

**APPROACHES AND BARRIERS TO INCORPORATING SUSTAINABLE  
DEVELOPMENT INTO COAL MINE DESIGN**

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John Raymond Craynon

## **ABSTRACT**

It is widely recognized that coal is and will continue to be a crucial element in a modern, balanced energy portfolio, providing a bridge to the future as an important low-cost and secure energy solution to sustainability challenges. The designer of coal mining operations needs to simultaneously consider legal, environmental, and sustainability goals, along with traditional mining engineering parameters, as integral parts of the design process. However, traditional coal mining planning seldom considers key “sustainability factors” such as societal impacts; dislocation of towns and residences; physical and economic impact on neighboring communities and individuals; infrastructure concerns; post-mining land use habitat disruption and reconstruction; and long-term community benefit.

This work demonstrates the advantage of using a systems engineering approach based on the premise that systems can only be optimized if all factors are considered at one time. Utilizing systems engineering and optimization approaches allows for the incorporation of regulatory and sustainability factors into coal mine design. Graphical approaches, based on the use of GIS tools, are shown as examples of the development of models for the positive and negative impacts of coal mining operations. However, this work also revealed that there are significant challenges inherent in optimizing the design

of large-scale surface coal mining operations in Appalachia. Regulatory and permitting programs in the United States, which give conflicting and ill-defined responsibilities to a variety of federal and state agencies, often focus on single parameters, rather than the full suite of desirable outcomes for sustainability, and serve as barriers to innovation.

Sustainable development requires a delicate balance between competing economic, environmental and social interests. In the context of coal mining in the U.S., the current regulatory frameworks and policy-guidance vehicles impede this balance. To address this problem, and thus effectively and efficiently provide energy resources while protecting the communities and environments, the U.S. will likely need to fundamentally restructure regulatory programs. Ideally, revisions should be based upon the key concepts of public ecology and allow for a systems engineering approach to coal mine design.

## **DEDICATION**

This dissertation is dedicated to the memory of my parents, John and Joy Craynon, and to my children, Johanna, Megan, Colleen and Robert, my son-in-law Steven, and my grandchildren, Rebekah and Everett. I have been shaped by all of you and your love for me.

## ACKNOWLEDGMENTS

I would like to sincerely thank Dr. Emily Sarver for taking on the responsibility of advising me after I was already deep into the process of this degree. She is co-author for three of the manuscripts that make up the chapters of this dissertation and has provided me significant insight into this process.

I would also like to thank the other members of my committee, Dr. Gerald Luttrell, Dr. W. Lee Daniels, Dr. Kramer Luxbacher, and Dr. Dirk van Zyl, for their participation and input. I have known many of them for many years and respect them greatly. I would also like to thank the previous members of my committee, Dr. Antonio Nieto, who is now at Penn State, and Dr. David Trauger, who has retired from Virginia Tech but remains active in research and teaching. Their input also helped provide me with insights about the problems I was dealing with in my work and the places where my strengths and weaknesses existed. Additionally, Dr. David Robertson, who instructed one of my favorite classes in my PhD program and who is a co-author on one of my papers, has been an invaluable resource.

I would further like to single out Dr. Michael Karmis for acknowledgement. In addition to being my co-author for four of the five manuscripts that make up the chapters of this dissertation, he was formerly chair of my advisory committee and he is currently my supervisor at the Virginia Center for Coal and Energy Research. I have known Dr. Karmis since I was an undergraduate many years ago, and have benefited through the years from his wise counsel, his support in my career, and his encouragement and assistance in undertaking this educational journey. I have been truly fortunate to have him as a mentor, confidant and friend.

I would be remiss if I did not thank Dr. Gregory Adel and the faculty and staff in the Department of Mining and Minerals Engineering at Virginia Tech for their assistance and encouragement along the way.

Finally, I also want to my family, co-workers and friends who have been an encouragement to me throughout several semesters of completing my course work, hours spent complaining, the weeks and months when it seemed that I did nothing at all related to this endeavor, and the years it has taken to get me here. Words are inadequate to adequately express what I feel for all of you.

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## PREFACE

Coal mining may not fit into commonly understood definitions of sustainability. Mineral and energy extraction and reclamation operations do, however, contribute significantly to sustainability through the benefits they provide to society, when they are conducted in a manner that supports sustainable economies, social structures and environments throughout all phases of mining, including closure.

Traditional mining engineering designs for coal mines rarely consider the compliance with environmental laws and the protection and enhancement of community well-being as an integral part. As sustainable development requires that economic, social and environmental goals all be pursued, this work was undertaken in order to better define a systems engineering approach to allow for the incorporation of sustainable development requirements simultaneously with more standard coal mining considerations. A mathematical model using multi-variate, multi-outcome techniques was proposed, based in part on utilizing geographic information systems (GIS) and detailed information about coal mining properties, environmental resources, and social values and considerations. During the preliminary examination, the committee provided input on the scope of the work and suggested that the detailed modeling was far too large an undertaking in a dissertation. They suggested that a new focus on surface mines in Appalachia, with an emphasis on issues related to the regulatory framework, was a more reasonable scope.

In addition, as the work progressed attempts to build specific mathematical models for large-scale surface coal mines in Appalachia were unsuccessful in part due

to the complexity of relationships among the parameters listed in Appendix C. Additional difficulties in modeling arose as a result of barriers which exist in the legal and regulatory framework for coal mining in the United States. Based on those failures, as well as input from the Advisory Committee, the work was refocused to identify the extent of the barriers and the necessary facets of a new approach allowing for the incorporation of sustainable development principles into coal mine designs. It was suggested that a simple case study, which demonstrated the use of GIS and the basic approach to identifying conflicts that exist on a site between the environmental, economic and social components of sustainable development.

The chapters that comprise this dissertation are derived from manuscripts prepared over nearly five years and follow the development of the concept for a systems engineering approach to incorporate sustainable development into coal mine design, as well as the change in direction of the study to address the development of recommendations for addressing the barriers to sustainability in coal mine design.

## **ORGANIZATION OF DISSERTATION AND ATTRIBUTIONS**

This dissertation is composed of five manuscripts, each of which has been presented at an international meeting and subsequently published in peer-review proceedings of those conferences, accepted for presentation and publication, or recently submitted to a peer-reviewed journal (as noted at the beginning of each chapter). In addition to the collaborative efforts of the author and his current and former advisors, Dr. Emily Sarver and Dr. Michael Karmis, Virginia Center for Coal and Energy Research and Department of Mining and Minerals Engineering, others provided invaluable assistance. Dr. Nino Ripepi, Virginia Center for Coal and Energy Research,

Virginia Tech, provided assistance with the development of GIS figures in Chapter 3 and in review of the analysis of those figures. Dr. David Robertson, Department of Forest Resources and Environmental Conservation, Virginia Tech, contributed significantly to the development of Chapter 4. It should also be noted that the manuscripts are formatted according to the requirements of the publications where they were submitted, even when adapted for this dissertation, and organized as follows:

- Chapter 1, “Integrating Sustainability in Coal Mining Operations,” is adapted from a paper presented at the Third International Conference on Sustainable Development Indicators in the Minerals Industry, held on the Island of Milos in Greece in June 2007. The paper introduces the need for a better means to incorporate sustainable development principles into coal mining design, and suggests a mathematical approach relying on advanced techniques in multi-variate, multi-outcome optimization. Dr. Michael Karmis co-authored this paper.
- Chapter 2, “An Approach for Optimizing Coal Mine Design for Sustainable Development,” is adapted from a paper presented at the Fourth International Conference on Sustainable Development Indicators in the Minerals Industry, held on the Gold Coast of Australia in June 2009. This paper presents discusses the parameters being evaluated for inclusion in the optimization model, and the need to simplify the model by using index variables, as well as the planned use of a geographic information system to facilitate modeling and analysis. Dr. Michael Karmis was a co-author of this work.
- Chapter 3, “A GIS-Based Methodology For Identifying Sustainability Conflict Areas In Mine Design – A Case Study From A Surface Coal Mine In The USA,”

demonstrates the use of a GIS approach to identifying the areas on a large surface mining permit in Appalachia with the greatest potential for creating conflicts among the sustainability goals related to economic, environmental and social performance. The case study also identified issues in the regulatory program in the United States that hamper the use of such approaches. This work was co-authored by Dr. Emily Sarver, Dr. Nino Ripepi and Dr. Michael Karmis. It is being prepared for submission to a peer-reviewed journal during November 2011.

- Chapter 4, “Could a Public Ecology Approach Help Resolve the Mountaintop Mining Controversy?” suggests that the emerging concept of *public ecology* could be useful in addressing the controversy surrounding mountaintop coal mining in Appalachia. Public ecology includes both environmental and social concerns, thus dovetailing with the tenets of sustainable development. Dr. Emily Sarver and Dr. David Robertson are co-authors of this manuscript. It will be submitted for peer-review and publication in December 2011.
- Chapter 5 provides a wrap-up of this work and discusses the barriers to incorporating sustainable development in coal mining and details the core concepts for a new regulatory approach is entitled “Incorporating Sustainable Design Principles into Coal Mine Design: Regulatory and Policy Barriers in the United States”. This paper incorporates ideas first presented in the other four manuscripts, including the adoption of a public ecology approach for coal mining. Dr. Emily Sarver and Dr. Michael Karmis are co-authors of this paper. This work has been accepted for a workshop at the Eighth International Conference on Environmental, Cultural, Economic and Social Sustainability being held in January 2012 in

Vancouver, BC, Canada. It will also be submitted for publication in *The International Journal of Environmental, Cultural, Economic and Social Sustainability*.

- Chapter 6, “Conclusions and Next Steps”, provides overall conclusions for all the work and suggests next steps in research that may be warranted.
- Appendix A provides the copyright permissions for previously published work included in this dissertation.
- Appendix B, entitled “Optimizing Coal Mine Design for Sustainable Development at Large Surface Coal Mining Operations in Appalachia,” is adapted from a paper presented in June 2011 at the Aachen International Mining Symposium: Fifth International Conference on Sustainable Development in the Minerals Industry held in Aachen, Germany. This paper addresses the use of a model for optimizing coal mine design, but concludes that there are several barriers that exist in the regulatory framework in the United States that make the use of the systems engineering approach impossible. Dr. Michael Karmis co-authored this paper.
- Appendix C provides a table of parameters which were considered for inclusion in quantitative and qualitative models for sustainable development at surface coal mining operations in Appalachia discussed in Chapter 3 and Appendix B. These parameters illustrate the complexity of developing such a model.
- Appendix D provides some of the preliminary draft GIS figures that were used to prepare the papers provided in Chapter 3 and Appendix B.

# CHAPTER 1: INTEGRATING SUSTAINABILITY IN COAL MINING OPERATIONS

*John R. Craynon and Michael E. Karmis*

Adapted from a paper presented at the Third International Conference on Sustainable Development Indicators in the Minerals Industry (SDIMI 2007) and published in: Proceedings 3rd International Conference on Sustainable Development Indicators in the Minerals Industry (ed: Z. Agioutantis), pp. 73-76, Heliotopos Publications: Athens. Used with Permission.

## **ABSTRACT**

It is widely recognized that coal is and will continue to be a crucial element in a modern, balanced energy portfolio, providing a bridge to the future as an important low cost and secure energy solution to sustainability challenges. In response, the global coal and energy production industries have begun a major effort to identify and accelerate the deployment and further development of innovative, advanced, efficient, cleaner coal technologies. A number of coal producers are also involved in sustainable development (SD) activities, including economic support of communities and regions, environmental restoration and social well-being. These companies have corporate sustainable development policies and guidelines in place that provide guidance for operations, and report annually on their contributions to sustainability. However, even with these efforts, the continued controversies surrounding coal mining in the United States indicate the need for a different approach to address the environmental, social and economic dimensions of coal mining.

This paper will discuss the integration of public policy, law, environmental management and engineering, particularly as that integration relates to the recovery of energy and mineral resources. This paper suggests that the legal, social and environmental requirements for mining

operations be fully integrated into the mining and reclamation plan. Treating SD and engineering considerations as complementary parameters results in optimized mining operations. Such a systematic approach is necessary in order to achieve economic, social and environmental sustainability, environmental protection and restoration, and effective, efficient and economically sound mining and reclamation.

## **INTRODUCTION**

The importance of sustainable development (SD) principles has been increasing within the mining sector over the past two decades. Early work focused mainly on mining metals and commodities other than coal and energy fuels. Because sustainability, however, is an important consideration for all human endeavors in the 21<sup>st</sup> century (Gibson et al., 2005), the coal industry has become active in sustainability efforts. A number of global coal mining companies have embraced sustainability as a key aspect of corporate philosophy. The National Mining Association has also published “NMA Sustainable Development Principles” which detail the considerations that their member companies must employ in their operations (NMA, 2011). However, the efforts to address sustainable development in the coal mining industry have not been fully successful, as demonstrated by the continued controversy around coal operations in the United States (see e.g., Reece, 2006).

Continued production of minerals and fossil energy fuels may not fit into commonly understood definitions of sustainability. Mineral and energy extraction and reclamation operations do, however, contribute significantly to sustainability through the benefits they provide to society, when they are conducted in a manner that supports sustainable economies, social structures and environments throughout all phases of mining, including closure. Significant progress can also be made through the inclusion of sustainability concepts in the

original design of the operation, as well as in ongoing operations. Innovative engineering, mining and reclamation operations can be optimized through consideration of environmental and economic sustainability goals, side-by-side with traditional technical mining engineering considerations.

## **CURRENT ISSUES**

### *The future of coal extraction*

It is widely recognized that coal is and will continue to be a crucial element in a modern, balanced energy portfolio, providing a bridge to the future as an important low cost and secure energy solution to sustainability challenges. A review of the Annual Energy Outlook 2007 report from the Energy Information Administration (EIA, 2007) indicates that United States energy demand is expected to grow at an average annual rate of 1.1% for the next 25 years. Almost every energy source is expected to grow, with coal, petroleum and natural gas dominating the energy mix. US electricity generation relies heavily on fossil fuels. Coal is the dominant component, with a share of about 50% in 2004, and is expected to increase to 57% by 2030, according to EIA.

Similar increases in coal utilization are anticipated worldwide. Overall, world use of coal is projected to grow by 44 % by 2025 (Waddell and Pruitt, 2005). Total world energy usage will increase by 34 % over that same period (IEA, 2004). In China, the International Energy Agency projected that the demand for coal to generate electricity will increase by 2.2 % annually, and coal-fired power will represent 72 % of China's generation in 2030 (IEA, 2004).

In addition, coal and crude oil can both be used as feed stock for conversion into liquid fuels and the choice depends on the price of feed stock. Energy economists maintain that coal liquefaction is viable for crude oil prices greater than \$40 per barrel. EIA predicts that Coal-to-

Liquids will be the largest contributor of “un-conventional” fuels, up to 7% of national supply. These potential demands will necessitate an increase in US coal production from the current level of just over 1.1 billion tons per year to almost 1.8 billion tons by the year 2030.

### *Corporate policies*

The global coal and energy production industries have recently begun a major effort to identify and accelerate the deployment and further development of innovative, advanced, efficient, cleaner coal technologies. A number of U.S. coal producers are also involved in sustainable development activities, including economic support of communities and regions and environmental protection and restoration. These companies have corporate sustainable development policies in place that provide guidance for operations, and some report annually on their contributions to sustainability following the Global Reporting Initiative (GRI, 2007) or other guidelines. The U.S. coal industry is also very active in the World Coal Institute and its efforts related to sustainability (WCI, 2007).

The World Business Council on Sustainable Development working with the International Institute for Environment and Development created the Mining, Minerals and Sustainable Development (MMSD) project in 1999. This project published its report in 2002 (IIED and WBCSD, 2002). The report includes an agenda for change and outlines nine sustainable development challenges facing mining:

- ensuring the long-term viability of the minerals industry,
- control, use, and management of land,
- using minerals to assist with economic development,
- making a positive impact on local communities,
- managing the environmental impact of mines,
- integrating the approach to using minerals so as to reduce waste and inefficiency,
- giving stakeholders access to information to build trust and cooperation,
- managing the relationship between large companies and small-scale mining,
- sector governance: clearly defining the roles, responsibilities, and instruments for change expected of all stakeholders.

As a follow up activity, the MMSD project in North America developed *Seven Questions to Sustainability: How to Assess the Contribution of Mining and Minerals Activities*, a practical means of planning or evaluating the contribution of mining to sustainable development (IISD, 2002). The seven questions in brief form are:

1. **Engagement.** Are engagement processes in place and working effectively?
2. **People.** Will people's well-being be maintained or improved?
3. **Environment.** Is the integrity of the environment assured over the long term?
4. **Economy.** Is the economic viability of the project or operation assured, and will the economy of the community and beyond be better off as a result?
5. **Traditional and non-market activities.** Are traditional and non-market activities in the community and surrounding area accounted for in a way that is acceptable to the local people?
6. **Institutional arrangements and governance.** Are rules, incentives, programs and capacities in place to address project or operational consequences?
7. **Synthesis and continuous learning.** Does a full synthesis show that the net result will be positive or negative in the long term, and will there be periodic reassessments?" (IISD, 2002).

These seven questions have been described by Hodge (2004) as demonstrating the shift from "analysis and mitigation of 'impacts' to analysis and encouragement of 'contribution.'"

#### *Traditional mine design considerations*

Most mine designs are based on traditional mining engineering factors, such as the quality of the commodity being mined, the geology, topography, hydrology, land ownership, geography, infrastructure, etc. Currently, environmental compliance and sustainability are considered in mine design and operation as a modifying factor to those designs. A cursory review of a few permit applications received by state and federal regulatory agencies in the US suggested that the designs used environmental requirements as constraints or modifiers on the plan, not as co-equal considerations. While practices may become more responsive to

sustainability, mine design continues to be governed by established mining engineering approaches.

### *Optimization*

Although some have suggested that it is impossible to properly define sustainable development in a way that allows for operational consideration (Norgaard, 2004), optimization of sustainability goals along with the operational outcomes for coal mining can and should be addressed. A cursory review of the available literature on engineering optimization reveals an emerging focus on mine design, environmental protection associated with mines or sustainability (Stewart and Petrie, 2006; Petrie, 2007; Petrie et al., 2007).

Mathematical multi-criteria optimization approaches, have previously been used in resource management (Stadler, 1988). There has also been significant effort related to the development of similar decision making approaches in environmental management, process engineering, energy network planning, and related complex decisions (Seiffert and Loch, 2005; Sadiq and Khan, 2006; Basson and Petrie, 2007a; Basson and Petrie, 2007b; Benetto et al., 2008; Beck et al., 2008; Miettinen, 2008; Miettinen et al., 2008; Hector et al., 2009; Eskelinen et al., 2010).

As with any optimization problem, mine design optimization would need to consider all constraints, system parameters and characteristics and desired outcomes in order to build a useful and reliable model. Since optimization of mine design, and in particular coal mine design, to address sustainability along with other parameters has not been widely practiced, identifying the appropriate parameters for measurement and the mathematical or logical relationships between these parameters is not a trivial task.

One area of concern is to define “sustainable development principles”. While these principles are derived from the three pillars of sustainability – economic, environmental and social – they must be more practically expressed. Harris (2000) discusses principles related to these three aspects of sustainable development. In the arena of local comprehensive planning, those principles have been distilled down to six areas related to compatibility with ecosystem functions, development of “livable” communities, focus on local economic issues, providing for equitable treatment among various social and economic populations, providing that responsible parties pay the cost of mitigation, and consideration for extra-local impacts (Berke and Conroy, 2000). As mentioned above, the NMA has also published their principles for mining operations, which include twenty detailed considerations (NMA, 2011).

#### *Public policy and legal framework*

Another important constraint on coal mining operations is the statutory and regulatory frameworks within which they are required to operate. Many of these legal and policy structures are based on a fundamental distrust of the regulated industry. In addition, while most have some means for public participation, the processes dictated by the laws and regulations are often ineffective at promoting meaningful public participation. Many of the laws tend to create an adversarial approach by instituting a system where one or more parties must respond to actions, proposals, decisions, etc. of another party. The participation is often late in the design process, or after design has been completed, and thus any change to mine or reclamation design necessary as a result of public or regulatory agency input creates a retrofitted design that cannot possibly be optimal.

## **SUGGESTED APPROACH**

In order to optimize the design of coal mining and reclamation operations, traditional mining engineering considerations and environmental and sustainability goals must be accounted for simultaneously. It is essential to identify all of the parameters, relationships, constraints and desired outcomes related to the widely varying factors that contribute to mine design, as well as the additional factors that should be considered as a part of a new, sustainable design approach.

### *Parameters*

For successful optimization of mine design, required parameters must be identified and measured as part of mine design and planning. To build an accurate model of those operations, data must be collected on ongoing operations. This data accounts for the modification of long-term designs as a part of permitting and the acquisition of information during mine operation. The design and operation of current coal mining properties should be evaluated by looking both at permitting documents and additional data obtained from mining companies and other public and private sources. These data reflect the mining engineering, geologic, economic and other considerations currently integrated into the design and planning process.

It can then be determined how legal, policy, environmental protection and sustainability should be incorporated in mine design. Whenever possible, the effect of environmental and post-mining land use considerations on mine design and operation needs to be quantified in economic terms, so as to be on par with other engineering considerations.

### *Relationships*

Once sufficient data is collected, it will be necessary to determine if and how these parameters influence one another and the desired outcomes for the specific mining operation. These relationships may be apparent based on scientific, engineering or other considerations, or

may require detailed statistical analysis in order to determine them. It may not be possible to state the precise interrelationships between numerous parameters, particularly given the lack of complete independence of many of them. It may be possible, however, to derive qualitative rather than quantitative models for those relationships.

### *Desired Outcomes*

In most cases, the ultimate desired outcomes are the profitability and long-term stability of the site. These are driven by corporate realities as well as the concern for long term liability. Coal mining is, after all, a business focused on profitability and long-term economic benefit for the shareholders or other owners. Additional outcomes for community economic benefits, enhanced environmental quality, and corporate image are also significant for mining companies in many locations.

The optimization approach must address the relative importance of these outcomes in order to weight them in the development of optimized models. For example, in an area with low availability of safe drinking water, protection of hydrologic resources may prove to be of primary significance, and thus of higher weight in the models, since it will greatly impact the feasibility and long-term profitability of the operation as well as the post-mining health of the community.

