SUSTAINABLE MINED LAND RECLAMATION IN THE EASTERN U. S. COALFIELDS: A CASE FOR AN ECOSYSTEM RECLAMATION APPROACH[1]

J. A. Burger[2]

Abstract. The demand for energy throughout the world grows each day, and coal will be needed to meet a large portion of that demand. Coal mining techniques in the Appalachian and Midwestern coalfields have evolved to mine larger land areas and multiple seams at greater depths. New reclamation methods and approaches also must evolve to minimize cumulative impacts on aquatic, terrestrial, and human resources. Mined land reforestation practices over the past 80 years illustrate the evolution of reclamation in the eastern coalfields of the U. S. Prior to the implementation of the Surface Mining Control and Reclamation Act (SMCRA), tree planting was synonymous with reclamation. Grassland reclamation became the dominant approach post-SMCRA. As stakeholders of the mining and reclamation process have begun to appreciate the value of forest ecosystems, there is greater emphasis on ensuring land and forest restoration and proper ecosystem functioning on reclaimed mined land. A forestry reclamation approach is supplanting grassland reclamation where forests are the logical post-mining land use. Restoring forestland capability, native species, and watershed protection are positive outcomes. However, greater public demand for stream protection, water quality, biodiversity, carbon sequestration, native wildlife habitat, and human protection may require a more comprehensive *ecosystem reclamation approach*. In my view, the components of such an approach already have a good basis in science and could be applied through a process of adaptive management in the event such an approach is needed to help the coal industry in the U. S. maintain its social license to operate.

Additional Key Words: mountaintop mining, coal mine reclamation, mine reforestation, Forestry Reclamation Approach, ecosystem restoration.

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[2] James A. Burger is Garland Gray Professor Emeritus of Forestry and Soil Science, Virginia Tech University, Blacksburg, VA 24061.

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Introduction

The Appalachian coalfields cover a broad area from western Pennsylvania to northern Alabama. Portions of the region also lie in Ohio, West Virginia, Maryland, Virginia, Kentucky, and Tennessee (Fig. 1). The Midwestern coalfields cover parts of Illinois, Indiana, and Kentucky. Over 600,000 ha have been disturbed by surface mining in the region, and more than 15,000 ha are surface mined each year (US OSM, 2008). Coal from the region supplies approximately 15% of the total used in the US for power production, and high-quality metallurgical coal is shipped regionally and abroad. Mining in the region over the past century has evolved from mostly deep, post-and-pillar exploitation of coal seams one meter thick or more, to a process of open pit and long-wall mining in the Midwest, and to mountaintop removal surface mining in the Appalachians that removes as much as 100 m of overburden for multiple seams of coal. Several hundred contiguous hectares can be disturbed in a single mine operation resulting in environmental, economic, and societal impacts that are controversial. Given the current and projected demand for coal nationally and internationally, it is highly likely that land disturbance associated with surface mining will become even more extensive.

Largely unregulated mining at a smaller scale than practiced today prompted the enactment of the Surface Mining Control and Reclamation Act of 1977 (SMCRA, 2006) with mining and reclamation provisions appropriate for the time and scale of mining. Three decades later, the spatial scale of mining and the techniques used are quite different and require a commensurate change in reclamation techniques to meet the intent of the SMCRA provisions. Another significant change in the past three decades is society's awareness of and demand for processes that assure sustainable environments, economies, and human communities. Businesses of all sizes and types are now compelled to show how their activity meets the triple bottom line of being economically viable, environmentally benign, and socially responsible, a widely accepted definition of sustainability (Bruntland, 1987). The purpose of this paper is to present the evolution of mined land reforestation in the eastern U. S. and to suggest an ecosystem reclamation approach that better addresses the impact of surface mining within a sustainable mining and reclamation paradigm.

Value of Native Forests of the Eastern Coalfields

The Appalachian and Midwestern coalfields are within the mountainous, largely-intact part of the eastern deciduous forest biome of the United States; most land was forested prior to mining. The forests are Mixed-Mesophytic, Appalachian Oak, and Oak-Hickory forest associations (Braun, 1950), some of the most diverse, contiguous, temperate, broadleaved forests in the world (Rickets et al., 1999) (Fig. 1). These forests have provided products and services to their human inhabitants for centuries. During the past 150 years, virgin timber and second-growth forests supported an important forest products industry. According to the American Forest and Paper Association (http://www.afandpa.org/), the eastern coal producing states (WV, KY, MD, IN, IL, OH, PA, TN, VA) have more than 6,300 wood products manufacturing facilities that employ over 300,000 workers with an annual payroll over $15 billion. The overall value of annual industry shipments exceeds $62 billion. The services provided by forests, which include watershed control, water quality, carbon sequestration, biodiversity, and habitat, are reportedly more valuable than the wood products they provide. Forest services are poorly monetized, but their collective value has been estimated at three to ten times the value of wood products extracted (Contanza et al., 1997; Heal, 2000). There is a rich history of human communities using these diverse forests for sustenance and shelter, and the use of non-timber forest products is an important part of local culture (Bolgiano, 1998). On the steep terrain of the Appalachian Mountains where mean annual rainfall exceeds 1300 mm, much of it as intense, high-energy storms, forest cover is especially important for sediment and flood control and water quality. Therefore, there are many compelling social, economic, and environmental reasons to restore the forest on land disturbed by mining.

