ARIES Research Summary

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January 3, 2019

Introduction

In the mid-2000s, concerns were raised about the impact of Appalachian coal mining and especially mountaintop mining. These concerns were prompted by various research studies that alleged a direct link between coal mining and various negatively trending aspects of community health. Some studies related coal mining to higher rates of cancer and infant mortality. Other investigations claimed that coal mining perpetuated poverty and harms community character. These alarming reports prompted a significant public outcry that resulted in litigation and regulatory attention toward the coal industry.

In response, a number of meetings and strategic sessions were held in 2009 and 2010 to address these concerns. Major Appalachian coal producers, coal associations, and essential coal infrastructure companies participated in these conferences. After rigorous debate, the participants decided to form an independent research program designed to address community concerns through objective, focused research. This program was designated the Appalachian Research Initiative for Environmental Science (ARIES). ARIES would be a research consortium designed to elicit the participation of major research universities across the U.S. The primary objective of this research collaboration would be to investigate the impacts of coal mining and energy production on Appalachian communities. To support this goal, ARIES adopted a research paradigm that delivered objective, robust, and transparent results though the support of industry. This paradigm was composed of four core principles:

1. Independent research conducted at universities
2. Wide dissemination of results through peer-reviewed publications
3. Realistic timeframes for research and reporting
4. Applying sound scientific principles

The Virginia Center for Coal and Energy Research (VCCER) at Virginia Tech was tasked to lead and develop ARIES to ensure transparency, independence, and diverse involvement. Upon inception, ARIES was financially supported by a multi-year commitment from industrial affiliate partners. These partners were Alpha Natural Resources, International Coal Group, Massey Energy, Natural Resource Partners, TECO Coal Corporation, Patriot Coal Corporation, Cliffs Natural Resources, Mepco, CSX Corporation, and Norfolk Southern. The resulting grant of $15 million was established by these affiliates to fund the ARIES program over the first five years. The ARIES program was announced publically on March 31, 2011. The announcement received immediate support from State governments including direct endorsements by the governors of five Appalachian states.

ARIES research encompassed four topic area categories: 1) Impacts on Ecosystems, 2) Waste and Water Management, 3) Environmentally Responsible Mining Technology, and 4) Health, Social and Economic Impacts. A brief description of each category is provided in the list that follows:

- **Impacts on Ecosystems** - Changes to habitat, water chemistry, and other environmental variables from human development have direct implications for upland and aquatic ecosystems. Although some seemingly minute stressors result in minor impacts when acting individually, cumulative impacts and interactions may result in dramatic ecological effects. ARIES researchers investigated both issues of concern as well as the more subtle, complex stressors that were suspected of affecting the ecological balance around energy production industries. For this area, the impacts, if any, of mining activity and other notable anthropogenic activities on the Appalachian ecosystem were evaluated. If any effect was either identified prior to research or elucidated from ARIES research, possible means for preventing or mitigating negative effects were also examined.

- **Waste and Water Management** - Concerns have been raised about the impact of mining operations on the chemistry of surface and ground water, especially implications for aquatic ecosystems and human health. The waste treatment methodology, placement of waste materials, and wastewater flow paths has been shown to affect surface and ground water. ARIES researchers expanded the current state of waste and water management methodologies by improving management principles and developing new water treatment methodologies/technologies. Additionally, ARIES researchers also addressed issues related to the prediction, impacts, and treatment of water chemistry concerns.

- **Environmentally Responsible Mining Technology** - Mining activities, like any large industrial or commercial project, generally result in significant disturbance of existing natural features. Research completed in this area examined techniques that would allow energy production industries to perform primary functions in a manner that improved the long-term sustainability of natural resources and geologic features relative to presently implemented methods. ARIES researchers investigated techniques and technologies that would allow mining activities to be conducted in a manner that minimized effects on air, water, and ecosystems.

- **Health, Social and Economic Impacts** - Among the most controversial issues related to coal mining in Appalachia are the alleged impacts on community health in the context of both economic and human health. In terms of the economy, allegations have long existed regarding the resource curse that accompanies mining, which implies mining perpetuates poverty. For human health, mining operations have recently been identified as possible causes for a range of diseases from birth defects to cancer. To address these concerns, ARIES researchers evaluated the impacts of coal mining on the Appalachian community. A variety of research approaches were applied, including standard epidemiologic, pathway analysis, and factor association techniques to determine specific causes, if any, for these issues.

Research institutions that participated in ARIES included Virginia Tech, West Virginia University, Marshall University, University of Kentucky, Ohio State University, Pennsylvania State University, University of Pittsburgh, the Edward Via College of Osteopathic Medicine, Consultants in Epidemiology and Occupational Health, Georgetown University, Johns Hopkins University, University of Virginia at Wise, and St. Francis University in Pennsylvania. Since 2011, ARIES researchers produced nearly 100 peer-reviewed publications in addition to numerous conference presentations and papers. The research involved more than 75 undergraduate and graduate student researchers, as well as 60 faculty and research associates. The chapters that follow contain an executive summary of key findings organized by research group within each research category. The researchers listed under each summary heading represent the Primary Investigators (PI) indicated in the proposals approved by ARIES. Each project may have also included a number of research associates and students that meaningfully contributed to the summarized research.

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Chapter 1

Impacts on Ecosystems

1.1 Impacts of Mining on Aquatic Ecosystems

Mindy Armstead, Marshall University

Mandee Wilson, Marshall University

Recent attention has been given to the effects of dissolved solids discharged as a byproduct of mountaintop removal mining in the Appalachian region. The complex nature of these materials exhibit varying levels of toxicity that may affect ecosystems. No Federal mandates for limiting sulfate mixtures or for implementing indicator parameters, such as total dissolved solids (TDS) and specific conductivity, are currently available. Conductivity, however, has recently been implicated as a cause of declining mayfly populations in Appalachian mining regions. The goal of this research project was to determine the impact of TDS on aquatic organisms with specific emphasis on investigating the effect of mine discharge on mayfly populations. The following section contains an overview of the various standalone research initiatives completed in support of this project. Each initiative will be overviewed individually to present research conclusions clearly and concisely.

Determining the level of TDS resulting in toxicity to aquatic organisms using whole effluent toxicity tests

The objectives of this study were to examine existing water chemistry data to determine the ionic composition of mine effluent dominated receiving streams in the region, to evaluate the available toxicity testing database regarding toxicity to *C. dubia*, to relate toxicity to discharge constituents, and to determine the level of TDS that is toxic to aquatic organisms. The results of this study showed little variability in conductivity at the majority of test sites. However, higher conductivities were seen during lower flow conditions within seasons. The monitored streams were dominated by the anion, sulfate, followed by bicarbonate

(measured as alkalinity) and then, to a lesser extent, chloride. The cations, calcium, magnesium, and sodium, balanced the anionic concentrations. **Overall, no relationship was apparent between conductivity and mortality over a conductivity range of about 100-3,000 μS/cm. No relationship was also apparent between maximum conductivity and reproductive impairment (IC25) in the range of conductivities tested. While a correlation could not be established with the NOEC endpoint, higher conductivities were associated with lower NOEC values. However, the average conductivity in the few tests with an NOEC of 12.5% was not dissimilar to those which generated no toxicity. This result likely indicates that factors not associated with dissolved solids were responsible for toxicity in these tests**.

Selenium uptake into biota

Recent attention has focused on the presence of selenium above the chronic water quality standard, 5 μg/L, in the coal mining region of Appalachia. The United States Environmental Protection Agency has proposed chronic tissue criteria and a significant effort is underway to develop state-specific tissue criteria in West Virginia. The objectives of this study were to support the development and implementation of fish tissue criteria by evaluating variability in selenium uptake and accumulation at three Appalachian mine sites. Minimization of treatment volumes through the identification of critical conditions for selenium uptake in the aquatic environment was also attempted. **The results of this study showed that water and periphyton selenium levels varied greatly throughout the year.** This variation was possibly due to precipitation, scouring, rock weathering, and/or sedimentation. **Benthic macroinvertebrate, crayfish, and fish concentrations were elevated in the spring and the summer when feeding was accelerated and more selenium-laden foods were accessible. The lesser selenium-influenced stream exhibited less variation in selenium tissue concentrations throughout the year. The reduced selenium concentration was likely caused by the organisms ability to regulate selenium levels at lower concentrations**. The research hypothesis for this study, that critical conditions for selenium uptake will occur under low flow conditions was not supported by study results.

Examination of TDS properties and their effect on aquatic biota

Numerous objectives were defined to examine the interaction of TDS with aquatic biota. These objectives included investigating the point at which TDS impaired aquatic biota and to define a point of comparison for impairment based on the data available in the ECOTOX database. Comparisons regarding the response of headwater communities and mayfly taxa exposed to simulated mine effluent to other mayfly taxa and surrogate test organisms were explored. The relative sensitivities of mayfly taxa resident in Appalachian streams to elevated

conductivities were also investigated. Finally, the investigators sought to expand the capabilities for laboratory testing of mayfly taxa beyond 10-day tests, which allowed sub-lethal endpoints (growth, molt, and emergence).

The results of this study showed that mayfly abundance in rock baskets were not significantly reduced under elevated conductivity conditions. However, a declining trend in mayfly abundance was qualitatively apparent. Differences in the test responses between the Ash Fork and Cox Fork sites may have been caused by variations in the mayfly species present at each sampling location. The dominant taxon of the Cox Fork site was *Stenonema sp.*, a Heptagenid, whereas mayfly abundance in Ash Fork was equally distributed between five taxa: Ameletidae, Baetidae, Ephemerillidae, Heptageniidae and Leptophlebiidae. Significant reductions in mayflies at 100 μS/cm was perhaps due to increased stress from a lack of ions essential for establishing osmotic equilibrium in a hemolymph. Lack of response in the 30 day sampling at Cox Fork potentially resulted from low abundance of mayflies at test initiation. Comparison of the mesocosm studies with laboratory endpoints showed that reproductive impairment of *Daphnia pulex* was similar to the response of mayflies in the 10 and 30 day Ash Fork tests.

Mayfly experimentation method development

Mayflies are declining in ecologically disturbed areas regardless of the disturbance source. Thus, the results of this research are applicable and transferable to any industry/sector that results in land disturbance, which includes residential and recreational development. The objectives of this study involved testing juvenile mayflies at sensitive life stages, comparing mayfly response with standard laboratory test organisms, investigating rearing chamber success for individual mayfly taxa, investigating reproduction among mayfly taxa and their ability to exhibit parthenogenesis, investigating dietary needs and preferences of mayfly taxa, and rearing newly hatched nymphs for use in toxicity testing. Method development for culturing and rearing of field collected mayflies was successful. However, the fitness of developed techniques for conducting acceptable toxicity testing with confidence was not demonstrated. This portion of the research is currently ongoing.

