FEASIBILITY STUDY OF CARBON SEQUESTRATION THROUGH REFORESTATION IN THE CHESAPEAKE BAY WATERSHED OF VIRGINIA

TOPICAL REPORT

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ABSTRACT

The Chesapeake Rivers conservation area encompasses approximately 2,000 square miles of agricultural and forest lands in four Virginia watersheds that drain to the Chesapeake Bay. Consulting a time series of classified Landsat imagery for the Chesapeake Rivers conservation area, the project team developed a GIS-based protocol for identifying agricultural lands that could be reforested, specifically agricultural lands that had been without forest since 1990. Subsequent filters were applied to the initial candidate reforestation sites, including individual sites > 100 acres and sites falling within TNC priority conservation areas. The same data were also used to produce an analysis of baseline changes in forest cover within the study period.

The Nature Conservancy and the Virginia Department of Forestry identified three reforestation/management models: (1) hardwood planting to establish old-growth forest, (2) loblolly pine planting to establish working forest buffer with hardwood planting to establish an old-growth core, and (3) loblolly pine planting to establish a working forest. To assess the relative carbon sequestration potential of these different strategies, an accounting of carbon and total project costs was completed for each model. Reforestation/management models produced from 151 to 171 tons carbon dioxide equivalent per acre over 100 years, with present value costs of from $2.61 to $13.28 per ton carbon dioxide equivalent.

The outcome of the financial analysis was especially sensitive to the land acquisition/conservation easement cost, which represented the most significant, and also most highly variable, single cost involved. The reforestation/management models explored all require a substantial upfront investment prior to the generation of carbon benefits. Specifically, high land values represent a significant barrier to reforestation projects in the study area, and it is precisely these economic constraints that demonstrate the economic additionality of any carbon benefits produced via reforestation – these are outcomes over and above what is currently possible given existing market opportunities. This is reflected and further substantiated in the results of the forest cover change analysis, which demonstrated a decline in area of land in forest use in the study area for the 1987/88-2001 period.

The project team collected data necessary to identify sites for reforestation in the study area, environmental data for the determining site suitability for a range of reforestation alternatives and has identified and addressed potential leakage and additionality issues associated with implementing a carbon sequestration project in the Chesapeake Rivers Conservation Area. Furthermore, carbon emissions reductions generated would have strong potential for recognition in existing reporting systems such as the U.S. Department of Energy 1605(b) voluntary reporting requirements and the Chicago Climate Exchange.

The study identified 384,398 acres on which reforestation activities could potentially be sited. Of these candidate sites, sites totaling 26,105 acres are an appropriate size for management (> 100 acres) and located in priority conservation areas identified by The Nature Conservancy. Total carbon sequestration potential of reforestation in the study area, realized over a 100 year timeframe, ranges from 58 to 66 million tons of carbon dioxide equivalent, and on the priority sites alone, potential for carbon sequestration approaches or exceeds 4 million tons of carbon dioxide equivalent. In the absence of concerted reforestation efforts, coupled with policy strategies, the region will likely face continued declines in forest land.

ACKNOWLEDGEMENTS

The study was completed by a partnership of the U.S. Department of Energy, Mirant Corporation, The Nature Conservancy, the Virginia Department of Forestry, and several forestry and remote sensing consultants.

The Nature Conservancy (TNC)

The Nature Conservancy of Virginia is working with private, local, state, and federal partners to construct and implement strategies to protect the land and waters of the Chesapeake Rivers conservation area by addressing threats including development, incompatible forestry and water use, and invasive species (plant and fish). The restoration and preservation of upland forests in the Chesapeake Rivers program area and the larger Chesapeake Bay region is a high priority for TNC.

Additionally, the Global Climate Change Initiative of TNC works to link forest restoration and protection to climate change mitigation. Over the past seven years, TNC has been a leader in the field of carbon sequestration by developing forest protection and management projects through innovative cooperation with the private sector. TNC is currently involved in the management and oversight of five carbon projects in the U.S., Belize, Bolivia, and Brazil. These projects are being funded by American Electric Power, Cinergy, BP-America, General Motors, Texaco and other leading companies.