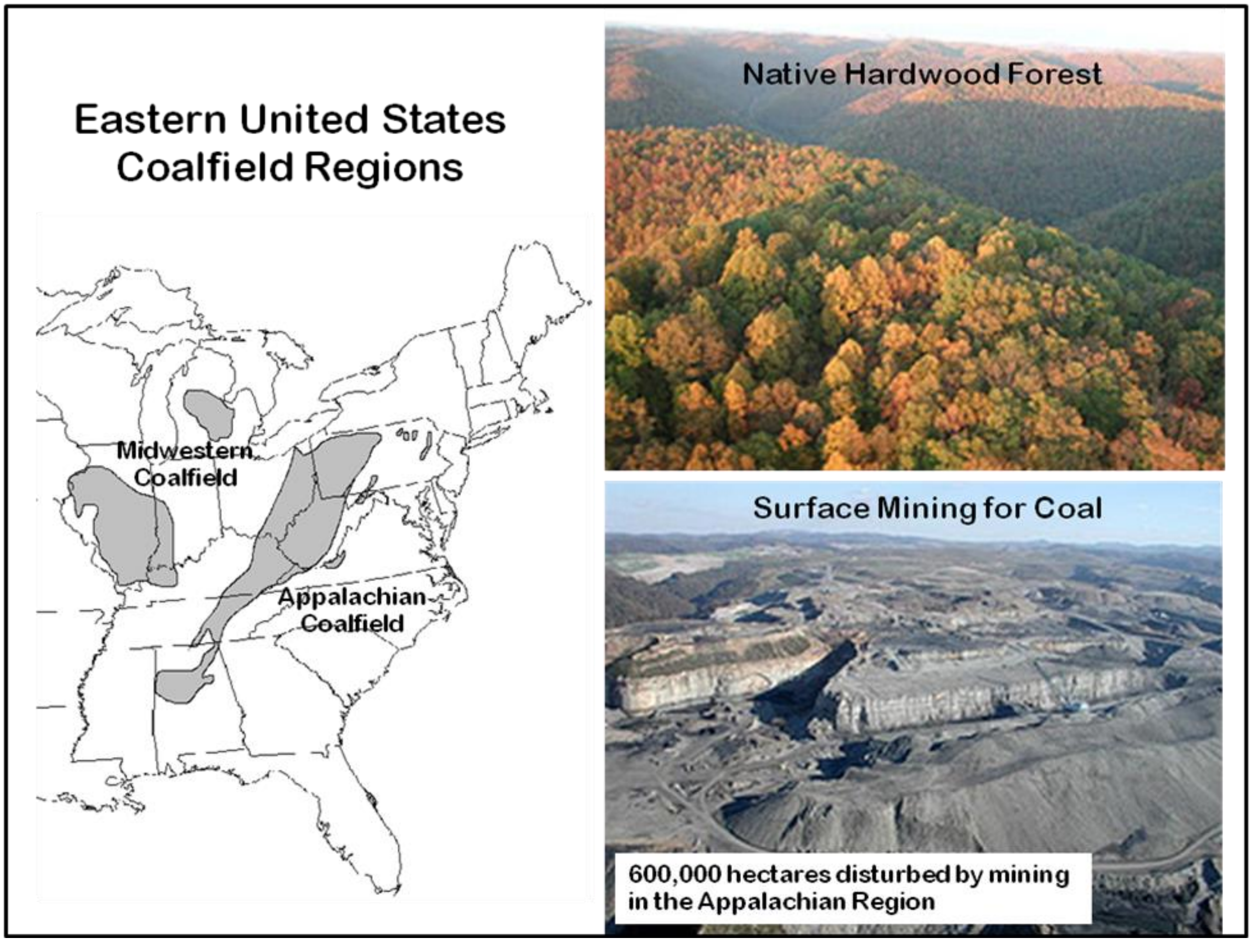

Figure 1. The Appalachian and Midwestern Coalfields region in the eastern United States.

Early reports and records summarized by Utley (2008) show the evolution of strip mining for coal in the United States. In 1804 coal was reportedly dug by hand and with mule scrappers from the bottom of a creek near Lancaster, PA. Mechanized strip mining was accomplished with Otis steam shovels and Vulcan railroad shovels by 1907 in KY and other regions of the Appalachian and Midwestern Coalfields. Electric stripping shovels were used as early as the 1920s and modern versions continue to be used nearly a century later. Early on, stripping followed coal outcrops, but electric and diesel-powered shovels allowed removal of large amounts of overburden in area and contour mines. By 1980, the scale of mechanization was such that entire ridgelines and mountain tops consisting of several hundred contiguous hectares were being removed in the process of harvesting multiple coal seams lying approximately horizontally with the landscape. This complete removal of landscape features is called mountain top/valley fill mining and is now quite common (and controversial) in the Appalachian region.

Explosives are used to break rock layers and large shovels and draglines remove the overburden and interburden between coal seams. Excess spoil is typically placed in valley fills, some of which may be 1 km wide and 3 km long. Despite the tremendous change in scale and method since the SMCRA was implemented three decades ago, reclamation methods used on most surface mines have changed little.

Mined Land Reforestation History

There are four periods of mined land reforestation over the past 80 years that influenced the composition and productivity of woody vegetation on surface mined sites in the eastern coalfields: 1) pre-federal law tree planting period; 2) grassland period; 3) woody shrub period; and 4) native forest restoration period (Fig. 2). Except for tree planting, rehabilitation of areas disturbed by mining was negligible until the passage of the SMCRA in 1977. Most Appalachian and Midwestern states had rudimentary reclamation laws with provisions for revegetation, but few required highwall and pit backfilling or landscape reshaping to approximate original contour (AOC). According to Medvick (1980), Indiana was the first state to organize a tree planting program for mined land in 1928. Over the next four decades land reclamation and tree planting became synonymous terms in most eastern coal field states. State coal operator associations enlisted the aid of state, federal, and academic forestry researchers which resulted in reforestation guidelines for pre-law mined sites (Davis et al., 1965; Vogel, 1981). Prescribed tree mixes, including valuable native hardwood species, generally grew well on loose, deep, overburden materials and many of these forest stands have become quite valuable for saw timber (Ashby, 1996; Rodrigue et al., 2002).

Rodrigue et al. (2002) documented the productivity, diversity, and value of these new pre-law forests. They measured 14 stands on mined sites across a seven-state area in both the Appalachian and Midwestern Coalfields and compared them with adjacent, mature stands on non-mined areas with similar pre-mining conditions. The forest stands were mixes of native hardwoods, native conifers, or a mix of hardwoods and conifers, and ranged in age from 18 to 71 years. Growth rates, expressed as mean annual increment, were greater on 10 of the 14 mined sites than on adjacent non-mined sites (Rodrigue et al., 2002). In most cases, depending on the value of the species mix, the wood product value on mined sites exceeded the value of that on non-mined sites. Carbon sequestration on the reforested sites ranged from 3 to 4 Mg $ha^{-1}yr^{-1}$, and

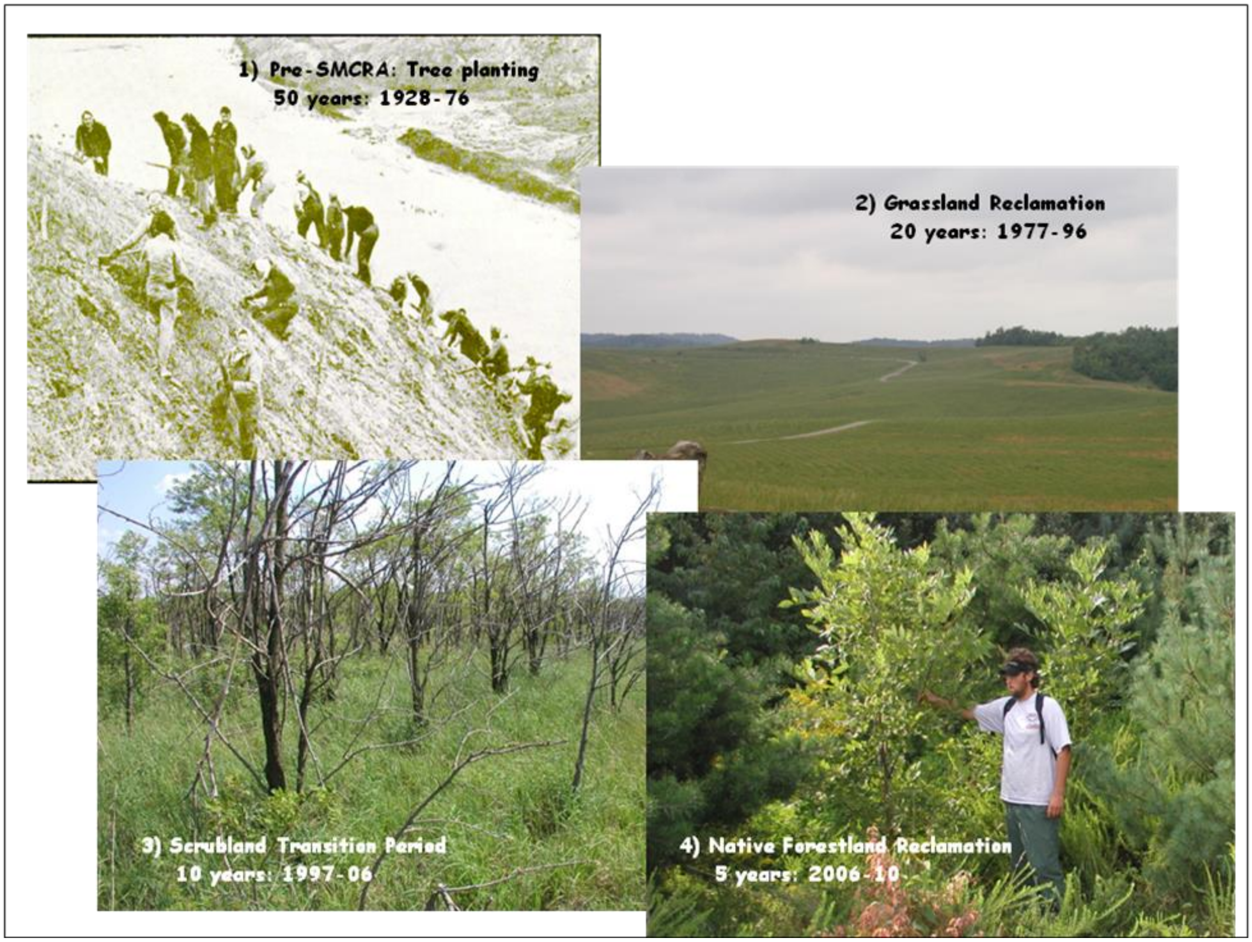

Figure 2. Eighty-year history of reclamation in the Appalachian Coalfields.

based on a sequestration projection, carbon accumulation will reach the average level in adjacent, non-mined stands by age 80 (Amichev et al., 2008). Despite widespread tree planting during the decades of the 1950s, 60s, and 70s, and the overall success of tree planting programs, environmental and human safety issues remained. Mass wasting of debris slopes, dangerous highwalls, acid mine drainage, and sediments in streams ultimately led to passage of the SMCRA.

