of Investigations 9468, p. 37, 1993.

Aljoe, William and Hawkins, Jay, *Application of Aquifer Testing in Surface and Underground Coal Mines*, Proceedings, 5th International Mine Water Congress, Nottingham, U.K., Vol. 1, pp. 3-21, 1994.

Bader, J. S., Mathes, M. V., & Runner, G. S., "Water Resources of the Tug Fork of the Big Sandy River Basin, West Virginia, Kentucky, and Virginia, and Twelvepole Creek Basin, West Virginia*," River Basin Bulletin 8* [Morgantown, WV]: West Virginia Geological and Economic Survey, 1989.

Brady, K.B.C., Rose, A.W., Hawkins, J.W., and DiMatteo, M.R., *Shallow Groundwater Flow in Unmined Regions of the Northern Appalachian Plateau: Part 2 - Geochemical Characteristics*, presented at the 13th Annual National Meeting of the American Society of Surface Mining and Reclamation, 1996.
https://doi.org/10.21000/JASMR96010052
Code of West Virginia, Chapter 22 – Article 11, *Water Pollution Control Act*, March 12, 1994.

Code of West Virginia, Chapter 22 – Article 12, *Groundwater Protection Act*, March 12, 1994.

EPA publication SW-846, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, United States Environmental Protection Agency, 3rd edition, 1995.

EPA Analytical Methods Approved for Drinking Water Compliance Monitoring of Inorganic Contaminants and Other Inorganic Constituents, United States Environmental Protection Agency, June 2008.

EPA Analytical Methods Approved for Drinking Water Compliance Monitoring of Radionuclides, United States Environmental Protection Agency, June 2008.

EPA Analytical Methods Approved for Drinking Water Compliance Monitoring of Organic Contaminants, United States Environmental Protection Agency, June 2008.

EPA Analytical Methods Recommended for Drinking Water Monitoring of Secondary Contaminants, United States Environmental Protection Agency, June 2008.

EPA Analytical Methods Approved for Compliance Monitoring under the Ground Water Rule, United States Environmental Protection Agency, June 2008.

EPA Drinking Water Contaminants, United States Environmental Protection Agency, September 2007.

EPA Unregulated Contaminant Monitoring Rule 2, United States Environmental Protection Agency, June 2007.

Environmental Restoration Program Quality Assurance Project Plan for Multiple Projects for the 15th Airlift Wing Hickam Air Force Base, Oahu, Hawaii, November 17, 2006.

Ferguson, H.F., *Valley stress release in the Allegheny Plateau*, Engineering Geology, Association of Engineering Geologists Bulletin v. 4, n. 1, pp. 63-68, 1967.

Ferrell, G.M., "West Virginia Groundwater Quality," in Moody, D.W., Carr, J., Chase, E.B., and Paulson, R.W., comps., *National Water Summary, 1986—Hydrologic Events and Groundwater Quality*, United States Geological Survey, Water-Supply Paper 2325, p. 523-530, 1988.

Fetter, C. W., *Applied Hydrogeology*, third edition, Prentiss Hall, 1994

Freeze, R. A., and Cherry, J. A., *Groundwater: Englewood Cliffs, New Jersey*, Prentice-Hall, 604 p, 1979.

Galya, T., Hager, J., and Simmons, W., *Investigation of stream loss in Spruce Laurel Fork, Boone County, WV*, report prepared for the West Virginia Division of Environmental Protection, Nitro, WV, p. 348, 1997.

Galya, T., *Investigation of residential complaints along Buffalo Creek, near Sanders, Logan County, WV*, report prepared for the West Virginia Division of Environmental Protection, Nitro, WV, 2000.

Geissman, T.A., Chapter 3, *Organic reactions*: *Synthesis of an organic compound*, *in Processes for Preparing B-hydroxy-ketone and A,B, Unsaturated Ketones*, freepatentsonline.com, 1999.