The Virginia Department of Forestry

The mission of the Virginia Department of Forestry is to protect and develop healthy and sustainable forests in Virginia. The Department provides fire protection to all forestland in Virginia and technical assistance in the reforestation and management of the 77 percent of Virginia's forestland managed by private, non-industrial, landowners. Recognizing that forest resource benefits are dependent on land protected and retained in forest, forestland conservation is paramount and serves as the agency's core foundation. Restoration of natural forests on marginal agricultural lands serves the agency's mission by increasing the land area of forests, reducing forest fragmentation, providing improvements in air and water quality, moderating climate, and increasing carbon stocks retained in Virginia's forests.

The Department has three tree nurseries that together produce approximately 50 million seedlings each year for reforestation efforts. The Department has technical assistance foresters and technicians assigned to each county who assist private landowners with management planning and reforestation, and provide cost-share programs for eligible projects. Department personnel inspect timber harvests for compliance with best management practices. The Department has a resource information program that conducts annualized forest inventories that monitor forest land area, forest conditions, biomass and timber volumes, growth, mortality and timber harvests. The resource information program derives information from a variety of sources, including on-the-ground inventory plots (part of the national Forest Inventory and Analysis program of the U.S. Forest Service), aerial photography, satellite imagery and forest products tax receipts.

Other Consultants and Project Partners

Several other organizations and individuals contributed to this study, providing technical and logistical assistance. The project team recognizes the following individuals for their contribution to this project.

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U.S. Department of Energy

Through a Cooperative Agreement with the Department of Energy (DOE) National Energy Technology Laboratory (NETL), TNC is leading the Climate Action Project Research Initiative, working in close collaboration with NGO partners, government and academic institutions, and U.S. based companies to undertake research that will continue to explore the technical feasibility of implementing climate action projects in a way that will deliver lasting conservation of biodiversity, and measurable greenhouse gas benefits.

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INTRODUCTION

The issue of climate change has emerged as a topic of significant international discussion in the past decade. Many countries and corporations are now taking steps to position themselves to reduce their financial exposure when or if regulatory actions are taken. Some companies are investing in carbon sequestration projects that would allow them to receive carbon benefits from their investment if regulations are promulgated. The majority of these projects have been implemented outside the United States, however, U.S. companies are now looking to fund domestic projects, especially in proximity to their service or operating territories.

Forests act as carbon “sinks” by absorbing atmospheric carbon dioxide and as emissions “sources” when carbon stored in trees during photosynthesis is released into the atmosphere. Deforestation currently accounts for about 25 percent of annual human-induced CO_2 emissions (Houghton 2005). Well-designed and implemented land use projects, including natural forest restoration and forest protection activities that serve to sequester carbon or prevent emissions, offer a scientifically valid and potentially cost-effective approach to mitigating emissions of CO2 from the burning of fossil fuels or other activities. Carbon sequestration is most applicable, and often provides the greatest and most cost effective carbon benefits for the investors, in areas that have been degraded, such as marginal agricultural lands, or areas that will not recover without the management implemented through the carbon project. In many cases this entails replanting a degraded site with trees native to that particular region. In addition, many restoration projects can provide significant “co-benefits” such as conservation of biodiversity, creation or enhancement of wildlife habitat, public relations, and even economic benefits.

This study will help the potential investor to understand issues related to the planning, implementation and monitoring of carbon sequestration projects in the Chesapeake Bay watershed of eastern Virginia. Specifically, this study assessed the costs, benefits, barriers and strategies that are integral to a successful carbon project. As global and national policy changes, the investor and carbon practitioner will be better able to plan for cost-effective emissions reduction initiatives.

This study identified several thousand sites on which reforestation activities could occur and would demonstrate significant climate change, emissions offset and biodiversity benefits. Many of these candidate sites are located in priority conservation areas identified by The Nature Conservancy. Additional analysis of sites reveals the potential for successful implementation of carbon sequestration projects.