Evaluation of non-mining disturbance

The objectives of this study were to identify baseline biological, physical, and chemical conditions for undisturbed watersheds with 100% canopy coverage as well as to evaluate biological community conditions before, during, and after activities that caused 0–3% canopy loss in the watershed. Additionally, the investigators evaluated physical and chemical changes in the aquatic ecosystem and riparian area to determine whether a relationship existed with disturbance to the biological community. Baseline data for this study was collected starting in late June 2015 and continued until August 2, 2015. Approximately 0.35 acres of the watershed were timbered (about 0.4% of the entire watershed). The

results of this study showed that stream canopy cover did not change in response to the disturbance. However, a noticeable reduction in infiltration was observed. This behavior was evidenced by the base flow into the stream that followed the bank down gradient of the disturbance. **Conductivity increased at the disturbance site following timbering activity and quickly recovered to values close to the pre-disturbance conditions. However, these levels remained slightly higher at the disturbance influenced sites with respect to other monitoring locations throughout the sampling period.**

1.2 The Effect of Microhabitat and Land Use on Stream Salamander Occupancy and Abundance in the Southwest Virginia Coalfields

Sara Sweeten, Virginia Tech

Mark Ford, Virginia Tech

Large-scale land uses such as residential waste and coal mine discharge are of particular ecological concern in Appalachia. Identification and quantification of both large-scale land use and microhabitat alterations to ecosystems are a necessary first-step aid in mitigating negative consequences to biota. In central Appalachian headwater streams, salamanders are the dominant vertebrate predator and serve in a significant, intermediate trophic role. They are also considered sensitive to aquatic stressors and environmental alterations. Past research has demonstrated linkages among microhabitat parameters and large-scale land use, such as urbanization and logging, to salamander abundances. However, little information examining these linkages in the coalfields of central Appalachia is available. The focus of this research was to examine stream salamander response to coal mining compared to reference conditions for a variety of land use categories. In this project, the effect of coal mining on stream salamanders compared to other land uses, the correlation between stream salamander assemblages and habitat parameters at both a microhabitat and a landscape-level, and the use of stream salamanders as biotic indicators were examined.

In support of this research, salamanders were collected from 70 sites in southwest Virginia coalfields to quantify stream and riparian microhabitat parameters. Using an information-theoretic framework, the effects of microhabitat and large-scale land use on salamander occupancy and abundances were compared. **Findings from this study indicated that dusky salamander (*Desmognathus spp.*) occupancy and abundances were correlated more to microhabitat parameters, such as canopy cover, than to subwatershed land uses. Brook salamander (*Eurycea spp.*) abundances showed strong negative associations to the suspended sediments and stream substrate embeddedness**. Management implications of these findings include

the prevention and control of erosion as well as the protection and management of riparian habitats. However, quantifying physical environmental quality can be very difficult and time consuming.

1.3 Suitability of Abandoned Minelands as a Habitat for Cliff-Dwelling Salamander Assemblages

Walter H. Smith, The University of Virginias College at Wise

Robert VanGundy, The University of Virginias College at Wise

Recent concern surrounding the impacts of mining and mine reclamation activities on vertebrates has been centered on salamander taxa native to the central Appalachian Mountains. This concern largely stems from the salamanders overwhelming diversity in the Appalachian region, their central trophic roles in forest and stream food webs, and their function as the top predator in detritus-limited headwater streams. Salamander research has primarily focused on the impacts of mining and mine reclamation on aquatic and semi-aquatic salamander taxa found directly in headwater streams. Less emphasis has been placed on the impacts of surface mining and reclamation on terrestrial salamander taxa across this same region.

The biphasic life cycles of salamanders provide unique linkages between headwater stream habitats as well as adjacent terrestrial riparian zones and upland areas. As a result, salamanders are integral to understanding the impacts on ecological functioning of surface mining immediately after mineral extraction and throughout the reclamation process. Cliff-dwelling salamander taxa are of particular interest in the Appalachian region because their natural habitats are mimicked in physical structure by mine highwalls and other escarpments on mined sites, which are often located close to streams and riparian zones. At least eight salamander species have been recorded using such vertical cliff and bluff habitats in Appalachian forests as refugia, most known to alternate between these habitats and aquatic/semi-terrestrial stream and riparian habitats during various phases of their life cycles.

No work to date has been conducted to compare natural cliffs with mined cliffs to examine the potential suitability of mined cliffs as wildlife habitats. Additionally, no survey work has been performed to determine if and how cliff-dwelling salamander species may be utilizing mined sites as a habitat across the coalfield region. This information is important as State and Federal conservation agencies review the conservation status and level of protection afforded to cliff-dwelling salamanders. Recent work by the research team suggests that the rarity of salamander species has been vastly overestimated. As such, an investigation into the use of mined habitats is a crucial next step into understanding the ecology of terrestrial salamanders in the Appalachian coalfields region.

The following research study addressed the aforementioned deficiencies through

field comparisons and surveys. Research objectives included completing a comparative study of the structural habitat characteristics of highwalls and naturally-occurring cliff/bluff habitat on recently-mined and reclaimed sites against habitat characteristics of cliff/bluff systems known to harbor cliff-dwelling salamander assemblages at unmined sites. Sites with potential cliff-dwelling amphibian assemblages on mined lands were also identified. Biotic surveys were performed on these identified sites to determine the extent and scope of habitat use by cliff-dwelling amphibians. Concurrently, unmanned aerial vehicle (UAV) and multi-spectral imaging technology were adapted to perform wildlife surveys and habitat assessments on highwalls.

Contrary to assumptions about green salamander sensitivity to anthropogenic disturbance, the results of this research project revealed that populations of salamanders can and do persist on sites that have been heavily disturbed through surface mining activities. This ability seems to be facilitated by the preservation of local habitat features relevant to green salamander presence at mined sites. Sites with a similar structure to vertical cliff and bluff habitats surrounded by woody vegetation were particularly beneficial. Any original cliffs and bluffs remaining after surface mining also appeared to be a crucial habitat feature. This observation suggests that the preservation of original features and the restoration of native forest cover are critical to ensuring the persistence of salamanders on mined lands. In contrast, mined highwalls did not appear to be a suitable habitat replacement for natural cliffs, bluffs, and outcrops with respect to the examined salamander species.

Surface mining is expected to produce a net negative effect to the green salamander population because of habitat cover loss. However, results from this research suggest that mined areas of the central Appalachian coalfields present a reservoir of Green Salamander populations whose rarity had been overestimated. This underestimated salamander population has flourished because of the resemblance of some post-mining structural features to natural salamander habitats. Mining activities that preserved or restored the original structural features further benefited the green salamander, thus allowing the species to persist. Further work including both basic biotic surveys and population genetic studies is needed to address the integrity of these populations. Guidelines are also needed for the management of existing populations and the potential restoration of habitat connectivity between populations.

1.4 Investigating Influences on Benthic Macroinvertebrate Communities in Appalachian Coalfield Streams

Stephen Schoenholtz, Virginia Tech

Carl Zipper, Virginia Tech

In a number of recent studies, investigators found altered biotic condition in streams with watershed mining activity in the central Appalachian coalfields. Although strong correlations were found between specific conductance (SC), an indicator of total dissolved solids (TDS), and metrics for benthic macroinvertebrate community structure/composition (e.g. multimetric indices) in mining-influenced streams, causative factors affecting benthic macroinvertebrate communities remain unknown. Determining causality for observed patterns in ecological systems is often complex and challenging, a characteristic that is exacerbated by mining disturbances.

Appalachian surface mining and valley fills have been found to influence not only the chemical composition of headwater streams but also physical habitat factors, such as hydrology and sediment regime, with subsequent changes to channel morphology. These habitat factors have the potential to affect benthic community structure. As such, these factors warrant inclusion as possible confounding influences in an intensive approach to assess the relative impact of TDS on benthic communities. Direct toxicity of any dissolved compound on macroinvertebrates can be investigated through controlled experimentation. However, potential TDS and SC effects on benthic macroinvertebrate metrics must be investigated in-situ by careful measurement and evaluation of confounding factors.

This research addressed these deficiencies by examining relationships between SC and selected community structural response metrics. Research objectives included an assessment of benthic macroinvertebrate community structure along a gradient of specific conductance. This assessment was also conducted across seasons in streams influenced by Appalachian coal mining. The research was designed to identify environmental factors that were potentially confounding to previously observed associations of reduced benthic macroinvertebrate community structural metrics with TDS and SC. Field study streams included four reference streams and eleven mining-influenced streams along a gradient of increasing SC (electrical conductance standardized for 25°C) within a range of 14 to 1,900 μS/cm. Each of the test streams was equipped with a continuous conductivity logger.

Relationships between SC and selected community structural response metrics (i.e., density and richness metrics of Total, EPT, Ephemeroptera, Plecoptera, and Trichoptera) were examined. **Major determining factors of community structural metric responses to SC were found to be seasonality and dominance by seemingly SC-tolerant taxa in high-SC samples. The genus Leuctra in the order Plecoptera was an example of such a tolerant and dominant taxon. During months when this taxon was abundant, the response of Leuctra density to SC strongly determined the responses of the community in which it was a member. Ephemeroptera density and richness responded negatively to SC regardless of season.** Research results illustrated the utility of density in assessments of community structure responses to pollutants. Density data were found to provide accurate estimates of individuals for a given area. Thus, these data enabled a more thorough assessment of benthic macroinvertebrate community status than results from conventional fixed-count sampling techniques.

1.5 Managing Spatial Data

Michael Strager, West Virginia University

Accurate disturbance mapping is critical for modeling the environmental effects of surface mining activities. Previous studies attempted to link mine land disturbances to water quality have not been successful. These previous efforts did not accurately account for the extent and the variation in the disturbance that occurred within a permitted mine area. In order to address these deficiencies, spatial data to effectively classify and characterize the landscape were developed. Statistical analyses and modeling were also completed including the integration of geospatial technologies to collect, maintain, store, analyze, and output the data distribution. The main spatial data of interest for this project were land use changes and disturbances related to mining activity.

Primary research objectives included generating data that spatially and temporally classified all appropriate features to build robust cause and effect relationships. These data were also used to determine the degree of impairment to aquatic species critical in an aquatic ecosystem. Finally, additional capabilities were added to the Watershed Planner spatial decision support system that allowed the quantification of impacts from alternative landscape conditions. The overall goal of this project was to provide insight into the features and locations throughout a watershed that may contribute to impaired water quality and ecological conditions. The results of this research are a critical first step for later modeling and water quality analysis.

A methodology was developed to map disturbance in the coalfields of West Virginia using publicly available National Agriculture Imagery Program (NAIP) orthophotography. A traditional image classification method was not conducted because of compression, reduced spectral resolution, variable illumination, color balance inconsistencies, shadowing, and the high spatial resolution of the data.

Instead, a combination of object-based image analysis, GIS overlay of ancillary spatial data, and manual digitizing were incorporated to complete the mapping. This updatable and transferable approach relies on publically available imagery and ancillary GIS data to map landscape disturbance extents, which are not captured by currently available data. The south western part of West Virginia contains the majority of MTR/VF activity in the state. As such, these data provided the opportunity to assess the use of high resolution imagery for mapping a landscape that has experienced rapid forest loss.