When the SMCRA was implemented in 1978, it greatly changed the way coal surface mines were reclaimed. Toxic materials that could lead to degraded water quality were buried and isolated to prevent oxidation and seepage of acids and minerals into downstream aquifers; pits and highwalls were backfilled and the landscape was returned to approximate original contour; strict sedimentation and air quality provisions prevented off-site pollution; and the graded mined sites were sown with agricultural grasses and legumes for erosion and sediment control. This grassland reclamation approach (GRA) was based on a reclamation model used by the U.S. interstate highway system, refined in the 1960s and 70s, to ensure long-term stability of the road base by limiting water infiltration and maximizing runoff. Compacted soils and agronomic ground covers limited water infiltration and significantly reduced invasion of native trees which were considered road hazards. Water diversion structures were designed as straight riprap flumes to facilitate and expedite runoff. This GRA proved to be a good fit for interstate road stability and long-term grassland maintenance, but resulted in a sterile and un-natural aquatic and terrestrial habitat.

Because of their previous success with tree planting, coal operators, responsible for all reclamation treatments under the new law, also planted trees but with little to no success. The extensive grading with heavy equipment needed to achieve AOC and the GRA model severely compacted the mine soils, and the herbaceous ground cover sown for erosion control overtopped planted seedlings, causing high mortality rates, stunted growth, and low species diversity (Groninger et al., 2006). As a result, within two years after implementation of the new federal law, coal operators reclaimed most mined lands to alternative, approved uses that fit the GRA model such as *hayland/pasture* (italics indicates a defined, post-mining land use (PMLU) in the federal regulations) for the 15-year period from 1980 to 1995. Very few of the approximately 300,000 ha reclaimed in the Appalachian region during this time were managed and used for their prescribed PMLU. There is no significant livestock industry in the central Appalachians, and most mined sites are remote, without water for livestock, and difficult to fence and manage. Without management these *hayland/pastures* were quickly (within 10 yr) overcome with invasive species such as serecia lespedeza (*Lespedeza cuneata*), Japanese honeysuckle (*Lonicera japonica*) and autumn olive (*Elaeagnus umbellata Thunb.*).

By the mid-1990s, landowners, ecologists, and the general public expressed concerns to coal operators and regulators about the low value and poor condition of reclaimed land. This initiated a 10-year period (1996-2005) during which the predominant PMLUs in some areas of the Appalachian coal fields were *wildlife habitat* and *unmanaged forest* (GAO, 2009). In actual practice, coal operators simply added the additional step of planting shrubs and tolerant tree species to grassland reclamation to achieve these PMLUs; the mined land was still heavily graded, compacted, and sown with agricultural grasses and legumes as required by most federal and state regulators. Within 10 years, the *wildlife habitat* prescription was largely overtaken by invasive species that were more competitive than the planted wildlife shrubs. *Unmanaged forest* consisted of a few early-successional species such as black locust (*Robinia psuedoacacia)* and *Pinus spp*. that could tolerate the inhospitable, compacted mine soils covered with sown, competitive herbs. By the year 2000, on a half-million hectares reclaimed under the provisions of the new law in the Appalachian region, approximate post-mining coverage consisted of 35% *hayland/pasture*, 45% *wildlife habitat*, 15% *unmanaged forests*, and 5% other uses (OSM, 2010). Based on anecdotal reports and surveys, very little reclaimed land is in productive use, and regardless of the prescribed PMLU, most of it is in a state of arrested succession (Williamson and Gray, 1996; Putz and Canham, 1992; Holl, 2002) and heavily infested with invasive and exotic species. By the turn of the century, it was clear to many in the mining and reclamation community that a different approach to rehabilitation of mined land was needed.

A Forestry Reclamation Approach for Reclaiming Mined Land

In 1980, shortly after the implementation of SMCRA, Virginia Tech University established the Powell River Project (PRP http://www.cses.vt.edu/PRP/Overview.html) with a mission to conduct research and education programs to enhance restoration of mined land for the benefit of communities and businesses in the region. The PRP, funded by government and industry, supported research on AOC methods, mine soil suitability, forage and livestock production, acid mine drainage remediation, water quality, horticultural and tree crops, and forest restoration. For over 30 years, reforestation research through the PRP has been conducted in a seven-state region on issues including selection and placement of mine soils suitable for native forest restoration; development of erosion-control ground covers compatible with native plant colonization; and researching methods for increasing diversity, productivity, and value of restored forests. The PRP reforestation research program was built upon several decades of pre-law research by agency, university, and industry scientists. Because the federal SMCRA dramatically changed the way mined land was reclaimed, additional research was needed after 1977 to assess the impact of AOC grading, heavily compacted mine soils, suitability of overburden as plant growth media, compatibility of traditionally-used reclamation species with native forest trees, and the integration of the biology of reforestation with site preparation, regulatory requirements, and cost optimization. In many respects, the SMCRA created a whole new landscape that required new reclamation approaches for which there was little science for guidance.

The culmination of this long-term PRP reforestation research program, and that of several others established in adjacent states a decade later, was a Forestry Reclamation Approach (FRA) (Zipper et al., In review; Burger et al., 2005; Burger and Zipper, 2002) very different from common practices used previously. The FRA entails: 1) selection of soil and overburden growth media specifically for forest trees; 2) placement of mine soils 1.2 m deep in a loose, un-compacted condition; 3) use of tree-compatible ground cover that minimizes competition and allows germination, emergence, and establishment of native, volunteer vegetation; and 4) planting by professional tree planters of valuable, native trees and shrubs that enhance biodiversity and other forest services. Forest productivity can be assured by salvaging and returning to a depth of 1 to 2 m soil and regolith materials with physical and chemical properties similar to native soils. Biodiversity is enhanced by restoring a portion of the native seed pool, planting up to 10 native tree species, and creating surface conditions that allow unimpeded natural colonization. Hydrologic flow paths are restored by loosely placing mine soils that allow water infiltration, storage, drainage, and groundwater recharge.

Short-term reforestation success using the FRA has been documented in a number of research studies (Burger, 2008; Emerson et al., 2009; Fields-Johnson, 2010). When the FRA is used, hydrologic flow paths and runoff and infiltration processes are more like native forests than mined land reclaimed using traditional methods (Taylor et al., 2009). Field surveys show diverse (10 planted woody species and as many naturally colonized), fast-growing stands of native trees intermixed with native herbs and grasses (Angel et al., 2008). The extent to which native biodiversity will be restored using the FRA is still unknown, but initial observations suggest that many FRA sites planted with a variety of native species are on a normal, natural-succession trajectory.

