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Technical Progress Report

"Restoring Sustainable Forests on Appalachian Mined Lands for Wood Products, Renewable Energy, Carbon Sequestration, and Other Ecosystem Services"

Quarterly Report

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ABSTRACT

The overall purpose of this project is to evaluate the biological and economic feasibility of restoring high-quality forests on mined land, and to measure carbon sequestration and wood production benefits that would be achieved from forest restoration procedures. We are currently estimating the acreage of lands in VA, WV, KY, OH, and PA mined under SMCRA and reclaimed to non-forested post-mining land uses that are not currently under active management, and therefore can be considered as available for carbon sequestration. To determine actual sequestration under different forest management scenarios, a field study was installed as a 3 x 3 factorial in a random complete block design with three replications at each of three locations, Ohio (Figure 1), West Virginia (Figure 2), and Virginia (Figure 3). The treatments included three forest types (white pine, hybrid poplar, mixed hardwood) and three silvicultural regimes (competition control, competition control plus tillage, competition control plus tillage plus fertilization). Each individual treatment plot is 0.5 acres. Each block of nine plots requires 4.5 acres, and the complete installation at each site requires 13.5 acres. The plots at all three locations have been installed and the plot corners marked with PVC stakes. GPS coordinates of each plot have been collected. Tree survival, height and diameter were measured after the first growing season. There were significant treatment and treatment x site interactions. A STELLA®-based model helped us develop insight as to whether it is possible to differentiate the permanent SOC from the C contained in the labile forms of SOM. The model can be used for predicting the amount of C sequestered on mine lands, and the amount of C that is expected to reside in the mine soil for more than 1,000 years. Based on our work, it appears that substantial carbon payments to landowners would be required to reach “profitability” under present circumstances. However, even though the payments that we examine could generate non-negative LEVs, there is no guarantee that the payments will actually cause landowners to reforest in practice. It is landowner utility associated with forestland profitability that will be the determining factor in actual conversion—utility that likely would include cash flow timing, amenities, and even the credit position of the landowner.

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INTRODUCTION

Public Law 95-87 mandates that mined land be reclaimed in a fashion that renders the land at least as productive after mining as it was before (Torbert et al. 1995). Research has shown that restored forests on mined lands can be equally as or more productive than the native forests removed by mining (Burger and Zipper 2002). Given that most land surface-mined for coal in the Appalachians was originally forested, forestry is a logical land use for most of the reclaimed mined land in the region (Torbert and Burger 1990). However, since implementation of the SMCRA, fewer forests are being restored in the eastern and Midwestern coalfield regions (Burger et al. 1998). In several states, most notably Virginia, the majority of mined land is now being restored to forests. Over eighty percent of Virginia's mined land has been reclaimed to forested post-mining land uses since 1991. However, region-wide, the majority of mined land that was originally forested is not being reclaimed in a way that favors tree establishment, timber production, carbon sequestration, and long-term forest productivity (Torbert and Burger 1990).

We believe that these reclaimed mined lands are producing timber and sequestering carbon at rates far below their potential for reasons that include poor mine soil quality, inadequate stocking of trees, lack of reforestation incentives, and regulatory disincentives for planting trees on previously forested land (Boyce 1999, Burger and Maxey 1998). A number of these problems can be ameliorated simply through intensive silvicultural management. Through established site preparation techniques such as ripping, weed control, fertilizing, and liming, the quality of a given site can be improved. Other management and silvicultural techniques such as site-species matching, correct planting techniques, employing optimal planting densities, post-planting weed control, and thinning can also improve normal development of forest stands, and improve timber production and carbon sequestration.

Similar to the much-debated topic of converting agricultural land to forests, the conversion of reclaimed mined lands to forests carries with it many economic implications. The primary difference between converting agricultural lands to forests and converting reclaimed mined lands to forests is the absence of any obvious extrinsic opportunity cost in the latter scenario; this, of course, assumes that the reclaimed mined land has been abandoned and is not being utilized for any economically beneficial purpose.

A fair amount of research has been conducted regarding the amounts and values of timber produced on reclaimed mined lands. The effect that a carbon market may have on decisions pertaining to the reclamation of mined lands has also been researched. According to previous research, it appears that mined lands are capable of sequestering carbon and producing harvest volumes of equal or greater magnitude to similar non-mined lands. This fact alone, however, does not render afforestation of mined lands economically profitable or feasible in all cases. There is a lack of research pertaining specifically to the conversion of reclaimed mined lands from their current uses to forests and the economic implications of such a land use conversion. Furthermore, the potential for an incentive scheme aimed at promoting the conversion of reclaimed mined lands to forests has yet to be explored in depth.

This study ultimately addresses the potential for increasing carbon sequestration on surface-mined land. The overall research objective of this study is to determine the economic feasibility of carbon sequestration through converting reclaimed mined lands to forests using high-value tree species, and to demonstrate the economic and decision-making implications of an incentive scheme on such a land use conversion.

EXECUTIVE SUMMARY

The purpose of this project is to evaluate the biological and economic feasibility of restoring high-quality forests on abandoned mined land, and to measure carbon sequestration and wood production benefits that would be achieved from forest restoration procedures. The project is based on 14 afforested mined sites varying in age from 20 to 56 years located in a seven-state area of the eastern coalfields, and a new field study which is a 3 x 3 factorial in a random complete block design with three replications at each of three locations: Ohio (Figure 1), West Virginia (Figure 2), and Virginia (Figure 3). The treatments included three forest types (white pine, hybrid poplar, mixed hardwood) and three silvicultural regimes (competition control, competition control plus tillage, competition control plus tillage plus fertilization). Each individual treatment plot is 0.5 acres. Each block of nine plots is 4.5 acres, and the complete installation at each site is 13.5 acres. During this reporting period, all experimental plots at all three sites were assessed for first-year survival, height growth, and diameter growth. These data were analyzed for differences in survival, height growth, and diameter growth among species and treatments. Preliminary classification and inventory criteria and procedures for mined land were developed. We achieved our task of identifying groups of plots with similar soil properties within each plot but differing soil properties between the groups of plots. These criteria are being validated on sites with existing tree stands. Upon validation, the classification criteria will be used to assign forest productivity ratings to each of the experimental plots. A carbon prediction model was built within a dynamic system modeling environment in order to estimate the amount of sequestered C that is permanently stored in the mine soil. We estimated that between 88% and 142% more C will be permanently stored in the passive soil organic matter pool than the C that is predicted to be in the aboveground tree biomass at hardwood harvest age (60 years). Terrestrial carbon markets provide one opportunity for forestry to become a financially viable post-mining land use in the Appalachian coal mining region. For carbon payments to make reforestation financially viable, our results indicate that annual values of up to $5.32 per ton of carbon stored in hardwoods and $9.77 per ton of carbon stored in pines would be required to make reforestation profitable.