Land cover data were extracted from true and color infrared NAIP imagery. These data were classified as forested, grassland, or barren using manually interpreted training data and the object-based image analysis program of Feature Analyst 5 by Overwatch. The object-based results were combined using a GIS rule-based overlay approach in which vector surface mine permit boundaries were utilized to differentiate landscape disturbance. The feature extraction and GIS overlay approach resulted in the following seven classes: Forested, Grasslands/Pastureland/Agricultural Land, Barren, Forested in Permit, Grass in Permit, Barren in Permit, Open Water. An assessment, accounting for both producers and users accuracy resulted in an overall accuracy of 92%, KHAT statistic of 88%.

For the size of the study area, the object-based results were considered adequate concerning classes obtained and overall thematic map accuracy for describing generalized land cover as forested, grasslands, and barren. Manually digitized data further augmented the object-based image analysis and GIS overlay results to map specific mining related features. Valley fill faces, which were of specific concern, were easily outlined in the imagery. Object-based image analysis of general land cover was shown to be a viable approach for describing disturbance in regional and watershed extents. Landscape data could be applied to modeling in-stream conditions at the watershed scale using recent imagery.

These modeling approaches were successful when using mine permit boundaries to define mine disturbance extents and applying manual digitization to refine the object-based results. The methodology developed by this project allows for publically available, high resolution, temporally appropriate data to be utilized in mapping a landscape that is experiencing accelerated disturbance and loss of forests. Additional research should focus on further differentiating vegetation types and utilizing digital elevation data for the extraction of valley fills.

1.6 Impact of Mining Effluent on Fish Populations

Serena Ciparis, Virginia Tech

Paul L. Angermeier, U.S. Geological Survey and Virginia Tech

Donald J. Orth, Virginia Tech

Mining effluent is known to have environmental impacts on waterways in which discharge is released. Recent studies have been broadly scoped to describe the overall ecological impacts of mining effluent rather than a focused sector. One such research area is the impact of mining effluent on fish populations. The fish responses along a gradient of mining intensity in the coalfield regions of the upper Powell River and the upper Clinch River watersheds in southwest Virginia were investigated in the following research project. The explicit project objectives were to 1) synthesize existing data on water quality, fish communities, and mining characteristics at a selection of previously studied sites; 2) quantify and qualify individual fish health/condition at stream reaches along a gradient of coal mining characteristics and associated in-stream conditions; 3) quantify population (i.e., age) structure and reproductive success for selected focal species at stream reaches along a gradient of coal mining characteristics and associated in-stream conditions; and 4) quantify fish community composition at stream reaches along a gradient of coal mining characteristics and associated in-stream conditions.

Data were collected and analyzed from 16 sites ranging from low to high mining impact. These data included water quality, physical habitat, fish community, and individual fish condition information. The Middle Creek test site experienced an extremely low flow period that dried some stretches of stream-bed between habitat sampling and fish sampling. This site was excluded from further analysis. An exploratory multivariate and correlative analysis was performed with the fish community, physical habitat, and water quality data. **In a hierarchical cluster analysis that characterized similarity in species based on occurrences at sites, species fell into two distinct groups: widespread species (e.g., *Campostoma anomalum*, *Rhinichthys obtusus*, *Etheostoma flabellare*, and *Semotilus atromaculatus*) and patchily distributed species (i.e., all others). Even as *E. flabellare* fell into the widespread species cluster, this species was absent from four of the five high-impact sites as well as from a single medium-impact site. In a cluster analysis describing similarity in study sites based on species composition, no strong correspondence between composition and the three mining impact classes was observed**.

Further interpretation of the fish community analyses should be paired with physical habitat and water quality data. Analyses in future reports will link these variables. Strong correlations were present between our mining gradient and measured specific conductivity and concentrations of HCO_3^-, Ca, Mg, Na, K, and SO_4^{2-}. The central focus for ongoing studies at the test sites will be to process biochemical samples of fish tissues. Additional field surveys focused on comparing the reproductive potential and distribution of *E. flabellare* will be conducted in the future.

1.7 Evaluation of Metrics for Assessing Stream Restoration Success and Failure in Mined Areas

Cully Hession, Virginia Tech

Nationwide, stream restoration is a multi-billion dollar industry in the U.S. that encompasses activities from simple tree planting to ecological re-configuration. Typically, the goals of a restoration project include improving water quality/habitat, managing riparian zones, and stabilizing streambanks. More intensive restoration activities can include rerouting streams and installing engineered structures for grade control, hydraulic manipulation, and aquatic habitat improvement. Despite the presence of an established stream restoration industry, post-reclamation assessments are rare. Evaluating success or failure of these activities is essential for gauging the impact of the restoration as well as for improving restoration techniques.

The following research project was designed to evaluate potential metrics for measuring the success or failure of stream restoration activities, particularly within the mining regions of Virginia, West Virginia, and Kentucky. The specific objectives of this project were to conduct a thorough review of metrics used for valuation of stream restoration activities in the U.S. and internationally, to develop a tiered assessment protocol for use in evaluating restoration projects, and to develop a pre-restoration planning tool to evaluate probability of a successful restoration. In this project, metric categories for evaluating post-restoration activities included biological conditions, chemical conditions, physical conditions, functional characteristics, in-stream variables, riparian variables, visual quality, sense of place, real estate value, and education opportunities.

Within each of these categories are innumerable variables that range across different temporal and spatial scales. Since 1990, more than 600 manuscripts were published related to "stream restoration assessment" with more than 50% published since 2010. A database for quantifying/categorizing the reviewed literature was developed that included basic information from each reference and detailed information regarding the applied metrics. This database composed the decision support system for evaluating stream restoration success in this project. Over 100 publications were analyzed for basic background information, such as

article citation, location and type of study, scale, impairment addressed, and restoration type. **The range and type of metrics used to assess success or failure of restoration activities were then examined to identify general metric categories. From this assessment, invertebrates (53%) were found to be the most popular organisms used for assessments with fish being second (26%).**

This research project is currently in-progress with additional publications and metrics being evaluated. Upon completion, a set of holistic metrics will be compiled and used to evaluate the success of a completed stream restoration project. These metrics will be used to form an assessment protocol for evaluating the success of projects as well as to provide a planning tool for determining the probable success of a proposed restoration project. Once developed, the proposed assessment protocol and pre-restoration planning tool will be tested by applying collected data on paired restored and unrestored reaches in southwest Virginia.

1.8 Conductivity and Stream Health

John Craynon, Virginia Center for Coal and Energy Research

This study focused on the health of the Dumps Creek watershed located in Russell County, VA, which has a long history of mining and industrialization. During this study, the historic and current relationships between total dissolved solids (TDS)/conductivity and benthic health in this watershed was explored using the Virginia Stream Condition Index (VSCI) as the rating for benthic health.

The research and findings, which are summarized below, were released in ARIES Technical Bulletin No. 1, published in March 2013. The primary conclusion in the bulletin was that both the historical and collected data in the watershed did not support a direct correlation between TDS and VSCI score. Subsequent to release of ARIES Technical Bulletin No.1, the U.S. Environmental Protection Agency (EPA) Region 3 provided its input on the bulletin and additional subjects related to stream health.

The EPA commented that VSCI scores evaluate the impacts of a number of stressors on stream health, not just conductivity, and are therefore not able to discern the impacts of any individual stressor. Additionally, EPA indicated that the use of its guidance in any given watershed should only be done when the full ionic chemistry of the stream is understood and is compatible with the guidance. Finally, EPA stated clearly that the issue of benthic macroinvertebrate community well-being is far too complex to be predicted or measured using only a single parameter, such as conductivity.

Based on the results from this work, the following findings can be highlighted:

1. The results of data collection and analysis in Dumps Creek showed no identifiable correlation between conductivity (as a measure of TDS) and VSCI score (as a measure of biological health of the stream).

2. While a general downward trend is exhibited between conductivity and VSCI scores, aquatic systems are far too complicated to predict stream health using a single parameter.

3. Water quantity and stream flow appeared to have a more significant impact on stream biological health than previously realized. Data collected suggested that a stream's bilogical health is improved by a constant water flow.

Chapter 2

Waste and Water Management

2.1 Mine Spoil Fills for Reduced Total Dissolved Solids in Discharged Waters

Carl E. Zipper, Virginia Tech

W. Lee Daniels, Virginia Tech

The effects of total dissolved solids (TDS) in waters discharged from surface mines are a growing interest in the Appalachian coal industry. This research project aimed to address some of the concerns regarding TDS discharge by developing, demonstrating, and assessing effectiveness of improved practices for constructing mine spoil fills. In order to accomplish this goal, specific conductance (SC), a frequently used proxy for TDS, water chemistry, and water discharge were monitored from valley fills at two coal mines. The strata at these field sites were comprised of hard, durable sandstone, which were used to construct core drains. Fill material were composed of low-TDS spoils considered suitable for use in valley fills.

The field site valley fills were categorized as either experimental or conventional. The experimental valley fills employed specialized spoil handling and reclamation techniques designed to reduce TDS levels in discharge. These techniques in addition to reducing TDS/SC in water outflows also reduced hydrologic alterations and restored forest plant communities during fill construction. The experimental-fill design procedures were intended to achieve a more rapid SC decline following reclamation and revegetation activities. Methods for TDS management included characterization of rock strata for TDS generation potentials, specialized handling and placement of high-TDS spoils, and construction of post-mining landforms intended to minimize interactions of high-TDS spoils

with environmental waters. The conventional valley fills implemented construction techniques commonly used in the mining industry.

Water discharged by experimental valley fills had SC levels well below conventional fills. However, SC levels from both experimental and conventional fills remained above both natural background level and levels recommended in studies of biotic thresholds. Both geochemical principles and other studies indicate that SCs of waters emerging from the experimental valley fills decline with time. However, re-vegetation had not yet been completed at the conclusion of this study. Thus, long-term SC outcomes were not evaluated.

2.2 Assessment of Weep Berm Effectiveness for Surface Mining in Appalachia

Richard C. Warner, University of Kentucky

A weep berm is an earthen berm constructed perpendicular to the direction of runoff along the perimeter of the mine near the lowest mined coal seam. These berms are designed to encapsulate the entire mine in a manner that allows temporary storage of runoff. The stored sediment and associated metals settle out of suspension before the water is slowly released through multiple highly permeable lenses to down-gradient areas. This process allows the passive treatment of mine runoff. Weep berms have the added advantage of being constructed from loose-dumped spoil thus reducing or eliminating the need for valley fills. Weep berms were introduced by the Surface Mining Institute, LLC in 2000 at a construction site near Atlanta, GA. Approximately 40% of this area was converted to impervious parking lot surfaces and roof tops. This preliminary project showed that the weep berms surrounding the development did not allow sediment to enter adjacent streams before, during, and after construction. As a result, the use of weep berms was expanded through a U.S. Environmental Protection initiative as well as through numerous voluntary applications at international mining and agricultural sites.