The nine factors related to sustainability in the minerals industry, identified by MMSD, can serve as the basis for desired sustainability outcomes. The first factor, industry viability, is addressed primarily through consideration of the economic profitability of an operation. Giving stakeholders access to information; defining the roles, responsibilities and instruments for change; managing the relationship between companies of different scales; benefiting local communities; and, promoting efficient use of minerals, are social factors that may be more

difficult to measure and may not directly impact the design and operation of a specific mining property.

Using the “seven questions” (IISD, 2002) is an additional basis for implementing sustainable development in coal mining. For example, Gardner and Sainato (2007) used the questions to examine how coal mining operations in Appalachia may be considered as contributing to sustainable development. A review of their analysis could provide a straightforward means for development of an optimization model.

However, managing the environmental impact of mines and the control, use and management of lands are both more easily quantified and related to accepted practices and legal frameworks. Future work should focus on the parameters related to these goals. Many of these parameters may already be routinely measured as a part of environmental or other compliance mechanisms.

## **CONCLUSION**

Many mining companies and operations are enhancing their commitment to sustainability and the long-term economic, social and environmental health of the communities where they operate. In order to maximize the profitability of these operations and enhance the business case for sustainability, it is necessary to optimize mine designs. The designer of coal mining operations needs to simultaneously consider legal, environmental, and sustainability goals along with traditional mining engineering parameters as an integral part of the design process.

The role of coal in the global energy supply mix makes this of primary importance. There is a need for research into the parameters for mining design that allow the building of models for optimization, the relationships between those parameters, and the desired outcomes that the system is being optimized to produce. In addition to quantifying the economic viability

of the operation, a number of sustainability goals should be built into the model and the relative importance of those goals determined.

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## **CHAPTER 2: AN APPROACH TO OPTIMIZING COAL MINE DESIGN FOR SUSTAINABLE DEVELOPMENT**

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### **ABSTRACT**

Traditional coal mining planning in the United States seldom considers key “sustainability factors” such as: societal impacts in the area; jobs (both created and lost); dislocation of towns and residences; impact on neighboring communities and individuals; infrastructure concerns; post-mining land use (except when limited by law or other factors); habitat disruption and reconstruction; long-term economic impacts in the community; and net long-term community benefit.

This paper discusses the development of a systems engineering approach based on the premise that systems can only be optimized if all factors are considered at one time. In theory, coal mine designs can be optimized for return on investment, environmental protection, and sustainability. Using this approach, the permitting process may be quicker and less costly, relationships with neighbors, communities, and environmental groups may be improved, the mining industry may be seen as a positive for the short-term and long-term, and the mining industry may increase profits.

This paper also discusses geographic information system (GIS) tools that may be used to incorporate ecological and other sustainable development concerns into models of coal mine

sustainability performance. Along with coal production cost and value information obtained from past and present coal mining operations, GIS data can be used to develop mathematical cost and equation models. By analysis of on-the-ground data, the parameters to be included in these models are identified, the relationships between these parameters quantified, and the models developed.

The paper suggests the next phases of the work to be completed once the data is obtained and the models are adjusted and validated. At that time, site-specific information will be input into the models and the approach to mining a particular property evaluated and optimized for financial rate-of-return and other desired outcomes, such as preservation or enhancement of sustainability values. Finally, the paper will examine how this approach can be combined with traditional mining engineering considerations in order to develop an optimized mine plan for a specific mining property.

## **INTRODUCTION**

In the past several years, a large group of multinational metal, non-metal, and coal mining companies developed policies and processes for incorporating sustainable development principles into the design and operation of their mines (ICMM, 2009). Sustainability factors that have been considered include environmental and societal impacts and economic benefits (Dourojeanni, 1993). In practice, this has included community involvement and the adoption of a “beyond compliance” ethic as it relates to environmental impacts. However, these efforts have generally relied on a traditional mining engineering approach to design, modified through iterative processes to accommodate environmental and sustainability goals.

The desired outcomes for coal mining in the United States are focused on maximizing coal recovery and corporate income while providing benefits to the local community and

protecting the health and safety of that community and the environment. The primary regulatory framework under which coal mining in the United States is conducted is the Surface Mining Control and Reclamation Act of 1977 (SMCRA). This act, which is implemented primarily by the States under delegated primacy, is applied in conjunction with other environmental laws, such as the Clean Water Act and the Endangered Species Act. SMCRA applies to both surface coal mining operations and the surface impacts from underground coal mining operations, so it is applicable to all coal mines in the United States. Several sustainability factors, particularly those related to community and social concerns, are not explicitly addressed through the regulatory programs under these laws. However, requirements for public involvement in permitting and the possibility of litigation have created opportunities for those factors to be considered.

A more integrated approach relying on systems engineering principles and engineering optimization can achieve better outcomes. Many environmental and social factors related to sustainability are geographic in nature, as are such mining engineering considerations as coal seam characteristics, mine location, and topography. Thus, geographic information system (GIS) tools, such as ESRI's ArcGIS™, can be usefully integrated into this systems engineering approach. The first step in this approach is the identification of the appropriate parameters for inclusion. Subsequently, the interrelationships of those parameters need to be determined so models that describe those relationships can be developed. Through a determination of desired outcomes, the models for the coal mining system can be optimized to achieve those outcomes (Craynon and Karmis, 2007). By comparing the models to data from specific coal mining sites, the models can be refined and used in coal mine design to address sustainability. The expected benefits of such an approach include the ability to modify mine designs to achieve multiple

goals, including profitability of the operation, minimizing long-term negative impacts to the environment and communities, and maximizing long-term benefits to the community. This approach allows stakeholders to better understand the potential risks and benefits of coal mining operations and to provide input on the nature of desired outcomes.

## **SYSTEMS ENGINEERING AND OPTIMIZATION**

Systems engineering is a methodical approach to addressing a problem. According to the International Council on Systems Engineering, “Systems Engineering is an engineering discipline whose responsibility is creating and executing an interdisciplinary process to ensure that the customer and stakeholder's needs are satisfied in a high quality, trustworthy, cost efficient and schedule compliant manner throughout a system's entire life cycle. This process is usually comprised of the following seven tasks: state the problem, investigate alternatives, model the system, integrate, launch the system, assess performance, and re-evaluate” (INCOSE, 2006). Although this approach is most often used in manufacturing, network design, and engineering construction, it has also been taken to support environmental management and sustainable development (Seiffert and Loch, 2005). The systems engineering process is applicable to the field of coal mine design as well, particularly when considering sustainable development.

A related discipline is that of process optimization. Optimization has been defined as “a technology for calculating the best possible utilization of resources (people, time, processes, vehicles, equipment, raw materials, supplies, capacity, securities, etc.) needed to achieve a desired result, such as minimizing cost or process time or maximizing throughput, service levels, or profits. Optimization technology improves decision making speed and quality by providing businesses with responsive, accurate, real-time solutions to complex business

problems” (E-optimization.com, 2000). The focus of optimization is often on planning a process prior to implementing it, or on the “model” and “integrate” steps of systems engineering. Through combining systems engineering principles with optimization, systems design can focus on the best possible approaches to achieving desired results. For coal mining operations, those results include achieving environmental, economic, and sustainable development goals. Others have suggested optimization as a means of achieving sustainable environmental management (Shastri et al, 2008). These approaches to problem-solving require that the problems, constraints, resources, timelines and desired outcomes be identified as a part of building the system model and design.

## **REGULATORY FACTORS FOR COAL MINING**

SMCRA and other regulatory programs that apply to coal mining operations in the United States include a number of factors that must be considered in designing and operating coal mines. These factors include environmental concerns such as water quality and wildlife protection, engineering design criteria such as slope stability, and concerns such as post-mining land use. These factors relate directly to performance standards identified in Sections 515 and 516 of SMCRA and are reflected in the regulations. Similar factors relate to regulatory programs under the Clean Water Act and other environmental laws. Table 2.1 includes a listing of the most important of these regulatory factors.

In addition to these primary factors, there are a number of related component factors that are easier to evaluate. For example, slope angle, soil type, soil depth, solar exposure, precipitation, ground cover, and vegetation type can be used to evaluate the value of current vegetation and revegetation potential. Factors such as water quality, vegetative cover, and vegetation type can influence parameters such as habitat value and fish and wildlife population.

Riparian vegetation cover and type can influence water temperature, and thus the composition and health of aquatic communities and habitats.

**Table 2.1: Regulatory Factors Considered for Coal Mining  
(SMCRA Sections 515 and 516)**

<b>Regulatory factor</b>	<b>Related information and factors</b>
Maximize coal recovery	Coal volume, geologic information
Restore land use or achieve higher or better land use	Pre-mining land use, post-mining land use, land cover, regulatory restrictions on land use
Backfill mined area and restore approximate original contour	Pre-mining topography, post-mining landform, surface hydrology
Control erosion and related water and air pollution	Geologic information, topography, land cover, surface hydrology
Save topsoil and restore it to support vegetation	Soil maps and surveys, pre-mining topography
Create stable permanent impoundments, engineer waste piles and impoundments	Post-mining topography, mine plan, hydrology, engineering designs
Minimize disturbance to hydrology	Surface hydrology, geology, ground water hydrology, water quality information, water use information
Barrier from other active or abandoned mines	Mine maps, topography, mine permitting information
Isolate acidic and toxic materials	Geologic information
Proper use of explosives	Blasting information, geologic information
Environmentally sound road construction away from streams	Road plans, public road maps, surface hydrology
Revegetation of mine site, with a preference for native plants	Land cover, pre-mining vegetation survey, ecosystem surveys
Minimise adverse impacts on fish, wildlife and related environmental values and where possible enhance them	Habitat assessments, pre-mining land cover and land use, threatened and endangered species information
Prevent subsidence damage from underground coal mines to structures and water supplies	Surface structures, subsidence plans, water supplies, surface utilities, residential maps, surface hydrology
Seal portals, drill holes and openings related to underground mines	Location information on mine openings, drill hole locations, geology, topography

In some cases, the basic regulatory factors can be combined into an index factor that looks at the interrelationships of various parameters. These indices are valuable as a measure of overall system function. One example of such an index is EPA's Rapid Bioassessment Protocol

(Barbour et al., 1999), which evaluates water quality, water quantity, vegetation, habitat suitability, and the population and viability of plant and animal species. Differences in habitat indices may be used in a variety of regulatory programs to represent the change or potential change in a system due to a proposed activity, such as the impacts of mining or the effectiveness of site reclamation or restoration.

## **SUSTAINABILITY FACTORS FOR COAL MINING**

The regulatory factors discussed above relate in part to sustainable development. Some of the factors related to sustainable development in coal mining may not be as easily identified, since they are not (as yet) based on specific legal requirements. However, by examining sustainability considerations included in agreed upon protocols, such as the Global Reporting Initiative (GRI, 2009) and those identified by the United Nations (UNCTAD, 2003), some issues can be discerned. Additional sustainability factors can be gleaned from the specific approaches used by mining companies internationally. Among the key factors are jobs created and lost, dislocation of towns and residences, impact on neighboring communities and individuals, infrastructure concerns, post-mining land uses, habitat disruption and reconstruction, long-term economic impacts in the community, and net long-term community benefits. Although there are additional site-specific considerations based on community needs, local resources, and other social and cultural issues, a general listing of some of the important sustainability factors is shown in Table 2.2.

**Table 2.2: Sustainability Factors Considered for Coal Mining  
(After GRI and UNCTAD)**

<b>Sustainability factor</b>	<b>Related factors and information</b>
Economic performance	Employee compensation, revenues, operating costs, community investment
Local market presence	Proportion of spending at local suppliers, hiring from local community
Indirect economic impacts	Infrastructure development, in-kind donations, pro bono community engagement
Materials and energy used	Volume or weight of materials used, energy consumed
Water use	Source of water
Biodiversity	Land ownership, land use, habitats impacted by operation, fish and wildlife populations
Waste and emissions	Gas emissions, water discharge, fugitive dust, waste disposal location, type of waste, material spills
Regulatory compliance	Fines and non-monetary sanctions
Products and services	Mitigation of environmental impacts of products
Transport	Roads, railways, conveyors, employee transportation
Environmental impacts	Environmental mitigation and protection expenditures
Employment	Workforce, employment type, employee turnover, employee demographics
Labour relations	Collective bargaining
Occupational health and safety	Injury and accident rates, education and training
Training and education	Hours of employee training, career development plans
Procurement and investment	Human rights screening, labour practices, non-discrimination
Community involvement	Outreach, community involvement programs

As for environmental resources, sustainability factors may be defined by component values. For example, community economic benefit from a mining operation may be derived from population, per capita income, local tax revenues, property values, unemployment rates, commercial property vacancy rates, residential occupancy rates, etc. Other factors, such as the

availability of community services, including schools, hospitals, libraries, retail businesses, roads and recreational facilities may also be seen as a measure of community benefits. The potential impacts of coal mining operations can also be measured by some of these social factors. The proximity of the coal mining operation to community services, residences, and infrastructure can be used as a measure of the risk that operation imposes on the community and the potential for the operation to impact those facilities.

Indices can also be developed for sustainability factors within a community. For example, livability indices are often developed for communities, taking into account many of the factors listed above. Values for changes in factors such as population, income, infrastructure investment and property values, can be used as measures of the increasing or decreasing stability and health of the community. Sustainability measures related to ecosystem health and functioning are also often based on indices based on a number of individual parameters. Some have suggested that approaches based on indicators have become of “paramount importance” (Diaz-Balteiro and Romero, 2004). More difficult to account for are issues such as community involvement and satisfaction, which are critical to measuring the contributions to sustainable development. A National Research Council report (NRC, 2002) discussed in detail the range of data and types of information necessary to evaluate community livability.

Significant efforts have been undertaken over the past several years to use life cycle assessment (LCA) as a means of evaluating the sustainable development impacts of industrial activity, including mining. Reviews by Rebitzer et al. (2004) and Pennington et al. (2004) provide an overview of the methodology and approaches that have been developed. There has been a number of applications of LCA in the mining context that provide detailed models for evaluating the contribution of mines to sustainable development (Czaplicka-Kolarz et al, 2004;

Stewart and Weidma, 2005; Mangena and Brent, 2006; Durucan et al., 2006; Awuah-Offei and Adekpedjou, 2011). Specific work on coal mines has also been undertaken by Brent (2011) and Ditsele and Awuah-Offei (2011) focusing on coal mining operations in Australia and the United States, respectively.

These studies indicate use of LCA in mining applications have some limitations (see for example, Stewart and Weidma, 2005 and Awuah-Offei and Adekpedjou, 2011). LCA approaches emphasize environmental and economic aspects, as these are quantifiable and indicators are regularly available and agreed upon. The social aspects of sustainable development are less prevalent in this type of modeling. However, the indicators used in LCA are very useful in modeling and optimization.

#### **USING GEOGRAPHIC INFORMATION SYSTEMS IN A SYSTEMS APPROACH**

Since coal mining operations occur in a specific geographic location, GIS tools are extremely useful. Figure 2.1 illustrates the use of a GIS to identify the volume and value of coal in place at a specific location prior to mining, as would be done in traditional mining engineering. Similar analysis can be done to determine the volumes and depths of overburden at properties to be mined by surface techniques or the competency and thickness of overburden to determine the technical feasibility of underground mining. This sort of data is critical in determining whether a particular property is worth mining. The use of such tools by coal mining operations in the United States is relatively common and is expanding.

GIS can also be used in evaluating the pre-mining conditions of various factors and to evaluate changes in those values over time. GIS tools are commonly employed to describe environmental and sustainability factors such as those listed in Tables 2.1 and 2. 2. For example,

Figure 2.2 shows land cover at the same location shown in Figure 2.1. It is not common practice to use this sort of representation when developing mine designs under current practice.

There is growing availability of GIS data from public sources related to topographic, geologic, environmental, social, and culture factors. One issue with the data is resolution, however. Much of the publicly available data is at such coarse resolution that it is not particularly useful for site-specific evaluation. In most cases, high-resolution geographic data must be collected for it to be useful for analysis and modeling.

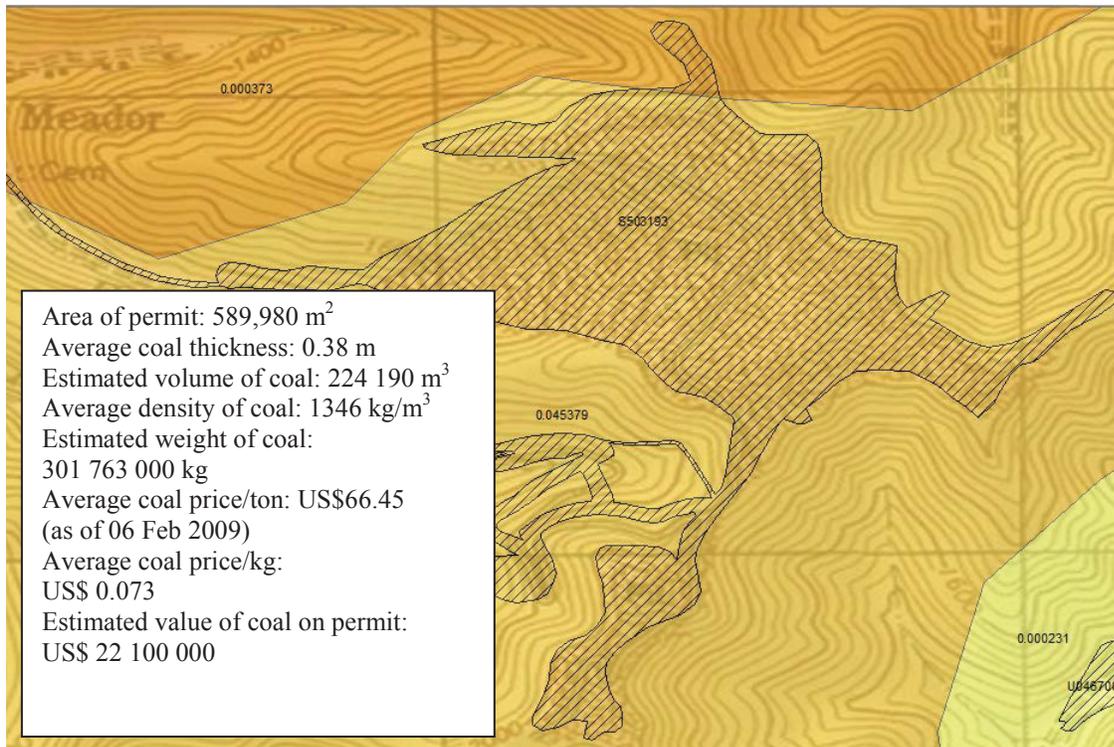


Figure 2.1: Location of coal mine permit with coal volume and value calculations. Data from West Virginia State GIS Technical Center. Source: <http://wvgis.wv.edu/data>.

Many GIS tools, such as ESRI's ArcGIS™ include spatial analysis capabilities enabling evaluation of proximity and determination of the probability of interaction between factors and allows for the modeling of impacts. These tools also allow for dissimilar information to be

overlaid in order to identify the potential conflicts between competing factors. For example, using these tools, the coal data from Figure 2.1 can be overlaid on the habitat quality information in Figure 2.2 to identify specific areas on the proposed mine site with high value coal and high value habitat resources. It is those areas where the design of the mine must consider both factors in order to achieve the most optimum results.

## **DEVELOPING MODELS AND DETERMINING DESIRED RESULTS**

A systems approach to mine design which includes optimization involves identifying the best possible approach that considers stakeholder needs and achieves the best possible outcome. Following the key steps in systems engineering involves a primary statement of the “problem”.

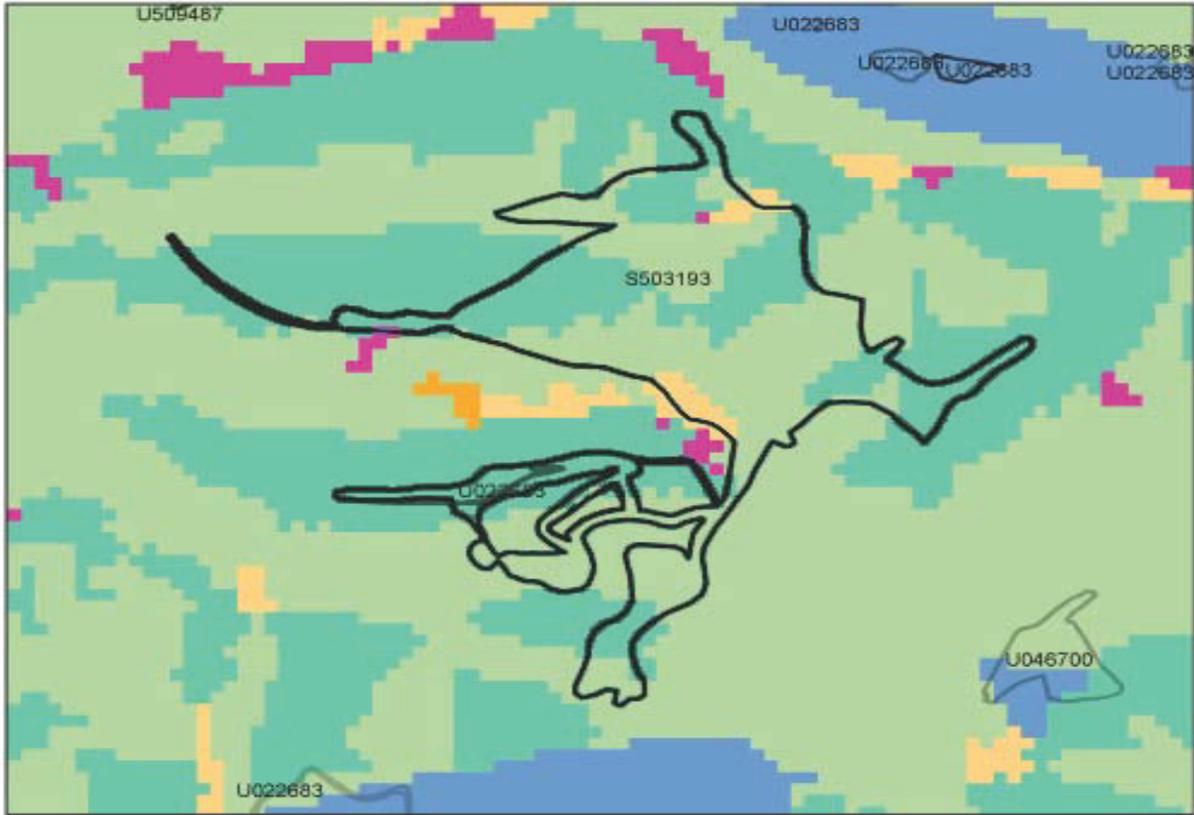
For coal mining operations, that problem statement fundamentally changes based on what the desired outcomes are. One component of the problem is the extraction of the maximum economic volume of coal, at the lowest possible operational cost. A related component is related to the net income and cash flow of the coal mining company. Additional desired outcomes may include maximum local payroll and increases in employment in the region. Another aspect of the problem is the protection or enhancement of public health and safety, based on legal requirements and sustainability factors. Economic and societal factors, such as increases in per capita income or availability of hospitals and schools, can be seen as desired outcomes of the coal mining operation. Long-term factors, such as preservation of ecosystem functions, elimination of environmental contamination, minimization of contingent risk for the mining company based on unknown environmental or safety issues created by the operation may also enter into the development of the problem statement for the coal mining model. Less-measurable outcomes, such as the effectiveness of community engagement and

residual social attitudes towards coal mining may be of significant importance, but are difficult to incorporate into the problem statement.