EXPERIMENTAL

The Chesapeake Rivers study area

The Chesapeake Rivers conservation area encompasses approximately 2,000 square miles of agricultural and forest lands in four Virginia watersheds that drain to the Chesapeake Bay. The Mattaponi, Pamunkey, Rappahannock River systems and the Dragon Run watershed represent some of the most pristine examples of tidal freshwater systems remaining in the Chesapeake Bay ecosystem and the eastern seaboard of the United States. These river systems, known collectively as the Chesapeake Rivers, support viable occurrences of rare and endangered plant species, high quality freshwater tidal marshes and bottomland hardwoods, and nesting grounds for bald eagles, resident and migratory waterfowl and are an integral part of the Atlantic Flyway, the migratory avenue for songbirds that nest and breed in the United States and winter in the Caribbean or Latin America.

The study area totals 2,718,785 acres encompassing 16 counties in the state of Virginia: Caroline, Essex, Gloucester, Hanover, King and Queen, King George, King William, Lancaster, Mathews, Middlesex, New Kent, Northumberland, Richmond, Spotsylvania, Stafford, and Westmoreland.

Site selection and candidate sites

The project team developed a GIS-based protocol for identifying agricultural lands that could be reforested so as to sequester carbon and provide a number of environmental co-benefits. The project team identified agricultural lands that had been without forest since 1990, referencing the eligibility requirements for reforestation and reforestation carbon sequestration projects established under the Clean Development Mechanism of the Kyoto Protocol. This criteria is the most widely accepted eligibility metric for carbon sequestration projects at this time. Advances in carbon policy and carbon credit markets may influence the ultimate definition of lands eligible for carbon sequestration crediting programs.

To identify potential reforestation sites meeting the requirement of not being without forest cover since 1990, it was necessary to obtain land use classifications covering a period of pre-1990 to the present. Satellite imagery from the Landsat Thematic Mapper (Landsat 5 TM) and Landsat Enhanced Thematic Mapper Plus (Landsat 7 ETM+) were acquired for the following dates and paths:

- 2001 November 6 Path 15 / Row 33 & Path 15 / Row34
- 1988 September 23 Path 15 / Row 34
- 1987 May 16 Path 15 / Row 33

Using the GIS data, we applied several additional filters to the analysis. Specifically, we identified candidate sites which fall within TNC priority conservation areas. In the study area TNC is working to protect and restore forests and protect riparian buffers to ecologically significant stream and wetland systems. This effort is coordinated through the delineation of priority forest matrix blocks designed to protect large forested areas. Within forest matrix blocks, forest restoration should occur with a goal of reconnecting fragmented forest patches. TNC has delineated three forest matrix blocks in the study area: the Upper Rappahannock, Dragon Run, and Fort A.P. Hill.

Additionally, these data were used to produce an analysis of baseline changes in forest cover within the study period. The analysis distinguished the following:

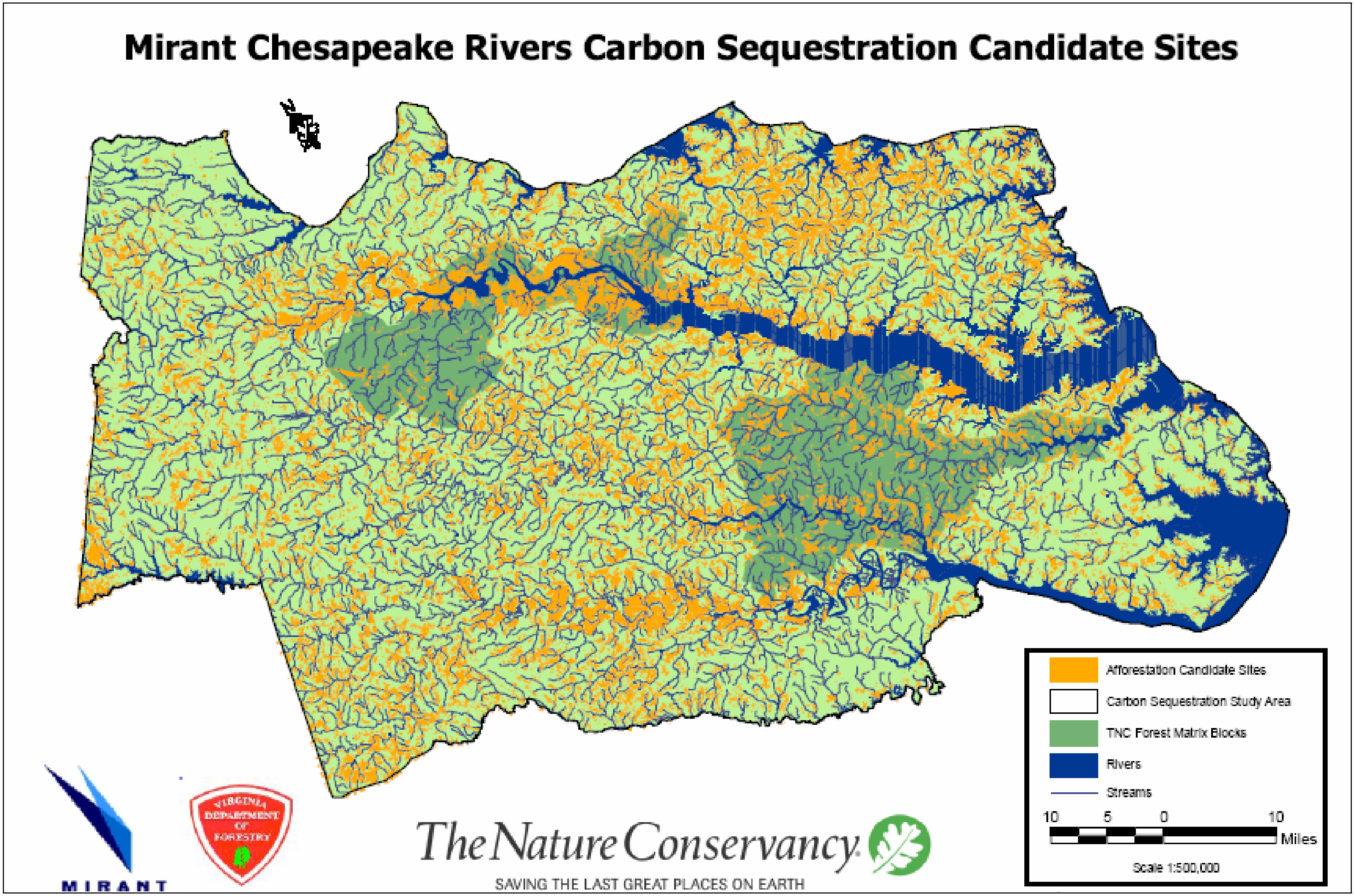
- “candidate reforestation sites” = agricultural sites continuously without forest cover since 1990 or prior, through 2001
- “conservation priority candidate reforestation sites” = agricultural sites continuously without forest cover since 1990 or prior, through 2001, individual sites > 100 acres (a size adequate for conservation and forest management objectives), and location coinciding with TNC-delineated priority forest matrix blocks
- “baseline or business as usual reforestation (1987/88-2001)” = agricultural land without forest cover in 1987/88 (i.e. since 1990) and with forest cover in 2001
- “baseline or business as usual deforestation (1987/88-2001)” = with forest cover in 1987/88, and without forest cover and with a conversion of land use to agriculture or urban in 2001

RESULTS AND DISCUSSION

The site selection methodology produced a coverage of the study area which identified 18,601 eligible candidate reforestation sites totaling 384,498 acres (~10% of the study area). Mean site area was 20.67 acres (range = 1.25 to 1307 acres; 786 candidate reforestation sites in excess of 100 acres).

Applying the TNC-delineated forest matrix block boundaries, and restricting the analysis to sites greater than 100 acres in area, 111 conservation priority candidate reforestation sites were identified, totaling 26,105 acres (Figure 1). Mean site area was 235 acres. Sixteen of the 111 sites intersect with an already protected conservation area.

Figure 1. Candidate reforestation sites and TNC conservation priority forest matrix blocks in the study area.



Trends in forest cover/baseline rates of change

The time series of classified satellite imagery provided a basis for determining trends and changes in forest cover. Table 1 details county forest cover information. Core counties (in bold) are those counties which overlap well with TNC forest matrix block priorities. In the 16 counties in the study area, which cover approximately 2.7 million acres, forest cover was relatively stable between 1987/88 and 2001, covering 1.9 million acres, or approximately 70% of the study area.

Table 1. Forest cover in the study area (values in acres).