Long-term evidence showing that forest productivity can be restored using the FRA was reported by Burger and Zipper (2009) and Casselman et al. (2007) in studies of an eastern white pine (*Pinus strobus* L.) stand established in 1978 using FRA procedures (Fig. 3A). White pine is a native species sensitive to gradients of soil quality; therefore, it provides a good bioassay of forest land capability. Forest site index projected to age 50 was 34 m, which is excellent land capability on any site, disturbed or not. Figure 3B shows white pine cross sections, all 17 years old, growing on soils of different quality. The intermediate-sized stem cross-section of 17-year-old white pines shown in Fig. 3B depicts the average growth rate of white pines across the

Appalachian region (Doolittle, 1962; Vimmerstedt, 1962). The smallest cross-section depicts growth on compacted, alkaline overburden prepared for grassland PMLUs. The largest cross-section depicts growth on mine soils prepared using FRA techniques (Fig. 3A). Burger and Zipper (2009) summarized data comparing wood production and value of stands growing at these different rates (Table 1). Wood volume increases disproportionately faster as site index increases, and wood value at rotation age increases exponentially with site quality because large trees have greater value for more diverse products. Pre-mining capability in terms of tree growth and forest economic value can be restored using the FRA. Preliminary studies indicate that other ecosystem services provided by forests such as biodiversity, watershed control, and wildlife habitat can be restored using the FRA, but more research is needed to determine the extent of recovery toward pre-mining conditions.

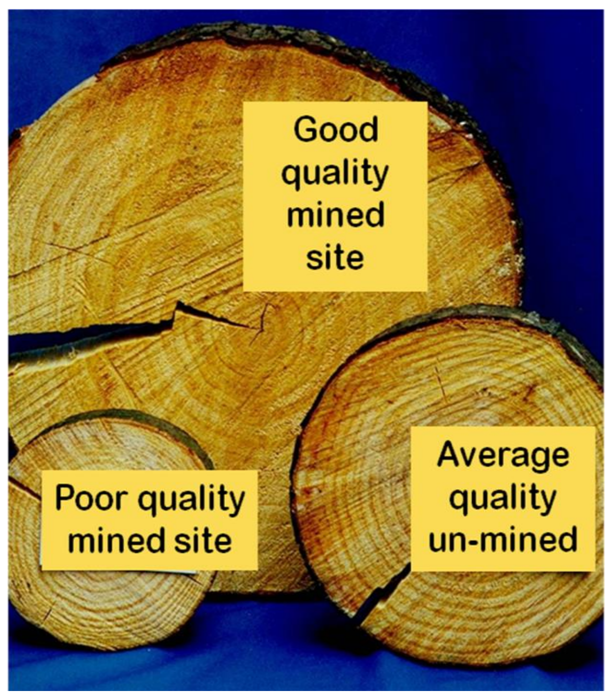

Figure 3A. Twenty-eight year-old forest stand on mined land reclaimed using FRA procedures.

Figure 3B. Comparative growth of 17-year-old white pine for average un-mined site, mined site with poor soil quality, and mined site with excellent soil quality.

Table 1. The effects of reclamation technique on white pine productivity and stand value at 30 years with average management.

Case	White Pine Site Type	Site Index[a]	Timber Volume (m^3/ha)[b]	Harvestable Wood Products	Total Value ($/ha)[c]
I	Average quality of an undisturbed Appalachian forest site (Doolittle 1962)	17	500	small sawtimber	$3460
II	Average quality of a post-SMCRA non-FRA mine soil (Torbert et al., 1988)	14	90	pulp	$250
III	Actual quality of a white pine stand on a good mine soil in Virginia (Kelting et al., 1997)	21	670	large sawtimber	$6900

[a] Site Index = expected eastern white pine height after 25 years, in meters.
[b] Harvestable timber volume at age 30, expressed cubic meters per hectare, based on yield tables prepared by Vimmerstedt (1962).
[c] Harvest price, estimated as an average of what was typical over the 1999-2009 period. Actual harvest prices vary with market conditions.

Adoption of the Forestry Reclamation Approach

After much public criticism of the extensive amounts of unused and unproductive mined land being created throughout the Appalachians, the U.S. Office of Surface Mining established the Appalachian Regional Reforestation Initiative (ARRI) in 2004 for the purpose of communicating and encouraging mine reclamation methods that plant more high-value hardwood trees, increase the survival and growth rates of planted trees, and expedite the establishment of forest habitat through natural succession (Angel et al., 2005; ARRI, 2010). ARRI is organized with teams of federal and state regulators, and a science team consisting of reclamation researchers. The ARRI adopted and encouraged the application of the FRA to improve mine soil and forest productivity and to restore forest services including watershed control, water quality, biodiversity, carbon sequestration, and habitat. The ARRI program has achieved modest success: during the past six years about 40 million trees have been planted on 30,000 ha using FRA practices. This represents approximately 15% of the land mined and reclaimed. Based on reported tree planting data (Zipper et al., In review), use of the FRA has leveled off short of expectations, despite evidence showing that use of the FRA is not significantly more costly than reclamation practiced traditionally to produce grassland (Baker

2009), especially when including lower costs for maintaining erosion control structures due to reduced runoff and sedimentation.

The reasons for limited adoption of the FRA are unclear, but it may be a function of the institutional context within which mining and reclamation is done (Zipper, 1987). Reforestation to pre-mining capability is a function of the quality of the post-mining landscape (Fig. 4). The biology and "best management practices" for the FRA are well established by science and experience (Zipper et al., In press), but applying the FRA is voluntary. The cost is not significantly different, but the coal operator has little economic incentive after final bond release given no long-term interest in the PMLU. From an economic perspective, the landowner is most concerned with coal royalties and is unlikely to participate in the permitting process and selection of the PMLU; it is the coal operator's responsibility to meet reclamation standards required by regulations. In many cases the landowners do not appreciate the potential for post mining income through establishment of productive forest land. State and federal regulations do not prevent the use of the FRA in any way, but current interpretations do not require its use even when the pre-mining condition consisted of native forest. Wider adoption of the FRA and restoration of pre-mining forest capability would be enhanced if restored forests were properly categorized as a "higher and better" PMLU than abandoned, unproductive grassland of largely non-native species. Requiring topsoil replacement and a capability standard equivalent to pre-mining forest site index would also enhance biodiversity and forest productivity (capability or yield standards are required for other PMLUs, but no yield or productivity standard is required for forest land). A final institutional constraint for adopting the FRA is little expressed support by leading environmental groups whose primary agenda is restricting surface mining through litigation based on interpretations of the SMCRA in federal and state regulations. Expressed support for better reclamation using the FRA would undermine their position that surface mining causes irreversible damage to terrestrial ecosystems, meaning that restricting surface mining is the only solution.

In any case, restoration of the native forest and all its services, in lieu of other PMLUs that add little or no value to the mined landscape, would appear to be in the best interest of all current stakeholders of this institutional arrangement. This is the case given that recent rulings associated with litigation dealing with disposal of mining spoil in valley streams (Bragg v. Robertson, 72 F. Supp. 2d 642 S.D.W.Va. 1999) have created even higher expectations for good reclamation, especially for mountaintop/valley-fill mining (Palmer et al., 2010). Given current expectations, a sustainable mining and reclamation philosophy and a holistic, ecosystem approach for reclamation is needed to deal with aquatic, terrestrial, and human justice issues associated with surface mining in the eastern U. S. coalfields. Offered below are suggestions for "what" an ecosystem reclamation approach (ERA) would consist of, "how" an ERA could be applied and adopted by all involved, and "why" it may be important for the coal industry to pursue an ERA.

