

ARIES Executive Summary

Edmund C. Jong, Gregory D. Boardman, and Michael E. Karmis

Appalachian Research Initiative for Environmental Science,
Virginia Center for Coal and Energy Research, Virginia Tech

January 20, 2020

Introduction

The following document contains an executive summary of key findings from the Appalachian Research Initiative for Environmental Science (ARIES). Further details for these findings may be found in the referenced peer-reviewed publications and project reports. The ARIES body of work was developed from 2011 to 2016. Thus, published ARIES results will not reflect any evolutions in policy and research that occurred after this timeframe. Although some issues may be different today, the breakthrough research conducted by the ARIES community continues to provide invaluable insights into these areas of interest.

In the early 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 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 formed 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 consortium that elicited the participation of research institutions 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 through 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 full transparency, independence, and diverse involvement. Upon inception, ARIES was financially supported by a multi-year commitment from industrial affiliate partners. The resulting grant of \$15 million was established to fund the ARIES program over the first five years. The ARIES program was announced publically on March 31, 2011, which received immediate support from State governments including direct endorsements by the governors of five Appalachian states.

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

- **Environmentally Responsible Mining Technology** - Mining activities, similarly to any large industrial or commercial project, generally result in significant disturbance of existing natural features. ARIES researchers investigated techniques and technologies that would allow mining activities to be conducted in a manner that minimize 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 of a “resource curse” from which poverty is perpetuated with mining has long accompanied this industry. 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.

- **Impacts on Ecosystems** - Changes to habitat, water chemistry, and other environmental variables from human development have direct implications for upland and aquatic ecosystems. ARIES researchers evaluated the impacts, if any, of mining activity and possible means for mitigating any negative effects.
- **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. Waste treatment methodology, placement of waste materials, and wastewater flow paths have been shown to affect impacts on 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 addressed issues related to the prediction, impacts, and treatment of chemical constituents.

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 ARIES body of work opened avenues for additional research and topics that continue to be explored. The funds awarded by this project created and reinforced a cadre of researchers whose contributions continue beyond ARIES.

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Chapter 1

Environmentally Responsible Mining Technology

Ground strain calculations provide an accurate and realistic evaluation of the structural integrity of a stream bed. However, horizontal strain calculations may over predict the overall strain regime. The ability to generate accurate approximation of ground movements will allow the optimization of extraction sequences. Increasing the precision and efficiency of extraction activities will additionally reduce the effects of underground mining on surface streams.

Agioutantis, Z., and M. E. Karmis. 2013. "Recent developments on surface ground strain calculations due to underground mining in Appalachia." 32nd International Conference on Ground Control in Mining, Morgantown, WV, 30 Jul-01 Aug.

Agioutantis, Z., C. Newman, G. B. J. Leon, and M. Karmis. 2014. "Minimizing impacts on streams due to underground mining by predicting surface ground movements." *Mining Engineering* 68 (3):28-37.

Barrier pillar width derived using rules of thumb overestimate the required pillar size. This overestimation decreases the amount of available coal reserves. Using ground strain and barrier pillar stability as the primary design criterion can optimize coal extraction while maximizing the protection of surface water bodies.

Agioutantis, Z., M. E. Karmis, and L. Kirby. 2013. "Application of subsidence prediction methodologies for sizing barrier pillars for stream protection in Appalachia." *Environmental Considerations in Energy Production*, Charleston, WV, 14-18 Apr.

The cost of energy from extracting coal and overburden comprises one-fourth of the total mine revenue generated by bituminous mines. Diesel and explosives were the primary drivers of energy consumption. The proportion of net revenue relative to total coal revenue with regard to the total energy consumption cost was approximately 76%, with a coefficient of variation of 3%.

Kecojevic, V., I. Vukotic, and D. Komljenovic. 2014. "Production, consumption and cost of energy for surface mining of bituminous coal." *Mining Engineering* 66 (1):51-57.

Matching explosives product to ground conditions could be crucial in controlling NO_x emissions. Haul trucks, blasting, front-end loaders and bulldozers contributed 93.6% of the total NO_x emissions, while graders, drills, water trucks, and hydraulic shovels contributed the remaining proportion of the NO_x emissions. Confinement and contamination from drill cuttings and water have a significant impact on the volume of NO_x produced from a blast.

Lashgari, A., C. Johnson, V. Kecojevic, B. Lusk, and J. M. Hoffman. 2013. "NO_x emission of equipment and blasting agents in surface coal mining." *Mining Engineering* 65 (10):34-41.

The EPA AP-42 emission factor method may over-predict dust emission for overburden loading operations at certain surface coal mines.

The main causes of over-prediction may include non-representative data being used in development of AP-42 EF estimation equations, imprecise methodology being applied in calculating emission rates, and/or invalid pressure-gradient curves being referenced for estimating emissions. A reconsideration of estimating factors (EF) for loading operations is needed.

Lashgari, A., and V. Kecojevic. 2015. "Comparative analysis of dust emission of digging and loading equipment in surface coal mining." *International Journal of Mining, Reclamation and Environment* 30 (3):181-196. doi: 10.1080/17480930.2015.1028516.

Prakash, B. B., V. Kecojevic, and A. Lashgari. 2016. "Analysis of dust emission at coal train loading facility." *International Journal of Mining, Reclamation and Environment*:1-19. doi: 10.1080/17480930.2016.1253138.

Careful attention to individual variations in sensor performance is needed when selecting an EC25°C sensor, particularly when the intended use is regulatory enforcement.

The YSI, HOBO, Solinst, and Aqua Troll sensors exhibited notable differences when applied under identical conditions. These functional discrepancies may cause one sensor to identify a stream as compliant while another sensor of the same type may indicate the same stream as non-compliant. Based on these findings, EC25°C sensors used for regulatory enforcement should be regularly validated against NIST EC25°C standards.

Maupin, T. P., C. T. Agouridis, C. D. Barton, R. C. Warner, and X. Yu. 2013. "Specific conductivity sensor performance: I. Laboratory evaluation." *International Journal of Mining, Reclamation and Environment* 27 (5):329-344. doi: 10.1080/17480930.2013.764701.

Maupin, T. P., C. T. Agouridis, D. R. Edwards, C. D. Barton, R. C. Warner, and M. P. Sama. 2013. "Specific conductivity sensor performance: II. Field evaluation." *International Journal of Mining, Reclamation and Environment* 27 (5):345-365. doi: 10.1080/17480930.2013.764702.

Residual diesel range organics (DROs) should be present at only very low concentrations under normal operating conditions for fine coal flotation circuits. If diesel is overdosed, DRO levels in concentrate and tailings waters might be significantly increased, which should be avoided. Conscientious diesel dosing should increase performance of coal processing systems.