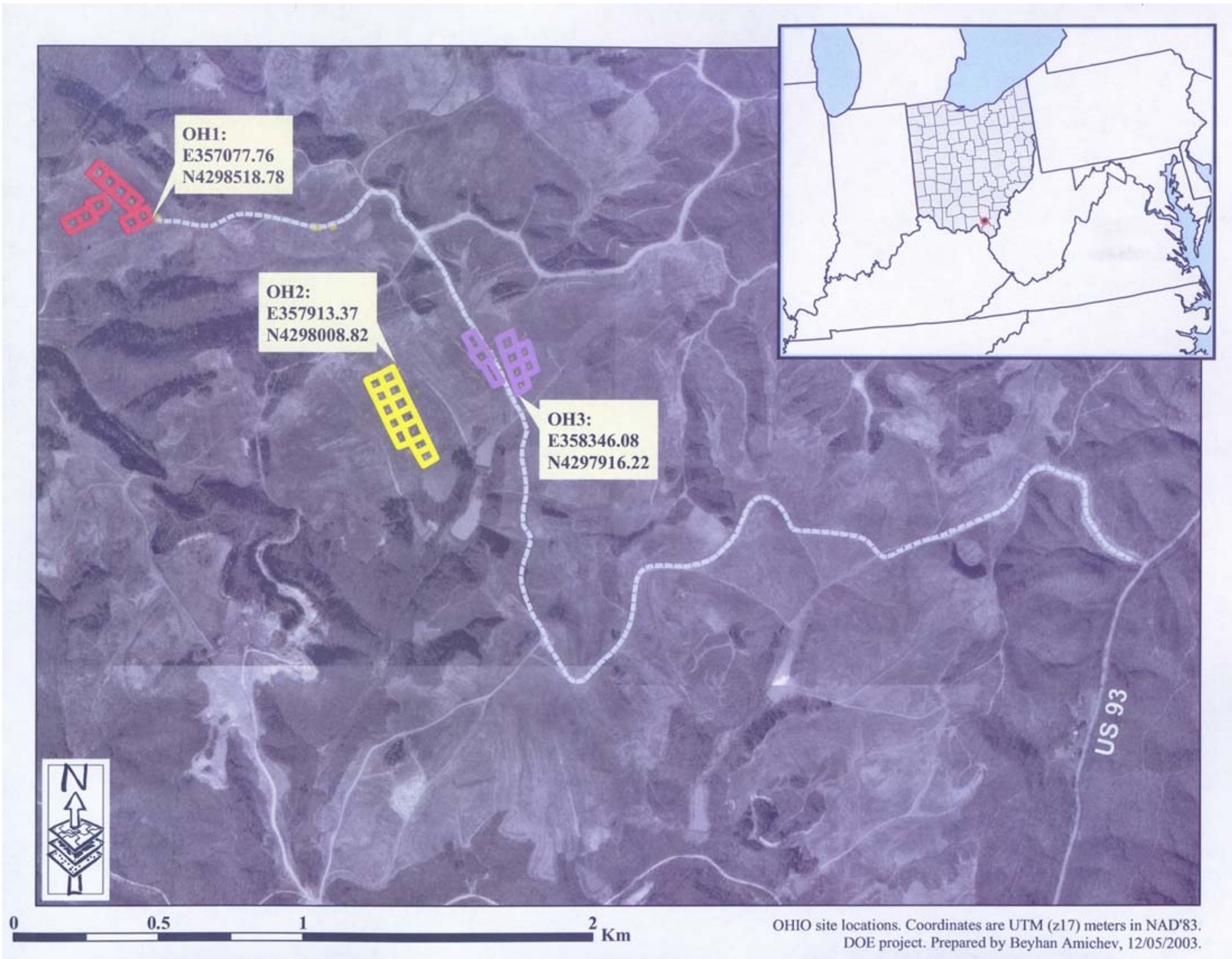

Figure 1. Map of field sites in Lawrence County, Ohio.

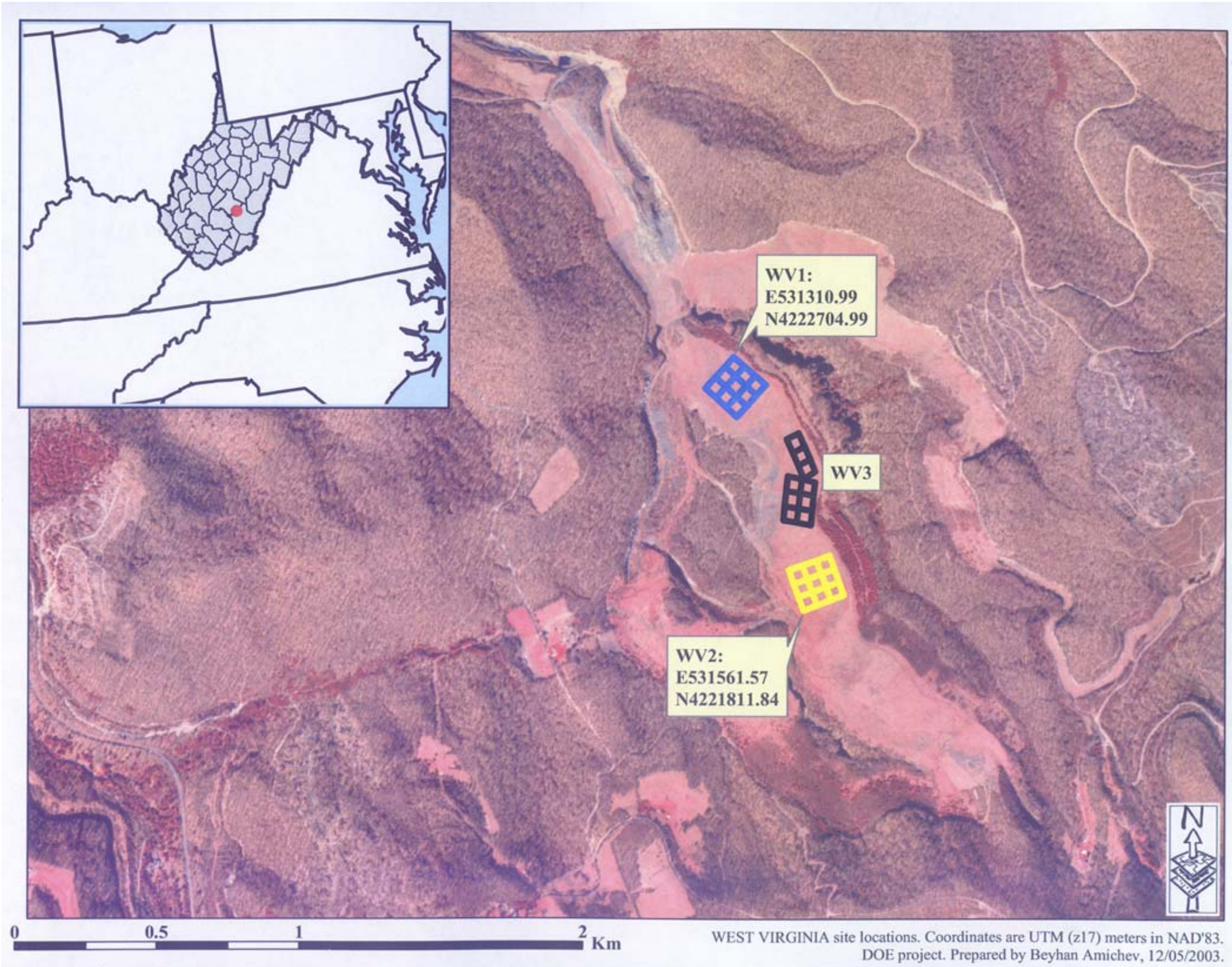

Figure 2. Map of field sites in Nicholas County, West Virginia.