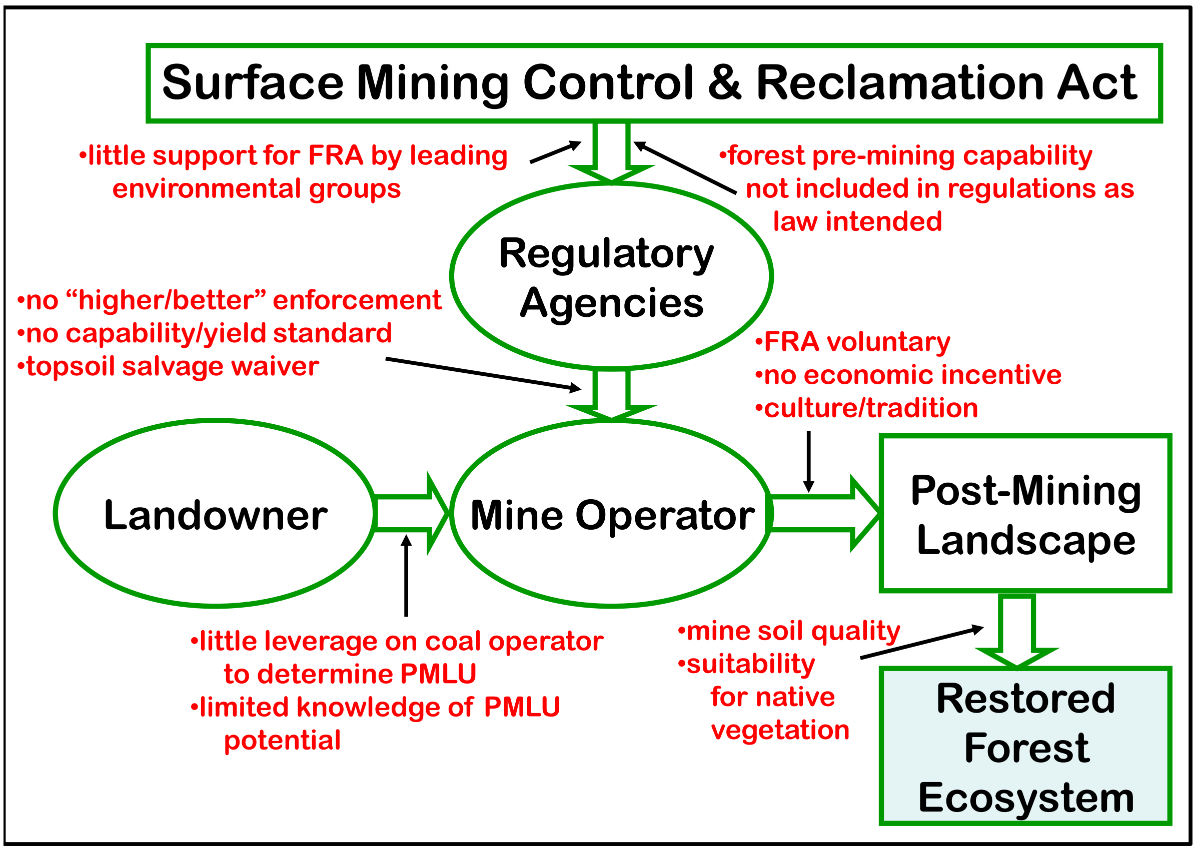

Figure 4. The institutional arrangement for mining and reclamation constraining the adoption or the Forestry Reclamation Approach.

Improved Reclamation Approaches

Mountaintop mining (MTM) has become increasingly common since the early 1990s. Even when constructed to AOC, excess spoil, steep terrain, and large scale of the operations create additional reclamation challenges. Because of the cumulative impacts of MTM on terrestrial, aquatic, and human conditions, citizen groups have been using litigation to challenge the practice, particularly the process of placing excess spoil in valley fills which reportedly violates the SMCRA buffer zone rule and provisions of the Clean Water Act (CWA). Litigation (Bragg v. Robertson, 1999) settlements ultimately led to 1) a multi-agency environmental impact statement (EIS) on the effects of MTM with alternative recommendations for reducing its impacts, and 2) a requirement that OSM revise its stream buffer rules to be consistent with CWA provisions (US EPA 2005). The final programmatic EIS (US EPA, 2005) required multi-agency actions addressing both aquatic and terrestrial impacts. On June 11, 2009, the U.S. Department of the Army, U.S. Department of the Interior, and U.S. Environmental Protection Agency signed a memorandum of understanding implementing the interagency action plan on Appalachian surface coal mining designed to "significantly reduce the harmful environmental consequences of Appalachian surface coal mining operations, while ensuring that future mining remains consistent with federal law" (US EPA, 2009). Impacts identified in the EIS included loss of terrain features, loss of headwater streams, modified hydrologic flow paths, degraded stream water quality, loss of forest and interior forest, reduced nutrient and carbon cycling, reduced soil and forest productivity, loss of required habitat and native biodiversity. In a recent article in the journal *Science*, 12 renowned scientists (Palmer et al., 2010) charged that MTM "… impacts are pervasive and irreversible and that mitigation cannot compensate for losses." They concluded that "MTM permits should not be granted unless new methods----- remedy these problems."

A new method to remedy these problems might include a holistic ecosystem reclamation approach (ERA) that includes the FRA as a component but also includes practices such as geomorphic landscape design, stream restoration, soil building, and techniques for restoring floral and faunal productivity and biodiversity. This approach is consistent with a reclamation model proposed by A. D. Bradshaw (1984) showing reclamation and restoration of ecosystems as a process of returning ecosystem function (y axis: biomass/carbon accumulation, hydrologic function, nutrient cycling, etc.) and structure (x axis: species diversity, habitat, water quality) from a degraded condition towards its original condition (Fig. 5). According to Bradshaw, achieving restoration requires establishing reclaimed mined land conditions that allow balanced restoration of both function and structure, represented by a trajectory within the large dashed arrow in the model. Several alternatives to restoration include neglect (pre-SMCRA), replacement (forest conversions to unused grassland/scrub), and rehabilitation (the forestry reclamation approach) (Fig. 5). Although rehabilitation using the FRA provides the best trajectory of these alternatives, it, too, when used alone, falls short of a level of ecosystem recovery that would likely meet the expectations of the public as expressed in the final programmatic EIS (US EPA, 2005).