Morris, J., R. Sellaro, and E. A. Sarver. 2015. "Residual diesel range organics in process waters from laboratory fine coal flotation tests." *Mining Engineering* 67 (8):67-73.

Regarding fate and transport of typical frother and collector reagents, no apparent environmental concern was discovered for coal preparation plants operating under normal conditions. Frother and collector reagents are not likely to partition completely to a single fraction of the process slurry. Low 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.

Morris, J., E. Sarver, and G. Luttrell. 2013. "Diesel Range Organics in Coal Preparation." In *Environmental Considerations in Energy Production*:51-57. Englewood, CO: Society for Mining, Metallurgy and Exploration.

Morris, J., E. A. Sarver, G. Luttrell, and J. Novak. 2012. "Reagents in coal processing: where do they go?" In *Proceedings of the 51st Annual Conference of Metallurgists*:359-370. Niagara Falls, Ontario: Canadian Institute of Mining, Metallurgy and Petroleum.

The influence function formulation in Surface Deformation Prediction System (SDPS) can be used to predict mining-induced subsurface and surface ground deformations. This general methodology for evaluating mining-induced impacts on the surface and subsurface may be used by operations personnel to obtain permits. For example, the Office of Surface Mining Reclamation and Enforcement (OSMRE) imposed new regulations in 2016 for the protection of streams and groundwater from adverse impacts of surface and underground mining operations (80 FR 44435), which increased the scrutiny of permit applications.

Agioutantis, Z., D. Barkley, M. Karmis, and S. Elrick. 2014. "Development of an enhanced methodology for ground movement predictions due to longwall mining in the Illinois Basin." 33rd International Conference on Ground Control in Mining, Morgantown, WV, 29-31 Jul.

Karmis, M. E., and Z. Agioutantis. 2015. "A methodology to assess the potential impacts of longwall mining on streams in the Appalachian basin." 2nd Environmental Considerations in Energy Production, Pittsburgh, PA, 20-23 Sep.

Newman, C., Z. Agioutantis, and G. B. J. Leon. 2017. "Assessment of potential impacts to surface and subsurface water bodies due to longwall mining." *International Journal of Mining Science and Technology* 27:57-64. doi: 10.1016/j.ijmst.2016.11.016.

Newman, C., Z. Agioutantis, and G. B. J. Leon. 2016. "Evaluation of potential impacts to stream and ground water due to underground coal mining." 35th International Conference on Ground Control in Mining, Morgantown, WV, 26-28 Jul.

The application of the surface miner (SM) method can reduce the environmental impact of overburden removal. Although beneficial, the downside of using the SM method in surface mining operations begins with the limited quantity of the overburden material being extracted and higher operating costs relative to other conventional approaches. To confirm the advantages of the SM method, an examination of existing surface coal mines in WV in terms of engine load factor, the amount of pick wear, cutting depth, and cutting velocity in sandstone and shale overburden and interburden is needed.

Nolan, T. A., and V. Kecojevic. 2014. "Selection of overburden surface mining method in West Virginia by analytical hierarchy process." *International Journal of Coal Science and Technology* 1 (3):306-314. doi: 10.1007/s40789-014-0019-0.

Coarse-high density fraction material provided supernatant liquid conductivity values that were significantly different from coarse-low density material and the small particle fraction. This finding is likely the result of high pyritic content present in the heavy fraction of unliberated clay minerals and low concentration of minerals like calcite that could provide neutralizing potential. The significance of the parameter and parameter interactions followed the order of 1) liquid volume-to-solid surface area ratio (VSAR), 2) oxidant amount and its interaction with VSAR, and 3) the interaction between VSAR and surface area.

Rezaee, M., R. C. Warner, and R. Q. Honaker. 2016. "Development of an electrical conductivity screening test for mine waste assessments." *Chemosphere* 160:13-21. doi: 10.1016/j.chemosphere.2016.06.050.

The settling rate of slurry solids was affected by pH. In general, at a given pH, 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 tended to have the lowest turbidity.

Klima, M. S. 2016. Strategies for improving water quality while enhancing dewatering performance. In Appalachian Research Initiative for Environmental Science Final Reports. Blacksburg, VA: Appalachian Research Initiative for Environmental Science (ARIES).

The filtration rate of coal slurry was significantly higher at a lower pH. The turbidity values of the filtrate samples were very low in all cases. Iron leached out from the slurries at a lower pH. Lower pH values also 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.

Klima, M. S. 2016. Strategies for improving water quality while enhancing dewatering performance. In Appalachian Research Initiative for Environmental Science Final Reports. Blacksburg, VA: Appalachian Research Initiative for Environmental Science (ARIES).

The dust generated from the West Virginia coal mines did not account for the majority of 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 the study. Further, direct respiratory risk from Cd, Mn, and SiO₂ did not reach levels that would require remedial action.

Lusk, B. 2016. Impacts of blasting and excavation. In Appalachian Research Initiative for Environmental Science Final Reports. Blacksburg, VA: Appalachian Research Initiative for Environmental Science (ARIES).

Basta, N. T., and S. D. Whitacre. 2016. Evaluation of soil and dust exposure pathways, and potential exposure risk to contaminants in Appalachian coal mining communities. In Appalachian Research Initiative for Environmental Science Final Reports. Blacksburg, VA: Appalachian Research Initiative for Environmental Science (ARIES).

Pyrite content was found to be the primary cause of acid generation and subsequent release of trace elements to the effluent. Based on this study, 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.

Honaker, R. Q. 2016. Solid waste segregation, treatment, and disposal. In Appalachian Research Initiative for Environmental Science Final Reports. Blacksburg, VA: Appalachian Research Initiative for Environmental Science (ARIES).

Strata barrier fracture permeability may be impacted by the overlying orientation and conditions of a stream channel. The three primary factors in controlling unplanned discharges to surface streams are 1) Thickness of the strata barrier, 2) Magnitude of the positive hydraulic head differential, and 3) Absence of high extraction ratio mining beneath stream channels.

Iannacchione, A., J. VanNess, H. Giacomini, and G. Frank. 2015. "The role of barriers beneath stream beds in preventing unplanned discharges from northern Appalachian coal mine pools." 34th International Conference on Ground Control in Mining, Jiaozuo, China, 17-19 Oct.

The depth of mining exhibited the most obvious effect on springs. Mining environment and topographic position had only moderate effects on a watershed scale and no obvious effects on a regional scale. Four factors (geographic location, topographic position, geologic characteristic of aquifer, depth of mining), four mining environments (mid panel, quarter panel, gate roads, and outside the mine), and three topographic categories (hilltop, hillside, and valley bottoms) were considered in the analysis.