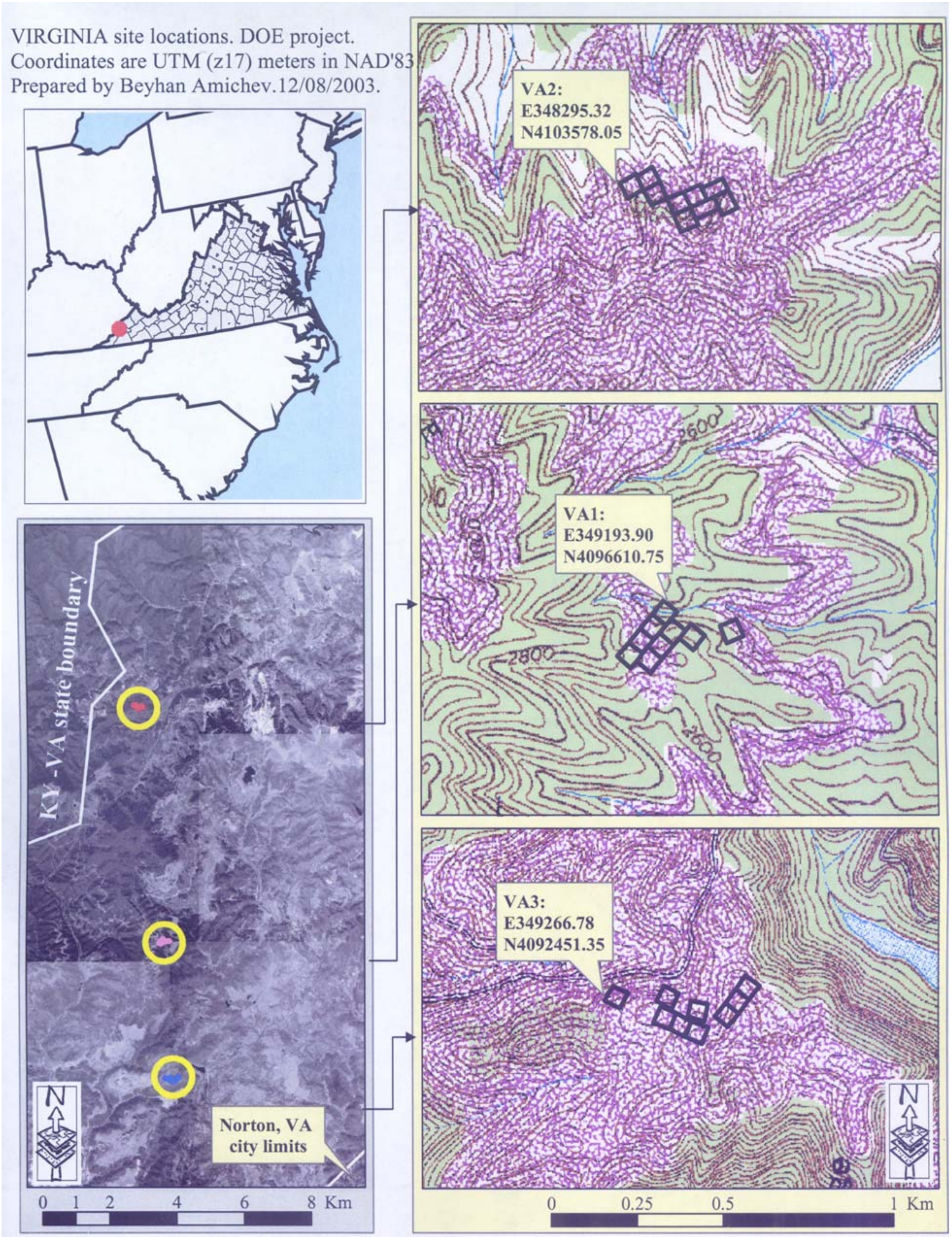

Figure 3. Map of field sites in Wise County, Virginia.

TASK 1: Estimate forest productivity and carbon sequestration potential on mined lands supporting abandoned grasslands. (Burger et al.)

Executive Summary

A carbon prediction model was built within a dynamic system modeling environment in order to estimate the amount of sequestered C that is permanently stored in the mine soil. We estimated that between 88% and 142% more C will be permanently stored in the passive soil organic matter pool than the C that is predicted to be in the aboveground tree biomass at hardwood harvest age (60 years).

Experimental

Because direct measurement of carbon addition and/or loss due to the effect of (i) tree biomass accumulation, (ii) sediment deposition, (iii) soil erosion, (iv) soil organic matter (SOM) decomposition and humification, (v) soil organic carbon (SOC) aggregation and protection), and (vi) soil leaching (Figure 4) is often a tedious and very costly task, and also because direct measurements are very likely to produce greatly varying results across the mined site and down the profile, we decided to develop a dynamic model incorporating these processes to best represent the complexity between all ecosystem components within the complex mined land dynamic system. We built a dynamic system model using the features of the STELLA® (High Performance Systems, Inc.) modeling software in order to describe and account for the processes affecting the rates of carbon sequestration and SOM decomposition on minelands. The processes included in our model follow the conceptual design of the CENTURY (Parton and Rassmusen 1994) model which divides the SOC pool into three pools according to the relative turnover times of the organic components within the respective carbon pools. In general, the processes that directly regulate the amount and distribution of terrestrial carbon between the different ecosystem components can be combined into three groups (Figure 4):

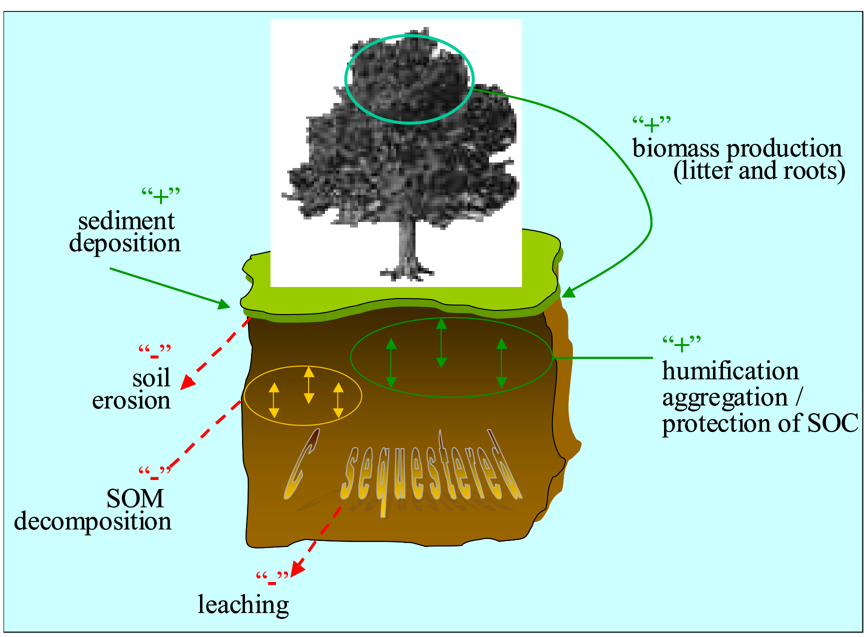

Figure 4. Schematic representation of the ecosystem processes considered to affect the amount of carbon sequestered on mined lands.

- C input (biomass production and sediment deposition)
- Chemical transformation of organic components (humification of SOM; protection of SOC)
- C loss (soil erosion and intersystem leaching)

All processes depicted in Figure 4, with the exception of (iii) and (iv), were modeled with adequate precision and accuracy based on our assessment of the mine soil properties and the mineland productivity and inferred from published information from the recent literature, such as forest biomass allocation to roots by tree species (Jenkins et al. 2003) and SOM decomposition rates (Fisher and Binkley 2000). Each model component, rate of SOM decomposition and leaching to mention a few, was modeled as a function of one or more basic mine soil properties that were readily and accurately measurable and that have been documented to affect the process at hand. The tree biomass in roots and litter was estimated from C-prediction models on minelands as function of site index (SI) and stand age that were described in detail in our previous reports.