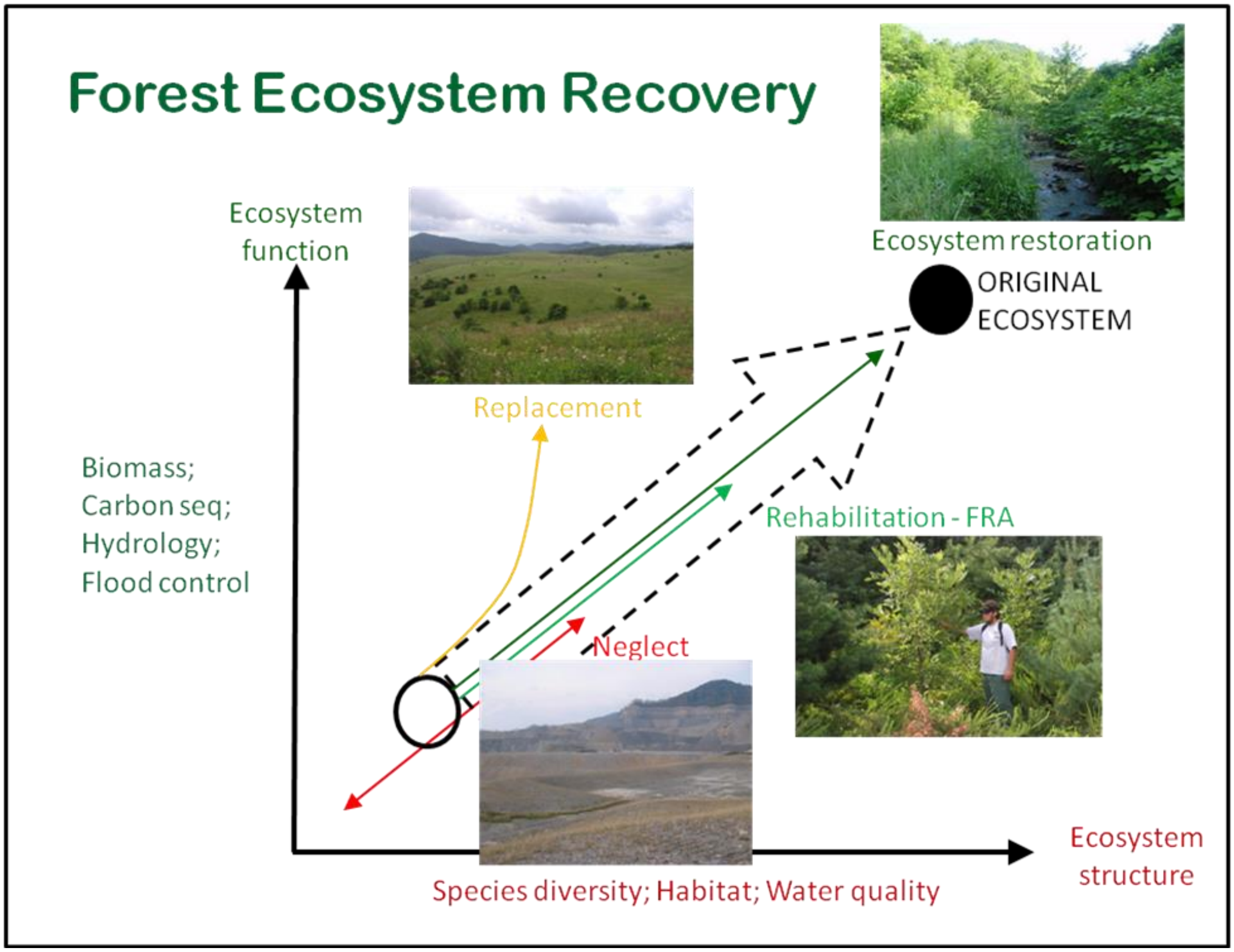

Figure 5. Reclamation alternatives after surface mining in the eastern United States coalfield regions (adapted from Bradshaw, 1984).

An improved approach, an *ecosystem reclamation approach* (ERA) (Fig. 6), might begin with a geomorphic landscape design that would accomplish AOC while creating a landscape that mimics stable, natural, mountain slopes while being cost-effective, attractive, and resistant to surficial erosion and mass wasting (Ayres et al., 2006). Geomorphic designs that mimic natural landforms and drainage patterns and achieve functional and aesthetic characteristics of pre-mined conditions are well established (Schor and Gray, 2007), but not without challenges. Michael et al. (2010) describe constraints to adoption that include regulations that are not supportive of geomorphic methodologies; increases in actual or perceived reclamation costs; and the challenge of constructing new, stable landforms similar to those that existed prior to disturbance. However, they conclude that techniques of landform grading are sound and that they have potential in steep-sloped Appalachia as well as other regions of the U.S.

An ERA would include stream reconstruction based on pre-mining patterns and capacities using a technique known as natural channel design (NCD), which seeks to reconstruct the pools, riffles, and other habitat features of undisturbed streams, with the goal of restoring the ecological functions that were lost due to stream disturbance (Rosgen, 1996; Keystone Stream Team, 2007; Fritz et al., 2010). In the process, backfill materials would be selected and placed to minimize hydrologic contact with materials with high soluble salt levels to minimize total dissolved solids in stream water (Orndorff et al., 2010). Stream water chemistry and other structural and functional components will surely be affected by the new landform and unweathered materials on its surface. Bernhardt and Palmer (2011) point out that NCD has no design provisions for restoring ecological functions. In addition to minimizing dissolved salts in stream water, they argue that biophysical factors such as controls on intensity and duration of sunlight reaching the stream, inputs of organic matter and nitrogen and carbon levels in the soil and streambed must be in place for streams to function biologically. Establishing riparian forest species along reconstructed streams using the FRA should help initiate these processes.

Soil suitability for native, deep-rooted tree species and associated flora and fauna is a function of both quality and depth. Salvaging topsoil, litter layers, seed pools and coarse woody debris and placing these materials on the surface of reclaimed mined sites is critical for re-establishing native biodiversity, restoring soil organic matter and nutrient pools, encouraging further re-colonization of native species, and discouraging exotic, invasive plants (Skousen et al., 2011, these proceedings). To achieve a minimum depth of 1.2 to 1.5 meters for anchoring deep-rooted trees, weathered rock overburden materials, which are the parent materials from which native soils formed, may be removed and mixed with native topsoil in a single strip operation (Burger and Zipper, 2002). This approach accommodates the operational reality of working on steep terrain, salvaging soils of variable depth interspersed with stumps, roots and rocks, and the overall efficiency of a single-trip haul back and end dump for spreading the material on the reclaimed site.

Finally, all steps of the FRA would be incorporated to ensure native forest biodiversity, productivity, and connectivity that would potentially support native wildlife including interior forest species (McComb et al., 1989; Wood et al., 2006; Wickham et al., 2007) (Fig. 6). Surface mine soils would be spread and left un-compacted to encourage water infiltration and rapid establishment of native herbaceous and woody plants for erosion control and soil stability. Different tree and shrub species would be planted on different areas of the site to best accommodate their adaptations for certain slope aspects and positions and water requirements. Riparian species would be used along restored stream channels to facilitate recovery of biologic function (Anderson and Ohmart, 1985).

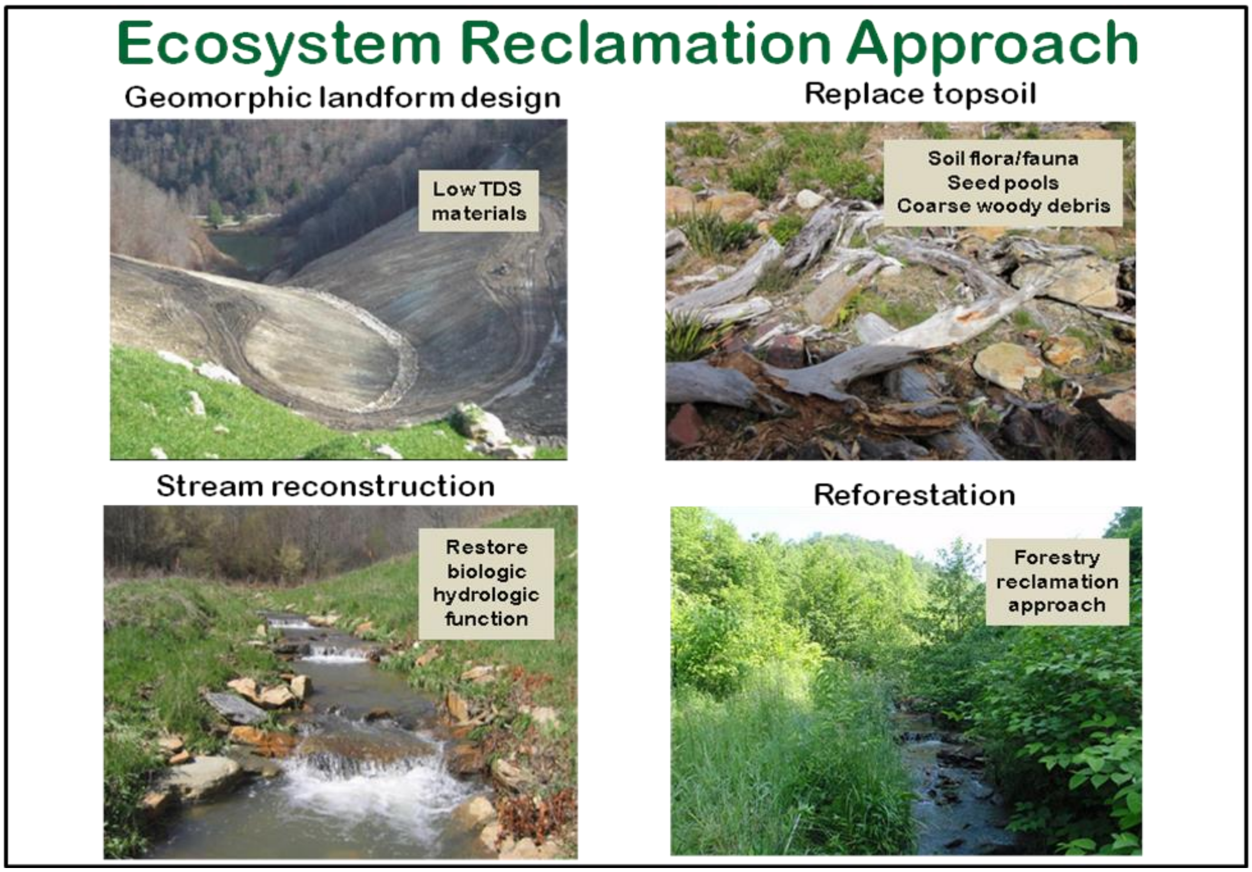

Figure 6. Reclamation steps implementing an ecosystem reclamation approach to restore pre-mining land capability.