County	1987/88 Forest Cover	2001 Forest Cover
Caroline	**266,424**	**269,922**
Essex	**106,615**	**110,241**
Gloucester	104,765	104,265
Hanover	203,672	203,751
King And Queen	**148,053**	**154,860**
King George	81,608	80,889
King William	**119,816**	**121,621**
Lancaster	58,236	58,610
Mathews	38,942	39,042
Middlesex	56,468	56,479
New Kent	103,953	104,580
Northumberland	75,605	75,627
Richmond	**80,106**	**80,674**
Spotsylvania	201,146	198,083
Stafford	128,513	129,240
Westmoreland	**93,613**	**92,864**
total	1,867,535	1,880,748
Core Counties	**814,627**	**830,182**

The project team assessed changes in forest cover in the study area by disaggregating losses and gains ("new") of forest cover. Table 2 details county level data on apparent changes in forest cover for the study period.

Table 2. Apparent changes in forest cover observed between 1987/88 and 2001 in the study area (values in acres).

County	"New" forest cover (1987/88-2001)	"Lost" forest cover (1987/88-2001)
Caroline	**14,133**	**10,635**
Essex	**7,794**	**4,168**
Gloucester	3,356	3,856
Hanover	6,531	6,452
King and Queen	**12,242**	**5,435**
King George	1,647	2,366
King William	**7,041**	**5,236**
Lancaster	1,974	1,600
Mathews	1,515	1,415
Middlesex	2,002	1,991
New Kent	4,019	3,392
Northumberland	2,232	2,210
Richmond	**3,574**	**3,006**
Spotsylvania	7,480	10,543
Stafford	4,997	4,270
Westmoreland	**2,787**	**3,536**
Total	83,324	70,111
Total (Core Counties)	47,571	32,016

Forest cover change presented in this way obscures an appreciation of change in forest use. An effort was made to further define reforestation and deforestation as fundamental, and presumably longterm, changes in forest use.

According to this analysis, there was a gain of 13,213 acres in forest cover in all the counties between 1987/88 and 2001. However, change in forest use followed a different trajectory. Some sites without forest cover in 1987/88 could be distinguished as recently clearcut, and subsequently with forest cover in 2001, and should thus be considered as in continuous forest use. These sites amount to 42,474 acres, and thus the total acres in forest use in 1987/88 was 1,910,009 acres (= 1,867,535 + 42,474). Furthermore, some sites without forest cover in 2001, that had been forested previously in 1987/88, could be distinguished as clearcut but still in forest management (i.e. no signs of conversion to agriculture or urban), and thus should be considered as still in forest use. These sites amount to 18,771 acres, and consequently area in forest use in 2001 is 1,899,519 acres (= 1,880,748 + 18,771). Thus, although forest cover apparently increased by 13,213 acres over the period, interpretation of the satellite imagery allows for distinguishing true or permanent changes in land use from temporary changes in forest cover, demonstrating a net loss of 10,490 acres in forest use between 1987/88 and 2001. Much (79%) of this area was converted to agriculture, which increased by 8,243 acres over the same period (575,322 acres in 1987/88 to 583,565 acres in 2001), though there may have been some errors in the classification distinguishing between agriculture and urban.

Thus, forest use conversion due to reforestation and deforestation over the 13/14 year period was 40,850 and 51,340 acres, respectively. These represent rates of 3,026 acres reforested (= 0.16% of 1987/88 acres in forest use) and 3,803 acres deforested (= 0.20% of 1987/88 acres in forest use) annually. Some of the 1,858,669 acres in continuous forest use throughout the study period undoubtedly displayed temporary loss followed by regain of forest cover, due to timber harvest and management, within the intervening period (i.e. 1989-2000).

Landowner incentive programs such as the Conservation Reserve Enhancement Program (CREP) provide funding for reforestation projects on marginal agricultural and sensitive lands. The data for this program suggest that as much as 100% of the net reforestation rate of agricultural lands may be attributed to the CREP program.