The mine soil properties that were used to predict the trend of each model component were pH, mine soil age, mine soil texture (projected into the future as a function of rock type and age), soil moisture, C/N ratio of the SOM, and soil temperature (inferred from climate data) (Figure 5). An emphasis was set on those site/soil conditions that modified the soil fauna type and the extent of microbial activity in the mine soil. The microbial component in the mine soil was hypothesized to be the key factor for SOM decomposition and ecosystem nutrient cycling.

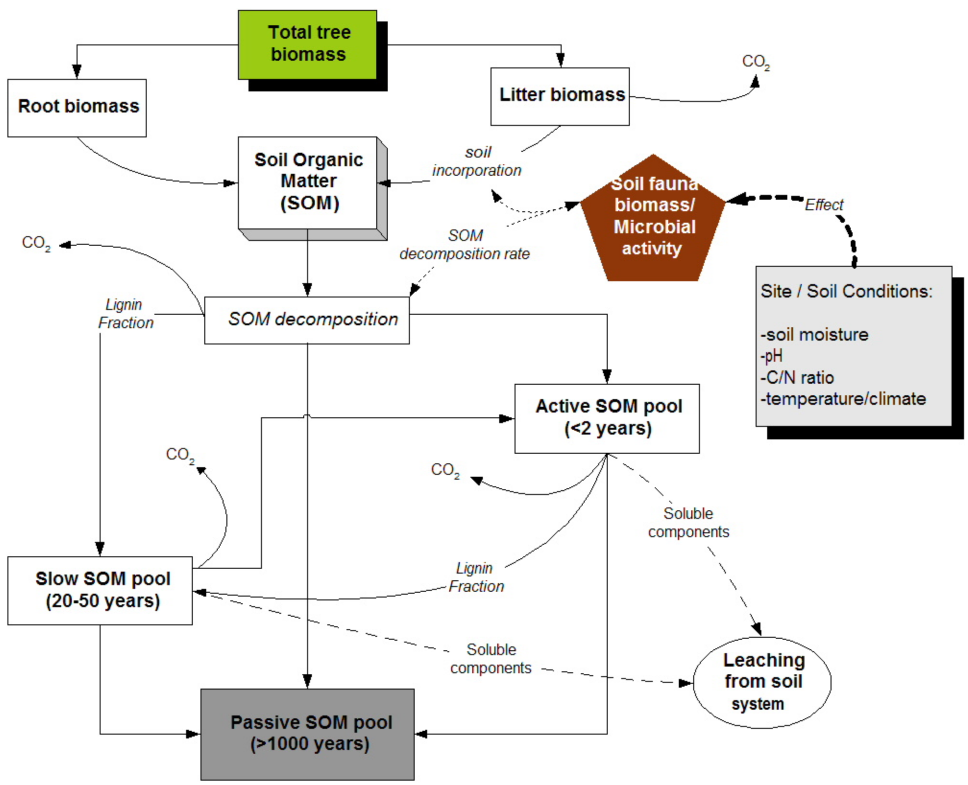

Figure 5. Model components for soil organic matter pools and processes modeled in a dynamic system modeling environment, STELLA®, to predict the amount and distribution among ecosystem components of the C sequestered on minelands.

Results and Discussion

Due to limitations regarding sediment deposition and surface runoff data for our study sites, the use of the current C sequestration model will be limited by the assumption that there are no significant additions and/or losses of soil carbon to and from the mine soil due to sediment runoff. However, if sufficient surface sediment runoff data becomes available, then the respective results will be incorporated into the current C prediction model.

The question that we addressed by creating the current C-prediction model in Figure 5 was, "How much of the C sequestered on mined lands can be regarded as permanently stored C in mined land ecosystems?" According to the CENTURY model, the SOM can be divided into three pools – active, slow, and passive – the respective turnover times of which are less than 2 years, between 20 and 50 years, and greater than 1,000 years (Figure 5). For all practical purposes, we considered the C in the passive SOM pool to be permanently stored in the mined land ecosystem.

The results from the model indicate that significant accumulations of permanent SOC, the C in the passive SOM pool, for a typical pre-SMCRA mined land occurred after stand age 35 years compared to age 30 for undisturbed forests (Figure 6). The rates of permanent SOC varied from 8.4 to 12.3 Mg ha^{-1} yr^{-1} depending on mine soil quality (Figure 7).

The C-prediction results indicate that significant amounts of organic matter start accumulating in the active SOM after age 27 on mined land ecosystems. A possible explanation of the lag period of no C accumulation in the mine soil from time of planting untill age 27 is that, depending on mine soil quality, an average of 20 to 50 years is needed for favorable mine soil properties to develop such that vigorous soil microbial communities can be sustained in the mine soil.

Under the cumulative effect of the soil forming processes, between two and five decades of rock weathering and mine soil transformation are necessary for weakly developed B_w subsurface soil horizons to begin forming, thus providing for improved water holding capacity, air-water balance, and organic matter incorporation in the mine soil via tree root growth and turnover. As a result of the improved soil conditions, microbial communities begin to dominate the soil system and promote the accumulation of permanent SOC within the passive SOM pool.

It is critical to note that the rock type mixture and the reclamation quality are of significant importance to the amount of time needed for proper mine soil properties to develop. For example, the graphs in Figure 6 show that about 20 years were required for the active SOM pool to reach a peak, compared to only 10 years on undisturbed forests.

Furthermore, a successful reclamation and reforestation operation will not only shorten the time period for mine soils to develop faster, but also will sustain better tree growth, thus increasing the C sequestration potential of the mined land. We estimated that between 88% and 142% more C will be permanently stored in the passive SOM pool than the C that is predicted to be in the aboveground tree biomass at hardwood harvest age (60 years) (Figure 6). The effect of SI was found to be exponentially related to the amount of permanent C stored in the mine soil (Figure 7).