Iannacchione, A., D. Bain, M. Keener, and C. Nealen. 2013. "Preliminary assessment of factors affecting springs undermined by longwall mines in Pennsylvania." Environmental Considerations in Energy Production, Charleston, WV, 14-18 Apr.

Chapter 2

Health, Social and Economic Impacts

Median income, obesity, and smoking were all found to be statistically significant predictors of Specific Standardized Mortality Ratios (SMRs) for heart disease and were found to have statistically significant interactions with coal production. Specifically, SMRs generally increased as median income decreased and obesity increased in mining counties. 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.

Balmert, L. C., A. O. Youk, S. M. Woolley, E. O. Talbott, and J. M. Buchanich. 2015. "Heart disease mortality in Appalachian coal mining counties." *SM Journal of Public Health and Epidemiology* 1 (1).

No strong evidence of a resources curse from coal mining in the Appalachian region was found. Modern coal mining has nuanced effects that differ between Appalachia and the rest of the U.S. Coal mining industry. For the Appalachian region over the entirety of the boom/bust cycle, coal employment is positively related to changes in per capita income and the employment-population ratio, but negatively associated with changes in population and measures of entrepreneurship, as reflected by self-employment data.

Betz, M. R., M. D. Partridge, M. Farren, and L. Lobao. 2015. "Coal mining, economic development, and the natural resources curse." *Energy Economics* 50:105-116. doi: 10.1016/j.eneco.2015.04.005.

Total and all external mortalities were not related to coal production in Appalachia. No coal-related, statistically significant elevations in total or all external mortality were found. Control for covariates attenuated rate ratios for all levels of coal mining. All forms of coal were statistically significant in the age adjusted rate ratio models for all cancer mortality, with 4% to 6% excesses in the highest quartiles of production.

Buchanich, J. M., L. C. Balmert, A. O. Youk, S. M. Woolley, and E. O. Talbott. 2014. "General mortality patterns in Appalachian coal-mining and non-coal-mining counties." *Journal of Occupational and Environmental Medicine* 56 (11):1169-1178. doi: 10.1097/JOM.0000000000000245.

Buchanich, J. M., E. O. Talbott, L. L. Brink, and R. K. Sharma. 2016. Mortality analysis of coal mining counties in Appalachia including a quantitative and qualitative analysis of health data in Appalachia. In *Appalachian Research Initiative for Environmental Science Final Reports*. Blacksburg, VA: Appalachian Research Initiative for Environmental Science (ARIES).

Human-specific Bacteroides-HF183 can be found in rural watersheds with known upstream direct discharges of untreated household waste. Used concurrently with *E. coli* monitoring, human-specific *Bacteroides* may provide strong evidence of human fecal contamination and contribute to justification or evaluation of infrastructure improvements. Ideally, epidemiological studies and water quality information at the most common point of exposure (i.e., private drinking water sources) alongside water surveys would allow for more informed decisions on the scale of investment in wastewater infrastructure.

Cantor, J., L. Krometis, E. Sarver, N. Cook, and B. Badgley. 2017. "Tracking the downstream impacts of inadequate sanitation in Central Appalachia". *Journal of Water and Health* 15(4):580-590. doi:10.2166/wh.2017.005.

The type and concentration of inorganic ions in impaired Appalachian streams correlated with upstream landuse patterns including the presence of surface or underground mining or untreated household waste (UHW) discharges. Impaired streams in the central Appalachian region are often characterized by elevated measures of conductivity. Notable associations with elevated conductivity were elevated P and UHW, Mn/Si/HCO₃ and underground mining, and Ni, Ca, K, SO₄, and Se with surface mining.

Cook, N. A., L. A. Krometis, E. A. Sarver, and J. Huang. 2015. "Inorganic constituents of conductivity in five central Appalachian watersheds with mixed source-driven pollutants." *Ecological Engineering* 82:175-183. doi: 10.1016/j.ecoleng.2015.04.090.

An increased risk of lung cancer associated with median drinking water arsenic levels in the range of 359 $\mu\text{g}/\text{L}$ was not found. Cancer risks were found to be indistinguishable from zero for males and females. The addition of arsenic within the examined levels did not significantly increase the risk of cancer. Stratified, or categorical, analysis yielded relative risks of 1.00 and unit risk estimates were non-positive and not significantly different from zero. The maximum (95% UCL) unit risk estimates for lung cancer were lower than estimates made by the U.S. EPA.

Ferdosi, H., E. K. Dissen, N. A. Afari-Dwamena, J. Li, R. Chen, M. Feinleib, and S. H. Lamm. 2016. "Arsenic in drinking water and lung cancer mortality in the United States: an analysis based on US counties and 30 years of observation (1950-1979)." *Journal of Environmental and Public Health* 2016:1-13. doi: 10.1155/2016/1602929.

No increased risk of birth defects was observed for births in mountain top mining (MTM) counties after adjustment for, or stratification by, hospital of birth. Reported associations between birth defect rates and MTM was a consequence of data heterogeneity. The associated analyses did not consider sources of uncertainty, such as unbalanced distributions or quality of data, which has been a continuing problem with birth certificate investigations.

Lamm, S. H., J. Li, S. A. Robbins, E. Dissen, R. Chen, and M. Feinleib. 2015. "Are residents of mountain-top mining counties more likely to have infants with birth defects? The West Virginia experience." *Birth Defects Research (Part A)* 103:76-84. doi: 10.1002/bdra.23322.

After adjustment, neither total, nor surface, nor underground coal production was significantly related to rate of hospitalization for circulatory disease. The relationships between county-level circulatory hospitalization rates (CHRs) in coal and non-coal mining communities of West Virginia, coal production, coal employment, and sociodemographic factors were examined. Direct age-adjusted CHRs were calculated and spatial regressions were conducted to explore associations between CHR and total, underground, and surface coal production. These findings underscore the significant role sociodemographic and behavioral factors play in the health and well-being of coal mining communities.

Talbott, E. O., R. K. Sharma, J. M. Buchanich, and S. L. Stacy. 2015. "Is there an association of circulatory hospitalizations independent of mining employment in coal-mining and noncoal-mining counties in West Virginia?" *Journal of Occupational and Environmental Medicine* 57 (4):30-36. doi: 10.1097/JOM.0000000000000425.

The number of coal mining facilities near a residence was not a statistically significant predictor of self-rated health. Employment in a coal-related occupation was a statistically significant predictor of self-rated health univariably; however, after adjusting for potential confounders, it was no longer a significant predictor. Self-rated health does not seem to be associated with residential proximity to coal mining facilities or employment in the coal industry.