Gomez-Hernandez, J. J., and Srivastava, R. M., "ISIM3-D: An ANSI-C Three-dimensional Multiple Indicator Conditional Simulation Program," Computers in Geosciences, v. 16, n. 4, p. 395-414, 1990. http://dx.doi.org/10.1016/0098-3004(90)90010-Q.

Groundwater Quality in Unmined Areas and Near Reclaimed Surface Coal Mines in the Northern and Central Appalachian Coal Regions, Pennsylvania and West Virginia, United States Geological Survey, United States Department of the Interior, 2006.

Groundwater Data Collection Protocols and Procedures for the National Water quality Assessment Program: Selection, Installation, and Documentation of Wells, and Collection of Related Data, United States Geological Survey, United States Department of the Interior, 1995.

Groundwater Data Collection Protocols and Procedures for the National Water quality Assessment Program: Collection and Documentation of Water Quality Samples and Related Data, United States Geological Survey, United States Department of the Interior, 1995.

Guidance for Contract Deliverables, Appendix C: Quality Assurance Project Plan, May 2006.

Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act; National Primary Drinking Water Regulations; and National Secondary Drinking Water Regulations; Methods Update, United States Environmental Protection Agency, 2001 and 2002.

Index to EPA Test Methods, United States Environmental Protection Agency, New England Region 1, Boston, MA, April 2003.

Health Consultation Martin County Coal Slurry Release, Inez, Martin County, Kentucky, United States Department of Health and Human Services, August 7, 2006.

Health Consultation Private Well Water Quality Williamson, Mingo County, West Virginia, West Virginia Department of Health and Human Resources, April 1, 2005.

Heath, R.C., "Basic Groundwater Hydrology," United States Geological Survey, *Water-Supply Paper 2220*, 84 p, 1983.

Hendryx, Michael, PhD, and Ahern, Melissa M., PhD, "Relations Between Health Indicators and Residential Proximity to Coal Mining In West Virginia," American Journal of Public Health, April 2008. http://dx.doi.org/10.2105/AJPH.2007.113472.

Hennen, R.V., and Gawthrop, R. M., "Wyoming and McDowell Counties," *West Virginia Geologic and Economic Survey County Report*, 783 pp. 31 pl, 28 f, 1915.

Hobba, W.A. "*Effects* of underground mining and mine collapse on the hydrology of selected basins in West Virginia," United States Geological Survey, *Report of Investigations*, RI-33, p. 77, 1981.

Jones, D.T. and David R. Woods, Acetone-butanol fermentation revisited, *Microbiological reviews*, Department of Microbiology, University of Cape Town, Rondebosch, South Africa, pp. 484-524, 1986.

Kendorski, F.S., *Subsidence and Water Intrusion for Shallow Longwall Mine Planning in the Illinois Basin - A Case Study*, Proceedings of longwall USA, 1993, Denver, CO., Peng, S.S., 1993 (ed.)., in Proceedings of 12th International Conference on Ground Control in Mining, West Virginia University, pp. 412-425, 1993.

Kozar, M.D., and Brown, D.P., "Location and Site Characteristics of the Ambient Groundwater Quality Monitoring Network in West Virginia, with Emphasis on the Carbonate Area," United States Geological Survey, *Water Resources Investigations Report 90-4118*, 93 p, 1995.

Lemkin, William, Ph.D., author, Rawson, Vinton R., editor, *Graphic Survey of Chemistry*, revised edition, Oxford Book company, 1961.

Lessing, P., and Hobba, Jr., W. A., "Abandoned Coal Mines in West Virginia as Sources of Water Supplies," West Virginia Geologicial and Economic Survey, *Circular Number C-24*, Morgantown, West Virginia, 1981.

Manual of Manuals, Summary and Information for Eight Laboratory Analytical Chemistry Methods Manuals Published by the EPS between 1988 and 1995, United States Environmental Protection Agency.