Expanding on these initial applications, the effectiveness of an in-field weep berm emplacement for mitigating surface mine runoff in Appalachia was investigated. An experimental practice was granted by the U.S. Office of Surface Mining for evaluating an engineered earthen weep berm system at the Middle Fork Development Corporation Mine in Magoffin County, KY. This experiment was designed to determine the environmental and economic improvements that could be realized by overcoming inherent deficiencies in current Appalachian runoff remediation methods methods. The experimental weep berm was anticipated to be more protective of the environment. As a result, the post-mining hydrologic regime would more closely match pre-mining hydrologic and water quality attributes, thus protecting the health and economic opportunities of down-stream communities.

The following benefits of employing weep berm technology are expected to be realized from wide-spread implementation by Appalachian surface mines:

1. Elimination or significant reduction in the number and size of valley fills and associated sediment ponds
2. No or minimal loss of streams through excess spoil placement in valley fills and therefore substantially reduced adverse environmental impacts and stream mitigation cost
3. Elimination of the requirement for an ACOE permit, if all valley fills are eliminated
4. Elimination of bench ponds resulting in a reduction in KPDES monitoring locations
5. Creation of the hydrologic regime (quality and quantity) during active mining and post mining that more closely mimics the pre-mining quantity and quality values both temporally and spatially
6. Significant reduction in flooding and water quality liabilities
7. Substantial reduction in mining and reclamation costs that allow for more profitable operations

Employment of weep berm technology would be a paradigm shift in the control and treatment of sediment laden runoff for the Appalachian coal mining industry. Instead of conveying runoff to central locations, such as bench ponds and sediment basins, for later discharge, runoff is passively dispersed throughout the entire perimeter of the mine site thereby maintaining the forest hydrologic functions. **Based on monitored data from the most representative streams around the experimental field site, the weep berm system proved to be successful in achieving electric conductance (EC) values that were substantially below U.S. EPA guidelines (500 μS/cm) throughout the course of this study**.

2.3 Prevention and Treatment Strategies for Environmental Issues Created by Water Discharge from Active and Abandoned Underground Mining Operations

Anthony Iannacchione, University of Pittsburgh

Section 516(b)(12) [30 USC 1266(b)(12)] of the Surface Mining Control and Reclamation Act of 1977 requires all new drift mines with acid-producing or iron-producing coal seams to locate openings in a manner that prevents gravity discharge of water from the mine. Hundreds of northern Appalachian bituminous coal mines have subsequently been developed, abandoned, and flooded to allow for an evaluation of acid remediation practices required by the 1977 Act. In the following research effort, 11 case studies produced from the aforementioned initiative were evaluated. Both successful and unsuccessful acid barrier case studies were included in the data. This project was undertaken to determine the characteristics of barriers (coal and strata surrounding the underground mine workings) that successfully and unsuccessfully prevented unplanned discharges from their associated coal mine pools and to reveal the main factors influencing the performance of these barriers.

Eleven underground bituminous coal mines in Pennsylvania were analyzed to determine critical factors for preventing unplanned discharges to surface waters. Mine maps, piezometer readings, core log data, water chemistry, and flow characteristics were examined from each case study site. The following three general classes of discharges were observed: horizontally through down-dip barriers containing coal and other fractured strata, vertically through overlying fractured strata barriers, and horizontally/vertically through a combination of fractured strata.

From this examination, eight conditions were identified as having the potential to decrease the probability of discharge through barriers:

1. Extraction ratio (Re < 0.7)
2. Hydraulic gradient (dh/dl < 0.1)
3. Hydraulic conductivity ("k" for coalbed and adjacent strata)
4. Overburden (h < 250 ft)
5. Geology (no significant discontinuities)
6. Location of critical hydraulic barrier (horizontal barrier above drainage)
7. Barrier thickness measurements (precise knowledge of barrier size)
8. Pool elevation (highest potential mine pool elevation)

In addition to identifying critical barrier characteristics, the results of this project established best-practice guidelines for designing bituminous coal mines barriers in the northern Appalachian coal basin to prevent unplanned discharges. For this task, experts from Rosebud Mining, Alpha Natural Resources, Mepco, and the U.S. Office of Surface Mining were interviewed to identify research topics for preventing and treating water discharge from active and abandoned underground mining in the northern Appalachian basin. One of the most significant environmental issues identified for the underground coal mining industries in western Pennsylvania, eastern Ohio and northern West Virginia, was the design of barriers in room-and-pillar mining operations.

2.4 Development of Methods to Predict and Manage TDS Production by Appalachian Mine Spoil Materials

W. Lee Daniels, Virginia Tech

Surface coal mines in the Appalachian region have faced a range of public and regulatory challenges over the past 30 years. These challenges include acid mine drainage, post-mining land use, and reach-of-stream losses from excess spoil valley fills. However, these issues have not threatened the long-term sustainability of the coal industry to the extent of total dissolved solids (TDS). Presently, pressures to reduce TDS in waters discharged into headwater streams are intense. These pressures were triggered by results from multiple studies that found altered aquatic communities in mining-influenced streams with elevated TDS. Thus, a clear need has emerged for industry, scientists, consultants, and regulators to develop strategies to minimize TDS release from active coal mines as well as techniques to predict long-term trends of TDS levels following mine closure.

The following research project addressed TDS discharge concerns through four research areas. The intent of this research was to develop new strategies and technologies for reducing TDS release. These research areas were (1) rapid lab prediction of TDS release potentials of overburden, (2) development of reliable field indicators to identify low vs. high TDS risk materials, (3) determination of the actual long-term pattern of TDS release from historic valley fills, and (4) implementation and verification/validation of new spoil placement and valley fill construction procedures to minimize TDS production. In the following section, an overview of this project including an analysis of current knowledge gaps and opportunities for improvement of mining practices to minimize TDS discharges are provided.

For this investigation, 39 bulk samples were collected from large active surface coal mines including five southwest Virginia sites, four eastern Kentucky sites, and three in West Virginia. These samples were categorized and then

analyzed to determine whether forced oxidation of sulfides and Fe + Mn species would improve column leachate prediction. A variety of neutralization strategies was also investigated to determine the neutralization potential and the resulting total net acidity produced by the applied techniques. A statistical analysis was also performed on the experimental results to determine leaching characteristics.

The results of this research indicated that mine spoils can be differentiated based on TDS production potentials using inexpensive laboratory procedures. Although the column-leaching procedures can provide a more robust characterization, static laboratory tests for pH, EC, and ABA are comparable and can be applied at greatly reduced costs. Hence, static tests can be used prior to or during mining disturbance as long as samples are tested when first exposed. **Results also revealed that certain principles might be applied as general field guidelines to discriminate non-acidic mine spoils based on TDS production potentials.** An overview of these guidelines is provided in the paragraph that follows.

First, non-weathered spoils will usually produce higher TDS than spoils that have been visibly weathered. Second, non-weathered fine-textured spoils (siltstones and shales) will often produce higher TDS than spoils that are more coarsely textured (sandstones). These guidelines were derived from analyzing a dataset from dominantly non-acid forming spoil samples as predicted by conventional ABA procedures. Although operational-scale applications of these TDS-reduction guidelines are limited, research examinations indicate that a successful reduction of water-discharge TDS levels below spoils are typical with conventional mine-spoil fill construction procedures.

Similar to the historical development and application of pre-mine acid-base-accounting for coal mine overburden, a new set of integrated procedures to identify and isolate high TDS producing materials was developed by this project. Findings indicate that a relatively simple combination of laboratory procedures (e.g., saturated paste or 1:2 water to soil specific conductivity (SC) and total-S) and field indicators (e.g., rock type and color) can be used to identify problematic TDS materials. This protocol may be implemented in improved mine-spoil fill construction procedures that isolate target materials from contact with surface runoff or percolating groundwater.

Based on the long-term analysis of discharge trends and assuming that excessive amounts of net acid-forming materials are isolated from valley fills, the SC of discharge waters for the vast majority of mining fills should decline to <500 μS/cm over time. This prediction may be nullified if pre-existing acidic seeps or other confounding factors are present. **However, some mine spoils may require several decades following mine closure for this reduction to occur.** These exceptions may additionally exhibit fill discharge SC levels at >300 μS/cm for an extended period.

2.5 Phase I: Gap Analysis for the Treatment of Mining Waters

Gregory D. Boardman, Virginia Tech

The Environmental Protection Agency (EPA) recommended in 2011 that the specific conductivity (SC) of discharged mine waters should fall between 300 μS/cm and 500 μS/cm. The EPA also suggested that mining operations include discharge- or watershed- specific data for conductivity, total dissolved solids, and selenium in evaluations. This recommendation was given in an effort to reduce the impact of surface mining activities on receiving streams in the Appalachian region. However, consistently meeting a SC limit of 500 μS/cm has proved to be a significant challenge for most mining operations.

In an effort to support the mining industry in achieving these EPA recommendations, a comprehensive literature review of mine discharge mitigation techniques was completed in this project. The review included an evaluation of methods, either in-practice or understudy, and all available technologies. The specific objectives of this project were to review EPA regulations concerning the specific conductance of Appalachian mining waters, to characterize the waters associated with Appalachian coal mining operations, to discuss available engineered and passive system options for water treatment, and to recommend promising treatment techniques for further investigation.

Literature in four primary areas was reviewed to understand how mining operations may meet EPA recommendations as well as to provide a framework for future research efforts. These areas were 1) Regulatory Framework for Coal Mining Operations, 2) Water Quality Characteristics from Surface Mines, 3) Passive Treatment Processes, and 4) Active Treatment Processes. The results of this review showed that waters discharged from mining operations exhibit highly varying SC levels. As such, mitigation techniques may need to be defined in a site-specific manner to meet the recommended SC limit of 500 μS/cm. Mining impacted waters in the Central Appalachian coal region do exhibit some general characteristics such as high levels of sulfate, calcium, magnesium, and bicarbonate that contribute to high levels of SC and TDS. However, treatments plans still require customization even in this context because water quality parameters in individual streams are contingent on site-specific factors. These factors include the mineralogy and geochemistry of the mine spoil, the amount of weathering that has taken place, and the amount of precipitation (i.e., "wet" season versus "dry" season).

As with any industry, an understanding of where and how contaminants originate must first be gained in order to identify the best practices for managing discharged contaminants, such as optimizing water containment and water discharge locations. This review showed that activities used to obtain necessary background knowledge, such as identifying and collecting waters requiring treatment, can be an especially challenging and expensive undertaking. **Both passive and active methods are available once site evaluations are**

completed. Passive treatment processes were best implemented in a series of unit operations, each with a focused treatment and contaminant objective. Since the characteristics of mining influenced waters vary greatly from site-to-site, unit operations for passive TDS removal require customization. Models describing TDS removal mechanisms in passive treatment processes are not well understood thus making the passive removal of TDS more challenging. In contrast, models describing removal mechanisms in active, engineered water treatment systems are better developed.