The second step in the systems approach is to investigate alternatives. For coal mining operations, this involves determining where there are conflicts or constraints on recovery of the coal resource. For example, stripping ratios may make coal recovery in some areas of the property uneconomic or impractical from a basic mining engineering standpoint. In other areas, the presence of a high-quality trout stream or proximity to a school or a hospital may make coal reserves unrecoverable for regulatory or public relations reasons. On a broader scale, the determination of mining methods and equipment, blasting procedures, or production rate may present other alternatives to be considered.

### **OPTIMIZATION APPROACHES**

Some have focused on linear programming and multicriteria approaches to model and optimize natural resource management. (Hof and Bevers, 2000; Stadler, 1988) One inherent problem in developing models using this approach is the complexity of the system. Coal mining operations impact a variety of factors in the economic, environmental and social realms. Shastri and Diwekar (2006a; 2006b) demonstrate the complexity of modeling environmental systems using optimization theory. Since this is but one of the systems involved in coal mining operations, it is clear that less-complex models may be necessary for optimizing coal mining operations. Because index parameters, such as ecosystem health indices and community livability indices, serve as simple representations of multiple factors, useful models of the coal mining system are best based on these parameters.



**Legend**

**Cover Type**

- Major powerlines
- Major highways
- Populated area - mixed land cover
- Low intensity urban
- Moderate intensity urban
- Intensive urban
- Planted grassland
- Conifer plantation
- Row crop agriculture
- Pasture/grassland
- Shrubland
- Woodland

- Floodplain forest
- Cove hardwood forest
- Diverse/mesophytic hardwood forest
- Hardwood/conifer forest
- Oak dominant forest
- Mountain hardwood forest
- Mountain hardwood/conifer forest
- Mountain conifer forest
- Surface water
- Forested wetland
- Shrub wetland
- Herbaceous wetland
- Barren land - mining, construction

Figure 2.2: Land cover at coal mine permit location. Data from West Virginia State GIS Technical Center and the U.S. Geological Survey. Sources: <http://wvgis.wv.edu/data> and <http://www.usgs.gov>.

While there are a number of mathematical models that can be built for coal mining operations, the use of GIS and graphical approaches provides a simpler approach. Through the use of graphical correlations to identify areas of conflict and proximity, either qualitative or quantitative models can be developed to enable consideration of those areas of a mining operation where the multiple desired outcomes are at odds. By evaluating these conflicts and determining those parameters that are most important in creating or resolving the conflicts, it is possible to derive graphically-based models for the mining operation. The models derived from this approach would have limited complexity, compared to others based on the multitude of possible factors and desired outcomes that could be used.

Additionally, multiple desired outcomes further complicate the modeling. In either approach, some of the possible desired outcomes are preservation of pre-mining environmental conditions, maintenance or improvement of social values, minimization of contingent long-term risk, and maximizing coal recovery and economic rate of return. These outcomes are not all straightforward to model or measure. For that reason, outcomes will be limited to maximizing rate of return (as measured by income versus capitalization), providing environmental protection (as measured by regulatory compliance), and enhancing social values (as measured by livability indices).

## **NEXT STEPS**

The next steps in this approach involve using data on existing coal mining operations to develop mathematical and GIS-based graphical models related to regulatory and sustainability factors, with an eye towards describing the system. By examining the models developed, using the available tools, alternative approaches should be developed to test the suitability of the

models to real world data. In this step, some level of sensitivity analysis should be conducted in order to determine which of the factors and model parameters are most important and deterministic of outcomes. Both quantitative and graphical approaches should be evaluated statistically and qualitatively with respect to the desired outcomes.

Once the models have been refined through this process, empirical data on coal mining operations should be combined with publically-available data to evaluate how well the systems approach fits multiple mining operations. In particular, there needs to be a focus on qualitative descriptions of sustainability outcomes and environmental protection. If possible, quantitative comparisons of economic outcomes, environmental damage, and contingent risk should be conducted.

The resulting quantitative and graphical models can then be used to evaluate the process for designing future coal mining operations in the United States. This would allow a determination of how this systems approach can be combined with traditional mining engineering to achieve optimal outcomes for economic, environmental, and social factors.

## **CONCLUSION**

Utilizing systems engineering and optimization approaches may allow the incorporation of regulatory and sustainability factors into coal mine design. Both mathematical and graphical approaches, based on the use of GIS tools, may allow the development of models of the positive and negative impacts of coal mining operations. Optimum outcomes may be numerous and focus on economic, environmental and social results of the operation. Because of the large number of factors that may be involved, and the inherent complexity in modeling the underlying natural, social, and economic systems, the use of index values, such as livability indices, and

surrogate values such as rate of return and regulatory compliance, may allow for the development of less-complex models that are more useful.

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## **CHAPTER 3: A GIS-BASED METHODOLOGY FOR IDENTIFYING SUSTAINABILITY CONFLICT AREAS IN MINE DESIGN – A CASE STUDY FROM A SURFACE COAL MINE IN THE USA**

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### **ABSTRACT**

Through proper design, coal mining operations can contribute to the social, economic and environmental aspects of sustainable development. The regulatory and permitting programs for coal mining in the United States, which often focus on several largely environmental parameters, are barriers to holistic consideration of these three sustainability pillars. Some changes in the current US regulatory framework may be necessary to allow for systematic consideration of economic, environmental and social factors in order to achieve more sustainable development mineral and energy resources. In the quest towards more sustainable mining activities, it has been suggested that mine design may be optimized in the context of sustainability by using a systems engineering approach that simultaneously considers economic, environmental and social factors. The use of geographic information system (GIS) tools may aid in this approach by allowing for spatial analyses of various resources (e.g., mineral values, water resources, community infrastructure) and identification of potential areas of conflict between these factors. By GIS analysis of the on-the-ground issues related to sustainability, the key parameters to be considered in decision making were identified. This type of analysis is crucial not only for regulatory compliance but also to ensure that the operation has obtained the “social license” to mine. To demonstrate this approach, a case study was conducted on a mountaintop coal mining operation in central Appalachia, where a permit was initially issued and subsequently revoked.

High-conflict areas were found to be primarily concentrated near streams and residential developments through the use of GIS. The case study suggests that use of this approach could have allowed for better communications and planning and that adoption of such a process could assist in the transition to a new regulatory framework that promotes and is based on sustainable development principles.

## **INTRODUCTION**

Since mineral and energy deposits are finite, mining *per se* is not a sustainable activity. In many cases, however, mining can contribute significantly to sustainable development through the numerous benefits it provides to society. The most basic of these benefits is the production of resources, necessary for all material goods not produced via agriculture and an overwhelming fraction of global energy generation. Other obvious benefits of mining activities include contributions to economies at various scales, employment opportunities for individuals, and additions to community infrastructure and the provision of access to services such as healthcare and education. Along with these benefits there are generally also some negative impacts of mining, including permanent severance of the mined resource, disruption of natural ecosystems and sometimes rapid decline in local socioeconomic conditions following mine closure.

In the United States, various types of mining operate under very different regulatory and permitting frameworks. The most easily understood is the case of coal mining. The Surface Mining Control and Reclamation Act of 1977 (SMCRA) (30 U.S.C. 1201 et seq.) is the primary law concerned with protecting the environment and society during coal mining and that post mining land uses are achieved. Additionally, other environmental laws, such as the Endangered Species Act and the Clean Water Act, have significant influence on how mining operations are conducted and their effectiveness at achieving the desired environmental outcomes. In the past

several years, a number of factors related to community and social concerns, key aspects of sustainability, have been integrated into the regulatory process, primarily through the implementation of the Clean Water Act by the U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (USEPA). However, because these regulatory programs do not have consistent requirements, nor do they all consider the same factors, some challenges are inherent in designing and operating a mine for sustainability. Most notably, the focus of many statutes (e.g., Clean Water Act) on a single environmental medium results in permitting and compliance schemes that emphasize singular goals, rather than an integrated sustainable development process.

## **SUSTAINABILITY METRICS AND COAL MINE PLANNING AND DESIGN**

Design of mining operations for sustainability might be approached in a number of ways, with varying degrees of success from the perspective of optimizing the triple bottom line.<sup>1</sup> Quite commonly, a traditional mine design based on economic optimization serves as the starting point, and is modified to ensure that basic environmental requirements are met, and, to a lesser degree, that social considerations are incorporated. While this type of design may represent great progress over pre-law designs (i.e., before SMCRA), it does not lend itself to true optimization for sustainability because all factors are not considered equally or at the same time. Moreover, there is no explicit mechanism for predicting or resolving conflicts between factors that can, and often do, interact (e.g., mine waste disposal, water resource quality, and community well-being). To evaluate the potential contributions of mining from economic, environmental and social perspectives, the Mining and Minerals Sustainable Development (MMSD) project in North America drafted *Seven Questions to Sustainability* (IISD, 2002). To affirmatively answer these

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<sup>1</sup> The triple bottom line is a term coined by Elkington (1999) to describe a business model for sustainable development that values economics, environments and societies.

questions, considerations should ideally be made during the mine design phase – long before development, exploitation and reclamation are underway. In the case of mines that are already active, significant redirection may be required to bring an operation in line with broad sustainability goals; but costs and efforts may be justified depending on individual drivers (e.g., compliance with new regulations, maintaining a social license) and potential consequences of failure. A recognized challenge for the mineral sector is the development of appropriate indicators for sustainable development (Azapagic, 2004). Approaches such as cost-benefit analysis of social and environmental impacts or natural resource damage appraisal may be useful in evaluating specific mining operations as they seek both regulatory permits and the social license to operate (Damigos, 2006).

Consistent with the shifting ideology from mitigation of negative impacts to contribution of net positive impacts reflected by the *Seven Questions* as discussed by Hodge (2004), it has been recently suggested that a systems engineering approach to mine design be adopted to allow for simultaneous optimization of economic, environmental and social issues (e.g., Craynon and Karmis 2007, 2009). Such an approach essentially may require trade-offs to be considered in an iterative process until the final design maximizes the net benefits of the proposed mining operation. While this would not usually allow for maximization of multiple individual factors (e.g., corporate profits), the goal is to design an operation that has the most positive overall positive impacts, such as protection of environmental resources, and maintenance or improvement of biodiversity; production of energy or minerals needed at local, regional or global levels to maintain or improve quality of life; improvement of local community assets and services that are sustained beyond the life of the mining operation; and assurance of financial security for corporate investors and the local community.

A particular benefit of a systems-engineering approach to design is the opportunity to map potential interactions between system components. In the case of sustainable mine design, these components are most simplistically categorized as the mineral or energy resources, the environmental resources, and the social resources; although each of these can be subdivided into multiple other categories. Appendix C provides a listing of some of the parameters and components that were examined for building a sustainability model at a coal mine site. While the system components and their areas of overlap could be illustrated on various diagrams (e.g., concept webs, Venn diagrams, flow charts, etc.), geographic mapping may be perhaps the most practical method – allowing for spatial interpretation and analyses of sustainability conflict areas (i.e., areas where positive impacts on one resource are near or overlapping negative impacts on another resource.)

The following sections describe a suggested method for using GIS tools to identify conflict areas as a necessary step in a systems-engineering approach to mine design, and highlight a simplified case study of this method and the results for the proposed Spruce No. 1 surface coal mine in Logan County, West Virginia.<sup>2</sup>

## **USING GIS TO IDENTIFY SUSTAINABILITY CONFLICT AREAS IN MINE DESIGN**

GIS tools are increasingly utilized in environmental, social and political applications. Sherrouse et al. (2011), for example, recently used GIS to analyze and display relative social values of ecosystem services for use in land and resource management; and Swetnam et al. (2011) investigated the implications of various policy-decision scenarios on land cover types and changes. In terms of incorporating sustainability concerns into mine design and performance evaluations, GIS tools present a rather straightforward yet extremely valuable approach (Craynon

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<sup>2</sup> This method was initially suggested by Craynon and Karmis (2009) and preliminary details of the case study were offered by the pair (2011) at bi-annual conferences on the Sustainable Development in the Minerals Industry.

and Karmis, 2009, 2011). By using spatial data to locate a variety of parameters associated with system resources (e.g., coal quality, residential density) and developing relatively simple relationships between them, interactions between the parameters with respect to their proximity to one another may be evaluated, as well as the effects of these interactions on desired outcomes (e.g., increased coal recovery, enhanced environmental protection and decreased impacts on residents). Thus, geographic areas of sustainability conflicts may be easily identified and interrogated for potential resolution strategies – critical steps in a systems-engineering approach to mine design and/or evaluation.

In addition to being relatively simple to assemble and interpret, the use of GIS analyses to evaluate sustainability of mine systems has several other advantages: they are dynamic, flexible, and data is generally easily accessed. A large amount of data is currently available for many parameters related to social and environmental resources (e.g., through land and water surveys or monitoring programs); and existing mines or those in advanced planning stages also typically have extensive datasets related to mineral or energy resource parameters, and environmental parameters on and around the mine site. While some basic parameters may be applicable to any mining operation (e.g., spatial boundaries of the operation, location and quality of surface waters), GIS analyses provide the flexibility to incorporate other specific parameters as necessary (e.g., habitat of endangered species).

Increasingly complex mathematical relationships may also be developed and included in analyses with the goal of improving the decisions made about the design of the mining operation. So, for example, instead of considering only simple linear relationships between parameters pairs, more intricate functions between multiple parameters could be evaluated. Graymore et al. (2009) discussed the use of multi-parameter analysis in decision-making for natural resource

management and land use planning. Their work demonstrates the ability to construct a “sustainability index” as a means of sorting and filtering various individual parameters on the basis of influence over desired outcomes.

In the case of mine design, sustainability indices must be constructed from at least one measure of economic, social and environmental impact, although an index will become increasingly meaningful as more parameters are considered. In the brief case study presented below, coal and overburden thickness are used to quantify economic potential, and proximity of the proposed mining operations to developed land or water resources is used to represent the potential for social and environmental impacts. Many of the other parameters detailed in Appendix C could have been used in a more complex model of the potential impacts of the mining operation. For example, the location and total area of wetlands and fish and wildlife habitat on the permit could have been used as a more detailed representation of the potential for environmental impacts. Similarly, a consideration of the population within specified distances of the mine permit could have been used as a representation of the potential for social impacts.

Once developed, based on choices of appropriate parameters and construction of multi-parameter indices, GIS models may be easily revised, updated and improved as new data becomes available or important for analyses. Moreover, because most impacts of mining occur at the local or regional scales, and those that occur at larger scales are typically relatable to local parameters (e.g., national resource supply from a given operation is related to the resource quantity, quality and accessibility at the operation), the suggested analyses need only occur over fairly small areas.

Considering all of the above, GIS tools appear well suited for evaluating the sustainability of mining systems – particularly those with mining activities occurring primarily on the surface.

## **CASE STUDY**

To demonstrate the use of the systems engineering approach and GIS to identify potential sustainability conflict areas in mine design, the Spruce No. 1 surface coal mine in Logan County, West Virginia was used as a case study. While there are numerous sources of information on the permit, the majority of data used in this case study is from the USEPA (2011). This mine was chosen for the study because much site-specific data and information was readily available, including elevation models, land cover data, and coal and overburden characteristics. It should be noted that the case study only illustrates the approach, and no attempt was made to evaluate the specific permitting issues that have occurred over the past several years.

### **Background Information**

The Spruce No. 1 operation is located two miles northeast of the town of Blair, West Virginia, at Latitude 38°52'39"N and Longitude 81°47'52"W. It was designed as a mountaintop removal operation, targeting the bituminous seams above and including the Middle Coalburg seam in the western part of the project and those above and including the Upper Stockton seam in the eastern part of the project area. In the eastern area, contour and auger or highwall mining were planned to recover the Middle Coalburg seam.

The mine was permitted by the WV Department of Environmental Protection (WVDEP) and the USACE in 1999 and 2007 respectively. The WVDEP permit was revised significantly in 2006 to reduce the impacts of the operation. The revised permit allowed for disturbance of a

total of 2,278 acres (3.5 square miles) and filling of approximately 7.5 miles of stream with excess spoil (i.e., overburden and interburden material). The operation was planned to recover about 75% of the coal reserves in the project area, necessitating removal of 400-450 vertical feet of the mountain and creating approximately 501 million cubic yards of spoil.

The majority of that material, nearly 391 million cubic yards, was planned to be place back onto the mined area. However, the remaining 110 million cubic yards would be placed in six excess spoil fills, burying some or all portions of the Right Fork of Seng Camp Creek, Pigeonroost Branch, Oldhouse Branch and their tributaries. The Spruce No.1 Mine surface mining permit issued by WVDEP describes the impacts of these fills and specifies that approximately 0.12 acre of emergent wetlands, 10,630 linear feet (2.01 miles) of ephemeral stream channels, 28,698 linear feet (5.44 miles) of intermittent stream channels, and 165 linear feet (0.03 miles) of perennial stream channels would be affected. Figure 3.1 shows the proposed mine site, including the locations of planned fills and a rendering of the topography based on a digital elevation model. The stream network on and around the proposed site and the proximity of the mine to developed areas (largely residential) along Spruce Fork are also shown.

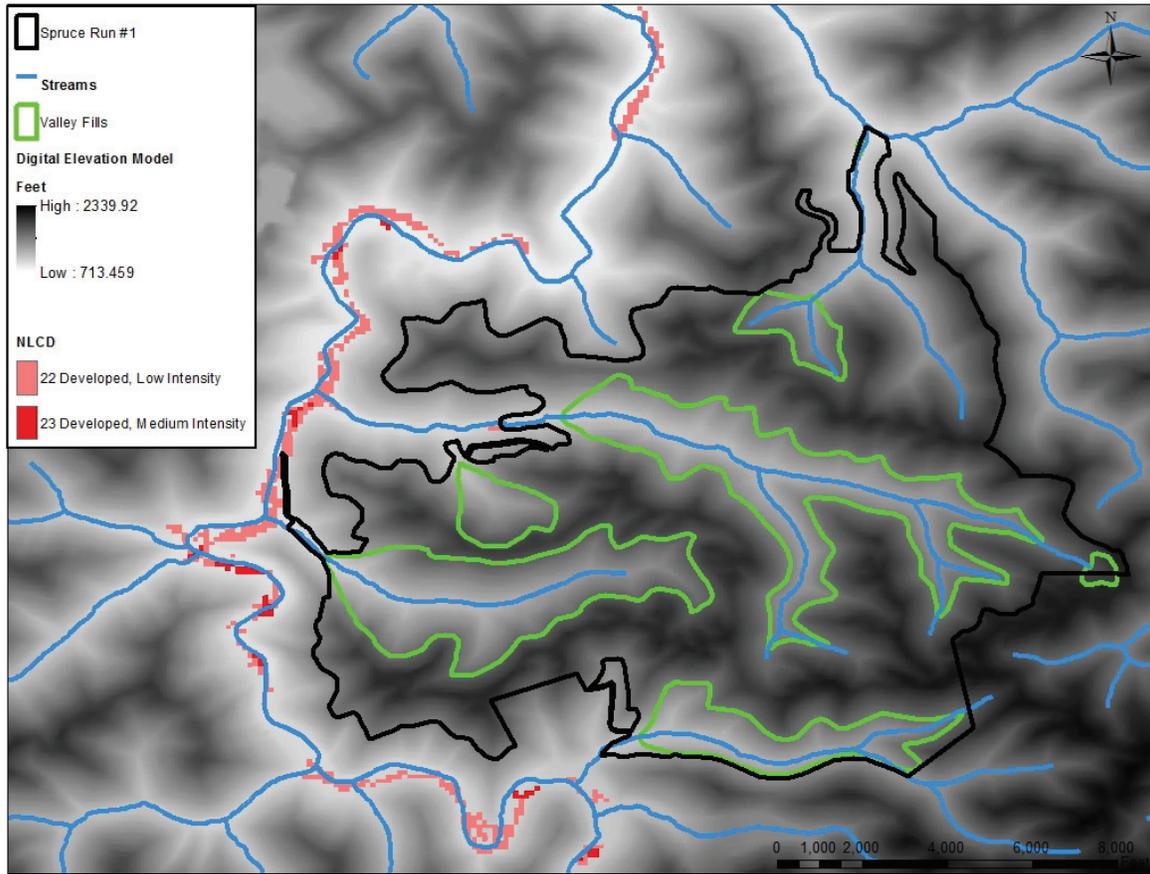


Figure 3.1: Spruce No. 1 Mine location and elevation. Data sources: WVGISTC, 2011 and WVDEP, 2011.

In January 2011, after mining had commenced in the Seng Camp Creek area of the permit in 2007, the USEPA, under authority granted by section 404(c) of the Clean Water Act (33 U.S.C 1344), overturned the permit issued by the USACE authorizing placement of spoil material into streams, which effectively also revoked the authorization to conduct operations under a surface mining permit previously granted by the WVDEP.