Adopting the Ecosystem Reclamation Approach

Compared to traditional reclamation approaches, the ERA may appear complex and difficult to implement. However, all of the practices associated with the steps above are well established in science and practice, but not widely applied together in the Appalachian coalfields. When and if coal operators are compelled or choose to implement an ERA, an iterative process of adaptive management (AM) might be the "how to" for adopting the ERA. AM is often characterized as "learning by doing," but that is an oversimplification. It is learning by doing, but in an organized way that combines ongoing operations with monitoring, research, assessment and training. AM was developed by ecologists at the University of British Columbia and initially applied in fishery management. It is now broadly applied in the natural resource fields and is being adopted by various industries. The U.S. Department of the Interior refined the process for use by all of its agencies (Williams et al., 2009). A good AM process is already in place for adopting the FRA by ARRI and its cooperators; its overall structure is an example that could be emulated for adopting an ERA (Fig. 7).

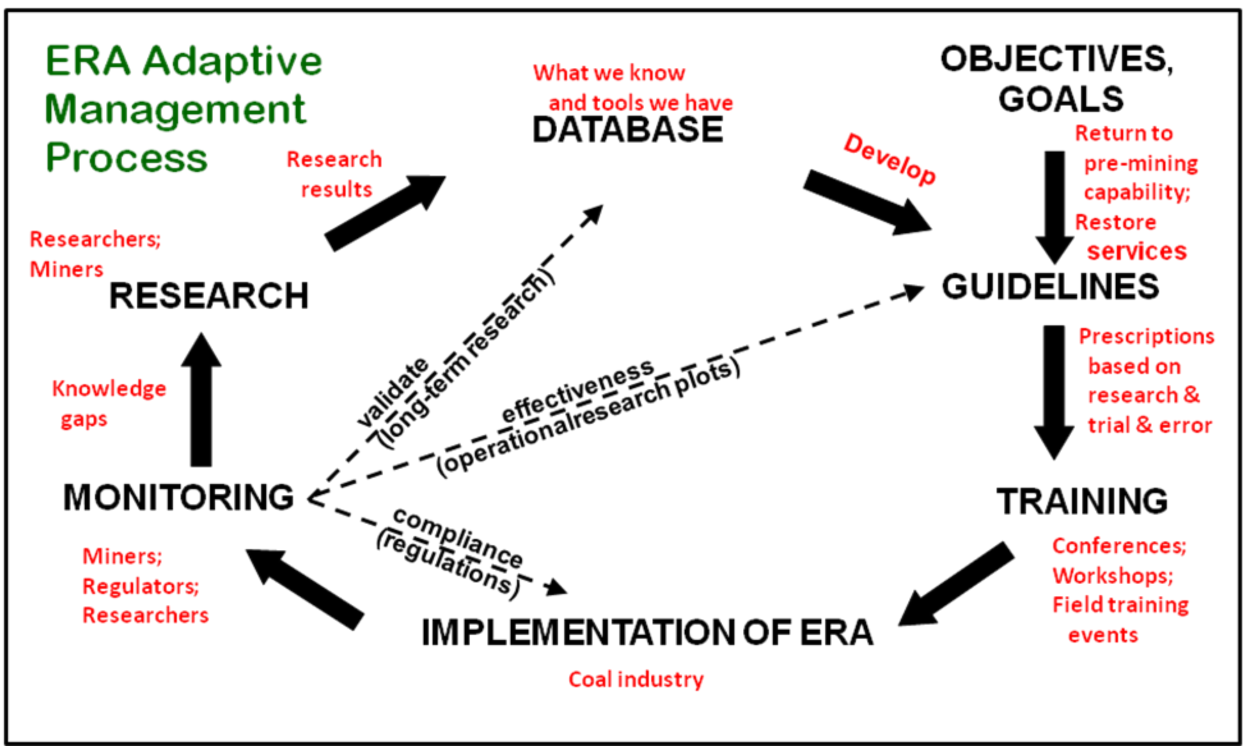

Figure 7. An adaptive management model for adopting an ecosystem reclamation approach for sustainable mined land reclamation.

AM begins with a clear statement of *objectives and goals* (Step 1); for example, "return the land to its pre-mining capability and restore all ecosystem services." With the objectives and goals firmly in mind, the second step is to develop reclamation *guidelines* and procedures by "reaching back" to the *database* of "what we know and tools we have." The database contains all existing knowledge and experience that can be brought to a first version of guidelines. It includes regulations controlling the mining process, practical reclamation experience, baseline information about the site, research results on reclamation processes, and local knowledge of climate, soils, plants and animals and their interactions. Collectively, these guidelines and procedures are called "best reclamation practices." They are "best" in the sense that they are based on a thorough analysis of what we know now, but they may not be adequate without further research to fill knowledge gaps. They will be improved as we increase our knowledge database with an applied, operational research plan. Best practices are always subject to change and improvement.

Step 3 of AM is *training* and *implementation* of the best practices. Training should involve all regulatory and mining personnel. Virtually all mine workers in all areas will affect the reclamation process directly or indirectly; it is important that everyone understands the goal and the process for achieving it. Step 4 entails *monitoring* the reclamation process for compliance, effectiveness, and validation. Compliance is simply a check to see if the best practices were applied. Effectiveness monitoring is a short-term check to see that best practices are working as intended; if not, immediate adjustments in practice can be made. Validation monitoring confirms without doubt that a practice is sound; it is based on long-term statistically-based research and repetitive practice. Mine operators, regulators, and researchers are involved in monitoring at various levels.

To fill the knowledge gaps in the database from which best practices are formulated, applied research is needed (Step 5). *Research* on several steps of the reclamation process can be done on site in conjunction with operational mining, as well as on adjacent sites and remote locations. Research by independent scientists in cooperation with company personnel, using the scientific method of testing multiple alternative hypotheses, with sound experimental designs and peer review, is essential for science-based mining and reclamation. Cooperative research among agencies, the industry, and universities has proven to be cost-effective, operationally feasible, and usually satisfies regulatory and public scrutiny.

AM is much more than simply tracking and changing reclamation direction in the face of a false start. It involves exploring alternative ways to meet reclamation objectives, predicting the outcomes of alternatives based on the current state of knowledge, implementing one or more of these alternatives, monitoring to learn about the impacts of current practices applied, and then using the results to update knowledge and adjust guidelines. Adaptive management focuses on learning and adapting, through partnerships of coal operators, regulators scientists, and other stake-holders who learn together how to reclaim mined land in a sustainable way (Williams et al., 2009).