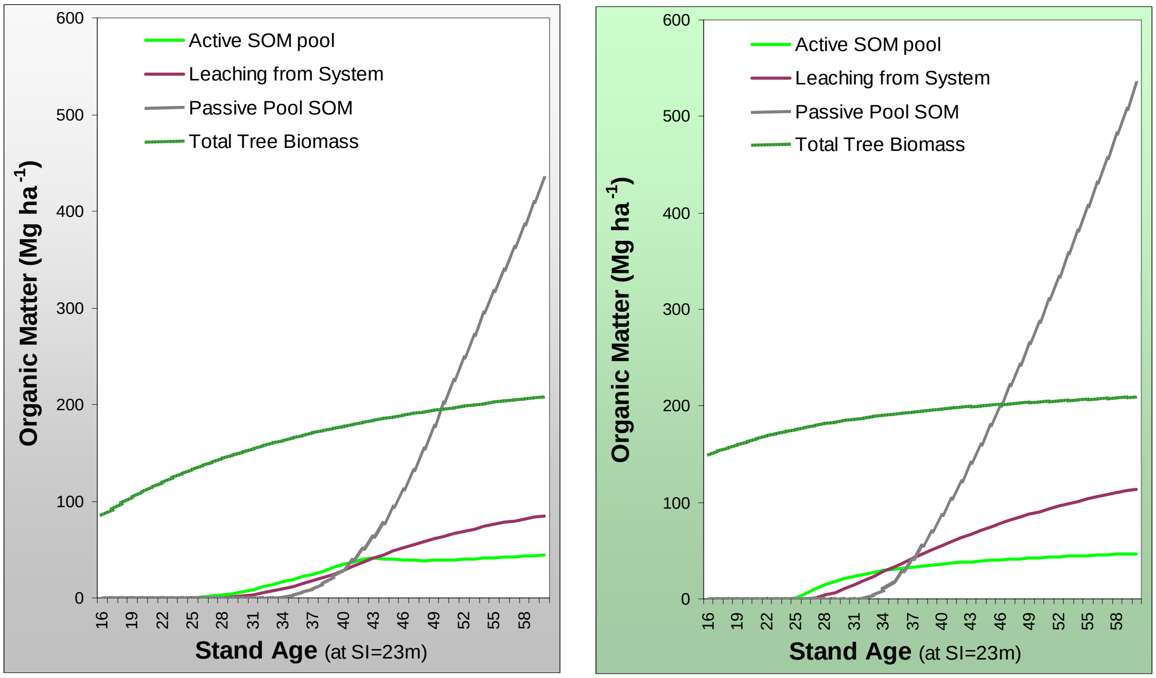

Figure 6. Results for organic matter accumulation as active and passive SOM pools and total tree biomass and for SOM loss via leaching predicted with a STELLA®-based model for minelands (left) **and for undisturbed forests** (right) **as a function of stand age. The graphed results are for minelands and undisturbed forests of equal site productivity represented by a SI of 23 m.**

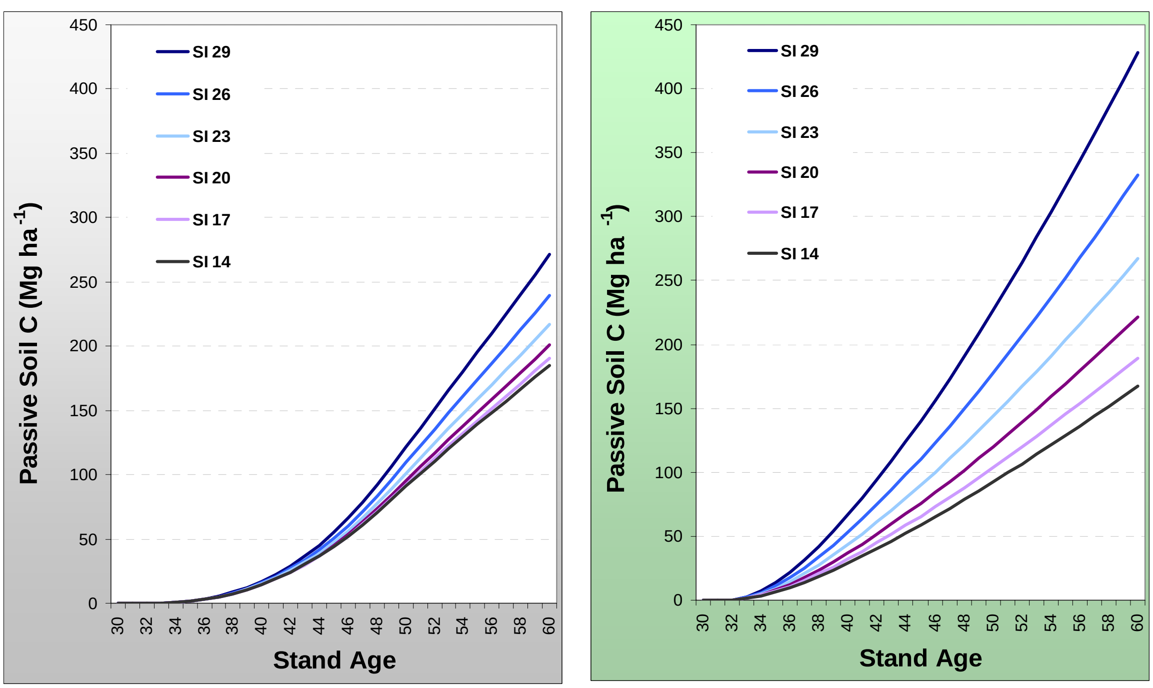

Figure 7. Permanent SOC stored in mine soils (left) **and undisturbed forest soils** (right) **as a function of stand age and SI.**

Conclusions

The proposed STELLA®-based model helped us develop insight as to whether it is possible to differentiate the permanent SOC from the C contained in the labile forms of SOM, whether modeling in a dynamic system environment can be used for predicting the amount of C sequestered on mine lands, and the amount of C that is expected to reside in the mine soil for more than 1,000 years. We are confident that the proposed modeling approach is adequate for the intended tasks.

More information, including surface runoff data, are needed in order to thoroughly describe the complete C cycle within a mined land ecosystem as depicted in Figure 4. We will focus on researching more information about the rates of CO_2 efflux both as root respiration and as a by-product from the microbial degradation of SOM, biomass allocation to roots, and SOM decomposition by tree species, and the correlation of these rates with SI and forest stand age.

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Jenkins, J. C., D. C. Chojnacky, L. H. Heath, and R. A. Birdsey. 2003. National-scale biomass estimators for United States tree species. *Forest Science* 49(1):12-35.

Parton, W. J., and P. E. Rasmussen. 1994. Long-term effects of crop management in wheat/fallow: II. CENTURY model simulations. *Soil Science Society of America Journal* 58:530-536.

STELLA® Research Software, Version 7.0.2. High Performance Systems, Inc.: The Systems Thinking Company™, Lebanon, NH.

TASK 2: Develop classification and inventory criteria and procedures for mined land. (Galbraith et al.)

Executive Summary

During the reporting period (July-September 2004), we have continued a literature search about classification criteria for reforestation on mine soils, and continued lab analysis on field samples collected in earlier reporting periods. A classification scheme has been developed and some field testing of the methods of implementation has begun.

Experimental

During the reporting period (July-September 2004), we have continued lab analysis as performed on previously collected samples. Lab analysis was conducted using the same materials and methods as described in the previous reporting period, and is nearly complete.

Results and Discussion

No new information has been gathered, although analyses of previously collected data are continuing. No new results were obtained during the July-September 2004 reporting period.

Conclusion

The classification scheme has been produced for softwoods (white pine), and validation points are being collected. Revisions of the point system and classification criteria will lead to accurate methods of classifying post-SMCRA abandoned mined lands into productivity classes for white pine. There were not enough existing stands of hardwoods to conduct testing for that group.

References

The references for the literature review will be updated continuously during the study. No new references have been added since the previous reporting period.

TASK 3: Develop reforestation methods and procedures for mined land. (Fox et al.)

Executive Summary

All experimental plots at all three sites were assessed for first-year survival, height growth, and diameter growth. These data were analyzed for differences in survival, height growth, and diameter growth among species and treatments. Deer fences at the sites in Ohio and West Virginia were maintained.

Experimental

There are three separate field locations in the study. The first site is located in Lawrence County, Ohio, on land owned by the Nature Conservancy. This site was previously owned by MeadWestvaco Corporation. The second site is located in Nicholas County, West Virginia, on land owned by Plum Creek Timber Company. The third site is located in Wise County, Virginia, on land owned by PennVirginia Company.

The study was installed and analyzed as a 3 x 3 factorial in a random complete block design with three replications at each location. There were three forest types established consisting of: (1) white pine (WP); (2) hybrid poplar (HP); and (3) a native hardwood mix. The three levels of silvicultural input applied to each forest type were: (1)competition control only (CC); (2) competition control and tillage (CC+T); and (3)competition control, tillage, and fertilization (CC+T+F).

The data on hardwood survival and growth data were split into three separate species groups for analysis. The first group comprised timber species that were planted at all three sites. The second group was shrub species planted to increase stand diversity. The third group was other timber species tailored to native forest surrounding each site (Table 1). These species groups were compared with each other as well as with the white pine and hybrid poplar forest types for differences in survival and growth parameters.