### GIS Analyses

As a demonstration of the concepts and process for graphical modeling, ESRI's ArcGIS™ was used to map a number of environmental, social and coal resources and data located on and

near the proposed Spruce No. 1 mine. Some of these analyses are shown below and others are shown in Appendix D. Additional graphical analyses attempted for some of the parameters listed in Appendix C did not prove to be useful, however, due in great part to the lack of publicly-available data at a suitable resolution for use in permit-scale analysis. The goal of the GIS analysis was to identify the areas where the desired outcomes of social benefits, environmental protection and economic value may be in direct conflict.

An examination of areas of potential conflict between mining operations, including excess spoil fills, and environmental and social resources (including many of those in Appendix C) showed a high level of concentration in and around streams. Stream quality, stream flow and other characteristics of streams, such as stream bed morphology, appeared to have the greatest impact on environmental resources such as wildlife habitat and population (EPA, 2011). Stream quality is inextricably linked with many published environmental quality indices, such as habitat quality scores, and appears to correlate with many social factors and parameters, such as recreation opportunities and livability indices which include environmental considerations, such as those developed using methodology similar to the Happy Planet Index (NEF, 2006).

Figure 3.2 shows the land cover data for the mining permit based on the National Land Cover Database (NLCD). Most of the permit area is covered by deciduous forest land, with some small grassland areas as well. The “developed, open space” adjacent to the stream is presumably flood plain areas.

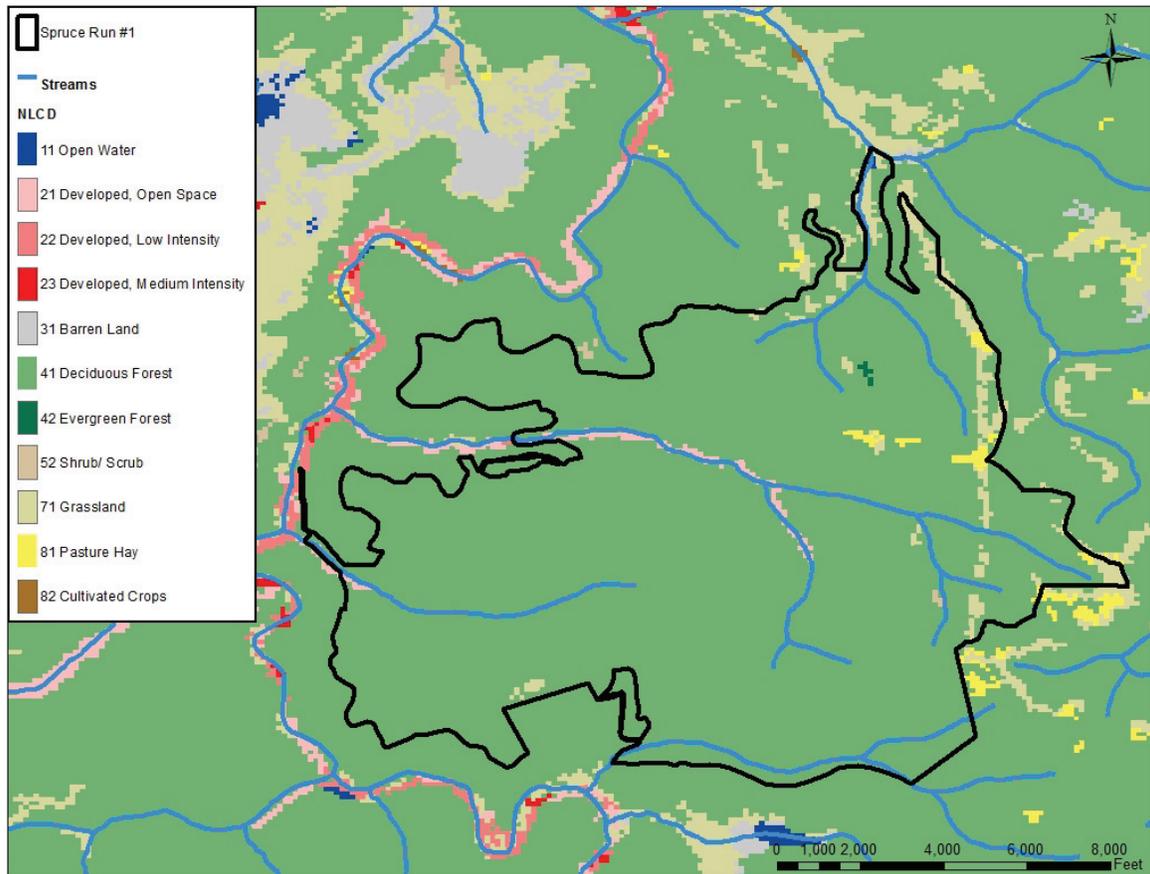


Figure 3.2: National Land Cover Data for Spruce No. 1 Mine. Data Source: WVGISTC, 2011.

Coal thickness is a major issue in mine design and the economic desirability of a particular coal property. Figure 3.3 shows the net coal contained in the four largest coal seams of concern on the mine site, the 5-Block, 6-Block, Coalburg and Stockton. As shown in this figure, net coal thicknesses exceed three meters (10 feet) in much of the northern third of the permit area.

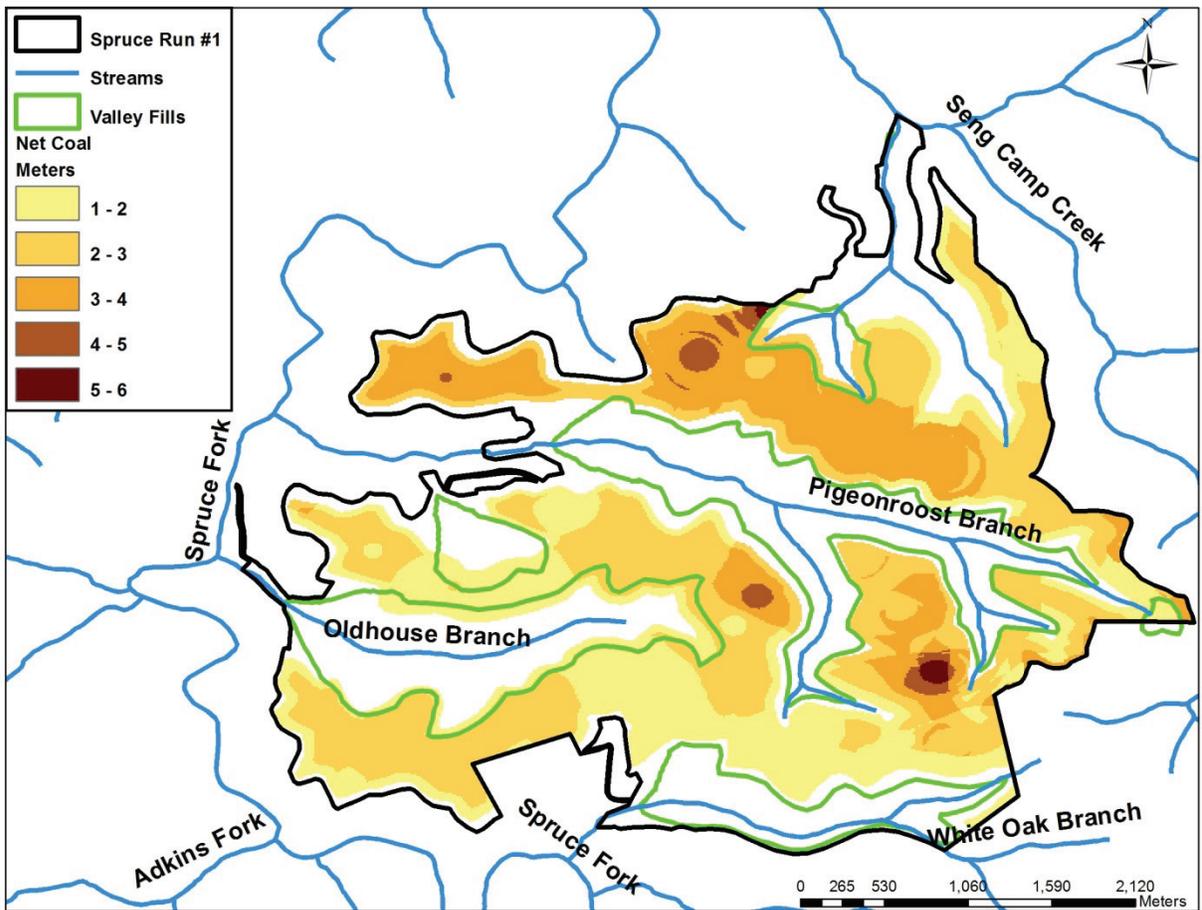


Figure 3.3: Net Coal Thickness: 5-Block, 6-Block, Coalburg and Stockton Seams. Data source: WVGES, 2011.

Because coal mining operations must move overburden and interburden between coal seams in order to recover the coal, the ratio of this excess material, usually expressed in volume units per saleable unit of coal, called the “stripping ratio”, is used to determine the relative cost of coal recovery for various blocks of coal on the site. Figure 3.4 illustrates the stripping ratio for the Spruce Number 1 mine; the lowest stripping ratios, and thus the coal with the lowest cost of recovery, often occur adjacent to the streams on the site.

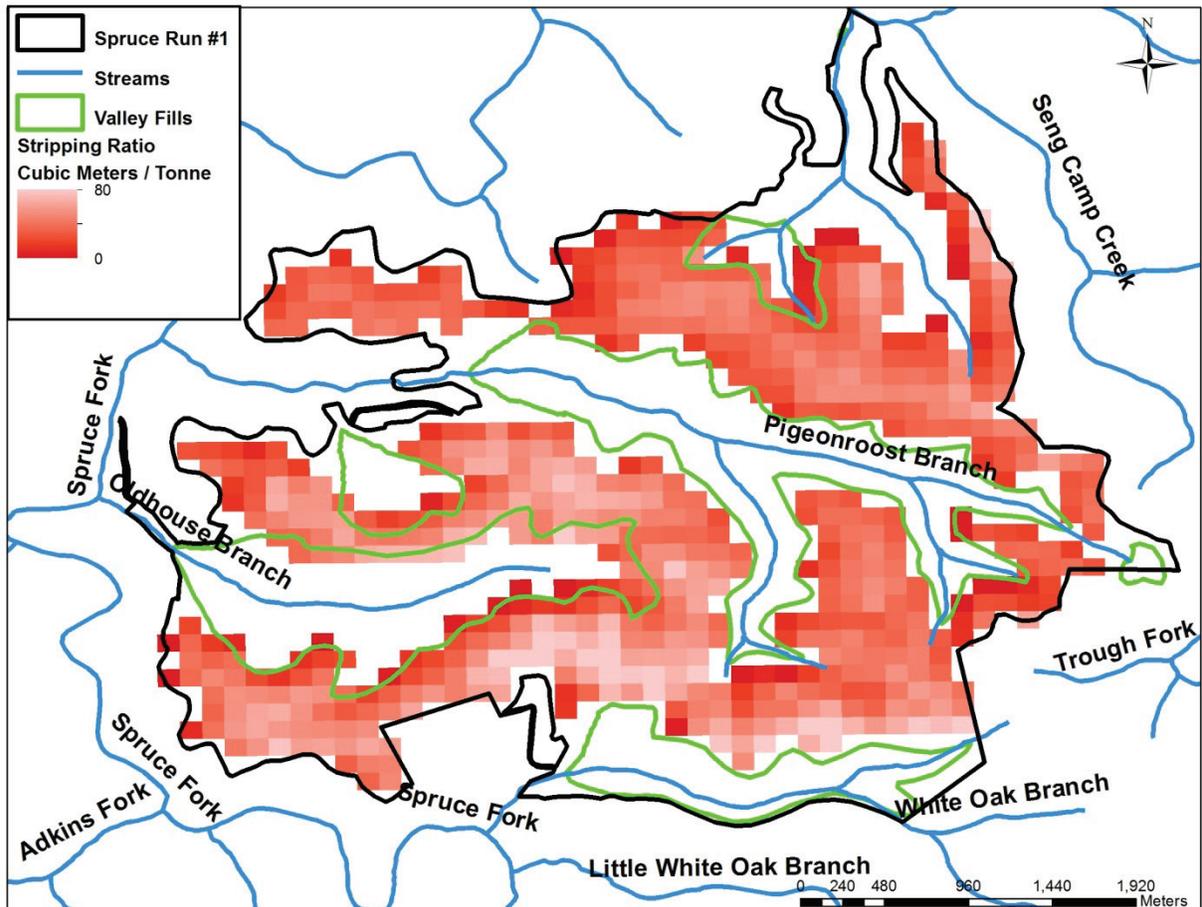


Figure 3.4: Stripping Ratio. Data sources: WVGES, 2011 and WVGISTC, 2011.

Figure 3.5 illustrates the proximity of areas on the mining permit to developed areas based on the NLCD. As the majority of development occurs to the west and south of the mine permit, the areas with the closest proximity are on those edges of the permit. This proximity data, when combined with the areas of low stripping ratio and high net coal thickness, can be used to identify portions of the permit with potential sustainability conflicts and where mine design may need to be modified to fully consider sustainable development principles.

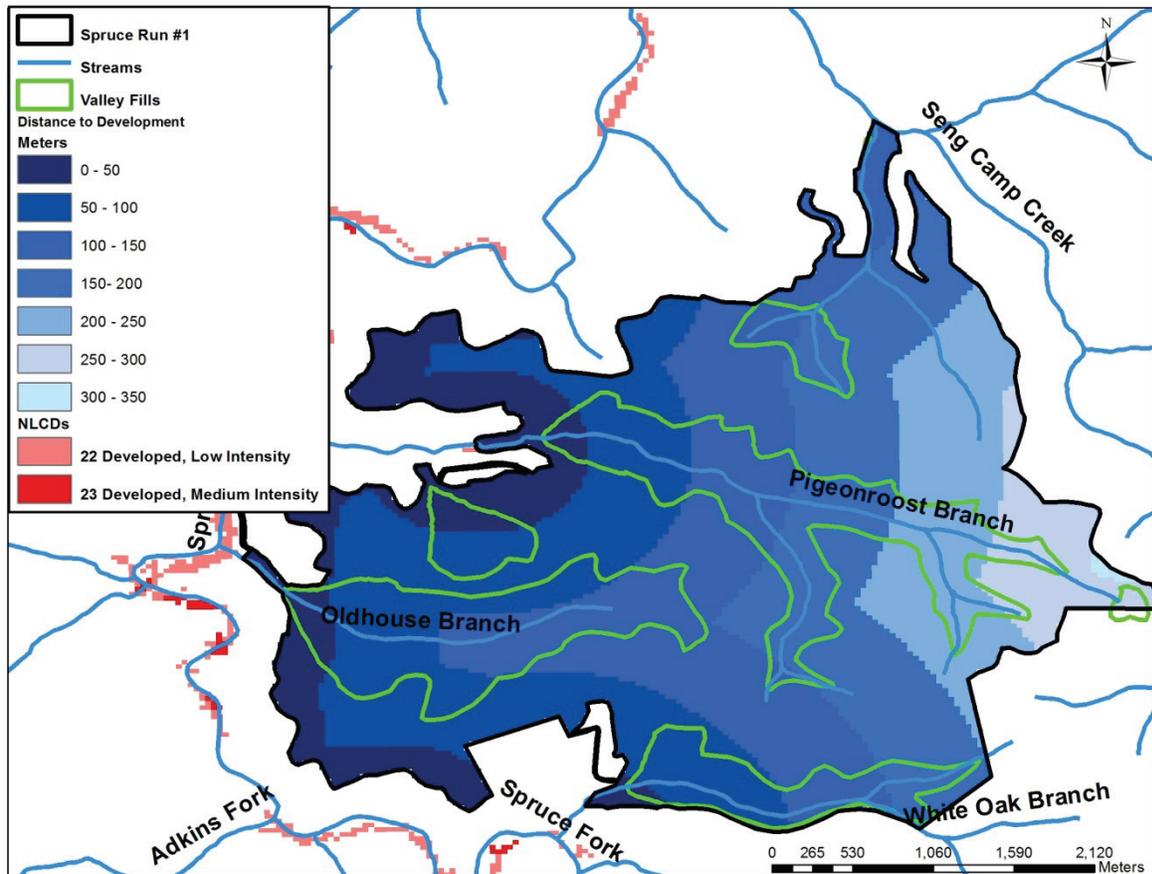


Figure 3.5: Distance of Spruce No. 1 Mine to Development. Data Source: WVGISTC, 2011.

Figure 3.6 shows the distance of areas on the permit from streams. A number of significant environmental resources are tied directly to streams, including overall environmental quality, fish and wildlife habitat, and ecosystem function. In particular, many of the biologic species that EPA cited in their overturn of the permit live in aquatic or riparian habitats. Further, the distance to streams can be considered as a measure of the likelihood of an operation to discharge potentially harmful substances to downstream environmental resources or residents.

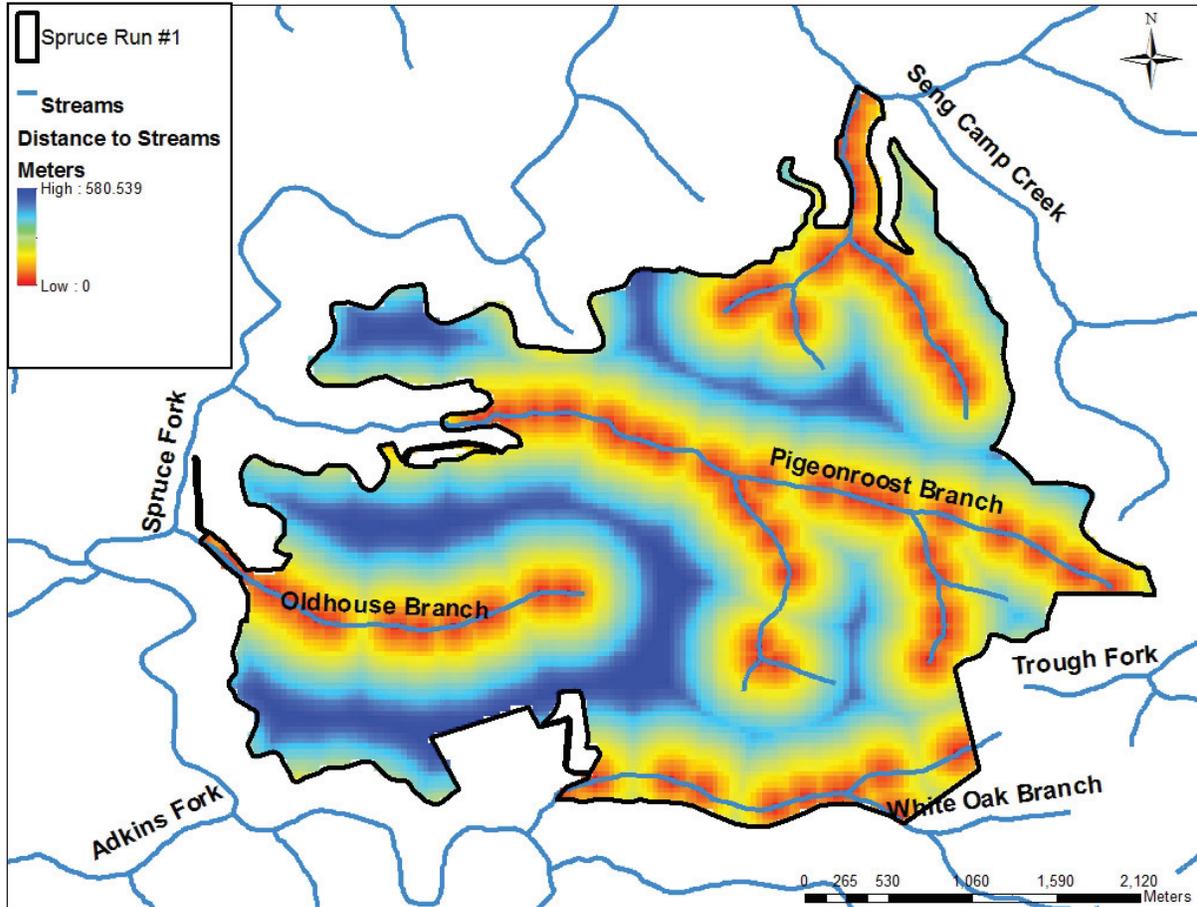


Figure 3.6: Distance to streams. Data source: WVGISTC, 2011.

The sustainability index for the site, and thus the potential for sustainability conflict, is illustrated in Figure 3.7. For the values in Figure 3.7, an equal weighting was given to relative coal thickness, stripping ratio, proximity to streams and proximity to development. In a more complex or robust analysis, other weighting of those values could be used to calculate the sustainability index and indicate those parts of the mining operation where the economic, environmental and social considerations are potentially in conflict. Based on equal weighting for the identified parameters, those areas of the permit located near the development along Spruce Fork to the west of the operation have the greatest potential for conflict, based on the high value

of the coal in that area, the relatively low cost of mining (based on low stripping ratios), and the proximity to streams and development. In particular, the northwestern lobe of the permit (north of Pigeonroost Branch) has a high potential for conflict.