Woolley, S. M., A. O. Youk, T. M. Bear, L. C. Balmert, E. O. Talbott, and J. M. Buchanich. 2015. "Impact of coal mining on self-rated health among Appalachian residents." *Journal of Environmental and Public Health* 2015:1-6. doi: 10.1155/2015/501837.

Discharges of untreated household waste (UHW) and discharges from mine sites 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, SO₄, Na, and Ni). Ions found in untreated household waste (P, Si, Mn, Co, and Cr) contributed to a secondary negative impact.

Cook, N. A., E. A. Sarver, L. H. Krometis, and J. Huang. 2015. "Habitat and water quality as drivers of ecological system health in Central Appalachia." *Ecological Engineering* 84:180-189. doi:10.1016/j.ecoleng.2015.09.006.

The principles of corporate social responsibility offer an opportunity to contribute to overall environmental and human health and well-being in Appalachian communities through investment in water and wastewater treatment. Although struggles to provide clean drinking water and to eliminate the "straight piping" of untreated household waste are well-known to water quality and health managers in the region, few sustainable solutions have been identified. Investment in water infrastructure through private-public partnerships, including mine industry partners, might be encouraged by the opportunity to earn mitigation credits and to develop positive community relationships.

Cook, N., E. Sarver, and L. H. Krometis. 2015. "Putting corporate social responsibility to work in mining communities." *Resources* 4:185-202.

No difference was found in birth defect rates between mining-active and non-mining areas. The birth defect reporting rates were thus found to 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.

Lamm, S. H. 2016. The effect of surface mining activities on neonatal health in Appalachian communities. In Appalachian Research Initiative for Environmental Science Final Reports. Blacksburg, VA: Appalachian Research Initiative for Environmental Science (ARIES).

Drinking water arsenic levels observed in the Appalachian region did not increase the risk of lung cancer. The systematic review of the literature and the meta-regression analysis of the data for arsenic exposure showed that lung cancer risk became positive when the arsenic exposure level exceeds 136 $\mu\text{g}/\text{L}$. Counties that depended upon groundwater for their drinking water sources and that exhibited median groundwater arsenic levels of 3-59 $\mu\text{g}/\text{L}$ showed no increase in lung cancer mortality risk based on 1950-1979 mortality data.

Lamm, S. H. 2016. The effect of surface mining activities on neonatal health in Appalachian communities. In Appalachian Research Initiative for Environmental Science Final Reports. Blacksburg, VA: Appalachian Research Initiative for Environmental Science (ARIES).

Chronic health conditions in WV-VA coal producing counties did not differ from non-coal producing counties based on current measures of environmental factors. Evidence reported for the inferred, cause-effect relationships, associating coal production with chronic health conditions was found to be weak. Further, 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.

Meacham, S. 2016. Environmental factors affecting chronic health in coal dependent and comparison communities in Appalachia. In Appalachian Research Initiative for Environmental Science Final Reports. Blacksburg, VA: Appalachian Research Initiative for Environmental Science (ARIES).

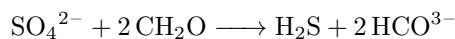
Water discharged by valley fills constructed using experimental approaches had specific conductance (SC) levels well below conventional fills. Methods for TDS management included characterization of rock strata for TDS generation potentials, specialized handling and placement of high-TDS spoils, and construction of post-mining landforms. However, SC levels from both experimental and conventional fills remained above both natural background and levels recommended by published studies of biotic thresholds.

Zipper, C. E., E. V. Clark, W. L. Daniels, R. J. Krenz, and J. Buckwalter. 2016. Mine spoil fills for reduced total dissolved solids in discharged waters. In Appalachian Research Initiative for Environmental Science Final Reports. Blacksburg, VA: Appalachian Research Initiative for Environmental Science (ARIES).

The weep berm system proved to be successful in achieving electrical conductivity (EC) values that were substantially below U.S. EPA guidelines (500 $\mu\text{S}/\text{cm}$). 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.

Warner, R. C. 2016. Assessment of weep berm effectiveness for surface mining in Appalachia. In Appalachian Research Initiative for Environmental Science Final Reports. Blacksburg, VA: Appalachian Research Initiative for Environmental Science (ARIES).

Literature indicated that the performance of passive biological treatment 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.



Since bicarbonate also contributes to conductivity, there is a limit to the reduction in conductivity that can be achieved through sulfate reduction alone.

Smyntek, P, R. Wagner, L. Krometis, S. Carvajal, T. Thompson, and W. Strosnider. 2017. "Passive biological treatment of mine water to reduce conductivity: Potential designs, challenges, and research needs." *Journal of Environmental Quality* 46:1-9.

Chapter 3

Impacts on Ecosystems

Streams receiving mining discharges were not consistently toxic to *C. dubia* and site-specific water chemistry characteristics were critical in determining potential toxicity. Although elevated concentrations of dissolved solids did not consistently result in *C. dubia* impairment, there was a significantly increased frequency of a toxic response at elevated conductivities. The lack of toxicity to *C. dubia* and the apparent effects of mining on macroinvertebrate communities suggest that either the surrogate test organism is not adequately protective of the native taxa or that other factors are contributing to community impairment.

Armstead, M. Y., L. Bitzer-Creathers, and M. Wilson. 2016. "The effects of elevated specific conductivity on the chronic toxicity of mining influenced streams using *Ceriodaphnia dubia*." PLoS ONE 11 (11):1-16. doi: 10.1371/journal.pone.0165683.

The TITAN approach is recommended to derive quantitative community thresholds across multiple species, as opposed to a derivation of multiple, single-species thresholds. Forest interior birds generally responded negatively to landscape metric thresholds, interior edge species responses were mixed, and early successional birds responded positively. Based on random forest importance ranks, total amount of landscape grassland/shrub land had the most influence, although this varied by guild.

Becker, D. A., P. B. Wood, M. P. Strager, and C. Mazzarella. 2015. "Impacts of mountaintop mining on terrestrial ecosystem integrity: identifying landscape thresholds for avian species in the central Appalachians, United States." Landscape Ecology 30:339-356. doi: 10.1007/s10980-014-0134-8.

National Agriculture Imagery Program (NAIP) was statistically less accurate than RapidEye satellite imagery for classifying land cover within a surface mine permit. Nevertheless, NAIP orthophotography has many characteristics that make it useful for surface mine mapping and monitoring, including its availability for multiple years, a general lack of cloud cover, contiguous coverage of large areas, availability, and low cost to the user. If the aim of a mapping project is only to differentiate vegetated and non-vegetated cover, or to differentiate woody vegetation from non-woody vegetation, NAIP may be adequate.