Table 1. Hardwood species groups for sites in Lawrence County, OH, Nicholas County, WV, and Wise County, VA.

	Common Timber	Shrub	Other Timber
Ohio	**Quercus rubra**	*Cercis canadensis*	*Quercus prinus*
	Acer saccharum	*Cornus florida*	*Carya cordiformis*
	Liriodendron tulipifera	*Crataegus spp.*	*Quercus velutina*
			Quercus coccinea
West Virginia	**Quercus rubra**	*Cercis canadensis*	*Acer rubrum*
	Acer saccharum	*Cornus florida*	*Fraxinus americana*
	Liriodendron tulipifera	*Crataegus spp.*	
Virginia	**Quercus rubra**	*Cercis canadensis*	*Quercus alba*
	Acer saccharum	*Cornus florida*	*Fraxinus americana*
	Liriodendron tulipifera	*Crataegus spp.*	*Carya cordiformis*

Survival data were arcsine transformed prior to statistical analysis to accurately perform mean separation procedures. Similarly, growth data were transformed using the natural logarithm when the variance of the data was found to be functionally related to the treatment means to accurately perform mean separations. Values reported in tables are plot means without any transformation.

Results and Discussion

The sites in Ohio and Virginia had no species by treatment interaction and as a result, only the main effect means were compared (Table 2).

Table 2. Average survival percentage for research sites in Lawrence County, OH, Nicholas County, WV, and Wise County, VA, by treatment and species group.

		Species Group					Treatment
Site	Treatment	HP	WP	Timber	Shrub	Other	Mean
Ohio	WC	49	46	67	47	64	52x**y
	WC+T	46	29	64	62	84	50y
	WC+T+F	16	6	14	0	25	13z
	Species Mean	37a*b	26a	43ab	48ab	58b	39
West Virginia	WC	33ax	41ab	71bcx	80cx	87c	51
	WC+T	62ay	50a	92by	94bxy	96b	69
	WC+T+F	27ax	33a	67bx	34az	85c	42
	Species Mean	41	41	78	71	89	54
Virginia	WC	78	55	74	69	93	71x
	WC+T	70	71	84	88	96	77x
	WC+T+F	69	50	84	75	88	67x
	Species Mean	72ab	59a	81bc	77abc	92c	72

*a, b, c – For each site, values within rows with the same letter are not significantly different at the 5% level using Tukey's mean separation procedure.

**x, y, z – For each site, values within columns with the same letter are not significantly different at the 5% level using Tukey's mean separation procedure.

Average height growth and diameter growth for all sites had significant species by treatment interactions, and mean separations were done for the simple effects only (Tables 3 and 4).

Conclusions

None to date. Data analysis is still in progress.

References

None.

Table 3. Average height growth (cm) for research sites in Lawrence County, OH, Nicholas County, WV, and Wise County, VA, by treatment and species group.

Site	Treatment	Species Group					Treatment Mean
		HP	WP	Timber	Shrub	Other	
Ohio	WC	33.1a*x**	5.3b	-1.3c	1.7bc	-0.9c	12.4
	WC+T	56.5ay	5.7b	-9.1c	2.9b	-3.5b	15.2
	WC+T+F	68.3ay	6.9b	-0.5b	-	-3.6b	26.7
	Species Mean	47.1	5.6	-4.3	2.4	-2.7	15.3
West Virginia	WC	22.3ax	5.5bx	-5.1cx	-1.4bc	3.0bx	1.2
	WC+T	60.0ay	9.2by	0.1cy	4.8bc	6.7bcx	3.0
	WC+T+F	57.7ay	5.8bxy	2.6by	8.9b	11.1by	2.9
	Species Mean	50.8	7.1	-0.8	3.2	7.3	16.4
Virginia	WC	40.7ax	5.6b	1.8b	7.3bx	2.8bx	2.2
	WC+T	66.1ay	6.0b	0.4c	9.9bxy	3.7bcxy	3.0
	WC+T+F	126.2az	5.4b	2.4b	19.4cy	7.4by	5.8
	Species Mean	122.6	5.7	1.5	11.6	4.6	45.9

*a, b, c – For each site, values within rows with the same letter are not significantly different at the 5% level using Tukey's mean separation procedure.

**x, y, z – For each site, values within columns with the same letter are not significantly different at the 5% level using Tukey's mean separation procedure.

Table 4. Average diameter growth (mm) for research sites in Lawrence County, OH, Nicholas County, WV, and Wise County, VA, by treatment and species group.

Site	Treatment	Species Group					Treatment Mean
		HP	WP	Timber	Shrub	Other	
Ohio	WC	3.9a*x**	1.0bx	0.9b	1.6b	0.7b	2.0
	WC+T	6.0ay	0.4by	0.9b	1.3b	0.6b	2.2
	WC+T+F	9.7az	0.7bxy	0.2b	-	0.3b	4.0
	Species Mean	5.5	0.6	1.4	0.8	0.7	2.3
West Virginia	WC	3.1ax	0.4bx	0.3bcx	1.2b	1.3bx	1.2
	WC+T	7.0ay	0.7bxy	1.1by	1.1b	1.9cxy	3.0
	WC+T+F	7.6ay	0.9by	1.2by	1.3bc	2.4cy	2.9
	Species Mean	6.2	0.7	0.9	1.2	1.9	2.4
Virginia	WC	4.9ax	0.6b	0.7bc	1.5cx	0.6bx	2.2
	WC+T	7.1ay	0.6b	1.2bc	2.0cxy	1.2bx	3.0
	WC+T+F	13.8az	0.7b	1.3b	2.8cy	2.6cy	5.8
	Species Mean	8.6	0.6	1.1	2.0	1.4	3.6

*a, b, c – For each site, values within rows with the same letter are not significantly different at the 5% level using Tukey's mean separation procedure.

**x, y, z – For each site, values within columns with the same letter are not significantly different at the 5% level using Tukey's mean separation procedure.

TASK 4: Conduct economic analyses of reforestation and forest management activites for carbon sequestration and a variety of forest products and services. (Amacher and Sullivan)

Executive Summary

Terrestrial carbon markets provide one opportunity for forestry to become a financially viable post-mining land use in the Appalachian coal mining region. This quarter, emphasis of Task 4 focused on the carbon values that would be required for profitability, using land expectation value as the profitability criterion. For carbon payments to make reforestation financially viable, our results indicate that annual values of up to \$5.32 per ton of carbon stored in hardwoods and \$9.77 per ton of carbon stored in pines would be required to make reforestation profitable.

Experimental

Land expectation value (LEV) has previously been calculated under Task 4 for three silvicultural options on five site classes of reclaimed mine lands that address incompatible ground cover, soil compaction, and site productivity. In addition, the burden that forest landowners bear when they have to pay the costs of returning the land to a forested condition has been considered. We also examined potential policy instruments for alleviating landowner burden of reforesting reclaimed mine lands that include lump-sum and annual payments to encourage landowners to reforest. In the preceding quarter, we extended our analysis of potential policy instruments to include payments to landowners for carbon produced and stored on reclaimed mine lands through reforestation.