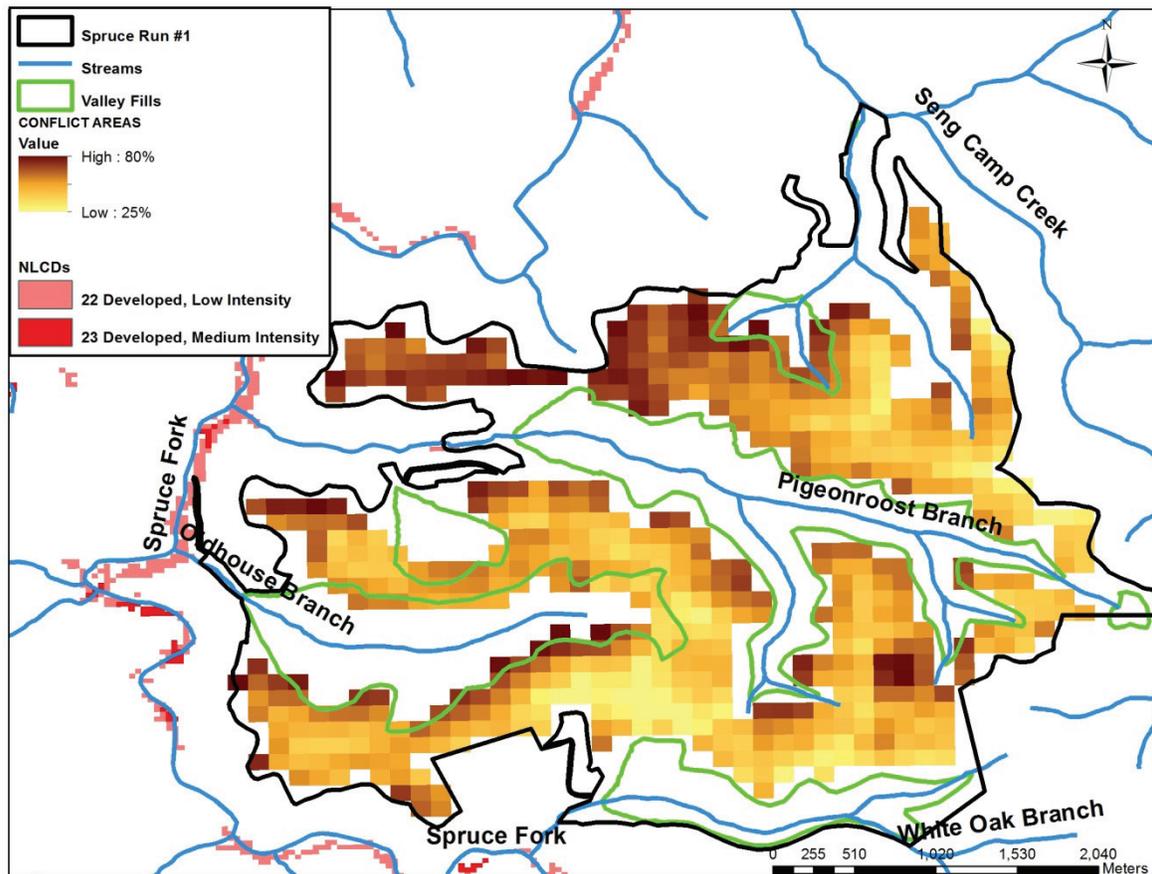


Figure 3.7: Sustainability Conflict Potential.

It should be noted that other key sustainability data that may be more variable across the permit area and that may not necessarily correlate well with stream characteristics were either not publicly available for this permit area or were not available in a format that would have made them useful for the purely graphical analysis done in this case study. For example, community

income and availability of community services, such as fire and police protection and health care, are not geographically distributed across the area surrounding this permit and thus were not able to be incorporated in this graphical GIS analysis. Much of the publically-available information on biological resources in the area, while correlatable to streams in general, was either at such low resolution or not geospatially anchored to make it useful for the identification and analysis of potential areas of conflict on the site.

## **Discussion**

The Spruce No. 1 mine permitting issues and ongoing controversy illustrates problems in the current approach to design and authorization of coal mining operations in the United States. In the case study, coal mining factors (coal thickness and stripping ratio) were used to represent the economic aspects of the operation. These are essential parameters in determining both the costs of mining and the economic value of the operation. The economic returns gained by coal sales were presumed to create economic benefit to the community as well in this simplified case study.

Environmental factors are captured in this study by looking at the proximity to streams. While many other environmental resources exist that could not be examined in this GIS analysis, streams provide a good surrogate for representing transport of any potential contamination around and from the site. Further, areas near streams often have biological richness, based on both aquatic and riparian habitats. Thus, the use of stream proximity provides a good measure of the potential for environmental impacts.

The use of proximity to residents as an indicator of social impacts of the operation is likewise a surrogate for a much broader spectrum of concerns. It was assumed that proximity provides the greatest opportunity for exposure to various aspects of the operation, including noise, dust and potential water contamination. Further, the impacts of the mining operation on

road usage and other public goods may also be greater for those residents in closest proximity to the mining operation.

The conflict analysis illustrates the areas of the permit and proposed operation where the assumed benefits of economic return and the negative consequences to environmental and social concerns are in greatest tension and have the greatest potential for creating controversy. This analysis would have been of most use in targeting the areas of the proposed mine that needed the most attention in design to ensure the economic viability of the overall operation while preserving or enhancing the quality of the environment and social resources that may have been impacted.

In addition to the GIS approach discussed above, another issue that was clear in this case study was the conflict between the rules, scope and oversight of the involved Federal and state agencies in regulating this operation. As previously mentioned, permitting of this coal mining operation involved the state agency with responsibility for the surface mining program under SMCRA, in this case WVDEP, the USACE, the EPA, the U.S. Fish and Wildlife Service and a number of other Federal and state agencies with regulatory interests and responsibilities. This large number of agencies with overlapping and often conflicting responsibilities, rules and definitions is unproductive and creates substantial conflicts. The details of the permitting issues at Spruce No. 1 shows that the agencies do not have the same views on their roles and boundaries, leading to general confusion and conflict on how to evaluate the impacts of the operation. Though the legal issues are far from resolved, Judge Walton's recent decision in NMA et al. v. Jackson et al. (2011) which stated that EPA had gone beyond their legal authorities under the CWA and the Administrative Procedure Act by instituting the expanded review process for permits, illustrates the difficulties in resolving conflicts between the regulatory agencies.

## CONCLUSIONS

In the real world case of the Spruce No. 1 Mine, while concerns were raised throughout the permitting process, changes to the design of the operation by the company in 2006 did not result in resolution of the controversy. If the type of GIS analysis used in this case study had been done at the onset of this project, the regulatory agencies, mining company and the public could have identified the areas of concern and the costs for the prolonged permitting process as well as those associated with the overturning of the permit and the inevitable litigation could have been avoided. While it is impossible to predict precisely what the outcome could have been, all parties would have been able to examine the pertinent information and make informed decisions.

Based on the failures seen in this case, the current segmented approach to mine design and permitting, which considers various sustainability issues at different times in the process but focuses primarily on single environmental concerns rather than a holistic examination of all critical issues, should be replaced with a systems engineering approach, based in part on GIS-analysis. Identification of areas of potential conflict prior to the permitting and commencement of operations would have allowed the company, regulators and the community to understand the issues and come to resolution in a much more efficient method relying on available science and provides all stakeholders with necessary information for decision making.

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## **CHAPTER 4: COULD A PUBLIC ECOLOGY APPROACH HELP RESOLVE THE MOUNTAINTOP MINING CONTROVERSY?**

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### **ABSTRACT**

In recent years, controversy has grown around decisions related to mountaintop mining of coal in Appalachia. While this mining method can be particularly efficient, it necessitates removal and relocation of huge volumes of earth and rock – permanently altering the natural landform and potentially impacting local environments and communities. Current decision-making systems and regulatory frameworks have been largely ineffective at incorporating the values and concerns of local communities. This is due in part to a legacy of distrust, problems related to scale and the legal framework itself. Further, the lack of good civic science related to mountaintop mining and effective means for public involvement have also hampered effective decision-making. Although there have been some recent attempts to address these challenges, there remain a number of lingering questions regarding whether a public ecology approach can resolve the complex issues related to this type of coal mining.

### **INTRODUCTION**

In 1997, an article by Penny Loeb appeared in the U.S. News and World Report that introduced the general public to the growing controversy over mountaintop [removal] mining of coal in Appalachia (Loeb, 1997). While the mining method has been practiced for over 30 years

in the region, its increasing footprint against the backdrop of national and global energy challenges has sparked much debate and tension between numerous entities, including members of the coal mining industry, federal and state agencies and courts, labor unions, environmental and community advocacy groups, land holding companies, private citizens, and researchers from both the public and private sectors and academia. As demands for inexpensive, domestic energy compete with those for sustainable development, alternative decision-making systems – perhaps one based in public ecology – are clearly needed to approach and resolve the issues surrounding mountaintop coal mining (Robertson & Hull 2001; 2003; Luke 2003).

The objectives of this article are to: 1) provide an overview of mountaintop coal mining in Appalachia and the current decision-making systems for related issues; 2) describe an alternative system based in the theory and practice of public ecology; 3) discuss the major challenges to actually applying public ecology to mountaintop mining issues in Appalachia, and some preliminary attempts to overcome these challenges; and 4) highlight the lingering questions that must be answered in order to move forward with a public ecology approach.

## **MOUNTAINTOP MINING IN APPALACHIA**

The coalfields of southern Appalachia are rich in high thermal efficiency, low-impurity (e.g., sulfur) coal. This coal has long served as a major energy resource for the U.S., and current projections show that both national (EIA, 2011) and global (Waddell and Pruitt, 2005) demands for it will continue for the coming decades.

### *Methodology and Potential Impacts*

Coal can be mined by either surface or underground methods, depending on the location, size and quality of the deposit, surrounding geology, and often a multitude of environmental, political and/or social factors. In Appalachia, where shallow coals seams can be relatively thin,

mountaintop mining has become popular. With this method, all of the overburden (i.e., overlying rock and soil) is excavated to expose the coal, which can then be nearly completely recovered. While some overburden material can be replaced on the mined mountaintop, much of it is deposited into adjacent valleys via a practice termed “valley filling.” Moving such massive volumes of overburden can only be justified economically by high quantities and qualities of coal, like those that exist in Appalachia. Furthermore, ownership of large tracts of land by holding companies has provided many mountaintop mining operations an “efficiency of scale.” For example, in West Virginia, some operations can remove over a dozen seams of coal from properties that extend over thousands of acres (EPA, 2005).

Despite its relative simplicity and high coal recoveries, mountaintop mining has become very controversial due to a variety of real or potential impacts on the mined land and surrounding environments and communities. Aside from the permanent alteration of natural landforms, significant impacts on ecosystems (e.g., habitat alteration or elimination) and water or air resources (e.g., decreased quality) might be caused by deforestation of mountaintop mining sites, chemical drainage from crushed overburden, and valley filling. With proper reclamation, many of these impacts can be mitigated or eventually reversed, but some may persist. Additionally, like for other types of mining, socioeconomic impacts of the production cycle on local communities are of concern for mountaintop mining operations.

Even with improved environmental management strategies and increasing emphasis on corporate responsibility at modern operations, “legacy” sites that have not benefited from the most progressive and current best-practices, have drawn much public attention and fueled public distrust of both the mining industry and the regulatory agencies. Moreover, the sheer size of even

the most modern operations, combined with the larger controversy over coal-derived energy, makes even a temporary footprint unacceptable to some who oppose mountaintop mining.

### *The Current Decision-Making System*

Decisions about mountaintop coal mining in the U.S. are primarily made via a well-established and continuously evolving Federal and state regulatory framework. Like other surface mining methods, mountaintop removal is governed by the Surface Mining Control and Reclamation Act of 1977 (SMCRA) (30 U.S.C 1201 et seq.), implemented by the Office of Surface Mining Reclamation and Enforcement (OSM) – a bureau within the U.S. Department of the Interior. SMCRA provides that states may take on the primary role for regulation under the concept of “primacy.” If a state has primacy, which requires that their regulations and law are “no less effective than” the Federal regulatory program, then the role of OSM becomes one of oversight of the state, rather than regulation of particular mining properties or companies. The regulatory program established under SMCRA is designed to protect the public and the environment from the detrimental effects of coal mining and reclamation operations.

In addition to the state-implemented SMCRA requirements, mining operations are governed by the regulatory programs under other environmental laws, including the Clean Water Act (CWA) (33 U.S.C. 1251 et seq.) and the Endangered Species Act of 1973 (ESA) (16 U.S.C 1531 et seq.). Section 404 of the Clean Water Act, regulated by both the U.S. Army Corps of Engineers (COE) and the Environmental Protection Agency (EPA), covers filling streams (i.e., as may occur with valley filling). State water quality agencies also have a role in regulation of the water impacts of coal mining operations.

Although the current regulatory framework has been conceived to address numerous environmental, and to a lesser extent social issues, the mining industry has seen a rapid

movement towards internal regulation and responsible decision-making. Through a multi-stakeholder process, an international consortium of government and industry produced a treatise on sustainability in the minerals industry that serves as a basis for many mining companies' corporate environmental and community engagement strategies (IIED, 2002). These companies have corporate sustainable development policies in place that provide guidance for many aspects of operations, and some provide voluntary annual reports on their contributions to sustainability following the Global Reporting Initiative (GRI, 2007) or other similar guidelines. The U.S. coal industry is generally also very active in the World Coal Institute and its efforts related to sustainability (WCI, 2007).

Though development of both government- and industry-led decision-making systems has undoubtedly provided impetus for more sustainable mining practices, including those used in mountaintop mining, there are two major problems with the current state of affairs. First, these decision-making systems are largely independent of one another and do not always share a common basis. And second, neither system has been inherently designed to require broad public involvement. The emergence of *public ecology* offers a more integrated approach, necessarily requiring cooperation amongst all interested parties.

## **PUBLIC ECOLOGY AND DECISION-MAKING**

Public ecology can be defined as the nexus of science, engineering, public policy and interest, citizen views and values, market forces, and environmental protection statutes and regulations that, through an open and participatory discourse, is intended to ensure that the ecological systems continue to function as societies operate within and derive benefits from them. According to Luke (2001), "(p)ublic ecology should mix the insights of life science, physical science, social science, applied humanities and public policy into a cohesive, conceptual

whole.” Robertson and Hull (2003) stated that, “(t)he primary goal of public ecology is to build common ground among competing beliefs and values for the environment.”

The importance of values within environmental, including socio-environmental, decision-making has been clear for many years. Aldo Leopold discussed the “land ethic” as a part of forest management in *A Sand County Almanac* (1948). He contended that a truly successful ethic requires individual persons, not just government agencies, to adopt a view of the land that embraces its value from broad perspectives; and he noted the absolute necessity of public conscience, not merely obligation. Leopold cited examples of how alternatives to a land ethic have fallen short of achieving real conservation, and have to great degree, often led to unintended consequences. One explanation may lie in the discrepancies between the various types of values placed on natural systems. Kennedy and Thomas (1995) casted the “natural resource or environmental professional’s primary role as managing for social value,” but proffered a conceptual model of natural systems that are comprised of four interrelated sub-systems: (1) the natural environmental system, including the biological and physical sciences; (2) the social system, including attitudes, institutions and technology; (3) the economic system, including resource values, institutions and behaviors; and (4) the political system, including policy, laws, and government. While Kennedy and Thomas did not term this model “public ecology,” they acknowledged the “interrelationship and interdependency” as being the critical characteristic. Through broader education and focus of natural resource professionals, they asserted that values and science may be more effectively integrated. Pritchard and Sanderson (2002) further highlight the significance of “political discourse” in such efforts toward sustainability.

In contemplating the usefulness of a public ecology system of decision-making in mountaintop mining issues in Appalachia, the following summary of important considerations by Robertson and Hull (2003) may be particularly helpful:

“Public ecology emerges at the confluence of three major currents shaping the contemporary environmental arena: first, the need for local communities to coalesce and use local knowledge and local action to address local concerns; second, the need for dialogue and collaboration across the many disciplinary and cultural boundaries that divide environmentally concerned scientists, policy-makers, and citizens; and third, the need for a vision of nature and human society that encourages people to create healthy human ecosystems and sustainable communities at local, regional and global scales.”

The above requirements simultaneously make a public ecology system of decision-making both very attractive and very challenging for mountaintop mining issues. There are complex decisions to be made, which *need* the input of science, public values, a legal framework and an overriding public policy; and these decisions have facets at national, state, and local permit-by-permit scales. But while the public ecology approach may be ideal, the reality is that differing values at these different scales, the current legal framework, and the heretofore lack of civic science and public involvement all present sizable hurdles – complicated by the animosity and distrust that have gradually emerged between various interested stakeholders (Goodell, 2006).

## **CHALLENGES OF A PUBLIC ECOLOGY APPROACH**

### *Legacy*

As noted above, the legacy of mountaintop mining in Appalachia has been one of adversity – and problems of the past are undoubtedly challenges for the future. Over time, groups and individuals on all sides of the issues have developed passionate feelings (e.g., Kentucky Coal Association, 2011; Reece, 2006), and many have engaged in a number of activities to express their views, and often to protest those of their opponents (e.g., see Slavin, 2007; SourceWatch, 2011). However, with little dialogue or compromise, it is no surprise that all-around satisfactory resolutions have been rarely achieved.

The ongoing controversy created by mountaintop mining is evidenced by frequent litigation surrounding the matter. Much of this litigation has been focused on implementation of the CWA and SMCRA, which are both particularly troublesome in the context of mountaintop mining (Beck, 2004) due to the involvement of both state and federal government and the differing requirements inherent in the regulatory programs. The bases of many legal proceedings (e.g., *Bragg v. Robertson*, 1999), as well as public comments on many environmental impact statements (EIS) (e.g., EPA, 2005), have underscored the fact that mountaintop mining methods have often contradicted, or have been perceived to contradict, the core values of many groups or individuals – and this is still the case, to date. For others, litigation against mining initiatives has been viewed as an external attack on the potential prosperity and livelihood of mining communities.

As the controversy has grown, in addition to working through the legal system, various parties on both sides have united like-thinkers and resources to act in other ways. For instance, numerous public discussion forums (e.g., via dedicated websites) have been created to distribute

information and facilitate strategizing of future actions (e.g., see OVEC, 2007). Such forums, themselves, illustrate both the significant interest of the public and its desire to participate in decision-making. Moreover, the content of these forums illustrates the public's history of frustration with and lack of trust in the mining industry, government agencies, and even "outsider" community- or environmental-advocacy groups, with respect to both the processes used to make decisions and the science or logic used to justify them.

It should be noted that frustration and distrust as related to decisions surrounding mountaintop mining issues have also been problematic between other parties (e.g., industry and policymakers, academia and industry, or academia and policymakers), and within the regulatory agencies themselves. In many instances, this may stem from the fact that regulators (e.g., the EPA) are often charged with guiding policy as well as conducting research. Indeed, various Federal scientists (UCS, 2004) have attributed policy decisions to political positions or ideologies, rather than to results of scientific inquiry. Such internal skepticism highlights the challenges to decision-making for such a controversial issue as mountaintop mining. However, science and policy have always been "tournaments of value" (Kimmel et al., 2011) as have been natural resources in the Appalachia region (Robertson & Hull, 2003b).

### *Scale*

Another inherent difficulty in application of public ecology to current mountaintop mining issues is the problem of scale as alluded to by Robertson and Hull (2003), and specifically examined by others (e.g., Meadowcroft, 2002; Adger, Brown and Tompkins, 2005; Cash et al., 2006). In the most basic sense, this problem arises from the fact that, while many impacts, including environmental and social impacts, of mining are largely local, decision-making tends to be driven by state, Federal or even global interests and values. For example,

energy production goals and coal-mining regulation are generally carried out under national policies established by statute or executive direction, and it is often multi-national or national mining companies and/or land holding companies that own the resources being exploited. At the state-scale, primacy to enforce certain regulations, tax revenues, and varying political climates can drive decisions surrounding mountaintop mining. At the finest scale, local citizens, business owners and elected officials have yet other perspectives and investments. Living in proximity to a mining operation, these stakeholders may experience both the negative and positive impacts of that operation, shaping their views in numerous ways such that even neighbors may substantially disagree and have differing interests.

The competing interests between and within each scale will clearly complicate any decision-making system for mountaintop mining issues. However, systems like public ecology that emphasize meaningful inclusion of all interested stakeholders, might ensure a better balance of power and access in the process and lead to more equitable, defensible and lasting outcomes. Swanson (2001) has discussed the partial “de-legitimization” of Federal authority accompanied by emergence of “locality-based” policy with respect to some issues, and noted effective results when decisions are made according to post-sovereignty or subsidiarity principles and thereby effectively decentralized or deconcentrated to the lowest relevant level (Karkkainen 2003).

### *Legal Framework*

The issue of scale is exacerbated by the legal structure in the United States which, by design, protects the rights of all stakeholders. In the case of mountaintop mining, this means that stakeholder groups are frequently pitted against one another, even though both appear to have the law on their side. For instance, property law generally protects the rights of landowners and mining companies to exploit their resources, but exploitation could directly challenge the rights

of the general public to clean water as granted by environmental protection law (i.e., the CWA). There are of course specific constraints on the rights of each interest group, intended to protect the other(s), yet the issues are still convoluted. Mine permitting processes, for example, require a mining company to verify its capacity for environmental protection to regulatory agencies; but, frequent litigation over this very issue exemplifies that the process does not always produce satisfactory results for all involved parties. Even if legal statutes like the CWA or SMCRA are implemented perfectly, mountaintop mining may be allowed to proceed with or without direct public approval.

Furthermore, the concept of state or local primacy, while intended to decentralize power from larger, less attuned government, has actually resulted in a multi-layered bureaucracy, which is inefficient and ineffective for local decision-makers (Landy, 1999). In the context of both the CWA and SMCRA, the threat of Federal agencies looking over the shoulder of state or local officials, not to mention other Federal officials, has confused responsibility, accountability and jurisdiction. Landy also discussed the dynamics of multiple levels of government operating on a local level to implement environmental policies. This work illustrates that, while it is not impossible to adequately incorporate local concerns within existing Federal environmental laws, it is difficult to do so in a manner that engenders trust and confidence in government, along with the ability to achieve results. In the case of mountaintop mining, wherein the public already doubts the intentions, legitimacy and/or authority of state and Federal governments, not to mention distant and transnational corporations, overcoming this challenge will be particularly arduous.

## *Civic Science*

Another major challenge for implementing a public ecology approach to problem resolution in mountaintop mining pertains to the application of science in the decision-making process. Here, in addition to the quantity and quality of available science, the value of that science in the context of stakeholder views is fundamentally important. For example, in order to make decisions regarding acceptable limits to water quality impacts of valley filling, adequate and valid data must be available for assessment, and all stakeholders must agree that the data is meaningful and significant. Robertson and Hull (2001) have contended that the failure to reach decisions that meet the needs of all the interested parties in some cases may reflect a lack of common/shared understanding of the issue rather than actual disagreement, i.e., appropriate kinds of knowledge (and effective social learning processes) have not been employed in the decision-making.