McSpirit, Stephanie, Ph.D., *Coal Impoundment Risk Assessment: A Survey of Mingo and Wyoming County, West Virginia, Households*, National Technology Transfer Center, Wheeling Jesuit University, WV, July 2006.

Montgomery, J.H., Groundwater Chemicals, Desk Reference, 4th Edition, CRC Press, Boca Raton, Florida, 2007. http://dx.doi.org/10.1201/9781420009132.

Mountaintop Mining/Valley Fills in Appalachia Draft Programmatic Environmental Impact Statement, U.S. Environmental Protection Agency, 2003.

National Environmental Methods Index, United States Geological Survey, United States Department of the Interior, September 2008.

Poth, C.W., "Geology and Hydrology of the Mercer Quadrangle, Mercer, Lawrence, and Butler Counties, Pennsylvania," *Water Resource Report 16*, Pennsylvania Topographic and Geological Survey, 4th Series, Harrisburg, PA, 149 p, 1963.

Price, W.E., Jr., and others, *Reconnaissance of Groundwater Resources in the Eastern Coal Field Region, Kentucky, 1962*.

RCRA Groundwater Monitoring: Draft Technical Guidance, Office of Solid Waste Management, United States Environmental Protection Agency, November 1992.

Report of the Black Water Task Force, Kentucky Environmental Protection, April 2005.

Reynolds, Osborne, "An Experimental Investigation of the Circumstances which Determine Whether the Motion of Water Will Be Direct or Sinuous and the Laws of Resistance in Parallel Channels," Phil Trans Roy Society, London, or *Scientific Papers, Vol. 2*, p.51, 1993.

Rose, A.W., and Dresel, P.E., "Deep Brines in Pennsylvania," *Water Resources in Pennsylvania: Availability, Quality and Management* (Chapter 31), The Pennsylvania Academy of Science, 1990.

Shuster, E.T, and White, W.B., "Seasonal Fluctuations in the Chemistry of Limestone Springs: A possible Means for Characterizing Carbonate Aquifers," Journal of Hydrology, 14, 93-128, 1971. http://dx.doi.org/10.1016/0022-1694(71)90001-1

Technical Notes on Drinking Water Methods, United States Environmental Protection Agency, October 1994.

United States Department of Health and Human Services, *Agency for Toxic Substances and Disease Registry*, Atlanta, Georgia, 1999.

U.S. Department of Health and Human Services-Public Service, *Martin County Coal Slurry Release, Inez, Martin County, Kentucky,* Atlanta, Georgia, p. 42, 2006.

Weast, Robert C., Ph. D., editor, *The CRC Handbook of Chemistry and Physics*, 51st edition, The Chemical Rubber Company, 1970 – 1971

West Virginia Bureau of Environment Quality Assurance/Quality Control Plan and Standard Operating Procedures for Groundwater Sampling, Division of Water and Waste Management, West Virginia Department of Environmental Protection, 2002.

West Virginia Title 38 CSR 2F, “Groundwater Protection Regulations [for] Coal Mining Operations,” June 1, 1994.

West Virginia Title 47 CSR 13, “Underground Injection Control,” August 25, 1993.

West Virginia Title 47, Series 2, “Requirements Governing Water Quality Standards,” July 1, 2008.

West Virginia Title 47, Series 30, “WV/NPDES Rules for Coal Mining Facilities,” June 1, 2004.

West Virginia Title 47, Series 58, “Groundwater Protection Rule,” June 1, 1994.

Windholz, Budavari, Blumetti, and Otterbein, editors, *The Merck Index: An Encyclopedia of Chemicals, Drugs, and Biologicals*, Tenth Edition, Merck & Company, Inc., 1983.

Wyrick, G.G. and J. W. Borchers. *Hydrologic Effects of Stress-Relief Fracturing in an Appalachian Valley*. United States Geological Survey, Water Supply Paper 2177, p. 51, 1981.