Among the most promising and practical active treatment systems are chemical precipitation, ion exchange, granular filtration, membrane technology, and biological treatment (sulfate reduction) technologies. Recent developments in the areas of ion exchange (coated zeolite) and precipitation (production of ettringite) are especially promising. However, none of these active techniques is intended for standalone use but rather in some combination of unit operations. For example, chemical precipitation would need to be followed by solids separation and ion exchange columns would require that waters be pretreated. Based on this review, the best system for treating mining waters at many sites is comprised of optimized management practices (for solids and water) in combination with tailored passive and active treatment systems.

2.6 Phase II: Gap Analysis for the Treatment of Mining Waters

Gregory D. Boardman, Virginia Tech

In recent years, the excessive specific conductance (SC) of runoff waters from Appalachian coal mining activities has become a parameter of concern with the EPA because of its relationship to negative effects on aquatic life and water quality. This study was performed to evaluate the capacity of various treatment methods to meet the proposed guidance limits by the EPA. Runoff water was collected from two sites in southwestern Virginia and characterized to determine the contributors to SC in the water. The main contributing ions were determined to be Na^+, Mg^{2+}, Ca^{2+}, $HCO_3{}^-$, and $SO_4{}^{2-}$.

Among the treatment methods investigated in this study were membrane technology, biological sulfate reduction, ion exchange, excess lime-soda softening, and the Cost Effective Sulfate Removal (CESR) process. Experiments were also performed to assess the possibility of using the speciation software, MINEQL+, with a set of empirical equations to predict SC using the ionic composition of the waters.

Three different nanofiltration membranes were evaluated: NF270, DK, and NFX. The DK and NFX nanofilters were able to reduce SC levels by an average of 84% for both mining waters tested and were able to reach SC levels below the proposed limit of 500 μ/cm. The SC levels achieved by the NF270 nanofilters were more variable. The inclusion of microfiltration and simulated-sand filtration were also introduced as a pretreatment to determine if they would improve nanofiltration performance.

In the biological sulfate reducing experiments, multiple bioreactors were established to identify the optimal organic mixture to foster both SC and sulfate reduction. Sulfate reduction began to occur after approximately 20 days. SC levels were greater than 13,000 μ/cm in each of the bioreactors by day 40. Future work in this area should include more sampling in the early phases to better define when water quality changes will occur.

With regard to ion exchange, both cation (H^+ exchanger) and anion (Cl^- exchanger) exchange media were tested separately in batch reactors, which resulted in an increased SC. Excess lime-soda softening also resulted in increased SC levels, which, in part, was due to non-carbonate hardness levels being high and carbonate concentrations being low. As a result, the addition of carbonate ions was needed. **The CESR process successfully lowered SC from 1,500–2,500 μS/cm to below the proposed EPA limit of 500 μS/cm. The success of this process was due to its ability to remove more than 85% of the calcium, magnesium, and sulfate from the water, which together accounted for more than 90% of ions in the source water.**

2.7 Evaluation of Potential Biological Treatment Design Options to Reduce Conductivity in Mine Discharges

Leigh-Anne Krometis, Virginia Tech

Tess Thompson, Virginia Tech

William Strosnider, Saint Francis University

Current regulation of mining discharges is increasingly focused on measures of specific conductance (i.e., SC) in receiving waters as a proxy for the potential degradation of downstream aquatic ecology. Debate as to a level of conductivity that is inherently harmful persists. Although several investigators have observed decreased benthic macroinvertebrate abundance and diversity in Central Appalachian watersheds at SCs greater than 300 μS/cm, laboratory studies have observed no change in the survival and reproduction of a wide variety of species at levels greater than 1,000 μS/cm. Regardless, the mining industry is under increasing pressure to comply with conductivity guidelines defined in the Clean Water Act. At present, acceptable water treatment technologies that reduce conductivity are expensive to acquire and maintain. Biological treatment systems present a potential cost-effective alternative.

Biological designs (e.g., wetlands, vertical flow bioreactors) rely on passive technologies and are thus less expensive in general. Such systems have been used to remove a variety of contaminants from mine waters, but their potential to reduce conductivity remains relatively unexplored. The overall goal of this research project was to conduct a comprehensive review of the literature to evaluate the potential usefulness of passive, biologically-based designs in reducing the conductivity of mine wastewaters. In parallel with this literature review effort, a study to identify and investigate currently installed wetlands, or similar biological treatment systems, in Pennsylvania and Virginia was also conducted. The results of this later study was intended for future analysis of underlying biological mechanisms to inform design recommendations.

The literature review effort used general searches for terms such as "mine water," "passive treatment," "acid mine drainage," "biological treatment" and "conductivity" in various combinations. While a number of articles noted that specific conductivity measurements were collected alongside pH and temperature measurements, these data were rarely presented. Only nine publications in peer-reviewed journals covering the treatment of mine wastewaters were identified that included conductivity performance data. In order to supplement this handful of articles, additional proceedings from the International Mine Water Association (1980–2014) and the American Society for Mining and Reclamation conferences (1980–2015) were included. From this review, an additional 13 studies were added to the peer-reviewed journal articles. **The collected literature suggests that the performance of passive biological treat-**

ment systems (i.e., bioreactors and wetlands) in reducing conductivity is highly variable. However, sulfate dominated systems exhibited a 30% decrease in conductivity, which is near the maximum reduction magnitude predicted by stoichiometry. Sulfate reduction results in the production of two moles of bicarbonate for every one mole of sulfate reduced, which is shown by the following equation:

$$SO_4{}^{2-} + 2\,CH_2O \rightarrow H_2S + 2\,HCO_3{}^{-}$$

Since bicarbonate also contributes to conductivity, the reduction in conductivity that can be achieved through sulfate reduction alone is limited. The theoretical decrease in conductivity from sulfate reduction can be calculated for the range of sulfate concentrations typically found in mine wastewater (0.001-0.025 moles/liter of $SO_4{}^{2-}$) using the recently validated approach by McCleskey et al. (2012). This method predicts that replacing all sulfate ions with bicarbonate ions in a 1:2 molar ratio would result in a reduction in conductivity of 27% to 37% over the indicated concentration range. However, as the pH decreased below 6.3, bicarbonate produced through sulfate reduction reacts with hydronium ions to form dissolved carbon dioxide and carbonic acid, which can further reduce conductivity. The reaction of iron and other hydrolyzable metals with sulfide to form metal-sulfide precipitates may also reduce conductivity. **As a general theoretical estimate, conductivity reductions of approximately 33% are possible for biological treatment systems, which agrees with the upper range of observed conductivity reductions reported in the available literature.**

Chapter 3

Environmentally Responsible Mining Technology

3.1 Strategies for Improving Water Quality while Enhancing Dewatering Performance

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The dewatering cycle in the coal mineral processing process requires a significant amount of energy and discharges a large volume of waste. Of the many dewatering techniques applied in the coal industry, pressure filtration is commonly used before other more energy intensive techniques, such as kiln drying. The objective of filtration is to maximize both liquid removal and solid recovery. Pressure filtration involves the separation of solids from liquid using pressure, which is typically produced by pumping the slurry into the filter chamber. Mechanical or air pressure may also be used, depending on the type of filter being applied. The dewatered solids are retained as a filter cake on a porous filter medium. For practical purposes, a moisture-free cake and a solids-free filtrate is not possible with current technologies.

Filtration has traditionally been used by the coal industry as a dewatering solution. As a result, the clarity of the filtrate is often a lesser concern. In the following research project, the effects of operating conditions on the performance of pressure filtration and the ability of mineral-based additives to capture dissolved metals produced during filtration were examined. The objective of this examination was to elucidate strategies for improving discharge water quality while enhancing the performance of the dewatering process. The specific optimization goals were to reduce water usage, improve dewatering, and improve water quality in coal cleaning facilities. Dewatering testing was done

in combination with mineral-based additives applications. The tested additives previously demonstrated an ability to trap many undesirable heavy metals.

The results of this study indicated that the settling rate was affected by pH. The effect of pH was, however, reduced when the amount of additive was changed at a given pH value. In general, the settling rate was primarily affected at the highest additive concentration (20%) because of the effects of hindered settling. Turbidity measurements indicated that the low pH slurry had the lowest turbidity. Although this slight relationship was observed, turbidity values tended to be highly variable.

A slight improvement in the filtrate recovered was realized at higher pressure over the range of pH values considered. However, the filtration rate was significantly higher when using the lower pH slurry. These results are consistent with other test results (i.e., lower pH slurries filtered at a higher rate). The turbidity values of the filtrate samples were very low in all cases as essentially all solids were recovered in the filter cake when using sharkskin filter paper.

Iron leached from the slurries with a lower pH. The leaching occurred over the course of slurry preparation and pressure filtration (about 90 minutes). Minimal leaching occurred when using slurries prepared at neutral pH values. **Tests at the lower pH values produced higher filtrate volumes, lower cake moistures, and shorter filter times.** These results are consistent with those obtained from the previous bench-scale pressure filtration tests.

Based on these experimental results, the performance of pressure filtration was found to depend on both the characteristics of the feed material as well as the operating conditions. Because of this interaction, the aforementioned relationships were observed but not concretely deduced. Additional testing is needed to provide a more detailed understanding of the effects of these variables. Testing is currently being conducted to develop an empirical model, which may be used to describe the performance of pressure filtration when dewatering coal refuse slurry. In addition, testing is continuing on the use of additives in conjunction with filtration to capture and sequester heavy metals from recovered filtrate.

3.2 Impacts of Blasting and Excavation

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Blasting and excavating are integral unit operations in the majority of surface coal mines. These operations also have a significant impact on the surrounding environment. This project dealt with environmental impacts of blasting with respect to coal mine reclamation. The main thrust of the work was focused on the concept of Mine-to-Fill in which blasts are designed to produce optimum fragmentation size and distribution to minimize environmental effects.

Research objectives included the determination of dust bioavailability produced at a typical West Virginia surface coal mine and the characterization of NOx gas production from equipment and blasting at surface mines.

To accomplish these goals, unitized systems were developed to accommodate each composition, median fragment size, and distribution required for fill construction. A cost/benefit analysis was performed for sub-optimum materials to determine their effect on fill construction. Specifications that were unattainable through blasting techniques required mechanical excavation or bench-level processing and sizing. Blasting and excavation impacts were investigated in a piecewise manner because of site access and scheduling constraints. As a result, experimental conclusions are presented in an itemized manner to present the major findings of this research.