Bäckstrand (2003) has termed this perhaps unconventional view of science (i.e., knowledge) in public ecology as “civic science,” and asserted that its requirement of public involvement is critical to restoring public confidence in the general role of science in decision-making processes. For example, while decisions driven by traditional scientific inquiries into the impacts of mountaintop mining have prompted questions of legitimacy – similarly to other recent controversial issues like global climate change – civic science may offer some resolution by incorporating the perspectives and knowledge of diverse stakeholders, including local expertise and situational knowledge. This is particularly important in environmentally- or socially-related decisions, as the inherent uncertainties and complexities of environmental and social sciences, and also risk evaluation, are subject to speculation and debate (Beck, 1992; Goldstein & Hull, 2008).

Although civic science might contribute to conflict resolution regarding mountaintop mining, it is substantially lacking – if not completely absent – from the existing decision-making systems. To change this, “social learning” will be key. As described by Schusler et al. (2003), social learning requires that all interested parties gain an appreciation and respect for the viewpoints and values of one another. To do so, these authors have identified seven critical components of an effective approach: open communication, diverse participation, unrestrained thinking, constructive conflict, democratic structure, multiple sources of knowledge, extended engagement and informal interactions, and facilitation. Given that communication between various stakeholders involved in mountaintop mining issues in Appalachia is presently tense, at best, social learning as a prerequisite to increased civic science presents a challenge in and of itself.

A specific form of social learning and civic science that may be useful in the case of coal mining conflict is an approach called learning action networks (LANs). Kimmel et al. 2011 describe LANs as:

“comprised of relationships and linkages between what might otherwise be disparate stakeholder groups and individuals, enabling opportunities for collaboration, mechanisms for exchange and learning, and pathways for shared understanding and mutual benefit (Stephenson 2011). Stephenson (2011) points to Booher’s (2008) concept of collaborative complex adaptive networks as similar to LANs, specifying their need to include institutions, government officials, nonprofit organizations, business leaders, as well as families and community members to catalyze effective community change. ... An important function of a LAN is to provide a platform from which to gather, test, and manage information

that helps the community understand its problems and opportunities, evaluate whether the costs of inaction merit the risk of change, and build confidence that a development scenario is possible and worth pursuing.”

### *Public Involvement*

Challenges of public involvement have been a recurrent theme in all aspects of mountaintop mining, and will undoubtedly be present in any decision-making system – including public ecology. Many of these challenges are inherently related to those described above, but one not yet discussed is how to actually define the “public” as a stakeholder group. From many perspectives, the local community to a nearby mining operation is the obvious choice; however proximity to the operation does not necessarily equate to any given type of interest (e.g., economic, environmental). At the other end of the spectrum, the “public” could encompass the entire nation with respect to views on U.S. energy independence or environmentally sustainable resource production. This question of the public’s definition is related to the challenges of scale, and also introduces the compounding complexity of individuals or groups having multiple roles and multiple interests in mountaintop mining issues. For instance, a member of a mining-impacted community may also be an employee of the mining operation or a regulatory agency, a member of an environmental advocacy group, or an elected official. The perspective gained via one role might inform decisions made in another might be considered a successful exercise in social learning, but could also contribute feelings of distrust in instances of conflicting viewpoints and multiple role-playing.

Although “the public” cannot always be exactly defined, there seems to be a growing trend to increase its involvement in decision-making regarding mountaintop mining issues. Some federal agencies have made concerted attempts on this front. For example, the OSM engaged in

stakeholder outreach prior to beginning work on a new regulation aimed at protecting streams (OSM, 2010a). OSM additionally used novel public involvement techniques to gather scoping information for the environmental impact statement to accompany that rulemaking exercise (OSM, 2010b). It is unclear how effective the process has been, however, as OSM's expected publication of the proposed regulation has been delayed to date (Ward, 2011).

The EPA also has engaged in deliberate activities to expand the level of public involvement in its decision processes. For example, it held a widely-attended hearing on its consideration of rescinding a CWA permit for the Spruce Number 1 mine in West Virginia (EPA, 2010), during which significant input was received from the public and the industry. EPA has cited the input from this meeting as being instrumental in its decision to overturn the permit previously issued by the COE (EPA, 2011). But that decision has led to new controversy, and contributed to adversity and animosity between various stakeholders (e.g., EPA and COE, the industry and Federal regulators, state and Federal regulators, etc.) (Power and Maher, 2011).

Beyond efforts by regulatory agencies, and some by industry under the emerging theme of corporate responsibility, to increase public engagement decisions surrounding mountaintop mining, interested citizens have also sought ways to involve themselves. The growing trend of civic environmentalism, for instance, utilizes legal frameworks already in-place to influence changes in policy and decisions that affect the environment (Sirianni and Friedland, 2001; Knopman et al., 1999). In Appalachian mining contexts, participation in litigation and other public involvement processes (e.g., hearings) related to development of EIS's have been the primary avenues for civic environmentalism.

## CONCLUSIONS AND LINGERING QUESTIONS

The adversarial and emotionally-charged legacy of mountaintop mining issues in Appalachia does indeed present a real obstacle to a public ecology approach to decision-making. However, many of the key aspects of such an approach, including broad participation and transparency, seem to be ideally suited to such a controversial issue where there are significant differences in the values and interests of various stakeholder groups. Recent attempts by some groups to increase public participation may signify that ideology is shifting in the general direction of public ecology, though a number of lingering questions remain:

- Can public ecology be effective within the complex system of laws and across the multiple scales of government and public communities currently involved in mountaintop mining issues, or would this approach require significant changes to the regulatory and legal framework?
- Can public ecology be effective in the long-term for mountaintop coal mining issues given the dynamic and overwhelming economic and/or national security issues associated with energy production?
- How can different levels of government maintain appropriate roles within a public ecology approach to mountaintop mining issues in the face of limited funding and internal cultures and paradigms?
- Are all of the interested stakeholders able and willing to participate in deliberative processes, many of which require not just collaboration but compromise in order to find a common and higher ground?

To answer these questions, and effectively and efficiently provide energy resources while protecting communities and environments, the U.S. may need to fundamentally restructure

regulatory programs in order to bring all the interested parties to the table with a meaningful role to play. Cases such as Lake Tahoe, Great Lakes, Chesapeake Bay (and other National Estuary Programs established by the EPA) might offer some useful examples and lessons. Likewise, the EPA's new Highlands Action Program (HAP) might be a vehicle for moving forward with some of the public ecology strategies and initiatives proposed above. The resolution of complex issues such as mountaintop mining may require radical boldness to break through years of distrust and allow for the adoption of a more public ecology.

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## **CHAPTER 5: INCORPORATING SUSTAINABLE DESIGN PRINCIPLES INTO COAL MINE DESIGN: REGULATORY AND POLICY BARRIERS IN THE UNITED STATES**

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This paper was accepted for presentation at Eighth International Conference on Environmental, Cultural, Economic and Social Sustainability, Vancouver, BC, Canada, January 2012. A manuscript for publication in *The International Journal of Environmental, Cultural, Economic and Social Sustainability* is in preparation.

### **ABSTRACT**

U.S. laws presently governing coal mining are primarily focused on environmental protection, while economic and community well-being considerations are largely excluded. This creates a fundamental contradiction in terms of sustainability, in which optimized mine designs should balance the impacts on and the demands of the environment, the economy and society. This paper discusses vital revisions to regulation and policy that are needed to remove the barriers between the current legal framework and sustainable coal mine design. These revisions must be based on established and broadly integrated scientific data; stakeholder involvement processes created to encourage compromise; and defined government oversight and coordination roles that ensure transparency. Moreover, it is imperative that the revised framework incorporate systems engineering and public ecology to promote holistic resolutions.

## **INTRODUCTION AND BACKGROUND**

Coal has been and will continue to be a major source of domestic energy in the U.S. (EIA, 2011). Coal mines have been traditionally designed around factors that directly impact the efficiency and economy of production, such as the coal quality and surrounding mineralogy, the geology, geography, topography and hydrology of the area, property ownership and existing infrastructure, etc; whereas environmental compliance and public approval have often been considered as modifying factors to those designs. As the demand for more sustainable design in mining has recently increased, the mining industry has responded via increased attempts at community engagement and a “beyond compliance” ethic with regard to the environment (IIED and WBCSD, 2002).

Building on this initial progress, a systems engineering approach to optimized coal mine design was previously proposed that would assess the overall impacts of mining on a given area by evaluating individual impacts on a variety of societal, environmental and economic factors (Craynon and Karmis, 2009). It was asserted that geographic information systems may be utilized to determine the relationships between specific mine designs and the factors of interest, but acknowledged that this would require careful selection and prioritization of these factors, which may be somewhat subjective. Furthermore, an attempt to use this approach to examine incorporation of sustainable development into a large-scale surface coal mine in Appalachia suggested that the existing regulatory structure in the U.S. creates significant barriers to optimizing multiple outcomes (e.g., efficient coal production, minimal environmental impacts, maximum socioeconomic benefits) (Craynon and Karmis, 2011).

The laws currently governing coal mining, including the Surface Mining Control and Reclamation Act (SMCRA) and the Clean Water Act (CWA), are primarily focused on

environmental protection, while economic and community well-being considerations are largely excluded. In the past several years, Federal and state agencies have made concerted efforts to integrate at least community concerns into the regulatory process, providing for increased public involvement in the implementation of the CWA by the U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (USEPA) and the implementation of SMCRA by the states and the Office of Surface Mining Reclamation and Enforcement (OSM). However, these regulatory programs are not consistent with each other (i.e., with respect to environmental requirements or implementation), and neither contains any explicit means of incorporating economic concerns. Thus, the concept of sustainability is inherently challenged in the current regulatory system.

Following on this, a public ecology approach to coal mining has also been suggested in order to bring regulators, the public, the industry and other interested stakeholder groups together in the decision-making process (Craynon et al., 2011). Such a design approach does necessarily include all of the essential ingredients – science, engineering, public policy and values, market forces, and environmental regulations meshed together in an open and participatory process (Robertson and Hull, 2003). But public ecology will undoubtedly be hampered by both the evolved legacy of distrust between various parties (e.g., public and industry, public and government, industry and government) and the inability of existing systems (e.g., legal, civic, business) to effectively function and interact.

Indeed, coal mining in the U.S. has all of the characteristics of a “wicked” problem as defined by Rittel and Webber (1973). While the “grass-roots” movement on sustainability has thrust the concept to the forefront of modern ideology, to move forward in the context of coal

mine design will additionally require a “top-down” approach that re-assesses and restructures the policies and regulations that govern mining.

## **DISCUSSION**

Observed issues of distrust, controversy and legal wrangling surrounding coal mining – particularly large-scale coal mining in the mountains of Appalachia – highlight the failures of the existing policies and regulations to achieve generally satisfactory, not to mention sustainable, results. To ensure that mining operations are optimized for economic return, social benefit and environmental protection, an effective system of regulations or policies must:

- require the use of the best available science;
- balance the desirable outcomes;
- be understandable and transparent to, and encourage the participation of, all stakeholders; and
- deal with legacy issues.

### *Addressing Barriers*

Embedded in the above list are several significant barriers that must be addressed between the current regulatory framework and sustainable coal mining initiatives, the first of which is the need to develop policies based on current, well-established and broadly integrated scientific data. Many of the existing regulatory programs that govern coal mining operations do have a stated goal to utilize “science-based” regulations (See Executive Order 13563, January 18, 2011). However, the underlying basis of some programs is not conducive to the use of inter- or trans-disciplinary scientific approaches that may significantly improve the overall understanding of mining impacts on terrestrial or aquatic environments, human health, or whole ecosystems; instead, the primary scientific tools used by the agencies that implement the

programs are more often related to specific disciplines (e.g., hydrology, biology, geology, chemistry). This is in part a result of the educational system and professional development framework that focus on building expertise in a single discipline. Furthermore, since current legal requirements and regulatory programs do not adequately consider social and economic factors along with environmental standards, truly sustainable design criteria are not emphasized, if even considered.

In order for sustainable development to be incorporated in optimized coal mine designs, some revisions to the regulatory structure are needed. Primarily, these revisions should involve moving beyond single-media approaches that focus on limiting specific discharges of concern at specific points, to a more holistic approach that incorporates a variety of statutory requirements along with community input and economic evaluation. For instance, instead of limiting to some discreet value the total dissolved solids discharges from valley fills to receiving waters, regulations might focus on limiting the combined discharges of problematic constituent species that comprise TDS (e.g., metals or aggressive anions) to appropriate values for a given site (i.e., based on historical data, ecological monitoring programs, and socially and economically acceptable tolerances at that site.) This would likely promote better environmental management in most cases, support sustainable development efforts, and foster continuous improvements in a “beyond compliance” ethic. It would additionally force agencies to develop sound, inter- or trans-disciplinary science-based, and up-to-date regulations (VCCER, 2008).

A recent National Research Council Report (NRC, 2011) looked at the necessary changes in the programs of the EPA to incorporate sustainable development. The study was done at the request of the EPA in order to develop an “operational framework for integrating sustainability as one of the key drivers within the regulatory responsibilities of the EPA.” The report made a

number of recommendations for actions that EPA should take, but did not evaluate the compatibility of the EPA's statutes and regulations with sustainable development. The recommended decision framework and other recommendations on organizational change necessary to address sustainable development would facilitate changing regulatory approaches, however.

Like an optimized coal mine design, an optimized regulatory framework in the context of sustainability must also be predicated on simultaneous consideration and prioritization of all relevant factors. This concept requires comprehensive incorporation, or the allowance for incorporation, of various types of fundamental knowledge (e.g., scientific, cultural, socio-economic, value-based, etc.) into environmental policy as discussed by Ascher et al. (2010). Their recommendations can be summarized as follows, and could significantly guide improvement of coal mining policies:

- enhanced collaboration between scientists and non-scientists;
- examination of the limitations of applicable science;
- development of a multi-disciplinary view of the issues in question;
- re-assessment of the standard for evaluating knowledge, particularly in light of timeliness issues;
- creation of “knowledge hybrids” that combine differing expertise;
- utilization of adaptive management to promote integration of science and values;
- protection and promotion of scientific integrity; and
- increased allocation of resources for enhanced non-science knowledge.

The barriers between stakeholders, including the legacy issues created by decades of controversy and adversity (see Craynon et al., 2011), are also significant and highlight a critical

lacking in communication and in acknowledgement of shared interests. The same may also be said of regulatory agencies. In addition to addressing environmental issues (Parr et al., 2003), engagement of local and regional communities in constructive partnerships with scientists, government and industry is key for the advancement of social, educational, and economic infrastructure. Through such partnerships, development of accurate cost-benefit analyses, differential welfare assessments, or other means of measuring overall impacts of mining may be possible. Although efforts have significantly grown to involve the public (Craynon et al., 2011), revised policies and/or regulatory frameworks must address this and other stakeholder barriers explicitly.

## **ROADBLOCKS TO EFFECTIVE CHANGE**

There are many challenges to overcoming the barriers highlighted above. With respect to the development of appropriate science and engineering, the control of research by regulatory agencies is problematic. In some cases, the objectivity of scientific findings has been questioned, and use of internal “peer review” at some agencies has raised additional concerns of legitimacy (See e.g., ALEC, 2011). While the long timeframes and large resource commitments for developing peer-reviewed articles for publication in the academic and relevant literature are often incompatible with the needs of regulators, industry and other stakeholders involved in coal mining decisions, it is imperative that research efforts are, and are perceived as, un-biased and fact-based. Some agencies have achieved separation of research and policy-guidance or regulation by physically and fiscally dividing the entities that participate in the respective activities. For example, the National Institute of Occupational Safety and Health (NIOSH) in the Department of Health and Human Services is responsible for conducting mining health and

safety research in support of the regulatory programs of the Mine Safety and Health Administration (MSHA) in the Department of Labor.

Another challenge is the creation of legitimate processes for stakeholder involvement that are capable of contributing to achieving the agreed-upon desired outcomes for coal mining operations. Past efforts to include the public have focused mainly on participation in meetings related to permitting, commenting on environmental documents, or involvement in litigation or administrative proceedings – none of which is sure to directly affect decisions made about coal-mining issues. Thus, these opportunities for participation are often viewed as being relatively trivial, and have resulted in increased mistrust and/or distrust by the public in the current decision-making systems. Strained communication between industry and government is also problematic with respect to pursuing balanced outcomes. It is vital that roadblocks to meaningful participation by all stakeholders be removed.

While the adoption of a public ecology approach as suggested in previous work may overcome some problems of stakeholder involvement – as well as problems of scientific legitimacy through increased civic science – the lingering questions raised by Craynon et al. (2011) are germane in discussing how an effective system might be created. Not only must all stakeholders be able and willing to participate and compromise in decision-making, but appropriate roles of different levels of government must be achieved in order to promote sustainable development in the midst of the economic and national security issues related to domestic energy production. To some extent, this requires re-assessment and re-allocation of the responsibilities of specific agencies and/or programs to provide support, guidance, oversight or enforcement of various policies or regulations. To implement sustainable development, “(i)deally and ultimately, government needs to be radically restructured.... Instead of departments and

ministries separated according to traditional areas such as environment, health, commerce, trade, energy, transportation, etc., governmental structures should focus on problem areas representing overlapping concerns” (Ashford and Hall, 2011). Such a consideration may be appropriate in this case.

## **CORE CONCEPTS FOR A REVISED REGULATORY APPROACH**

In order to overcome the barriers discussed above, a revised regulatory approach for coal mining operations that incorporates core concepts of both systems engineering and public ecology should be considered. The new governance structure must be comprehensive and holistic. With respect to mine design criteria, successful regulations should move away from the “narrowly framed” focus on a single environmental media such as air or water (Tickner, 2003), and instead be based upon overall system impacts. Such a program should additionally have consistent definitions and requirements based on objective, transparent science and engineering. While it is assumed that any program would have broad baseline standards, a transparent and participatory framework would need to be responsive to local, site-specific conditions and input.

Given the complexity of issues surrounding coal mining in the U.S., development of a revised regulatory framework will surely require the input of all interested parties in order to be robust, effective and universally satisfactory. Such insights have been previously noted by Voinov and Bousquet (2010): “(t)he drive towards participatory decision making is primarily fuelled by the increasing realization that the more humans impact the environment and the more they attempt to manage natural resources, the more complex and less predictable the overall socio-ecological system becomes and the harder it becomes to find the right decision....” It is therefore recommended that, while the Federal and state agencies that presently have statutory responsibilities should lead the development of the revised regulatory framework, other

interested agencies (e.g., U.S. Fish and Wildlife Service), the coal industry and the public should all be intimately involved in the process. Moreover, the academic and scientific community must be allowed to facilitate the incorporation of best-science approaches.

It is additionally imperative that a revised regulatory approach mandates complete transparency in process and function. This is required to not only address the legacy of distrust, but also to improve the quality of decisions reached under the new regulatory system. Public participation is key in achieving such transparency (Beierle, 2002), and to ensuring that decision-making is responsive to the needs and values of all stakeholders (Beierle and Cayford, 2002).

## **CONCLUSIONS AND RECOMMENDED NEXT STEPS**

Sustainable development requires a delicate balance between competing economic, environmental and social interests. In the context of coal mining in the U.S., the current regulatory frameworks and policy-guidance vehicles impede this balance. To address this problem, and thus effectively and efficiently provide energy resources while protecting the communities and environments, the U.S. will likely need to fundamentally restructure regulatory programs. Ideally, revisions should be based upon the key concepts of public ecology and allow for a systems engineering approach to coal mine design.

As the development of a new regulatory framework could take considerable time and political will, the following next steps seem appropriate:

- enhanced use of a public ecology approach to deal with coal mining controversies;
- focused discussions on what the processes for public involvement, decision making and regulation should look like and the barriers to implementing new approaches;

- continued development of transparent systems engineering approaches to incorporate sustainable development into coal mine design;
- continued provision for the development of good objective science by both the public and private sectors;
- development of cooperatively-planned projects to address barriers within the current legal and regulatory frameworks; and
- development of objective, multi-lateral recommendations for comprehensive new regulatory frameworks.

Through these actions, which give emphasis to the inclusion of best-science and the participation of interested stakeholders, the legacy issues of distrust can be addressed. In addition, the efforts of all involved parties can focus on balancing the desired outcomes for coal mining operations. Radical revisions to regulatory programs in the U.S. will undoubtedly be difficult, as noted by Coglianesse and Allen (2003): “fundamental change in a regulatory system that is governed by a highly detailed set of statutes will come about neither without changing those statutes nor through consensus.” However, these steps are necessary to address the wicked, intractable problems that are endemic in the controversies surrounding coal mining in the United States.

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## CHAPTER 6: CONCLUSIONS AND NEXT STEPS

Over the past several decades, the opinion of the public about coal mining operations has eroded. This has happened while many coal mining companies and operations have been enhancing their commitment to sustainability and the long-term economic, social and environmental health of the communities where they operate. The manuscripts that comprise this dissertation examine approaches and barriers to incorporating sustainable development into coal mine design.

It was proposed in Chapter 1 that in order to maximize the profitability of coal mining operations and to enhance the business case for sustainability, it is necessary to optimize mine designs by simultaneously considering legal, environmental and sustainability goals along with traditional mining engineering parameters as an integral part of the design process. Utilizing systems engineering and optimization approaches was shown to be a useful approach to the incorporation of regulatory and sustainability factors into coal mine design.

Chapter 2 discussed graphical approaches, based on the use of GIS tools, to allow the development of models of the positive and negative impacts of coal mining operations. Because of the large number of factors that can be involved at any one operation, and the inherent complexity in modeling the underlying natural, social, and economic systems, the use of index values, such as livability indices, and surrogate values such as rate of return and regulatory compliance, was suggested to allow for the development of less-complex models that are more useful.

The limited case study of the Spruce No. 1 Mine, presented in Chapter 3, demonstrated the type of GIS analysis that could allow the regulatory agencies, mining company and the public to identify the areas of potential sustainability conflicts. However, the current regulatory system

and segmented approach to mine design and permitting, which considers various sustainability issues at different times in the process but focuses primarily on single environmental concerns rather than a holistic examination of all critical issues, was shown to be a barrier to implementation of such a systems engineering approach, based in part on GIS-analysis. Identification of areas of potential conflict prior to the permitting and commencement of operations would have allowed the company, regulators and the community to understand the issues and come to resolution in a much more efficient method relying on available science and provides all stakeholders with necessary information for decision making.