Maxwell, A. E., M. P. Strager, T. A. Warner, N. P. Zgre, and C. B. Yuill. 2014. "Comparison of NAIP orthophotography and RapidEye satellite imagery for mapping of mining and mine reclamation." *GIScience and Remote Sensing* 51 (3):301-320. doi: 10.1080/15481603.2014.912874.

The combination of lidar-derived data and commercial satellite imagery aided in the classification of land-cover within the surface mine permitted area. High spatial resolution can yield fine detail for land-cover mapping; however, reduced classification accuracy is expected because of internal variability within classes and decreased spectral resolution. This poses a problem when high-resolution land cover data are required; e.g., mapping of mine permitted lands. One means to combat this problem is combining multiple data sources including imagery and lidar.

Maxwell, A. E., T. A. Warner, M. P. Strager, and M. Pal. 2014. "Combining RapidEye satellite imagery and Lidar for mapping of mining and mine reclamation." *Photogrammetric Engineering and Remote Sensing* 80 (2):179-189. doi: 10.14358/PERS.80.2.179.

The landform analysis methodology provided a means to quantify and spatially assess terrain alterations using categorical landscape data. This approach represents a potential first step for assessing the impact of mountaintop removal/valley fill (MTR/VF) on terrestrial habitat and ecosystems. Landscape analysis, utilizing light detection and ranging (LiDAR)-derived elevation data, showed specific landform types and distributions that were significantly altered after MTR/VF mining and reclamation. The use of categorical landform data provides insights to assessing and understanding the extent of topographically altered mountaintops.

Maxwell, A. E., and M. P. Strager. 2013. "Assessing landform alterations induced by mountaintop mining." *Natural Science* 5 (2A):229-237. doi: 10.4236/ns.2013.52A034.

Through principal component (PC) analysis, land use activities were correlated with three dimensions of water chemistry: 1) contemporary surface mining (PC 1: elevated sulfate, alkalinity, and selenium), 2) coal geology/legacy mines (PC 2: elevated trace metals), and 3) residential development (PC 3: elevated sodium and chloride). Chemical contaminants produced by each land use activity accumulate to become a dominant physicochemical driver of community composition. However, regional conditions and associated meta-community processes often play an important role in structuring aquatic communities. Consequently, improving water quality in central Appalachian rivers will require a balance of new mine regulations and a mitigation of legacy and non-mining-related contaminant sources.

Merriam, E. R., J. T. Petty, M. P. Strager, A. E. Maxwell, and P. F. Ziemkiewicz. 2015. "Complex contaminant mixtures in multistressor Appalachian riverscapes." *Environmental Toxicology and Chemistry* 34 (11):2603-2610. doi: 10.1002/etc.3101.

Scenario analysis has the potential to improve management of aquatic systems throughout the central Appalachian region. The authors derived equations for predicting in-stream response to landscape changes and predicted the outcome of a realistic future scenario involving the development of 15 permitted mines. An analytical software package, entitled the Watershed Futures Planner (WFP), was constructed that integrates data management, statistical and process modeling, results summary and visualization, and decision support.

Merriam, E. R., J. T. Petty, M. P. Strager, A. E. Maxwell, and P. F. Ziemkiewicz. 2013. "Scenario analysis predicts context-dependent stream response to land use change in a heavily mined central Appalachian watershed." *Freshwater Science* 32 (4):1246-1259. doi: 10.1899/13-003.1.

Petty, J. T., M. P. Strager, E. R. Merriam, and P. F. Ziemkiewicz. 2013. "Scenario analysis and the watershed futures planner: predicting future aquatic conditions in an intensively mined Appalachian watershed." *Environmental Considerations in Energy Production*, Charleston, WV, 14-18 Apr.

Multi-stressor land use models are needed for the reliable prediction of stream conditions. Predictive models based on a survey of 170 streams provided precise estimates of specific conductance, Se, and benthic macroinvertebrate community composition. Deletion tests supported the conclusion that stream degradation across the region is the result of complex, but predictable, additive and interactive effects of surface mining, underground mining, and residential development.

Merriam, E. R., J. T. Petty, M. P. Strager, A. E. Maxwell, and P. F. Ziemkiewicz. 2015. "Landscape-based cumulative effects models for predicting stream response to mountaintop mining in multistressor Appalachian watersheds." *Freshwater Science* 34 (3):1006-1019. doi: 10.1086/681970.

Temporal distance appeared to be as important as geochemical conditions in controlling microbial community structure. Even after long-term operation under nearly identical geochemical conditions, microbial communities enriched from two different sites remained distinct and maintained traits inherited from their respective seed materials. Both alpha and beta diversities of microbial communities were significantly correlated to temporal distance (the cumulative number of pore volumes from the start of flow-through mode).

Sheng, Y., K. Bibby, C. Grettenberger, B. Kaley, J. L. Macalady, G. Wang, and W. D. Burgos. 2016. "Geochemical and temporal influences on the enrichment of acidophilic iron-oxidizing bacterial communities." *Applied and Environmental Microbiology* 82 (12):3611-3621. doi: 10.1128/AEM.00917-16.

Spatial and demand forecasting in combination with previous wind and shale gas models for the Appalachian region make it possible for industry, regulatory agencies, and the public to have an informed and constructive conversation about extraction of the regions energy resources. A method for predicting future surface coal mining extents under changing economic and regulatory forecasts through the year 2035 was developed by integrating a spatial model with production demand forecasts. The result was a spatial distribution of probabilities allocated over forecasted demand for the Appalachian region, including northern, central, southern, and eastern Illinois coal regions.

Strager, M. P., J. M. Strager, J. S. Evans, J. K. Dunscomb, B. J. Kreps, and A. E. Maxwell. 2015. "Combining a spatial model and demand forecasts to map future surface coal mining in Appalachia." *PLoS ONE* 10 (6):1-25. doi: 10.1371/journal.pone.0128813.

Screening-level testing procedures indicated the potential capacity for identifying geologic strata that should be isolated from oxidation processes. Overburden field leach testing, which utilizes exploration cores, was performed to provide a comparative analysis of the potential for specific conductivity generation. The test was modified from a USGS field leach test.

Monday, T., and R. C. Warner. 2013. "Screening-level specific conductivity testing of drill core strata." *Environmental Considerations in Energy Production*, Charleston, WV, 14-18 Apr.