A detailed survey of blasting practices and NO_x emissions was completed for the Appalachian region. Unfortunately, no consistent control blasting practices could be identified, which prevented the specific examination of the most effective options. For the NO_x characterization, a single surface mine that resembled the average Appalachian mine was used as an analog. **Results showed that 877 tons (966 short tons) of NO_x per year were emitted from the mine. Haul trucks, blasting, front-end loaders, and bulldozers contributed to the total NO_x emissions by 44.69%, 22.25%, 13.37%, and 13.29%, respectively. Graders, drills, water trucks, and hydraulic shovels contributed 6.4% of total NO_x emissions.**

Environmental impacts from blasting are traditionally related to the control of vibration, airblast levels, and flyrock. A conceptual downstream cost analysis of the blasting activity was used to evaluate these impacts. Fragmentation was a key analytical element because of overburden material use throughout the mine process for reclamation and fill purposes. Environmental impacts of the earth fills in coal mines are directly related to the properties of material used for the fills. **This examination produced a framework for recommending materials that may be used in surface coal mines. A matrix of specifications was developed, which allows for future optimization of overburden handling with consideration for blasting parameters using finalized specifications.**

The results of the dust-specific portion of this research indicated that the field site was within the bounds of acceptable mining practices under the meteorological conditions encountered during the study period. **The dust generated from the active West Virginia coal mine did not account for a majority exposure to constituents that could potentially result in health effects**. Rather, default USEPA values for calculating ingestion exposure suggest that everyday residential exposure to native WV soil may account for more than 70% of the total exposure to the 18 constituents quantified in this study. **Further, direct respiratory risk from Cd, Mn, and SiO_2 did not reach levels that would require remedial action.**

3.3 Solid Waste Segregation, Treatment and Disposal

Rick Honaker, University of Kentucky

The waste byproducts of coal cleaning can contain minerals that may potentially have impacts on the environment. Identification, removal and isolation of problem minerals using separation techniques may prevent the development of these impacts. Conductivity of discharged mine water has recently been the subject of regulatory scrutiny. Research was conducted in this project to understand the effect of various parameters on conductivity in an effort to develop a quick, inexpensive test for material screening to address regulatory concerns. Studies conducted in this project included examining the effect of surface area, volume-to-surface area ratio, and the amount of oxidant on the electrical conductivity of the leachate generated from contact with coal refuse. Given the scope of these research objectives, a number of separate, standalone sub-projects were used to investigate mine waste at the selected field sites. As a result, experimental descriptions and results will be addressed in an itemized manner.

A three-level parametric study was used to develop empirical models that quantified the effect of the tested parameters on conductivity. Based on the results from the parametric study, a standard test was developed for a conductivity screening test (CST). This new procedure more accurately assesses the environmental sensitivity of a given material/fraction, thus identifying areas of potential need for separation and isolation processes.

Conductivity screening tests were used to quantify the electrical conductivity (EC) of slurries from preparation plant waste streams as a function of material properties. Leachate derived from coarse refuse streams were found to have conductivities much higher than fine refuse streams. Using a constant water volume-to-surface area ratio of 1:1, the order of electrical conductivity from highest to lowest was found to be dense medium vessel reject, dense medium cyclone reject, high frequency overflow, fine reject stream, and finally, thickener underflow.

Based on the conductivity screening results, coarse waste streams were further analyzed to characterize constituents that would have a negative impact on the environment. **These focused tests found that less than 5% of the material would be the source of environmental issues in terms of impacts derived from total dissolved solids and electrical conductivity. Dynamic leaching column tests suggested that the pyrite content was the primary cause of acid generation and subsequent release of trace elements to the effluent. Based on these results, liberation and separation followed by isolation of the target fraction would reduce the conductivity of the discharge significantly.** Subsequent co-disposal of the remaining coarse refuse with fine refuse streams was found to further buffer the supernatant water using the self-buffering capability of the fine refuse stream. Results obtained from similar acid neutralization tests were consistent with the

conductivity screening test in this study.

To develop strategies that minimized the conductivity level of discharged water from coal refuse, long-term leaching characteristics of refuse streams were examined as a function of particle specific gravity (SG). **The results showed that crushing the material to a 6.25 mm top size followed by removal of material with a S.G. >2.68 from the coarse refuse of low pyritic coal reduced the conductivity to <500 μS/cm.** The material in the 2.68 SG sink fraction represented 1.6% of the total waste. For the high pyritic northern Appalachian coarse refuse sample, the 2.95 SG sink material represented 4.4% of the total refuse material. The same treatment used for the 2.68 SG material resulted in a decrease in conductivity from 3,834 μS/cm to 1,508 μS/cm. Additional exclusion of the 2.68 x 2.95 SG fraction, representing 0.5% of the total material, resulted in a further 6% reduction in conductivity. The mineral liberation effect for the high EC generating fraction was assessed by crushing the high pyritic coarse refuse material to a top particle size of 1 mm prior to separation. In this case, the segregation and isolation of the high density fraction (SG >2.68) constituting 5% of the waste material resulted in an EC reduction from 3,834 μS/cm to 794 μS/cm.

The identification, separation, and isolation methods identified in this project could significantly reduce downstream physical or chemical treatment costs. The density separation required for separation and isolation of the highest density fraction in the refuse streams can be easily achieved by modifying the coal processing plants to treat refuse material prior to disposal. Based on the findings of this research, the leaching characteristics of refuse materials can be improved by 1) adding mineral spirals to the coal cleaning plant to treat the spiral refuse stream, 2) crushing the coarse and intermediate size fraction circuits (dense medium vessel and dense medium cyclone) to the suggested top sizes, and 3) rejecting the high density fractions through the use of density-based separators.

3.4 Developing Eco-Friendly Mining Systems

Vladislav Kecojevic, West Virginia University

Surface coal mining in the Appalachian region faces many regulatory challenges covering a variety of issues. Increasing public and regulatory pressures require the mining industry to focus on minimizing the environmental impacts of coal operations. In order to achieve this goal, design features and practices able to reduce environmental impacts while maintaining or lowering cost are needed. The objective of this research project in surface mining was to investigate a variety of mining systems to improve current surface mining practices and to reduce negative environmental impacts from overburden and coal removal. Concurrent with this effort was the quantification of exhaust and dust emissions along with sound pressure levels produced by mining equipment. A comparative analysis of dust emissions for digging and loading equipment at a West Virginia surface

coal mine and at a coal train loading facility was also completed.

The mining system portion of this project compared conventional surface mining methods (i.e., drilling, blasting, digging, and loading) to a Surface Miner (SM) method. An Analytical Hierarchy Process (AHP) was applied to help select the optimal mining method based on production, cost, and environmental criteria. A software tool for determining the impact of loading equipment based on the aforementioned criteria was developed. Loading equipment included rope shovels, front hydraulic shovels, backhoe shovels, and front-end wheel loaders. Environmental impact investigations included examinations of particulate matter (PM10), total suspended particulate matter (TSP), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), volatile organic compounds (VOCs), and sound pressure levels.

To determine the impact of the mining equipment, three interrelated modules were developed using the Microsoft Visual Studio.NET environment. Module I determined production parameters. Module II considered different components of ownership, operating costs associated with loading equipment, and the total operating cost. Module III determined the environmental impact of loading equipment, which included dust, exhaust, and sound pressure.

The results of these studies indicated that the SM mining method is the better option. SM was also found to be the most economical choice for the extraction of bituminous coal. As SM is far less expensive than the conventional extraction method, a crushing unit could be added if necessary and still remain the more economical option. The accompanying sensitivity analyses showed that optimizing the mining method is dependent on environmental factors. The combination of the results produced by the cost and production analysis with the AHP will inform future decisions about selecting the optimal method.

Various upgrades are available to reduce exhaust emissions from mining equipment. Reducing engine idling is one effective strategy for reducing exhaust emissions. For example, equipment operators may help reduce the air pollutants in working environments by turning off equipment engines when not in use. In planning day-to-day activities, mines may save on fuel costs by taking steps to maximize equipment use and minimize idling time. Using cleaner fuel may also be used to reduce exhaust emissions.

Based on the results of this study, it was observed that the application of SM would benefit surface coal mining operations in West Virginia. These benefits included 1) lower costs of coal extraction when compared with conventional mining unit operations; 2) improved selective mining where thin coal seams, overburden, and inter-burden are mined separately to prevent dilution of coal; 3) generate an even grade of coal which that reduces costs from further processing; and 4) environmentally friendly attributes. The negative aspects of using SM are a lower production rate when compared with conventional mining units, and a high operating cost or inability to work in rocks with a very high value of unconfined compressive strength of overburden/interburden material. Among the limitations of this research were the absence of haulage (specifically haul trucks) and dragline considerations as a digging and a disposal mining unit, respectively.

3.5 Improved Mining Systems

Michael Karmis, Virginia Tech

Zacharias Agioutantis, Virginia Tech

The development of rigorous ground deformation prediction methodologies for assessing mining impacts on surface structures and facilities is important for subsidence control. A number of techniques have been developed and validated using measured deformations (e.g., vertical and horizontal movements, ground strains, etc.), over mined panels. This task can be extremely complex because of the number and the nature of the parameters affecting ground deformation. Subsidence parameters, surface morphology, mine plan, coal structure characteristics, rate of mining, overburden lithology, and the type of surface facility to be protected must all be considered in the analysis.

The Surface Deformation Prediction System (SDPS) is a software package widely used by the U.S. mining industry as well as by State and Federal agencies for subsidence planning, prediction, and control. Initially developed over 25 years ago from an integrated research effort at Virginia Tech, the SDPS package has been continually updated with the incorporation of new analysis features. SDPS has evolved into a versatile prediction tool that can handle complex tasks, such as including multiple calibration routines, dynamic subsidence evaluation, and long-term subsidence effect estimation. Recently, the effect of sloping terrain in the prediction of horizontal displacements has been incorporated. This feature allows for accurate three-dimensional predictions of deformation vectors over undermined areas in hilly or mountainous terrain. Despite the considerable capabilities of SDPS and the advancement of rock mechanics research, aspects of ground deformation prediction from underground mining must still be addressed. One such issue is the interaction of several factors and the importance of calculations to assess and manage possible environmental impacts from underground coal mining.

The main goals of this research project were to 1) develop the applicable methodology to address some critical issues in ground deformation prediction (e.g., subsidence calculations in sloping terrain, strain calculations under variable terrain conditions, ground deformation calculations along linear surface water bodies, and estimation of potential surface impacts to surface areas protected by barrier pillars), 2) to enhance and update the windows based software package (SDPS) used for such calculations with these new technologies, 3) to prove the applicability of this technology by application to actual case studies, and 4) to verify regional subsidence engineering parameters in other coalfields and more specifically for the Illinois basin.

Several methodologies were developed from this project that allowed users to further investigate and analyze critical ground deformation issues. All of these enhancements have been implemented in the SDPS software. Thus, the current SDPS iteration is updated with functions for the calculation of subsidence and strain for areas of varying topography. Functionality for calculating

ground deformation indices along linear surface bodies of water has also been added. Additionally, innovative strategies that can be utilized for the analysis of potential impacts to surface areas protected by barrier pillars were developed. These techniques may additionally be applied for the verification of regional subsidence engineering parameters for the Illinois coalfields. **Through the validation of software, tools, and updates with respect to actual case studies, the enhanced ground deformation prediction abilities of the SDPS software allow users to make better and more informed decisions on environmental practices in planning coal mining operations**.