Differences in forest cover between the two sample events were too slight (0.7% change, equivalent to an annual rate of change of 0.06% for the 12 year period) to conclusively resolve. Without a quantitative accuracy assessment of classification error, we are unable to determine how much of the apparent change in forest cover we calculated (13,213 acres) was actual change, versus error in classification. Errors of omission from the NLCD classification, similarly derived from Landsat imagery, range from 24 to 85% for forest cover thematic classes at the pixel scale (corresponding Federal Region 3; USGS 2004), well exceeding the change in forest cover calculated here, and thus do not permit conclusive resolution of this magnitude of change.

Comparison with other observed trends and projections of forest land

The Southern Forest Resource Assessment provides projections for forest land cover and timber prices. Based on a model developed by Hardie et al (2000), the assessment describes the allocation of land between urban and rural uses driven by population density, personal income and housing values. Additionally, the assessment looks at the allocation of land between forests and agriculture driven by economic returns from agriculture, land and timber prices. In the assessment Scenario 1 assumes that relative returns from agriculture and forests remain constant at 1992 values. Scenario 2 assumes a real price 35% increase in timber prices by 2020. The data are at a county-level resolution.

For the study area, the Scenario 1 projection shows a decline in forest land of 14.9% from 2001 to 2020, a 0.7% average annual decline. Between 2001 and 2040, the decline is predicted to reach 23%, a 0.6% average annual decline. Scenario 2 reveals a projected decrease in forest land of 12.3% by 2020 (0.6%/year) and 16% (0.4%/year) by 2040 (Table 3).

Table 3. Application of Hardie et al (2000) forest land projections for the U.S. south to study area.

	Estimated	Scenario 1				Scenario 2			
County	**2001**	**2020**		**2040**		**2020**		**2040**	
Caroline	235,769	-4.2%	225,913	-12.9%	205,472	-1.0%	233,364	-3.1%	228,413
Essex	97,432	-0.1%	97,305	-2.9%	94,655	3.1%	100,452	6.8%	104,096
Gloucester	99,128	-17.8%	81,453	-33.8%	65,642	-15.0%	84,278	-28.1%	71,233
Hanover	178,642	-28.8%	127,158	-42.6%	102,505	-26.5%	131,338	-39.1%	108,829
King And Queen	142,348	-0.3%	141,906	-3.4%	137,550	3.0%	146,561	6.4%	151,472
King George	69,151	-15.2%	58,647	-31.3%	47,493	-12.0%	60,853	-23.4%	52,970
King William	125,703	-2.5%	122,573	-7.8%	115,861	0.7%	126,583	1.6%	127,652
Lancaster	45,100	-3.6%	43,481	-6.7%	42,060	-0.9%	44,703	1.4%	45,727
Mathews	34,551	-5.6%	32,602	-14.9%	29,396	-2.4%	33,728	-5.4%	32,681
Middlesex	52,076	-2.0%	51,029	-6.7%	48,592	1.2%	52,695	2.8%	53,528
New Kent	97,864	-19.5%	78,790	-37.9%	60,734	-16.4%	81,834	-31.2%	67,330
Northumberland	72,124	-0.7%	71,656	-3.4%	69,643	2.6%	74,007	6.3%	76,683
Richmond	75,420	-0.3%	75,217	-3.3%	72,917	3.0%	77,676	6.4%	80,262
Spotsylvania	148,954	-51.6%	72,064	-60.0%	59,626	-50.3%	73,971	-59.1%	60,982
Stafford	114,765	-46.2%	61,709	-47.7%	60,057	-46.0%	61,962	-47.6%	60,126
Westmoreland	85,440	-3.4%	82,518	-10.7%	76,332	-0.2%	85,304	-1.0%	84,552
total	**1,674,467**	**-15.0%**	**1,424,022**	**-27.1%**	**1,288,536**	**-15.9%**	**1,469,308**	**-18.2%**	**1,406,536**
	change		**(250,445)**		**(385,931)**		**(205,159)**		**(267,932)**
Core Counties	**762,112**	**-2.2%**	**745,434**	**-8.0%**	**702,788**	**1.1%**	**769,940**	**1.9%**	**776,447**
			(16,679)		(59,325)		7,827		14,335

Similarly, The Conservation Fund and USDA Forest Service's *The State of Chesapeake Forests* (2006) reports annual loss of 36,500 acres since 1982 for the entire Chesapeake Bay watershed, translating roughly to an equivalent annual decrease in forest land of 0.15%.