Trends showed benthic macroinvertebrate taxa responded to elevated total dissolved solids (TDS), represented by conductance, in the range of 600-2,400 $\mu\text{S}/\text{cm}$. However, no significant differences were found between the community metrics for organisms exposed to the high conductance test concentrations. The only significant endpoint was seen in mayfly abundance in leaf packs at a conductance of 2,400 $\mu\text{S}/\text{cm}$. Simulated stream exposures of the field collected organisms used in this study showed no significant differences between biological communities at test initiation and those exposed to test conditions in dilute or full-strength, reconstituted, moderately hard water.

Armstead, M. Y., M. Wilson, L. Keller, J. Kinney, K. McGill, and E. Snyder. 2013. "Methods for evaluating the effects of a simulated mine effluent with elevated ionic concentration to field collected benthic macroinvertebrates." Environmental Considerations in Energy Production, Charleston, WV, 14-18 Apr.

The most successful culturing unit based on mayfly emergence was the aquatic plant culturing system (Hexagon), which also generated the highest flow rate. Methods for rearing field-collected, larval mayflies using three types of recirculating culturing systems were investigated. This research is part of an ongoing effort to provide an opportunity for toxicity testing with native mayflies in the laboratory.

Rowsey, K., M. Y. Armstead, and M. Wilson. 2015. "Development of culturing methods for native mayfly taxa for use in laboratory toxicity testing." 2nd Environmental Considerations in Energy Production, Pittsburgh, PA, 20-23 Sep.

Aquatic ecosystem function may not always be inferred from macroinvertebrate assemblages alone. Assessment techniques range from simple single species examinations to complex multi-taxa/life history decision matrices. Benthic macroinvertebrates are valuable indicator species, but full assessment of stream health may require use of a suite of taxa, such as periphyton, macroinvertebrates, fish and/or salamanders.

Sweeten, S., J. Sweeten, J. R. Craynon, W. M. Ford, and S. Schoenholtz. 2013. "Evaluation of current measures of aquatic biological integrity in the Central Appalachian coalfields: efficacy and implications." Environmental Considerations in Energy Production, Charleston, WV, 14-18 Apr.

Microhabitat relationships suggest restoration of riparian habitats and erosion control are important conservation components for maintaining stream salamanders in the mined landscapes of central Appalachia. In central Appalachian headwater streams absent of fish, salamanders are the dominant, most abundant vertebrate predator providing a significant intermediate trophic role. Stream salamander species are considered sensitive to aquatic stressors and environmental alterations. Past research has shown linkages among microhabitat parameters and largescale land use, such as urbanization and logging, with salamander abundances.

Sweeten, S. E., and W. M. Ford. 2015. "Effects of microhabitat and land use on stream salamander abundance in the Southwest Virginia coalfields." 2nd Environmental Considerations in Energy Production, Pittsburgh, PA, 20-23 Sep.

Waste handling techniques that slow the oxidation of the Se-containing minerals should reduce Se concentrations in mine effluents. Elevated Se concentrations were measured within narrow bands of strata, mostly in grey or black shale, fireclay and coal. Selenium was found either in elemental form or as PbSe in all of the samples. Oxidation appears to be the rate limiting step in the release of Se from mine waste.

Unrine, J. M., B. Collin, and R. C. Warner. 2013. "Selenium concentrations and solid-state chemical speciation in black shale associated with a West Virginia coal seam." Environmental Considerations in Energy Production, Charleston, WV, 14-18 Apr.

WV streams draining watersheds with both residential and energy extraction landuses are generally in poorer ecological condition (as determined by benthic macroinvertebrate assemblages) than watersheds with residential development or energy extraction alone. Both low conductivity measurements and high physical habitat scores are predictive of healthier streams. Remediation efforts are therefore advised to focus on both water quality and physical restoration.

Liao, H., E. Sarver, and L. Krometis. 2018. "Interactive effects of water quality, physical habitat, and watershed anthropogenic activities on stream ecosystem health." *Water Research* 130:69-78.

Chapter 4

Waste and Water Management

The hydrochemistry of five streams emerging from Appalachian Valley Fills (VFs) varied by season, precipitation amounts during storm events, and among VFs. Stages were generally highest in winter and lowest in summer, while specific conductance (SC) was generally highest in summer and lowest in winter. All SC-Stage regressions indicated SC dilution during stormflow, but significance differed seasonally. Storm SC-Stage hysteresis patterns varied with storm precipitation amounts, season, and vegetative period, implying climatic controls on VF stream storm responses.

Clark, E. V., B. M. Greer, C. E. Zipper, and E. T. Hester. 2016. "Specific conductance-stage relationships in Appalachian valley fill streams." *Environmental Earth Sciences* 75 (1222):1-13. doi: 10.1007/s12665-016-6026-2.

Un-weathered samples released higher SCs throughout the leaching period relative to weathered samples, and rock type influenced the rate of SC release. The leaching patterns of central Appalachian mine spoils were modeled as a continuous nonlinear regression with an exponential phase and linear phase separated by a breakpoint. Each model parameter was significantly influenced by either rock or weathering type, and all but one parameter had predictive relationships with rapid laboratory assessment techniques.

Clark, E. V., C. E. Zipper, W. L. Daniels, Z. W. Orndorff, and M. J. Keefe. 2017. "Modeling patterns of total dissolved solids release from Central Appalachia, USA, mine spoils." *Journal of Environmental Quality* 46:55-63. doi: 10.2134/jeq2016.04.0149.

Lab columns can be used to predict total dissolved solids (TDS) and overall specific conductance (SC) decay for Appalachian coal mine spoils. These columns generated similar range and overall SC decay responses to field observations within 5-10 leaching cycles, while actual reduction in field SC values occurs over years to decades. Laboratory, unsaturated column leaching results for 39 overburden materials were correlated with a range of static lab parameters, such as total-S, saturated paste SC, and neutralization potential. Leachate SC was strongly related to rock type and pre-disturbance weathering.

Daniels, W. L., Z. W. Orndorff, M. Eick, and C. E. Zipper. 2013. "Predicting TDS release from Appalachian mine spoils." Environmental Considerations in Energy Production, Charleston, WV, 14-18 Apr.

Daniels, W. L., C. E. Zipper, Z. W. Orndorff, J. Skousen, C. D. Barton, L.M. McDonald, and M. A. Beck. 2016. "Predicting total dissolved solids release from central Appalachian coal mine spoils." Environmental Pollution 216:371-379. doi: 10.1016/j.envpol.2016.05.044.

USEPA method 200.7 biases the determination of total Al because of aluminosilicate clay dissolution. Results are affected by true bias because the digestion procedure is intended to liberate only those ions that occur in quasi-stable forms (e.g., Hydrous metal hydroxide floccs: $\text{Al}(\text{OH})_3$) that could mobilize upon reaching the receiving stream. Clay minerals in suspended solids are stable in the environment and are a weathering end-product of most aluminum silicates. USEPA digestion procedure 200.7 is inappropriate for the determination of total Al because aluminum silicates are being dissolved in an analytical procedure intended to measure only ions in quasi-stable mineral forms indicates.