3.6 Waste Residual Diesel Range Organics and Selected Frothers in Process Waters from Fine Coal Flotation

Emily Sarver, Virginia Tech

Modern coal preparation facilities incorporate a wide array of solid-solid and solid-liquid separation processes to meet market specifications. After crushing the run-of-mine coal, raw materials are treated in different particle size fractions within coal preparation plants. Coarse, intermediate, and fine sized particles are separated based on gravity, and ultra-fine sized particles are separated using chemical reagents (i.e., froth flotation), such as collectors. Most collectors are now derived from crude oil, which is a more environmentally friendly alternative, but they still contain a small amount of aromatics.

Diesel, developed from the fractional distillation of crude oil, is currently the most commonly used collector for coal flotation. Because of the complexity and variability of diesel, characterization is difficult. Broad categories are typically assigned to the diesel range organics (DRO). Saturated hydrocarbons (e.g., alkanes, cycloalkanes) usually compose about 90% or more of diesel by weight, whereas aromatics (e.g., naphthalenes, acenaphthenes, acenaphthylenes) make up about 10% or less. In small volumes or concentrations, saturated hydrocarbons are not typically considered an environmental concern because they tend to break down easily and are relatively non-toxic. However, the aromatics, specifically polycyclic aromatic hydrocarbons (PAHs), may be harmful even in small volumes or concentrations.

The environmental fate and transport of processing reagents has been scarcely examined. Collectors are generally expected to substantially partition to coal products because their chemistry promotes sorption to the coal particles. Any collector that does not sorb may remain with water floating on the water surface, as an emulsion, or as a dissolved species. Frothers, however, are not expected to sorb to coal and thus should follow water streams. Fate and transport of partitioned reagents are thus heavily dependent on the tailings disposal conditions.

Tailings are commonly disposed above ground in impoundments or ponds to allow the solid particles to separate from the liquid. A portion of the separated

water is released to the environment through evaporation, engineered discharges (i.e., through decant structures or spillways), or percolation to the subsurface. If reagents or reagent by-products are present in impoundments, water releases could possibly result in an interaction with the environment (e.g., via release into surface waters, seepage into underlying soil, or vaporization to the atmosphere). Other possibilities include photo- or biodegradation of an agent within the impoundment (e.g., methyl isobutyl carbinol (MIBC)), or sorption to soils beneath the impoundment (e.g., diesel).

Even reagents that partition to coal products can be released into waterways unless they volatilize during handling and transport. After the processed coal is combusted, byproducts of the reagents may enter the atmosphere as either gaseous or particulate emissions. Additionally, reagents or combustion by-products of reagents might become part of the solid fly ash (i.e., waste from coal combustion) and are eventually disposed (e.g., in landfills). Following atmospheric deposition or disposal of fly ash, coal processing reagents or their by-products could move through terrestrial and aquatic ecosystems through hydraulic or biologic transport processes.

The following research project examined the fates of processing reagents in coal preparation plants. The goal of this project was to investigate the movement of processing reagents in the coal preparations cycle as well as to characterize the environmental impact of any released reagents to waterways. Several aspects of this issue were addressed, including the partitioning of frothers, collectors, and PAHs between coal particles and water, the desorption of DROs/PAHs, the fractioning of DROs/PAHs in solid and liquid phases, and the environmental impact of coal cleaning reagents.

To examine partitioning of reagents in coal preparation streams, raw coal and flotation feed samples were obtained from various Appalachian preparation plants. Partitioning studies were carried out to obtain preliminary data on the potential fates of common frother and collector reagents used for fine coal flotation. The frothers were MIBC, polyoxyl sorbitan monolaurate (PSM), Dowfroth M150, and Nalco 8836. The collector was diesel fuel. For each test, a slurry sample was prepared by adding the required weight of raw coal to distilled water followed by the required volume of reagent. Slurries were mixed for a specified contact time, and then the coal particles were separated from the water by either centrifuge or filtration. Finally, the water was analyzed for residual reagents.

Results of this study showed that frother and collector reagents are not likely to partition completely to a single fraction of the process slurry. Further work demonstrated that sub-ppm levels of DRO dominated by the water soluble fraction of diesel are expected to be present in process waters. However, PAHs and insoluble DRO may be removed using volatilization and/or degradation. DRO and PAHs are also expected to desorb from coal particles when in contact with fresh water. Flotation tests have revealed that low levels of DRO were found in both the concentrate and tailings processing streams with slightly higher concentrations being found in the concentrate stream. **From the tests per-**

formed, no apparent environmental concern was discovered with coal preparation plants operating under normal conditions.

Chapter 4

Health, Social and Economic Impacts

4.1 The Mining Industry and its Relationship to Community Well-Being

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The objective of this research was to address the impacts of the mining industry on community well-being in terms of 1) how the mining industry influences Appalachian communities, 2) how do the effects of the mining industry on Appalachian communities compare with other U.S. regions, and 3) what factors distinguish the discrepancies in socioeconomic outcomes between some coal mining communities. These research topics were investigated by analyzing data collected from government secondary sources including the Census of Population, the American Community Survey (ACS), the Bureau of Economic Analysis/Regional Economic Information System (BEA/REIS), and private vendors, such as Economic Modeling Specialist, Inc. (EMSI) from 1990–2012.

Community well-being was measured using social science indicators. Two categories of indicators, coal mining and socioeconomic, were used to evaluate the data. Within the coal mining category, two sets of indicators, employment and the presence of mountain-top mining, were used. Socioeconomic indicators included per capita income, median household income, poverty, income inequality, employment growth, unemployment, population growth, disability rates, etc. Several relationships were drawn for this analysis in the context of the aforementioned topics.

Results indicated that coal mining tends to have a positive effect on community well-being in terms of decreasing poverty, increasing median household income, and decreasing unemployment than other industries in Appalachia. However, as expected, some exceptions are present in the data. Appalachian coal communities, when compared to other comparable U.S. regions, were not significantly different in terms of economic indicators. The mixed results suggest that coal mining, although influential, may not be the most substantial factor in terms of the observed socioeconomic trends, such as regulations, policies, and services established by local governments.

These aforementioned relationships appeared to be dependent on some factors that were not within the scope of this project. A temporal dependency was indicated as the majority of the results suggested that coal mining was positively associated with socioeconomic well-being indicators in recent history (2000–2010) when coal prices were higher relative to past time-periods. Results also appeared to be vary in relation to the well-being indicator being analyzed, which was expected. For example, coal employment was linked to positive well-being for poverty, median household income, unemployment, and change in per capita income. However, for percent change in population, the share of retail employment, and proprietors share of employment, coal mining had a significantly negative relationship.

4.2 Water Quality and Ecological Health in Central Appalachian Streams Affected by Surface Mining and Untreated Household Waste

Leigh-Anne Krometis, Virginia Tech

Emily Sarver, Virginia Tech

The Central Appalachian region is a mountainous region with rich species biodiversity. This areas economy is dominated by resource-extraction activities including coal mining, logging, and natural gas. These activities, along with other normalized regional practices, have affected both water quality and stream ecological health. This study addressed issues stemming from the discharge of untreated household waste and resource extraction activities through the characterization of ionic pollution and examination of biological effects from these ions in local freshwater. More specifically, research activities completed in support of this project included 1) examining publicly available GIS data for potential correlations between water quality designations and topographic or demographic factors, 2) investigating in-situ measurements of conductivity, 3) analyzing grab samples for inorganic ion concentrations using ICP-MS, 4) identifying macroinvertebrate stressors through field studies, 5) analyzing water samples using molecular source-tracking techniques, and 6) processing water

quality datasets to determine the interplay between water chemistry and physical habitat.

The results of this research showed that discharges of untreated household waste and waste materials from commercial projects affected stream ecological health as indicated by fecal bacteria and macroinvertebrate impairments. In terms of fecal bacteria, impairments were linked to discharges of untreated household wastes and cyclical seasonal variations. Fecal bacterial impairments were also found to occur most commonly in rural areas. For benthic macroinvertebrates, impairments at the study sites appeared to have been primarily associated with ions that constituted alkaline mine drainage (Ca, K, Mg, $SO_4{}^{2-}$, Na, and Ni). Ions found in untreated household waste (P, Si, Mn, Co, and Cr) contributed to a secondary negative impact. **Based on these findings, approaches used to improve water quality, upland hydrology, and localized habitat structures may be needed to improve aquatic ecosystem health. Significant opportunities exist for resource extraction companies to positively impact stream ecological health by participating in sustainable solutions and promoting these solutions to the community.** Such an initiative would have a positive impact on the community by addressing the long-standing problem of inadequately treated wastewater discharges.

4.3 The Effect of Surface Mining Activities on Neonatal Health in Appalachian Communities

Steven Lamm, Center for Epidemiology and Environmental Health

Concerns regarding the impact of industrial processes on the health of residents in Appalachia have been of public and professional concern for over 50 years. Recently, attention has been given to the relationship between mining activities and birth defects/cancer rates. Research by the West Virginia University School of Medicine suggested that adverse neonatal health in terms of birth defects and low birth weight was associated with maternal residence in Appalachian counties practicing mountain-top mining. However, this study was limited in that the consequences of the underlying data and details about the research methodology were not discussed. Similarly, the EPA released a toxicological review of inorganic arsenic that predicted an increased risk of lung cancer associated with the levels of arsenic (As) found in Appalachia. This research project addressed these concerns by examining neonatal health and cancer rate data. Specifically, the goals of this study were to determine whether adverse neonatal health is a consequence of mothers living in coal mining counties, and particularly, mountaintop coal mining activities. Additionally, the role of environmental exposure to As, a constituent of the soil and drinking waters in Appalachia, was investigated in the context of increased cancer risk, particularly lung cancer.

To investigate the impact of mining activities on neonatal health, live birth certificate information was analyzed to determine whether newborns were more likely to be born with (or recorded as having) birth defects than newborns from non-mining areas. These data were concurrently used to investigate whether Appalachian newborns were more likely to be small-for-gestational-age (SGA) including any confounding factors that may explain geographic differences in SGA prevalence. To investigate the effect of As, a systematic review of scientific literature covering the association between drinking water As levels and lung cancer was completed. Studies involving the full range of As in drinking water (very low to very high) were considered. Continuous modeling of the individual studies that best-fitted a meta-regression of the data from all the studies was also completed.

Results of this study revealed that although birth defects were higher in general for Appalachian newborns, this correlation was actually attributed to newborns from specific hospitals located in mountaintop removal areas. However, within these mountaintop mining hospitals, the birth defect rates were not significantly different from birth defect rates in non-mining counties. The birth defect reporting rates were thus found be a characteristic of the hospitals and not a characteristic related to residence in a mining-active or non-mining county. Further analysis of the data showed that some hospitals reported neonatal conditions as if they were congenital conditions and thus caused the rates to be inflated by an order of magnitude relative to other hospitals. **When accounting for how hospitals reported congenital conditions, no difference was found in birth defect rates between mining-active and non-mining areas**.

Pregnant women residing in mountaintop mining counties were found to have smoking prevalence rates twice those of pregnant women residing in non-mining counties. As a result, the former group was more likely to have newborns with SGA. However, stratifying the populations by smoking habit resulted in differences in SGA prevalence. **Based on this examination, mining activity was not found to be a significant risk factor for SGA. However, tobacco use by mothers, particularly in the third-trimester, did prove to be a significant SGA risk factor**.