These projections are an order of magnitude greater than the trend observed in this study over the period 1987/88 to 2001 (equivalent to an annual decrease in forest land of 0.04%). However, despite these differences, there is consensus among independent sources that carbon sequestration projects in the study area will sequester carbon in the context of continuing deforestation and related carbon losses.

Forest land will continue to decrease in the region where reforestation is not sufficient to offset permanent forest conversion to agriculture or urban use, as we demonstrate for the 1987/88-2001 period.

Reforestation/management alternatives

Biological sequestration of carbon has the potential to contribute measurable offsets of greenhouse gas emissions. An emerging voluntary market for carbon emissions reductions has created the opportunity for landowners to expand the range of forest management goals for consideration, including timber value, wildlife habitat enhancement, and now carbon sequestration. The appropriate reforestation strategy for each landowner and/or investor will represent the optimal composite valuation of these different goals.

The Nature Conservancy and the Virginia Department of Forestry identified three reforestation/management models based on three primary project goals including (1) carbon sequestration, (2) timber value from a working forest, and (3) biodiversity/wildlife value, and three desired future conditions, including:

1) Hardwood planting to old-growth forest
The goal of this reforestation/management model is to create an old-growth forest which maximizes habitat and environmental benefits for birds, mammals and wide-ranging species. This model generates carbon sequestration and wildlife/biodiversity values.

2) Loblolly pine working forest buffer with hardwood old-growth core
The goal of this reforestation/management model is to create an old-growth core of hardwood forest (50 acres on a 100 acre tract) which is buffered by 50 acres of loblolly pine working forest. This model offers a balance of carbon sequestration, wildlife values, and timber values and community benefits from maintaining elements of the working forest landscape.

3) Loblolly pine working forest
The working forest reforestation/management model maximizes timber values while additionally offering carbon sequestration values (in both living tree biomass and long-lived wood products). Biodiversity/wildlife benefits are minimal due to the low tree species diversity and frequency of disturbance.

Table 4. Reforestation/management models for a 100 acre candidate site, 100 year term.

	1) Hardwood planting to old-growth forest	2) Loblolly pine working forest buffer with hardwood old-growth core	3) Loblolly pine working forest
Desired Future Condition	Old-growth forest from hardwood planting	Old-growth forest core from natural regeneration buffered by working forest following 40-year loblolly pine rotation	Working forest (continuous 40 year rotation loblolly pine)
Afforestation / Forest management strategy	Plant hardwoods, allow 100 years of growth with minimal intervention to establish old-growth conditions	Plant loblolly pine at 600 stems per acre density; thinnings at ages 16 and 24, harvest at age 40, replant and repeat on 50 acres; on other 50 acres plant hardwoods, allow 100 years of growth with minimal intervention to establish old-growth conditions	Plant loblolly pine at 600 stems per acre density; thinnings at ages 16 and 24, harvest at age 40, replant and repeat

To assess the relative carbon sequestration potential of these different strategies, an accounting of carbon and total project costs was completed for each reforestation/management model.

Carbon sequestration potential

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Carbon dynamics were modeled applying the following assumptions:

- carbon sequestration rates for planted loblolly pine aboveground tree biomass were based on historical growth and yield models for loblolly pine growing stock volume developed by the Virginia Department of Forestry, where yield (volume) = f(age, site index (55), height, stand density, and basal area). Aboveground living biomass carbon was estimated from growing stock volume applying the conversion factor for planted pine in the southeast region developed by Smith et al 2003; aboveground biomass (mg/ha) = 187.3 * (0.0662 + (1-EXP(-growing stock volume (m3/ha)/184.9))), then multiplying by 0.5 for the carbon fraction of biomass (Figure 2)
- carbon sequestration rates for planted hardwood aboveground tree biomass were based on a Chapman-Richard's curve fitted to biomass carbon measurements from known age oak-pine/oak-hickory stands (data from Virginia Department of Forestry); aboveground biomass carbon (mg/ha) = 120*(1-EXP(-0.034*stand age (years)))^1.11 (R-squared = 0.72) (Figure 3)
- modeled pools limited to carbon in aboveground tree biomass and wood products (inputs to belowground tree biomass, forest floor, and soil carbon not considered)
- baseline (agriculture) carbon stocks are zero