He, Y.T., and Ziemkiewicz, P.F. 2016. "Bias in determining aluminum concentrations: Comparison of digestion methods and implications on Al management." Chemosphere 159: 570-576. <http://dx.doi.org/10.1016/j.chemosphere.2016.06.052>.

Active mine operations should reduce the contact between high TDS producing materials and percolating drainage waters in mine spoils.

Appalachian coal mines have been implicated as major stressors to aquatic life in headwater streams from the discharge of total dissolved solids (TDS). Multiple studies indicated that near-surface pre-oxidized and weathered strata will have much lower TDS producing potentials and should therefore be used as topsoil substitutes.

Odenheimer, J., J. Skousen, and L. and M. McDonald. 2013. "Predicting total dissolved solids release from overburden in Appalachian coal fields." *Environmental Considerations in Energy Production*, Charleston, WV, 14-18 Apr.

In-situ amendment using Fe-oxide obtained from treatment of mine water can sequester Se by adsorption on surfaces of goethite and possibly ferrihydrite.

The process was demonstrated to substantially reduce dissolved Se in leachate and improve compliance with regulatory discharge limits. The observed reductions in mean Se concentrations and fluxes are considered to have been significant and caused by an adsorption mechanism involving goethite formed from historic treatment of mine drainage in a treatment wetland.

Donovan, J. J., and P. F. Ziemkiewicz. 2013. "Selenium adsorption onto iron oxide layers beneath coal-mine overburden spoil." *Journal of Environmental Quality* 42:1402-1411. doi: 10.2134/jeq2012.0500.

Elevated specific conductance (SC) is common for two to three decades after valley fill (VF) construction, which exerts long-term impacts on aquatic life.

The SC in waters emerging from 137 VFs over periods of 1 to 23 years was monitored. Projections suggested that a wide range of times are required for waters emerging from VFs to reach 500 $\mu\text{S}/\text{cm}$. The wide range of times to partial recovery suggests that there may be controllable factors during the VF construction process that can be manipulated to reduce TDS production.

Evans, D. M., C. E. Zipper, P. F. Donovan, and W. L. Daniels. 2014. "Long-term trends of specific conductance in waters discharged by coal-mine valley fills in Central Appalachia, USA." *Journal of the American Water Resources Association* 50 (6):1449-1460. doi: 10.1111/jawr.12198.

Pilot-scale research suggests that surface hydrologic flow paths are not stable for years after mining ceases and reclamation is completed.

Two conceptual control points were found that govern hydrologic flow paths on mined lands, including the soil surface that partitions infiltration vs. surface runoff, and a potential subsurface zone that partitions subsurface storm flow vs. deeper percolation. There can be an evolution of new and abandoned flow paths that develop and change as the spoil or site characteristics change in response to mining and reclamation and hydrologic processes shift toward a new equilibrium.

Evans, D. M., C. E. Zipper, E. T. Hester, and S. H. Schoenholtz. 2015. "Hydrologic effects of surface coal mining in Appalachia (U.S.)." *Journal of the American Water Resources Association*:1-17. doi: 10.1111/1752-1688.12322.

The Cost Effective Sulfate Removal (CESR) Process was effective in reducing the specific conductance of mining waters from 1,500-2,500 $\mu\text{S}/\text{cm}$ to below the proposed EPA limit of 500 $\mu\text{S}/\text{cm}$. Sample water from southwestern Virginia mines was treated using a two-step precipitation method referred to as the CESR process. The SC of mining runoff waters (1,500-2,500 $\mu\text{S}/\text{cm}$) was consistently reduced below the proposed EPA limit of 500 $\mu\text{S}/\text{cm}$ when the second step of the CESR process lasted 18 hours and the reagent dose was 1.25 times the source water sulfate concentration.

Grey, C. V., G. D. Boardman, J. Parks, Z. Kemak, and K. Gunther. 2018. "Specific conductance reduction in valley fill runoff using the cost effective sulfate removal process." *Journal of the American Society of Mining and Reclamation* 7 (1):56-76.

Two (GE Osmonics model DK and Snyder Filtration model NFX) of the three examined nanofilters consistently met the proposed specific conductance (SC) limit for the two mining waters tested. The capacity of nanofiltration to meet the proposed SC limit of 500 $\mu\text{S}/\text{cm}$ for mining waters with moderate and high levels of SC from southwestern Virginia was evaluated. Performance in terms of SC reduction declined as influent ion concentrations increased. The pretreatment options tested did not improve the SC reductions accomplished by nanofiltration.

Kemak, Z., G. D. Boardman, J. Parks, and C. V. Grey. 2019. "Reduction of specific conductivity in coal mine effluent using membrane technology." *Journal of the American Society of Mining and Reclamation* (in press).

Natural or engineered terraced iron formations (TIFs) are underutilized for acid mine drainage (AMD) treatment because of uncertainties with respect to treatment performance. To address this problem, Fe(II) oxidation rates were measured at eight sites in the Appalachian Bituminous Coal Basin and at three sites in the Iberian Pyrite Belt (IPB). Zero-order Fe(II) oxidation rates ranged from 8.60 to 81.3 10^{-7} mol/L-s at the Appalachian sites and 13.1 to 67.9 10^{-7} mol/L-s at the IPB sites. First-order Fe(II) oxidation rate constants ranged from 0.035 to 0.399 /min at the Appalachian sites and 0.003 to 0.010 /min at the IPB sites.

Larson, L. L., J. Sánchez-España, and W. D. Burgos. 2014. "Rates of low-pH biological Fe(II) oxidation in the Appalachian Bituminous Coal Basin and the Iberian Pyrite Belt." *Applied Geochemistry* 47:85-98. doi: 10.1016/j.apgeochem.2014.05.012.

Conditions that favored the fastest rates of Fe(II) oxidation coincided with higher Fe(III) solubility. The kinetics of low-pH Fe(II) oxidation at five sites in the Appalachian Coal Basin in the U.S. and at three sites in the Iberian Pyrite Belt in Spain were measured. The fastest rates of Fe(II) oxidation occurred at the sites with the lowest pH values. The solubility of Fe(III) minerals thus plays an important role in Fe(II) oxidation kinetics.

Larson, L. L., J. Sánchez-España, B. Kaley, Y. Sheng, K. Bibby, and W. D. Burgos. 2014. "Thermodynamic controls on the kinetics of microbial low-pH Fe(II) oxidation." *Environmental Science and Technology* 48 (16):9246-9254. doi: 10.1021/es501322d.