Once again, recall that our analysis is based on an idealized model of forest landowner who is facing the decision to reforest previously mined land that was reclaimed into grass cover.[1] Suppose that in the absence of a reforestation option, the landowner possesses an *indirect* utility function given by:

$$V(r, I, L_0) = V[r(L_0), I] + \phi(L_0) \tag{1}$$

where $V()$ is indirect utility, r is the revenue generated from the property (which could be considered land rents, and consequently include the market value of the land), I is exogenous landowner income, L_0 is the current condition of the property, Φ measures non-market benefits (utility) derived from owning the land. The utility function indicates that land condition may be important to utility in multiple ways, including financial returns (first term on the RHS) and amenities that the landowner derives from the condition of the land (second term on the RHS). Moreover, each component of the indirect utility function could without loss be expressed as a stream of rents generated from using the land from grazing or hunting, or production of non-market benefits. That is, we could define discounted annual revenues and non-market benefits from the reclaimed land as follows:

[1] Owners of reclaimed mine lands are quite diverse, including mine operators, land-holding companies, and small private owners. Our representative landowner model is intended to be only a generalized depiction, and all elements of the model may not be applicable to a given owner.

$$r(L_0) = \int_0^{\infty} a[L_0(z)]e^{-iz}dz; \qquad \phi(L_0) = \int_0^{\infty} b[L_0(z)]e^{-iz}dz \tag{2}$$

where i is the interest rate, $a(.)$ are annual revenues generated from the land (perhaps grazing or hunting leases), $b(.)$ are non-market benefits derived from owning land each period, z is a variable of integration representing time periods $1,\dots t$, and $L_0(z)$ is land condition at each point in time.

Suppose now the landowner represented by (1) is offered the opportunity to reforest previously mined land that was reclaimed into grass cover. Not only will the reforestation provide potential harvest revenues when the timber matures, but the stream of non-market benefits may also be different than those identified in (2) above. Thus, the new indirect utility function can be written:

$$V(r, I, L_f) = V[r(L_f), I] + \phi(L_f) \tag{3}$$

where L_f is the condition of the land after reforestation, and discounted revenues and non-market benefits are calculated as follows:

$$r(L_f) = \frac{pQ_f(t)e^{-it} - c_f e^{it}}{(1 - e^{-it})} - c_0 + \int_0^{\infty} a[L_f(z)]e^{-iz}dz \tag{4}$$

and

$$\phi(L_f) = \int_0^{\infty} b[L_f(z)]e^{-iz}dz \tag{5}$$

where p is the unit price of timber, Q_f is the volume of timber produced from reforested land at age t, c_f is regular reforestation costs after timber harvest, and c_0 is initial reforestation costs incurred when converting grassland into forest[2].

Reforestation of the reclaimed land involves a welfare improvement only if:

$$\begin{aligned} &V(r, I, L_f) > V(r, I, L_0) \Leftrightarrow \\ &V[r(L_f), I] - V[r(L_0), I] + \phi(L_f) - \phi(L_0) > 0 \end{aligned} \tag{6}$$

or

[2] Note that this representation of the problem is slightly simplified for presentation, depicting reforestation cost as a single, one-time expense. In actuality, there may be multiple costs associated with site conversion (especially the control of established, competing vegetation) that occur over the first few years of initial forest stand establishment, which we address in our empirical analysis.

$$V\left[\frac{pQ_f(t)e^{-it}-c_f e^{it}}{(1-e^{-it})}-c_0+\int_0^\infty a[L_f(z)]e^{-iz}dz, I\right]-V\left[\int_0^\infty a[L_0(z)]e^{-iz}dz, I\right]$$

$$+\int_0^\infty b[L_f(z)]e^{-iz}dz-\int_0^\infty b[L_0(z)]e^{-iz}dz>0 \tag{7}$$

Net discounted revenues of timber harvesting in this calculation could be positive or negative, depending on conversion and regular reforestation costs, prices, interest rates and timber volumes produced. Annual revenues and non-market benefits may differ from pre-reforestation values, due to differing land attributes (L_f v. L_0), though it is difficult to imagine these annual values not increasing when the land is reforested. It should be noted that a major component of our calculation is the conversion cost c_0 in (4) and (7) above. This undiscounted cost must be paid up front, at the time of reforestation, without any offsetting revenues until the timber reaches maturity in *t* years. Hence, it is likely to play a major role in determining landowner welfare and, ultimately, the likelihood of reforestation occurring.

A potential market opportunity that can make conversion from grasslands to forests financially viable is revenue that could be provided through payments made to landowners for the carbon that is sequestered on these lands, which we examine using our landowner decision framework above. Extensive study has been directed toward the question of the cost of sequestering carbon through forest establishment in a variety of land-use situations, though not directly on previously reclaimed mine lands (examples include Moulton and Richards 1990, Adams et al. 1993, Hoen and Solberg 1994, Parks and Hardie 1995, Sedjo et al. 1995, Plantinga et al. 1999, and van Kooten et al. 2000). In the context of our study, rather than asking how much it would cost to sequester carbon on reclaimed mine lands, we ask how much carbon would have to be worth to make forest conversion viable. As before, we consider both the payment for carbon that would be required for a minimal level of profitability of forestry on these lands (LEV ≥ 0), and the payment required to provide a full reimbursement of the costs of reestablishing forests.

To determine the level of carbon payment required for a minimal level of profitability from forestry, we set the LEV of forestry plus carbon production equal to zero, and solve for s_c in:

$$r(L_f)=\frac{pQ_f(t)e^{-it}-c_f e^{it}}{(1-e^{-it})}-c_0+s_c\int_0^\infty x(z)e^{-iz}dz=0 \tag{8}$$

where $x(z)$ is the level of carbon produced on the forested site, which is a function of the volume of timber on the site at a given time plus carbon sequestered in the soil.

Similarly, to determine the level of payment for carbon that would provide for a full reimbursement of reforestation costs, LEV of forestry plus carbon are set equal to the LEV of forestry without conversion costs, and s_c' is computed in:

$$
r(L_f) = \frac{pQ_f(t)e^{-it} - c_f e^{it}}{(1-e^{-it})} - c_0 + s_c' \int_0^{\infty} x(z)e^{-iz}dz = \frac{pQ_f(t)e^{-it} - c_f e^{it}}{(1-e^{-it})}
$$

or (9)

$$
s_c' \int_0^{\infty} x(z)e^{-iz}dz = c_0
$$

Conversions from timber volume to total carbon content ($x(z)$) in equations (8) and (9) are based on the conversion factors used by van Kooten et al. (2000). This conversion process involves estimating total above-ground biomass and root biomass using a set of hardwood- and softwood-specific biomass factors, and then converting total biomass to carbon content. Given the difficulty of assessing soil carbon sequestration rates over the life of a stand, and across rotations, we focus on the carbon held in standing timber and the roots.

Results and Discussion

Calculated carbon payments required for a minimal level of profitability (Table 5) range from $0 per ton per year in white pine plantations with low to moderate interest rates and moderate to high productivity levels (where LEVs already are greater than zero), to $9.77 per ton per year for white pines in situations with a high interest rate and low productivity. Interestingly, neither forest type (white pine or mixed hardwoods) shows uniform dominance over the other in terms of requiring the lowest (or highest) carbon payment. On poor-quality sites, required carbon payments are higher for white pines than for mixed hardwoods, whereas on higher-quality sites, required carbon payments to achieve minimal profitability are lower for white pine. These findings are a consequence of differing relative growth rates between pines and hardwoods (which are dependent upon site quality), and rotation length (where hardwoods carry higher volumes of timber and carbon longer before starting the next rotation).

Carbon payments required for full reimbursement of conversion costs (Table 6) are somewhat higher than those required for providing minimal profitability, ranging from under $1 per ton per year for mixed hardwoods on high-quality sites with a low interest rate to almost $11 per ton per year for white pines grown on poor-quality sites in situations with high alternative rates of return. In this case, the required carbon payments for mixed hardwoods are uniformly lower that those found for white pines. The greater gap between the LEV when the landowner pays site conversion costs and the LEV when the mine operator pays the costs is apparently better mitigated by holding carbon volumes over a greater length of time, as occurs with the mixed hardwood scenarios.