The adversarial and emotionally-charged legacy of mountaintop mining issues in Appalachia presents a significant obstacle to effective decision-making. However, as suggested in Chapter 4, many of the key aspects of a public ecology approach, including broad participation and transparency, seem to be ideally suited to such a controversial issue where there are significant differences in the values and interests of various stakeholder groups. A number of important questions about using public ecology remain, however. It was suggested that to answer these questions, and effectively and efficiently provide energy resources while protecting communities and environments, the U.S. may need to fundamentally restructure regulatory programs in order to bring all the interested parties to the table with a meaningful role to play.

In Chapter 5, it was suggested that a revised regulatory approach for coal mining operations that incorporates core concepts of both systems engineering and public ecology be considered. The new governance structure must be comprehensive and holistic, based upon a thorough understanding of impacts. Such a program should additionally have consistent definitions and requirements based on objective, transparent science and engineering. While it is assumed that any program would have broad baseline standards, a transparent and participatory

framework would need to be responsive to local, site-specific conditions and input. Given the complexity of issues surrounding coal mining in the U.S., development of a revised regulatory framework will surely require the input of all interested parties in order to be robust, effective and universally satisfactory. It is additionally imperative that a revised regulatory approach mandates complete transparency in process and function.

Sustainable development requires a delicate balance between competing economic, environmental and social interests. In the context of coal mining in the U.S., the current regulatory frameworks and policy-guidance vehicles impede this balance and the utilization of available systems engineering approaches and tools. To address this problem, and thus effectively and efficiently provide energy resources while protecting the communities and environments, it is indicated that the U.S. will likely need to fundamentally restructure regulatory programs. Ideally, revisions should be based upon the key concepts of public ecology and allow for a systems engineering approach to coal mine design. Through these actions, which give emphasis to the inclusion of best-science and the participation of interested stakeholders, the legacy issues of distrust can be addressed.

## **SUMMARY CONCLUSIONS**

The fundamental conclusions in this dissertation are summarized below:

- Incorporation of sustainable development into coal mine design is desirable and necessary
- Systems engineering approaches, including the use of geographic information system (GIS) technologies are useful for considering sustainable development in coal mine design
- Current regulatory frameworks impede the process of using advanced tools and contributing to sustainable development in coal mining operations due to a focus on single environmental media and a lack of consistency in definitions and approaches among the various state and federal agencies involved
- Restructured regulatory programs are necessary to address sustainable development for coal mines

- Requirements for an effective regulatory system include:
  - Reliance of the use of best available science
  - Focus on a balance between the desired outcomes for coal mining and sustainable development
  - Understandable and transparent to and encourage the participation of all stakeholders
  - Realistically deal with legacy issues
- Revised regulatory programs should incorporate public ecology and allow for a systems engineering approach to mine design

## **NEXT STEPS**

As the development of a new regulatory framework could take considerable time and political will, the following next steps seem appropriate:

- Enhanced use of public ecology to deal with coal mining controversies
- Focused discussions on the appropriate processes for public involvement, decision making and regulation
- Continued development of transparent systems engineering approaches to incorporate sustainable development into coal mine design
- Continued provision for development of good objective science by public and private sectors (including academia)
- Development of cooperatively-planned projects to address barriers within the current regulatory frameworks
- Development of objective, multi-lateral recommendations for the new regulatory framework

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## **APPENDIX B: OPTIMIZING COAL MINE DESIGN FOR SUSTAINABLE DEVELOPMENT AT LARGE SURFACE COAL MINING OPERATIONS IN APPALACHIA**

*John R. Craynon and Michael E. Karmis*

Presented at the Aachen International Mining Symposium: Fifth International Conference on Sustainable Development in the Minerals Industry, June 14-17, 2011, and published in: *5th International Conference Sustainable Development in the Minerals Industry (SDIMI 2011)*, pp.75-82, RWTH Aachen University: Aachen, Germany.

### **ABSTRACT**

Traditional coal mining planning seldom considers key sustainability factors. Previous papers by the authors have presented a systems engineering approach based on the premise that systems can only be optimized if all factors are considered and integrated into mine planning. This paper discusses the challenges inherent in optimizing the design of large-scale surface coal mining operations in Appalachia. Regulatory and permitting programs in the United States often focus on single parameters, rather than the full suite of desirable outcomes for sustainability. By utilizing geographic information system (GIS) tools to evaluate available data on environmental and social resources, the regulatory barriers which prevent operations from incorporating ecological and other sustainable development concerns into coal mine sustainability performance were identified. By analysis of the on-the-ground issues related to sustainability, the key parameters to be incorporated into an optimized coal mine design in Appalachia were identified along with possible changes to the regulatory framework that would enhance the incorporation of sustainability into coal mine design.

## **SUSTAINABILITY METRICS AND COAL MINING PLANNING AND DESIGN**

The desired outcomes for coal mining operations are focused on providing coal for electric power generation, and raw material for steel production, through maximizing coal recovery and corporate income while providing benefits to the local community and protecting the health and safety of that community and the environment. Thus, optimizing coal mining plans is not simply a matter of focusing only on traditional mining engineering for achieving maximum coal recovery and revenue. As noted by Craynon and Karmis [1], the issue of sustainability in mining has become more important in the past several years. In practice, this has included community involvement and the adoption of a “beyond compliance” ethic as it relates to environmental impacts. However, these efforts have generally relied on a traditional mining engineering approach to mine design, which is modified through iterative processes to accommodate environmental and sustainability goals.

A systems engineering approach is needed to support the sustainability goals which are integrated in the desired outcomes [Sieffert and Loch, 2]. A more integrated approach relying on systems engineering principles and engineering optimization can achieve better outcomes. Many environmental and social factors related to sustainability are geographic in nature, as are such mining engineering considerations as coal seam characteristics, mine location, and topography. Thus, geographic information system (GIS) tools can be usefully integrated into this systems engineering approach.

The first step in this approach is the identification of the appropriate parameters for inclusion. Subsequently, the interrelationships of those parameters need to be determined so that models which describe those relationships can be developed. Through a determination of desired outcomes, the models for the coal mining system can be optimized to achieve those outcomes.

[Craynon and Karmis, 3]. Considering social cost-benefit analysis and natural resource damage appraisal as a means of assessing the impacts of a mining operation in economic terms are critical for the mining operations to be given both regulatory permits and the social license to operate [Damigos, 4].

Also critical in being able to incorporate sustainability into an optimized mine design is defining precisely what “sustainability” means. For the purposes of this work, we have adopted the definition of Agyeman and Evans [5], “the need to ensure a better quality of life for all, now and into the future, in a just and equitable manner, whilst living with the limits of supportable ecosystems.” This definition has the distinct advantage of incorporating temporal and environmental justice facets along with considerations of the human condition and human ecology into a balanced systematic whole.

Another area of concern is the process by which optimization is measured. Several researchers have focused on multicriteria, multivariate optimization approaches in other systems. A recognized challenge for the mineral sector is the development of appropriate indicators [Azapagic, 6]. The series of SDIMI conferences has also focused on various aspects of this challenge, and numerous suggestions have been made on how best to frame the indicators. Work in other arenas has focused on development of indices, such as the Sustainable Development Index (SDI) proposed by Barrera-Roldán and Saldívar-Valdés [7] and the Holistic Ecosystem Health Indicator (HEHI) discussed by Wiegand et al [8].

For some of the desired outcomes, there have been concerns that the appropriate indicators for human health may not have been determined. Cole et al [9]. Cloquell-Ballester et al [10] have also investigated the indicators used for environmental and social impact assessment and quantification. One of the challenges is dealing with the constant tension between science

and policy as related to ecological indicators [Turnhout et al, 11]. Nonetheless, Diaz-Balteiro and Romero [12] state that approaches based on indicators are of “paramount importance”.

Optimizations using linear programming and multicriteria modeling have also been used for natural resource management problems by Hof and Bevers [13] and Stadler [14]. As seen in the work of Shastri and colleagues [15, 16, 17 and 18], these models can become quite complex.

In the current work, it was determined to use indices that represent a broad number of parameters for use in modeling and development of optimized mine designs. For example, USEPA’s Rapid Bioassessment Protocol [Barbour et al, 19] and community liveability indices may be appropriate for use in modeling and optimization. Using the approach outlined by Shastri et al [18], the model can then be used to identify the design scenarios that do not represent sustainable approaches.

#### *Using GIS in Sustainable Development*

Sherrouse et al [20] have developed a GIS application as a means of better quantifying and displaying the relative social values of ecosystem services for use in land and resource management. Their system focuses on a series of measures of the physical environment, including elevation, slope, distance to roads, and distance to water. These factors were correlated to the results of a survey focused on social value and potential use issues and types. A similar approach was considered for determining areas on a potential mine site where societal values would have influenced the decision of whether and how to mine a particular part of a permit area.

Swetnam et al [21] used GIS to generate quantitative analyses of the results of various policy decision scenarios, with a primary focus on land cover types and changes. This

methodology could also be used as a means of evaluating the impacts of various mine designs and approaches.

The use of indices of sustainability using multiple criteria analysis for decision support and a GIS system was discussed by Graymore et al [22]. Their work was focused on watersheds and subwatersheds as a means of mapping environmental, social and economic condition and the sustainability of the area, based on a number of natural resource management and land use planning decisions. Their approach identifies the need to filter sustainability indicators to those that are best measured and have the most influence on the sustainability outcome. In their case study for Victoria, the decision support tool they developed showed how GIS may be used to quickly and thoroughly evaluate the sustainability of various options. Their tool provided a holistic method which considers interactions among the sustainability indicators as well as the differences in impacts that can be seen by the aggregation of sustainability indicators into regional indices. It was able to show differences across watersheds and subwatersheds, as well as mapping the environmental, social and economic condition of the areas being studied. This methodology should be very adaptable to use for looking at specific mine plan options and the impacts on the various watershed and subwatersheds on each of the sustainability pillars.

Tools such as this are built upon the foundation of decision analysis models such as those proffered by Martin et al [23], Shields et al [24], and Dourojeanni [25]. The use of spatial analysis and GIS provides the ability to quickly model multiple policy or design scenarios and determine which demonstrates the greatest degree of sustainability.

## **THE USA REGULATORY ENVIRONMENT AND SUSTAINABILITY**

In the United States, the Surface Mining Control and Reclamation Act of 1977 (SMCRA) is the primary law ensuring that those outcomes are achieved. Additionally, other environmental

laws, such as the Endangered Species Act and the Clean Water Act, have significant influence on how mining operations are conducted and their effectiveness at achieving the desired outcomes. In the past several years, a number of factors related to community and social concerns, key aspects of sustainability, have been integrated into the regulatory process, primarily through the implementation of the Clean Water Act by the U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (USEPA). However, because these regulatory programs do not have consistent requirements nor do they all consider the same factors; some challenges in addressing sustainability are inherent.

In examining large-scale surface coal mining operations in Appalachia, it was necessary to evaluate the regulatory environment under which they receive authorization in order to address sustainability. While some of the regulatory programs provide some means for addressing sustainability issues, in general, the compliance with multiple programs discourages the implementation of sustainable development approaches. In part, this is a result of the focus of statutes such as the Clean Water Act on a single environmental media, which results in permitting and compliance schemes that emphasize single standards, rather than an integrated sustainable development derived process.

Many of these regulatory programs have a stated goal to utilize “science based” regulations. However, the framework of the programs is not conducive to the use of interdisciplinary scientific approaches and the multi-criteria modeling discussed above, and the primary tools are related to specific disciplines, such as hydrology, biology, geology or engineering. Current legal requirements and regulatory programs do not adequately consider social and economic factors as co-equal with environmental standards, thus inhibiting the implementation of sustainable development. Even with the focus on environmental standards,

VCCER [26] found that, “coal mining continues to lack broad social acceptance”, thus demonstrating the failure of the regulatory structure to foster sustainability.

While many other factors are important in determining how a mining operation should incorporate sustainable development principles, it is clear that stream related issues are critical in achieving the desired outcomes for a surface coal mining operation. Stream related issues impact many of the other community issues, including post mining land use and public health. Regulatory focuses in the United States on water-related issues, particularly stream quality issues, including the presence of metals such as selenium and the levels of total dissolved solids, are driving the ability of mining companies to obtain permits and other authorizations to mine. A singular focus on stream issues in a systems engineering approach to optimization of coal mine design is inappropriate. The full spectrum of social, economic, and environmental issues must be represented in the modeling and optimization processes.

Based on the determination that streams and related environmental values are key driving factors for assessing the sustainability of a particular mine plan, optimization of coal mine designs must consider how to minimize the impacts of those operations on stream. Of particular concern are excess spoil fills and mining methods that bury or eliminate stream segments. This is particularly of concern in some areas of the United States where the local topography and hydrology have created vast networks of headwater streams. Ensign and Doyle [27] have noted the critical nature of headwater streams on downstream ecosystem health. However, the social and economic factors of sustainability must also be considered in mine plan optimization.

Additionally, the regulatory framework under the Clean Water Act often does not allow for consideration of the total spectrum of sustainability issues when evaluating an application for

a permit for discharge. The statutory focus of the Clean Water Act on “fishable, swimmable” waters gives rise to the focus on constituent chemistry rather than a holistic view of an operation.

## **CASE STUDY**

For this analysis, the Spruce Number 1 coal mine in Logan County, West Virginia was used as a case study. This operation demonstrates the conflicts that can occur and hinder sustainability and mine plan optimization under the current regulatory scheme in the United States. In January 2011, USEPA, under their authority granted by section 404(c) of the Clean Water Act, overturned the permit issued by the USACE, taking away the company’s authorization to place materials into streams. The mine had also already received its surface mining permits from the West Virginia Department of Environmental Protection (WVDEP).

This mine has been under development for many years, and significant amounts of information were available in public permitting files maintained by the WVDEP, the USACE and the USEPA. Data on the mine comes primarily from the USEPA [28]. The mine is located two miles northeast of the town of Blair at Latitude 38°52'39" and Longitude 81°47'52". It was designed as a mountaintop removal operation, targeting the bituminous seams above and including the Middle Coalburg seam in the western part of the project and those above and including the Upper Stockton seam in the eastern part of the project area. In the eastern area, the Middle Coalburg seam was planned to be recovered by contour and auger or highwall mining.

The mine was permitted by the WVDEP and USACE to disturb a total of 2,278 acres (3.5 square miles) and fill approximately 7.5 miles of stream with excess spoil. The operation was planned to recover about 75 percent of coal reserves in the project area. The mountaintop mining operation was engineered to remove 400 to 450 vertical feet of the mountain, creating

approximately 501 million cubic yards of spoil. The majority of that material, nearly 391 million cubic yards, would be placed back on the mined area.

The remaining 110 million cubic yards would be placed in six excess spoil fills, burying all or portions of the Right Fork of Seng Camp Creek, Pigeonroost Branch, and Oldhouse Branch and their tributaries. The Spruce No.1 Mine surface mining permit issued by WVDEP describes impacts from the project as including placement of dredged and fill material into approximately: 0.12 acre of emergent wetlands; 10,630 linear feet (2.01 miles) of ephemeral stream channels; 28,698 linear feet (5.44 miles) of intermittent stream channels; and, 165 linear feet (0.03 miles) of perennial stream channel.

ESRI's ArcGIS™ was used to map environmental resources located on and near the proposed Spruce No. 1 mine. Land cover, habitat condition, stream flow, stream networks, fish and wildlife species distribution, vegetation type, and topography were mapped and analyzed with regard to interrelationships between resources. Social resources, location of housing, income levels, proximity of people to environmental resources, transportation networks, and utilities were also mapped. Finally, the location of coal resources and the planned mining operation were overlaid on these resource maps to identify the areas of greatest concern. Analyses were done to determine the distance to streams and the distance to people of all of the mining and fill areas proposed at the Spruce No. 1 mine.

An examination of the areas of potential conflict between mining operations, including excess spoil fills, and environmental and social resources showed a high level of concentration in and around streams. Stream quality, stream flow and other characteristics of streams appeared to have the greatest impact on environmental resources such as wildlife habitat. Stream quality is

inextricably linked with environmental quality indices, and appears to correlate with many social factors, such as recreation and liveability indices.

However, other key sustainability data were not readily available for this area that may not correlate as well with stream-based issues. For example, community income, availability of community services, such as fire and police protection and health care are completely independent of stream-based considerations. Some specific standards, such as a focus on conductivity or other parameters in a stream, cannot be reliably used as a measure of the diverse and complex factors that need to be considered in determining whether an operation is sustainable and in optimizing a mining plan for a large surface coal mine.

Further, the denial of the permit after the operator and others made have made irretrievable commitments of resources and investments may have resulted in negative consequences to the community. The current regulatory structures and multiple permitting programs are not configured to allow for those sorts of determinations, and some argue that making tradeoffs between environmental protection and economic and social factors is inappropriate.

Development of a methodology to evaluate the potential on-the-ground impacts of a proposed mining operation using GIS technology to identify the primary areas of concern and the potential means for achieving sustainability and the desired outcomes of the operation could prevent similar conflicts by giving all parties an objective means for developing optimized mine designs. Additionally, adoption of an agreed upon framework, such as the “impact benefits agreement” discussed by Schafrik and Kazakidis [29], would allow the mine operators and communities agree on how best to incorporate social factors into optimization discussions.

Additionally, specific tools developed by other researchers should be evaluated to determine whether they are suitable for modification for use in evaluating the sustainability impacts of various mining plan scenarios. Through the use of these approaches, a custom tool and approach for coal mine design can be developed. There is a critical need to develop mining approaches that: assume a life-cycle approach to the operation; improve recovery while restricting waste generation, reactivity and water impacts; incorporate best practices in characterization and disposal of wastes; incorporate best practices in monitoring, transport and discharge of mine water; protect ecosystems and enhance biodiversity; and address social and economic concerns in the community.

Finally, the development of usable and scientifically sound protocols for determining the ecosystem functions of streams in a manner that allows spatial analysis with GIS tools can assist in ensuring that coal mining operations can be designed in a manner that achieves the desired outcomes while achieving sustainability.

## **CONCLUSIONS**

### *Identification of Key On-the-ground Factors in Sustainability*

By examining the three key aspects of sustainability in light of the available on-the-ground and GIS data and commonly held views of economic, environmental and social values, several factors can be identified which are critical for optimizing coal mine designs for large surface operations in Appalachia which incorporate sustainable development principles. First, from the economic standpoint, optimizing coal recovery to generate wealth and income in the local community is a key consideration. Mine designs must incorporate the principles of avoidance of waste and unnecessary sterilization of reserves. Ensuring the creation of

employment opportunities and local purchase of supplies and equipment are also key considerations in the economic sphere.

Secondly, from a social perspective, engagement of the local communities as a constructive partner for the advancement of social, educational, and economic infrastructure is a key. Development of impact benefit analyses and other means of measurement of community involvement is another key consideration. As VCCER [26] pointed out, “the mining industry today must clearly understand that local communities and people who are affected by a mining operation must be engaged at a much higher level and through a process based on respect, transparency, and dialogue among all stakeholders.”

Thirdly, from an environmental standpoint, recognizing and being responsive to potential impacts is a key. This requires fully understanding, representing, modeling and monitoring the environmental and ecosystem health prior, during and after an operation. The use of GIS tools provides a superb means of incorporating these considerations. Based on an analyses of factors related to our case study, many of these factors can be represented by habitat quality assessments, and are tied directly to issues of stream health.

#### *Regulatory Framework Revisions Needed*

As noted above, the regulatory structures for environmental protection in the USA do not foster the consideration of all of these key factors in an integrated systems engineering approach. In order for sustainable development to be incorporated in optimized coal mining designs, some revisions to the regulatory approach are suggested. Primarily, these revisions involve moving beyond single media approaches that focus on limits on specific discharges of concern. An holistic approach incorporating the variety of statutory requirements along with community input needs to be adopted. This sort of approach would foster the adoption of a “beyond compliance”

ethic in the industry and would force agencies to develop science-based, up-to-date regulations, as some have previously recommended VCCER [e.g., 26]. and others have recommended. Just as optimization of coal mining design requires considering all the factors at one time, an optimized regulatory framework that promotes sustainability also needs to consider all the necessary factors and requirements as a part of an integrated process.