Maximum potential acidity (MPA) had the strongest relationship to total dissolved solids (TDS) release. Forty-one overburden samples containing a range of sandstones and shales were collected from surface mines in West Virginia, Virginia, and Kentucky. Results were compared to Acid-Base Accounting parameters for each sample; i.e., paste pH, MPA, neutralization potential (NP), and net neutralization potential (NNP). Low, moderate, and high TDS release indices were developed based on MPA values.

Odenheimer, J., J. Skousen, L. M. McDonald, D. J. Vesper, M. Mannix, and W. L. Daniels. 2014. "Predicting release of total dissolved solids from overburden material using acid-base accounting parameters." *Geochemistry: Exploration, Environment, Analysis* 15:131-137. doi: 10.1144/geochem2014-276.

Passive biological treatment (PBT) systems can be effective in the removal of acidity and metals from mine water. These systems are a relatively low cost, low-maintenance treatment technology for mine waters that have been used for over three decades. However, their practical ability to reduce conductivity is unclear, given that previous research reports focused on the removal of metals, acidity, and solids.

Smyntek, P. M., R. C. Wagner, L. A. Krometis, S. C. Sanchez, T. Wynn-Thompson, and W. H. J. Strosnider. 2017. "Passive biological treatment of mine water to reduce conductivity: potential designs, challenges, and research needs." *Journal of Environmental Quality* 46:1-9. doi: 10.2134/jeq2016.06.0216.

Iron oxyhydroxide, when mixed with coal tailings, ameliorates selenium discharge. Iron oxyhydroxide was found to reduce the concentration of dissolved selenium by about 70%, which indicates that selenite is the dominant, mobile selenium species during initial weathering, and that selenium could be controlled at its source. No obvious relationship existed between sulfur and selenium release.

Ziemkiewicz, P. F., M. O. O'Neal, and R. J. Lovett. 2011. "Selenium leaching kinetics and in situ control." *Mine Water and the Environment* 30 (2):141-150. doi: 10.1007/s10230-011-0154-4.

Stabilization of mining reject through use of a plate and frame press with additions of Portland cement is effective and economical. With limited or no waste slurry storage areas, it is common to dewater thickener underflow and co-dispose with the coarse reject. However, the combined reject may be difficult to handle and may not meet regulatory requirements if it is not stabilized properly.

Honaker, R. Q., Z. Duan, D. Cobb, and S. Baird. 2013. "Stabilization of fine coal waste as an alternative disposal technique." *Environmental Considerations in Energy Production*, Charleston, WV, 14-18 Apr.

Predictions of total dissolved solids (TDS) release by Acid-Base Accounting were similar to the actual release of constituents. Sample WV 2 released the highest concentrations of elements, including high Fe, Al, Mn, and Ca. These results were consistent with this samples moderate pyrite and neutralization potential (NP) contents. WV 3 and WV 4 produced lower levels of TDS release, which was consistent with lower pyrite and NP contents in the samples.

Odenheimer, J., J. Skousen, and L. M. McDonald. 2013. "Predicting total dissolved solids release from overburden in Appalachian coal fields." Environmental Considerations in Energy Production, Charleston, WV, 14-18 Apr.

Higher amendment concentrations of ferrihydrite were more effective than thin ferrihydrite treated piles and unamended piles in removing Se. Lysimeters were installed in WV to test the transport rate of selenium in mine-run interburden and removal of selenium by adsorption to layered ferrihydrite (ferrihydrite). The interburden was placed over four different thicknesses of fine-grained ferrihydrite and in a cell without any ferrihydrite, which served as the control.

Ziemkiewicz, P. F. 2013. "Subsurface sequestration of leached waste-rock selenium in reactive ferrihydrite beds." Environmental Considerations in Energy Production, Charleston, WV, 14-18 Apr.

An electrical conductivity (EC) based regression model, while highly significant, only accounted for 26% of the variation in West Virginia Stream Condition Index (WVSCI) scores. No evidence was found that an EC value less than $300\mu\text{S}/\text{cm}$ is a reliable predictor of WVSCI values that meet the West Virginia narrative criteria for stream impairment. The population confidence intervals illustrate that a WVSCI = 68 (threshold value for impairment) can be attained at a very wide range of ECs.

Ziemkiewicz, P. F., and S. Northway. 2013. "How well does electrical conductivity predict stream impairment?" Environmental Considerations in Energy Production, Charleston, WV, 14-18 Apr.

Major determining factors of community structural metric responses to specific conductance (SC) were found to be seasonality and dominance of seemingly SC-tolerant taxa. Relationships between SC and selected community structural response metrics (i.e., density and richness metrics of Total, EPT, Ephemeroptera, Plecoptera, and Trichoptera) were examined. The genus, *Leuctra*, in the order Plecoptera, was an example of such a tolerant and dominant taxon.

Drover, D., S. Schoenholtz, and C. E. Zipper. 2016. Investigating influences on benthic macroinvertebrate communities in Appalachian coalfield streams. In Appalachian Research Initiative for Environmental Science Final Reports. Blacksburg, VA: Appalachian Research Initiative for Environmental Science (ARIES).

In a hierarchical cluster analysis that characterized similarity in species based on occurrences at sites, species fell into two distinct groups: widespread species and patchily distributed species. *E. flabellare* fell into the widespread species cluster, but 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.

Martin, Z. P., S. Ciparis, P. L. Angermeier, and D. J. Orth. 2016. Impact of mining effluent on fish populations. In Appalachian Research Initiative for Environmental Science Final Reports. Blacksburg, VA: Appalachian Research Initiative for Environmental Science (ARIES).

The current practice of using conductivity as a primary indicator of stream health may be premature without further understanding other significant influences on Benthic health. Historical and collected data from the Dumps Creek watershed located in Russell County, VA did not support a direct correlation between total dissolved solids (TDS) and the Virginia Stream Condition Index (VSCI) score. The U.S. Environmental Protection Agency (EPA) commented that VSCI scores are not able to discern the impacts of any individual stressor and any related EPA guidance should only be considered when the full ionic chemistry of the stream is understood. EPA also stated that benthic macroinvertebrate community well-being is too complex to be predicted or measured using only a single parameter.

Kirby, L., Craynon J. and Sweeten, S. 2013. Exploring Benthic Impairment and Total Dissolved Solids in the Dumps Creek Watershed. In: J.R. Craynon (ed.), Environmental Considerations in Energy Production, April 14-18, 2013, Charleston, WV. Soc. Mining Met. & Explor. Englewood, CO, pp. 362-370.