Table 5. Annual payment required per ton of carbon stored on-site to allow minimal profitability (LEV ≥ 0) for landowner of reclaimed mine land by site class, reforestation intensity, and discount rate ($/ton/year).

	Mixed Hardwoods (60-year rotation)			White Pine (30-year rotation)		
5% ARR, low prices						
Site/Intensity	Low	Medium	High	Low	Medium	High
V	2.45	2.54	2.82	4.13	3.99	4.36
IV	2.10	2.17	2.39	2.72	2.61	1.98
III	1.79	1.82	2.03	1.66	0.64	0.89
III	1.51	1.56	1.90	*	*	0.05
I	1.27	1.43	1.90	*	*	*
3.5% ARR, low prices						
Site/Intensity	Low	Medium	High	Low	Medium	High
V	1.37	1.42	1.61	1.73	1.62	1.91
IV	1.12	1.17	1.29	0.69	0.61	*
III	0.91	0.9	1.05	*	*	*
III	0.69	0.73	0.96	*	*	*
I	0.53	0.64	0.96	*	*	*
7.5% ARR, low prices						
Site/Intensity	Low	Medium	High	Low	Medium	High
V	4.68	4.83	5.32	9.42	9.20	9.77
IV	4.06	4.20	4.61	7.14	6.96	6.68
III	3.53	3.63	4.00	5.42	4.53	4.91
III	3.09	3.19	3.78	3.36	3.24	3.55
I	2.67	2.97	3.78	2.17	2.07	2.91

* Indicates LEV is positive without additional payments.

Table 6. Annual payment required per ton of carbon stored on-site to provide full reimbursement of forest conversion costs to landowner of reclaimed mine land, by site class, reforestation intensity, and discount rate ($/ton/year).

	Mixed Hardwoods (60-year rotation)			White Pine (30-year rotation)		
5% ARR, low prices						
Site/Intensity	Low	Medium	High	Low	Medium	High
V	2.62	2.71	2.98	5.64	5.56	5.85
IV	2.29	2.36	2.60	4.58	4.51	4.74
III	2.00	2.06	2.26	3.78	3.72	3.92
III	1.77	1.82	2.14	2.98	3.04	3.28
I	1.54	1.69	2.14	2.62	2.56	2.97
3.5% ARR, low prices						
Site/Intensity	Low	Medium	High	Low	Medium	High
V	1.64	1.69	1.86	3.48	3.42	3.62
IV	1.43	1.48	1.62	2.81	2.79	2.93
III	1.25	1.28	1.42	2.33	2.29	2.42
III	1.10	1.14	1.34	1.95	1.92	2.03
I	0.97	1.06	1.34	1.61	1.58	1.84
7.5% ARR, low prices						
Site/Intensity	Low	Medium	High	Low	Medium	High
V	4.75	4.90	5.39	10.55	10.38	10.91
IV	4.14	4.28	4.70	8.56	8.43	8.86
III	3.62	3.73	4.10	7.06	6.96	7.32
III	3.20	3.30	3.88	5.92	5.83	6.12
I	2.79	3.08	3.88	4.89	4.81	5.56

Conclusions

Based on our work in the preceding quarter, it appears that substantial carbon payments would be required to reach "profitability" under present circumstances. Further, even though the payments that we examine could generate non-negative LEVs, there is no guarantee that the payments will actually cause landowners to reforest in practice. Again, it is landowner *utility* associated with forestland profitability that will be the determining factor in actual conversion—utility that likely would include cash flow timing, amenities, and even the credit position of the landowner.

It is unclear when, or in what form, markets will develop to support the carbon values necessary to supplement commercial forestry revenues. However, as these markets do develop, they will only enhance the viability of forestry on reclaimed mine lands. Unfortunately, it is difficult to determine at this point whether our calculated carbon payments are reasonable. Sufficient experience with carbon trading markets for timber has not been gained to conclude with any certainty that these values could be achieved under the circumstances found on reclaimed mine sites. However, our calculated carbon payments do provide a basis for understanding the role that carbon trading could play in enhancing the financial viability of forestry on reclaimed mine sites as these markets develop more fully.

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TASK 5: Determine the potential of large-scale SMCRA grassland restoration to sequester carbon and create other societal benefits. (Zipper et al.)

Executive Summary

We have compiled a database containing mine permit information obtained from permitting agencies in Virginia, West Virginia, Pennsylvania, Ohio, and Kentucky. Due to differences and irregularities in permitting procedures among states, we found it necessary to utilize an alternative method to determine mined land acreages in the Appalachian region. We have initiated a proof of concept study, focused in the state of Ohio, to determine the feasibility of using images from the Landsat Thematic Mapper (TM) and/or Enhanced Thematic Mapper Plus (ETM+) to accurately identify mined lands.

Experimental

Landsat images from path 18, row 32, for each year and season from 1999 through 2004 were obtained. After inspecting the available images, it was determined that images from the spring would be best suited for this study. Currently we are in the process of performing a supervised classification of the images to identify mined areas. We intend to use the spectral characteristics, spatial trends, and temporal changes in land cover to identify areas that have been mined and reclaimed to non-forest land uses. We have obtained and refined a spatial dataset from the Ohio Department of Natural Resources, Division of Mineral Resources, and the Ohio Department of Administrative Services, Office of Information Services, which identifies the boundaries of permitted surface mines in the study area. We are using this dataset to select training sites for the spectral classification and to provide for an accuracy assessment after completion of the image classification stage.

Results and Discussion

No results have been generated at this time.

Conclusions

Currently, an accurate, consolidated dataset that identifies and locates reclaimed surface coal mines in the Appalachian region does not exist. Our work within this Task should provide such a spatial dataset. Production of this dataset is critical to achieve the overall objective of determining the potential of large-scale post-SMCRA grassland restoration to sequester atmospheric carbon. Moreover, this dataset should support policy decision-making, resource management, and research efforts related to coal mining well beyond the current project.

PROJECT TIMETABLE

Planned | Completed

Year:	2002	2003				2004				2005		
Quarter:	**4th**	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**
Task 1												
Subtask 1.1		Baseline CarbonSequestration Potential										
Subtask 1.2		Mine SoilProductivity										
Subtask 1.3						Carbon Sequestration by Forest Practice						
Subtask 1.4									Accounting Procedures			
Task 2												
Subtask 2.1	Classification Criteria											
Subtask 2.2				GIS Mapping								
Subtask 2.3				Test Remote Sensing								
Subtask 2.4							Experimental Plots					
Subtask 2.5									Soil Analyses			
Subtask 2.6											Validate classification criteria	
Task 3												
Subtask 3.1	Locate sites											
Subtask 3.2				Establish experiment								
Subtask 3.3				Silvicultural recommendations								
Subtask 3.4						Reforestation costs						
Subtask 3.5							Evaluate survival and growth					
Subtask 3.6							Estimate growth potential					
Subtask 3.7								Estimate timber & carbon value				
Task 4		Economic feasibility										
Subtask 4.1						Evaluation						
Subtask 4.2									Government policies			
Subtask 4.3												
Task 5												
Subtask 5.1			Identify SMCRA grassland									
Subtask 5.2				Use characteristics of permits								
Subtask 5.3							Soil properties by permit					
Subtask 5.4								Est. quantity grassland				
Subtask 5.5								Est. C sequ. by site quality class				
Subtask 5.6											Est. C sequ. by policy scenario	