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## Appendix C: Selected Parameters for Modeling of Sustainable Development at Coal Mining Operations

**Table C-1: Selected Model Parameters.**

Parameter	Source	Category	Impacts
Number of gas or oil wells on the permit	Maps, permits, surveys	Descriptive	Environmental, social economic
Area of developed lands within permit	Maps, permits, surveys	Descriptive	Environmental, social economic
Area previously disturbed	Maps, permits, surveys	Descriptive	Environmental, social economic
Permit Area	Maps, permits, surveys	Descriptive	Environmental, social economic
Coal value	Business data	Economic	Economic
Number of employees at maximum operation	Business data	Economic	Social, economic
Annual hydrograph of streams on the site	Permits, surveys	Environmental	Environmental, social, economic
Area of emergent wetlands on permit	Maps, permits, surveys	Environmental	Environmental, social, economic
Area of forest	Maps, permits, surveys	Environmental	Environmental, social, economic
Area of grassland	Maps, permits, surveys	Environmental	Environmental, social, economic
Area of non-flowing bodies of water	Maps, permits, surveys	Environmental	Environmental, social, economic
Area of permit in migratory bird flyway	Maps, permits, surveys	Environmental	Environmental, social, economic
Area of permit planned for “nondisturbance”	Maps, permits, surveys	Environmental	Environmental, social, economic

<b>Parameter</b>	<b>Source</b>	<b>Category</b>	<b>Impacts</b>
Area of permit with high-quality ecosystems	Maps, permits, surveys	Environmental	Environmental, social, economic
Area of permit within 5 miles of bat hibernation areas	Maps, permits, surveys	Environmental	Environmental, social, economic
Area of permit within 5 miles of bat roosting area	Maps, permits, surveys	Environmental	Environmental, social, economic
Area of riparian wetlands on permit	Maps, permits, surveys	Environmental	Environmental, social, economic
Area of T&E habitat	Maps, permits, surveys	Environmental	Environmental, social, economic
Area of T&E plant habitat	Maps, permits, surveys	Environmental	Environmental, social, economic
Area of T&E species habitat adjacent to permit area	Maps, permits, surveys	Environmental	Environmental, social, economic
Area of upland wildlife habitat	Maps, permits, surveys	Environmental	Environmental, social, economic
Area of wetlands	Maps, permits, surveys	Environmental	Environmental, social, economic
Area/length of aquatic habitat	Maps, permits, surveys	Environmental	Environmental, social, economic
Area/length of riparian habitat	Maps, permits, surveys	Environmental	Environmental, social, economic
Average annual precipitation on the site	Maps, permits, surveys	Environmental	Environmental, social, economic
Average habitat integrity score within the permit areas	Maps, permits, surveys	Environmental	Environmental, social, economic
Distance of disturbed area of permit to streams	Maps, permits, surveys	Environmental	Environmental, social, economic
Disturbed Area	Maps, permits, surveys	Environmental	Environmental, social economic

<b>Parameter</b>	<b>Source</b>	<b>Category</b>	<b>Impacts</b>
Habitat quality score	Maps, permits, surveys	Environmental	Environmental, social, economic
Length of ephemeral streams	Maps, permits, surveys	Environmental	Environmental, social, economic
Length of intermittent streams	Maps, permits, surveys	Environmental	Environmental, social, economic
Length of perennial streams	Maps, permits, surveys	Environmental	Environmental, social, economic
Length of protected streams	Maps, permits, surveys	Environmental	Environmental, social, economic
Length of streams designated as “better” than “warm water fishery” use	Maps, permits, surveys	Environmental	Environmental, social, economic
Maximum flow rate (volume and velocity) of streams on the site	Permits, surveys	Environmental	Environmental, social, economic
Number of animal migration routes on permit	Maps, permits, surveys	Environmental	Environmental, social, economic
Number of high-quality stream segments adjacent to permit area	Maps, permits, surveys	Environmental	Environmental, social, economic
Number of high-quality stream segments on permit area	Maps, permits, surveys	Environmental	Environmental, social, economic
Number of streams containing T&E species downstream of permit	Maps, permits, surveys	Environmental	Environmental, social, economic
Number of T&E species	Maps, permits, surveys	Environmental	Environmental, social, economic
Population of known or suspected T&E species downstream of permit	Permits, surveys	Environmental	Environmental, social, economic
Population of known or suspected T&E species on permit	Permits, surveys	Environmental	Environmental, social, economic
Species diversity index	Permits, surveys	Environmental	Environmental, social, economic
Stream-distance to major rivers	Maps, permits, surveys	Environmental	Environmental, social, economic

<b>Parameter</b>	<b>Source</b>	<b>Category</b>	<b>Impacts</b>
Total area of wetlands on permit	Maps, permits, surveys	Environmental	Environmental, social, economic
Total length of animal migration routes on permit	Maps, permits, surveys	Environmental	Environmental, social, economic
Total length of streams in permit	Maps, permits, surveys	Environmental	Environmental, social, economic
Water quality score	Permits, surveys	Environmental	Environmental, social, economic
Area of blasting magazine (explosive storage)	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Area of coarse waste disposal facilities	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Area of deciduous forest	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Area of electrical substations planned on the permit	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Area of parking lots planned for permit	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Area of permanent buildings planned for permit	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Area of permit planned for developed post-mining land use	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Area of permit planned for grassland reclamation	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Area of permit planned for reforestation	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Area of proposed excess spoil fills	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Area of slurry ponds and slurry cells	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic

<b>Parameter</b>	<b>Source</b>	<b>Category</b>	<b>Impacts</b>
Area of topsoil storage on the site	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Area of vehicle maintenance facilities planned for permit	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Average haul distance	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Blasting cost	Business data	Geologic/Mining	Environmental, social, economic
Cost of fuel	Business data	Geologic/Mining	Environmental, social, economic
Erodibility of soil materials on the site	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Length of ephemeral streams proposed to be filled	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Length of forest “edges” within permit	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Length of intermittent stream proposed to be filled	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Length of perennial stream proposed to be filled	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Length of powerlines planned for the permit	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Length of railroad spur planned for permit area	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Length of sediment “snakes” at maximum disturbance	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Length/area of roads	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Linear feet of highwall at maximum disturbance	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Number of aquifers in coal measures	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic

<b>Parameter</b>	<b>Source</b>	<b>Category</b>	<b>Impacts</b>
Number of mineable coal seams	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Number of sediment control ponds/structures	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Number of slurry ponds or slurry cells	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Number of water wells on the site	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Operating cost of planned mining equipment	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Planned area of wetlands on permit post-mining	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Stripping ratio	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Surface area of sediment control ponds/structures	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Total area of roads subject to dust suppression at maximum disturbance	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Total thickness of coal	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Total thickness of interburden	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Total thickness of mineable coal seams	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Total thickness of overburden	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Total volume of sediment control structures	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Total volume of slurry ponds and slurry cells	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic

<b>Parameter</b>	<b>Source</b>	<b>Category</b>	<b>Impacts</b>
Type of explosives used on site	Permits, surveys	Geologic/Mining	Environmental, social, economic
Type of fertilizers and soil amendments planned for use in reclamation	Permits, surveys	Geologic/Mining	Environmental, social, economic
Volume of acid or toxic forming materials on site	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Volume of coal combustion residues to be placed on the site	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Volume of durable rock on site	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Volume of excess spoil	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Volume of explosive stored on site	Permits, surveys	Geologic/Mining	Environmental, social, economic
Volume of fertilizer and soil amendments planned for use in reclamation	Permits, surveys	Geologic/Mining	Environmental, social, economic
Volume of groundwater used on the site	Permits, surveys	Geologic/Mining	Environmental, social, economic
Volume of spoil	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Volume of surface water used on the site	Permits, surveys	Geologic/Mining	Environmental, social, economic
Volume of topsoil on the site	Maps, permits, surveys	Geologic/Mining	Environmental, social, economic
Distance from public roads	Maps, permits, surveys	Social	Environmental, social, economic
Distance of permit from operating railroads	Maps, permits, surveys	Social	Environmental, social, economic
Distance of planned electrical substations to power grid	Maps, permits, surveys	Social	Environmental, social, economic
Distance to developed area	Maps, permits, surveys	Social	Environmental, social, economic
Distance to hospitals	Maps, permits, surveys	Social	Environmental, social, economic

<b>Parameter</b>	<b>Source</b>	<b>Category</b>	<b>Impacts</b>
Distance to police, fire, etc.	Maps, permits, surveys	Social	Environmental, social, economic
Distance to residences	Maps, permits, surveys	Social	Environmental, social, economic
Distance to schools	Maps, permits, surveys	Social	Environmental, social, economic
Number of residences adjacent and downslope of proposed operations on the permit	Maps, permits, surveys	Social	Environmental, social, economic
Number of residences downstream of permit with potential for inundation	Maps, permits, surveys	Social	Environmental, social, economic
Number of residences with drinking water wells within one mile of the permit	Maps, permits, surveys	Social	Environmental, social, economic
Number of residences within one mile of permit boundary	Maps, permits, surveys	Social	Environmental, social, economic
Number of residences within one mile of planned blasting on permit	Maps, permits, surveys	Social	Environmental, social, economic
Number of residences within one mile of proposed slurry ponds/cells and coarse waste disposal areas	Maps, permits, surveys	Social	Environmental, social, economic
Number of residences within one-half mile of permit boundary	Maps, permits, surveys	Social	Environmental, social, economic
Total population adjacent and downslope of proposed operation	Maps, permits, surveys	Social	Environmental, social, economic
Total population downstream of permit with a potential for inundation	Maps, permits, surveys	Social	Environmental, social, economic
Total population using drinking water wells within one mile of the permit	Maps, permits, surveys	Social	Environmental, social, economic
Total population within one mile of permit boundary	Maps, permits, surveys	Social	Environmental, social, economic
Total population within one mile of proposed slurry ponds/cells and coarse waste disposal areas	Maps, permits, surveys	Social	Environmental, social, economic

<b>Parameter</b>	<b>Source</b>	<b>Category</b>	<b>Impacts</b>
Total population within one-half mile of permit boundary	Maps, permits, surveys	Social	Environmental, social, economic

## **Appendix D: Selected Draft Maps of Parameters for Spruce No. 1 Mine**

The following draft maps were used in developing the paper given in Appendix A and served as inspiration for the more detailed geographic information system (GIS) analysis in Chapter 3 of this dissertation. No attempt was made to enhance the quality of these maps for this publication. The base maps used were obtained from ESRI Online and represent the U.S. Geological Survey topographic maps for the area shown. The majority of other data was obtained over several months from the West Virginia GIS Clearinghouse, although some was obtained from the West Virginia Geologic and Economic Survey. References to these online sites follows the maps.



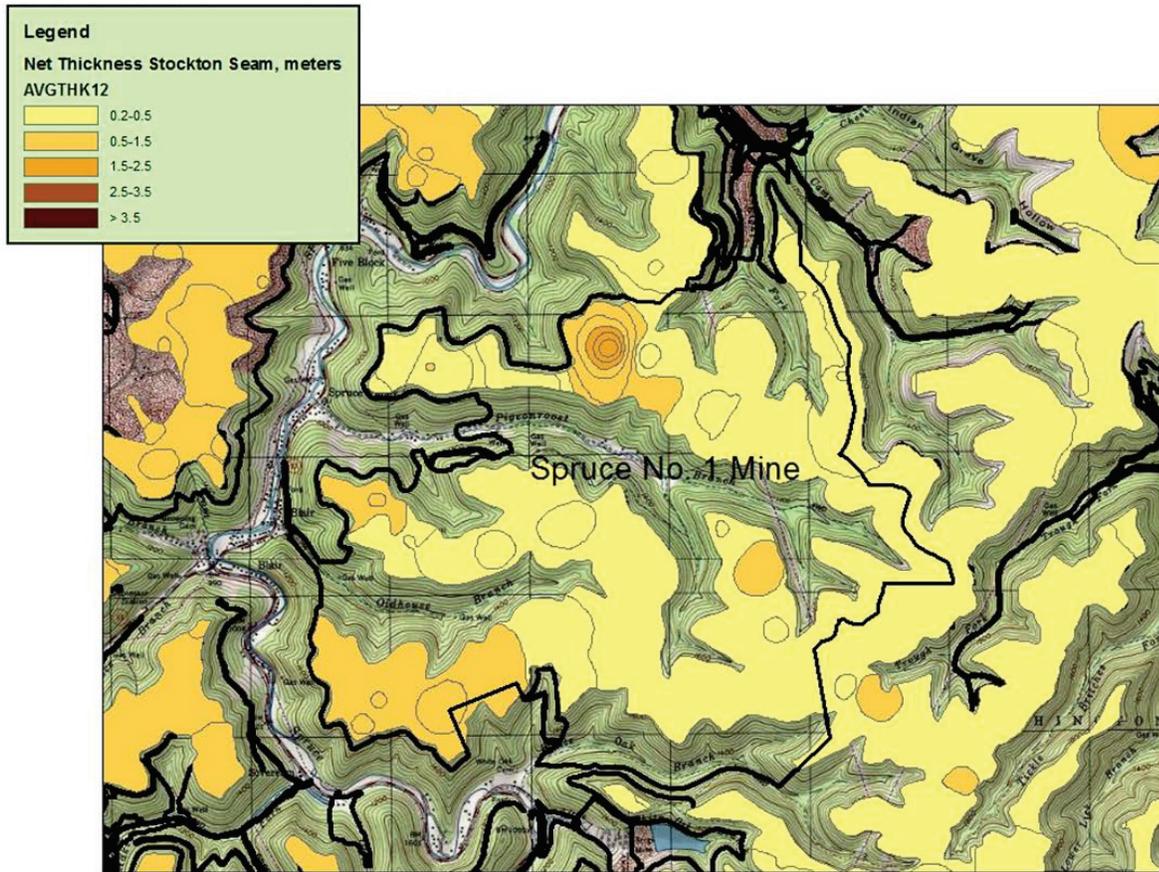


Figure D-2. Net thickness of Stockton coal seam on Spruce No. 1 mine permit. Sources: West Virginia GIS Clearinghouse, ESRI Online, and West Virginia Geologic and Economic Survey.

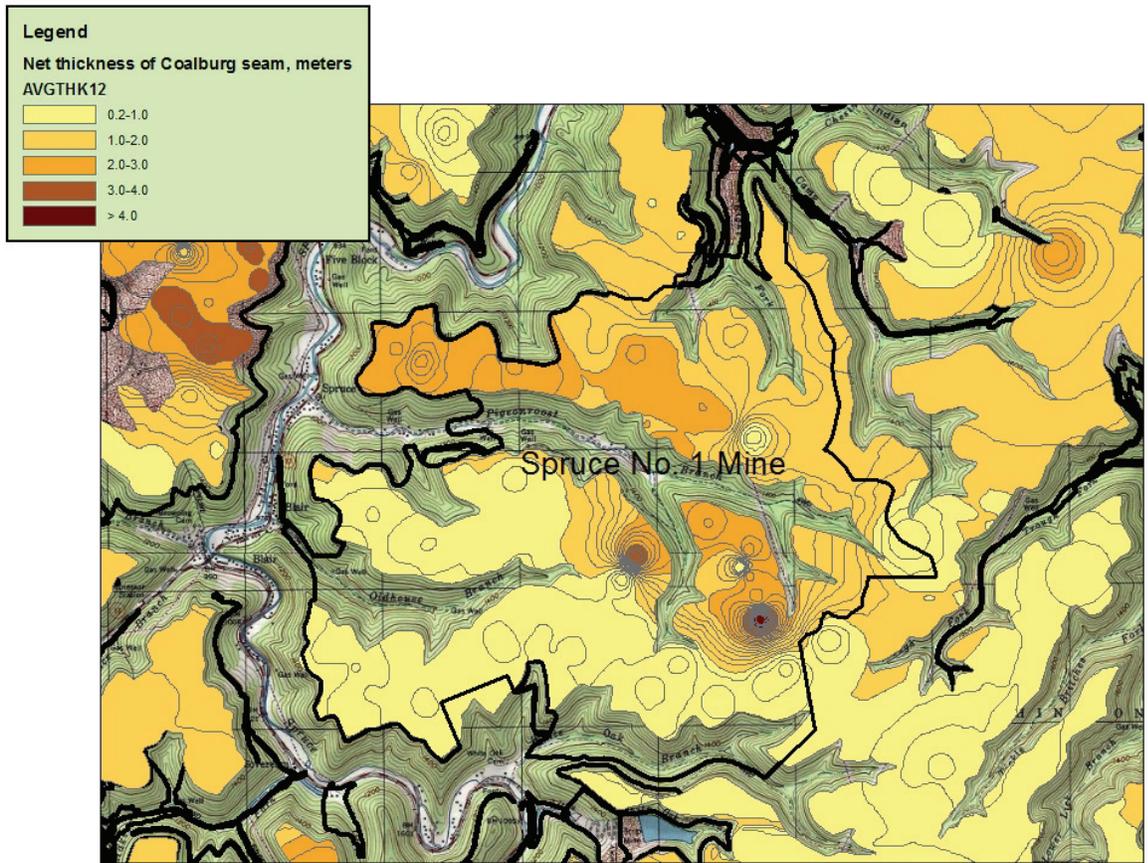


Figure D-3. Net thickness of Coalburg coal seam on Spruce No. 1 mine permit. Sources: West Virginia GIS Clearinghouse, ESRI Online, and West Virginia Geologic and Economic Survey.

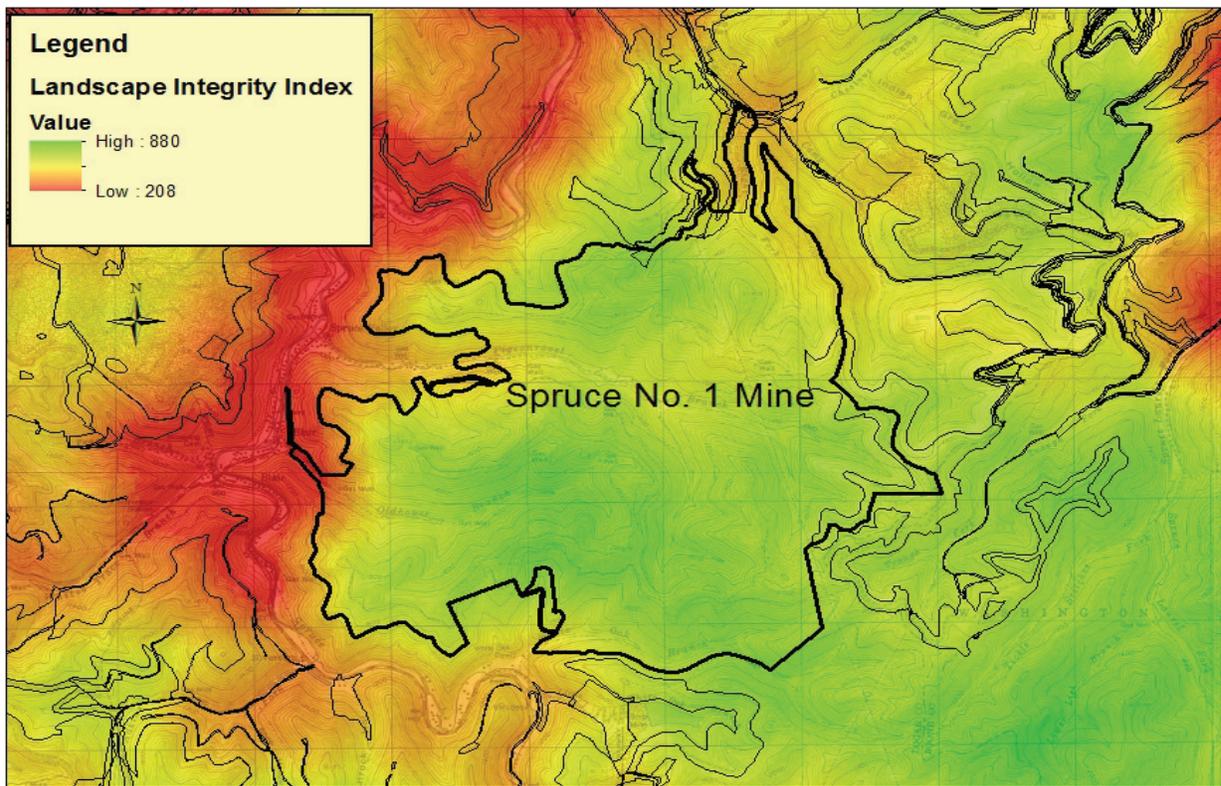


Figure D-4. Landscape Integrity Index on Spruce No. 1 mine permit. Sources: West Virginia GIS Clearinghouse and ESRI Online.

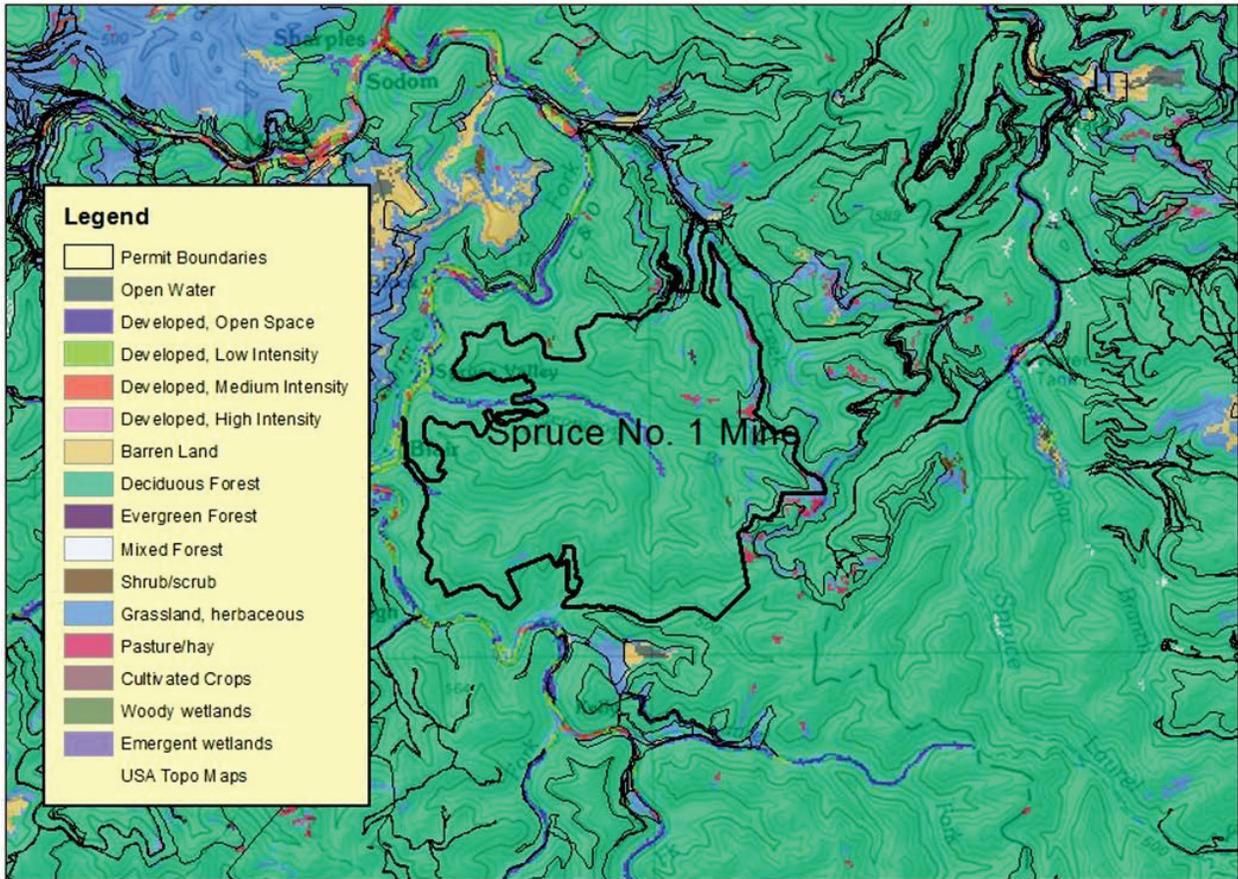


Figure D-5. National Land Cover Data Survey, 2001 shown on Spruce No. 1 mine permit. Sources: West Virginia GIS Clearinghouse and ESRI Online.

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