Sustainable Mining and Reclamation

An immediate, short-term reason *why* the coal industry might be interested in using an ERA was alluded to above. Adopting an ERA might alleviate litigation and imposition of stricter rule interpretations by the US EPA and other federal agencies. A long-term reason for adopting an ERA is to maintain a "social license to operate" (Joyce and Thompson, 2000; Kurlander, 2001). Surface mine reclamation plans contain detailed guidelines for restoring disturbed land to its pre-mining capability and uses; the plan is also a social contract with the company's customers and clientele public that ensures the land will be restored in a manner that will allow it to provide pre-mining ecosystem products and services (land capability). The reclamation plan, along with all other company plans of operation, reflects the company's Sustainable Mining and Reclamation Philosophy.

Operating with a sustainable mining and reclamation philosophy is becoming the rule for corporations involved in extractive and other natural resource industries. In an article in the journal *Resources Policy*, David Humphreys, now chief economist with Rio Tinto, posed the question, "Can the industry afford sustainable development?" He concluded that environmental and social costs have been more than offset by increased industry productivity. There is no conflict between the interests of mining profitability and sustainable development. He concluded that it is possible to create a confluence of interests between improved industry profitability and the provisions of sustainable development, and that this is not really about costs but about the alignment of mining industry's values with those of the societies in which it operates (Humphreys, 2001).

Sustainability is based on the notion that resources be used by current human generations without compromising their availability to future generations (Brundtland Commission, 1987). In the context of the minerals sector, the goal should be the integration of economic activity with environmental integrity and social concerns (triple bottom line) (Fig. 8). There should be ongoing availability of resources and a productive environment and healthy community at both current and former mining sites (Cowell et al., 1999; Mudd, 2010). In the past, mine operations focused primarily on production with little emphasis on environmental or social concerns. With increasingly rigorous environmental legislation controlling mining activities and heightened environmental awareness on the part of the general public and local communities, inclusion of mining activities within the sustainable development paradigm has become essential (Humphreys, 2001; IIED and WBCSD, 2002). In 1999, the program Mining, Minerals and Sustainable Development (MMSD) was initiated globally to develop ways for the mining industry to become sustainable. The International Institute for Environment and Development (IIED) was commissioned to undertake the project working on behalf of the World Business Council for Sustainable Development (WBCSD).

In the final report called *Breaking New Ground* (IIED and WBCSD, 2002), the MMSD group couched sustainable mining and reclamation within the "triple bottom line" used by other industries (Fig. 8). A mine project is sustainable *economically* if the viability of the project is assured, and if the community will be better off as a result; it is sustainable *ecologically* if pre-mining capability is restored and ecosystem services are recovered; and it is sustainable *socially* if people's well-being is maintained or improved. The major organizations representing the mining industry in developed countries have subscribed to sustainability principles and practices. They include the Minerals Council of Australia (http://www.minerals.org.au/environment/ index.html), the European Association of Mining Industries, the Mining Association of Canada, Chile's state-owned CODELCO, and the National Mining Association of the United States. And many individual international mining companies adopted sets of company-specific sustainability guidelines; Barrick (http://www. barrick.com/) and BHP Billiton (2009) (http://www.bhpbilliton.com/bb/ sustainableDevelopment.jsp) are examples and provide models that could be emulated.

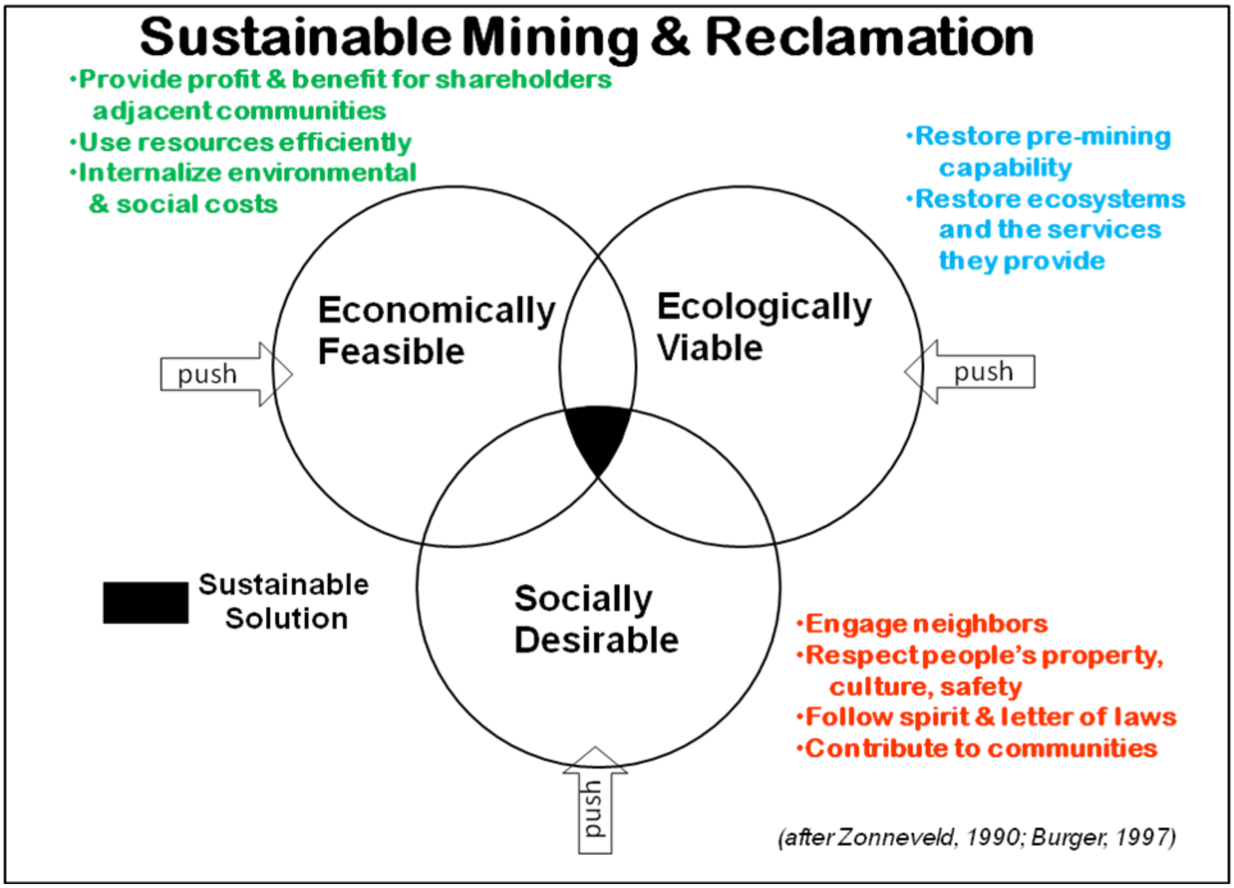

Figure 8. The "triple bottom line" for achieving sustainable mining and reclamation and maintaining a social license to operate.

Summary

The demand for energy throughout the world grows each day, and coal will be needed to meet a large portion of that demand. Coal mining techniques in the Appalachian and Midwestern coalfields of the U. S. have evolved to mine larger land areas and multiple seams at greater depths. New reclamation methods and approaches must also evolve to minimize cumulative impacts on aquatic, terrestrial, and human resources. Mined land reforestation was used here to illustrate the evolution of reclamation approaches over the past 80 years in the eastern coalfields of the U.S. As all stakeholders of the mining and reclamation process appreciate the value of forest ecosystems, there is greater emphasis on ensuring their restoration and proper functioning on reclaimed mined land. A forestry reclamation approach is supplanting a grassland reclamation approach where forests are the logical post mining land use. Restoring forestland capability, native species, and watershed protection are positive outcomes. However, greater public demand for stream protection, water quality, biodiversity, carbon sequestration, native wildlife habitat, and human protection may require a more comprehensive ecosystem reclamation approach. In my view, the components of such an approach already have a good basis in science and could be applied through a process of adaptive management in the event it is needed to help the coal industry maintain its social license to operate.

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