The systematic review of the literature and the meta-regression analysis of the data for As exposure showed that lung cancer risk followed a statistically significant positive coefficient for the quadratic term and a statistically significant negative for the linear term. The risk became positive when the arsenic exposure level exceeded 136 g/L. **The body of reviewed literature did not show an increased risk of lung cancer at exposures below this level. Counties that depended upon groundwater for their drinking water sources and exhibited median groundwater arsenic levels of 3–59 μg/L showed no increase in lung cancer mortality risk based on 1950–1979 mortality data. Thus, the results of this research project showed that drinking water arsenic levels observed in Appalachian region do not increase the risk of lung cancer**.

4.4 Evaluation of Soil and Dust Exposure Pathways, and Potential Exposure Risk to Contaminants in Appalachian Coal Mining Communities

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Shane Whitacre, Ohio State University

Recently concerns have increased about the health of Appalachian communities located near coal mining operations. An important consideration in community health is the physical health of residents. Several authors have reported that coal mining communities have a higher incidence of disease, including asthma, birth defects, black lung, cardiovascular disease, cardiopulmonary disease, hypertension, kidney disease, lung disease, and cancer. However, the authors identify a few, if any, toxic agents with alleged associations to mining. Pathways of exposure, which can be complex, must be established to identify the exact source of an issue and to design an effective remediation plan. Without exposure pathway identification, determining if and to what extent coal mining communities are affected by mining activities is impossible.

To address these deficiencies, the objectives of this research project included three areas of study: 1) toxic agents associated with coal mining to which communities are exposed, 2) physical exposure pathways, and 3) field site quantification of dust exposure on mine properties. To identify environmental and toxic agents linked to asthma, birth defects, cardiovascular disease, hypertension, kidney disease, lung disease, and cancer, a detailed literature review was conducted. This review was also used to identify potential exposure pathways associated with coal mining and to assemble an association matrix for analyzing health effects and identifying toxic agents potentially linked to coal mining.

Twenty-three toxic agents linked to coal mining were identified from the literature. The developed association matrices were successfully used to identify potential exposure routes. Given the toxic agents identified, the primary routes of exposure were ingestion/inhalation for soil/dust and ingestion for water. Major toxic constituents of interest in soil/dust were found to be arsenic (As), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), nickel (Ni), zinc (Zn), and silica (Si_{02}). In particular, As, Cd, and Pb were associated with many of the health effects reported in coal mining communities. However, total agent concentration often overestimates exposure because various physiochemical properties of the soil/dust matrix can sequester the agent and reduce its transmission. A more accurate exposure assessment accounts for the bioavailability of the agent in a soil/dust matrix. In order to address this issue, oral ingestion and inhalation exposure pathways from potential source materials generated from coal mining activities were examined.

Characterization of 35 potential source materials from surface coal mines

in southwest VA, WV, and KY was conducted. Results from the WV valley fill indicated that increased exposure from oral ingestion is not likely because agent concentrations were similar to background levels and bioaccessibility was limited. Further, this outcome combined with the transport limitations of size fractions applicable to oral ingestion (100 μm -250 μm) provided evidence that oral ingestion is not a major pathway of concern to coal mining communities. Based on these results, the size fraction that is most likely to be transportable from the coal mining site to surrounding communities is in the respirable range (less than 10 μm). In order to investigate exposure to respirable dust, a limited dust monitoring and sampling study was conducted at an active surface mine in WV. Real-time dust monitoring devices (i.e., DustTrak DRX Aerosol Monitor 8534) were used to measure total suspended particles (TSP) and particulate matter with diameters less than or equal to 10 μm (PM_{10}) and 2.5 μm ($PM_{2.5}$). Physical and chemical analyses were also used to calculate exposure to elemental constituents in the dust.

Dust monitoring results showed that material haulage by trucks have the potential to generate relatively large amounts of dust without the use of control measures, such as a water truck. Based on the scope of the field study in WV, only Cr found in PM_{10} haul roads was observed to be substantially above WV background concentrations. Only samples collected from the rope shovel yielded enough $PM_{2.5}$ to obtain detectable elemental contents. **Results from $PM_{2.5}$ for trace elements As, Ba, Be, Cd, Cr, Co, Cu, Pb, Ni, V, and Zn were within 90% to 160% of PM_{10} indicating little enrichment going from the PM_{10} to $PM_{2.5}$ size fraction. As such, the results of this monitoring study indicated that the dust generated from the monitored coal mine did not account for a significant increase in exposure to constituents that could potentially result in health effects**. Rather, the default U.S. EPA values for calculating ingestion exposure suggest that for most elements, the exposure from various coal mining sources does not exceed everyday residential exposure to native WV soil.

4.5 Environmental Factors Affecting Chronic Health in Coal Dependent and Comparison Communities in Appalachia

Susan Meacham, Edward Via College of Osteopathic Medicine

Health disparity and poverty are prevalent in central Appalachian communities, which have been persistent issues first identified over 50 years ago with the creation of the Appalachian Regional Commission. Recent publications in peer-reviewed journals indicate an association between coal production in central Appalachia with the high prevalence of various health conditions. However, these publications do not present specific evidence of a direct cause-effect relationship. A three-phase study was initiated with the overall objective of identifying demographic, geographic, economic, and social determinants of health contributing to the persistently high prevalence rates for common chronic health conditions in regions of southern Virginia.

In the first phase, a detailed literature review was completed. A method for evaluating data and publication quality for publications on coal, health, and Appalachia was also developed. In the second phase, county health data were obtained from various agencies including the American Cancer Society, MUSA, the Robert Wood Johnson Foundation, and the Virginia Department of Health. These mortality records provided data on demographic, geographic, economic, and social determinants of health from the four disparity regions in southern Virginia. For the third phase, a cross-sectional study was used to capture de-identified electronic medical record information and recorded disease conditions, family histories, medical histories, clinical results, laboratory findings, and physician notes. The aim of these combined findings was to help improve health and well-being for communities experiencing prevailing disparity.

After completing the first phase, the number of independently authored publications on coal, health, and Appalachia was limited. Additionally, experimental methods were hampered by protocol design because human or environmental exposures were not addressed. Other concerns prompted subsequent review of the original data and conclusions. **After review, evidence reported for the inferred cause-effect relationships associating coal production with chronic health conditions was found to be weak**. In addition to the literature review, the Phase I research objective required the development of a tool to obtain primary level data from electronic medical records and to provide training for inter-rater reliability, efficient data extraction, and data recording. The PRECEDE-PROCEED framework included in the tool provided a comprehensive structure for assessing health and quality of life needs. Thus, this tool may be used for future designing, implementing, and evaluating health promotions and other public programs addressing health disparities in Central Appalachia.

In the second phase, research findings showed that coal counties did display higher rates of chronic health conditions and poverty

rates in coal producing communities (i.e., unemployment, in WV and chronic disease mortality in VA). While positive trends in heart disease and strokes were apparent, rates of cancers and diabetes mellitus were especially troubling. In the WV-VA studies, coal producing counties did not differ from non-coal producing counties based on current measures of environmental factors. A lack of improvement and increased prevalence in some chronic health conditions have been attributed to income, unemployment, lack of access to care, lack of insurance, lower educational attainment, older population, substance abuse, rurality, and cultural barriers. The geographic specificity of these findings and professional inputs gathered from this research form the first steps for a theoretical framework for interventions and strategies for improving health disparities in central Appalachia.

Preliminary findings from the third phase served as probes into the compiled database of electronic medical records (EMR). These findings provided indicators to guide the final analysis, which is in-progress. Currently, meetings have been established with leading health professionals to communicate descriptive statistics and to gather input regarding what information will be helpful. The combined qualitative and quantitative review will fully utilize existing agency and VDH and EMR data that is specific to the catchment areas of these professionals. The full potential of the overall study is unfolding and beginning to yield data that will influence health outcomes in affected central Appalachian communities.

4.6 Mortality Analysis of Coal Mining Counties in Appalachia including a Quantitative and Qualitative Analysis of Health Data in Appalachia

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Recent studies have indicated that adverse health outcomes, including mortality, occur at higher rates in the Appalachian region of the U.S. Many of these negative effects have been anecdotally attributed to coal mining activities. However, evidence regarding the specific effect of coal mines on Appalachian communities is conflicting. In an effort to determine the impact of mining, if any, an ecological evaluation of total and select cause-specific mortality rates in West Virginia (WV) coal mining communities was compared to mortality rates in non-coal mining Appalachian counties. Data for these analyses were drawn from the Mortality and Population Data System (MPDS) and the West Virginia Office of Miners Safety and Training. In addition to this examination of community well-being in terms of mortality, a description of demographic information, amount of coal production, the distribution of cardiovascular and respiratory hospitalizations, and environmental exposures by county in WV were also provided. Finally, the potential associations between age-adjusted, county-level, respiratory hospitalization rates in West Virginia were explored.

A descriptive and statistical analysis of the total cancer (i.e., all heart disease, all-cancer, and lung cancer) mortality was performed. Controls for potential confounding factors, such as age, time, race, sex, socioeconomic status (SES), and geographic area, were used to limit the impact of extraneous characteristics. **Evidence of elevated total and cause-specific mortality rates when comparing coal-mining to non-coal mining counties in Appalachia was found**. These elevations appeared to be highest in earlier periods (1950s and 1960s). Several coal mining counties had lower Standardized Morbidity Ratios (SMRs) than their non-coal mining counterparts, but the southern-most WV counties consistently exhibited statistically significant elevations. No associations with total or all-external cause mortality were found.

Coal production was found to have a statistically significant relationship for all cancer mortality. All-cause mortality rates for males and females were higher in coal counties across all time periods. Virginia coal counties had statistically significant excesses for many causes of death compared to VA non-coal and WV coal and non-coal mining counties. **From this study,**

the median income, obesity, and smoking rates were statistically significant predictors of heart disease Standardized Morbidity Ratios (SMRs) with meaningful interactions with coal production. The same relationships were not evident in non-mining counties. Additionally, SMRs were elevated in the highest two quartiles of coal production in counties with high smoking prevalence. **Further examination of coal production and respiratory disease mortality revealed elevated mortality from respiratory system cancer (RSC), chronic obstructive pulmonary disease (COPD), and non-malignant respiratory disease (NMRD), particularly in relation to surface coal mining.**

In WV between 2005–2009, when controlling for important socioeconomic risk factors, total, underground, and surface coal production were not significantly related to rates of hospitalization for circulatory conditions. These findings reflect the role that socio-demographic and behavioral risk factors play in the health and well-being of coal mining communities in West Virginia. **Further analysis, after controlling for poverty, the proportion of urban/rural living, obesity, smoking, race, and the proportion of the residents working in mining, revealed that the total underground and surface coal production were associated with respiratory hospitalization rates. The reason for these differences in the analyses is unclear.** These data are ecological in nature and therefore may be subject to bias. Future studies should seek to quantify specific coal-related exposures and their associations with respiratory health in West Virginia.