- slash and incidental mortality from harvest (live volume felled – volume harvested) assumed to be immediately oxidized
- wood processing efficiency is accounted for using the following conversion: 230 ft3 harvested per MBF sawtimber stumpage sold (= 67% wood waste); no waste is assumed in conversion to products from pulp and chip-n-saw (conversion = 75-80 ft3 harvested per solid content cord stumpage sold)
- wood waste is assumed to be immediately oxidized
- The proportions of wood products destined for long-term (> 5 years) use of 80% for sawnwood and 60% for paper/paperboard (= 20% in long-term use + 40% in long-term landfill storage), based on findings summarized in Winjum et. al. (1998)
- Wood products in long-term use were decomposed over time using an annual oxidation factor, equivalent to k, of 0.01 for both sawnwood and paper/paperboard, as reported by Winjum et al. (1998).

Figure 2. Sequestered carbon accumulations projected for the loblolly pine working forest model (40 year rotation with thinnings at ages 16 and 24, historical growing stock volume yield model from Virginia Department of Forestry to biomass carbon applying conversions from Smith et al 2003, carbon storage in wood products modeled following parameters from Winjum et al 1998).

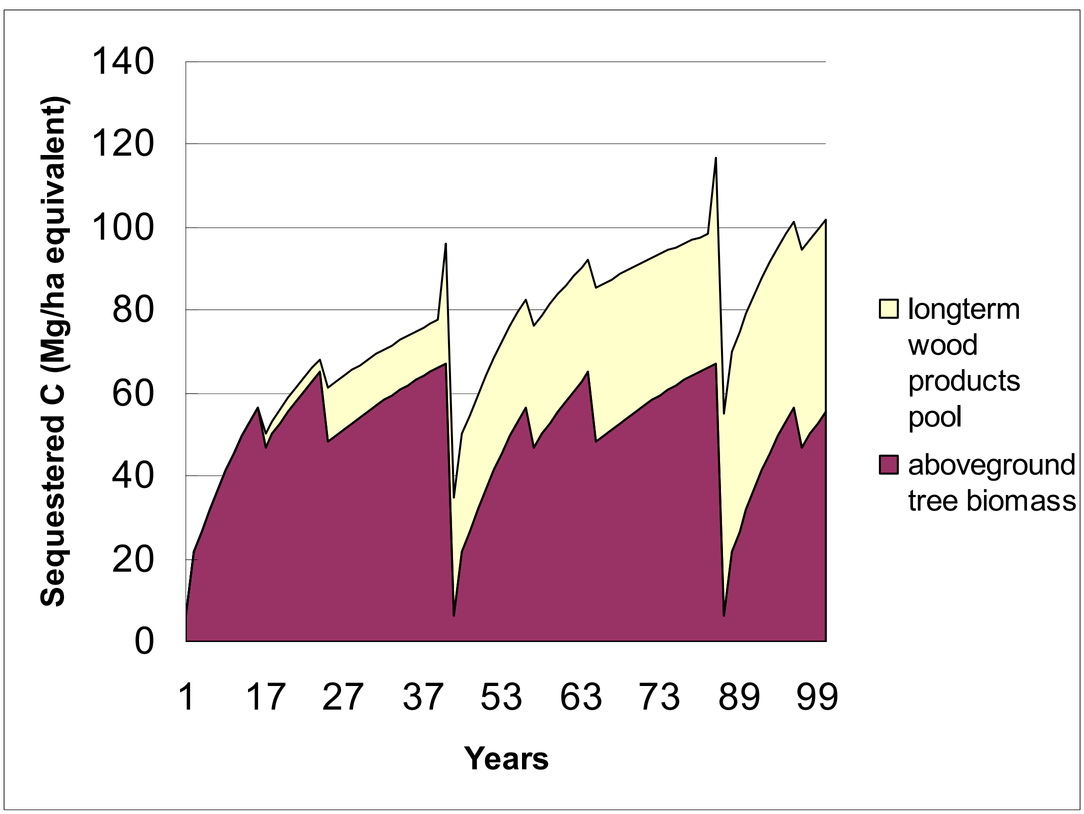
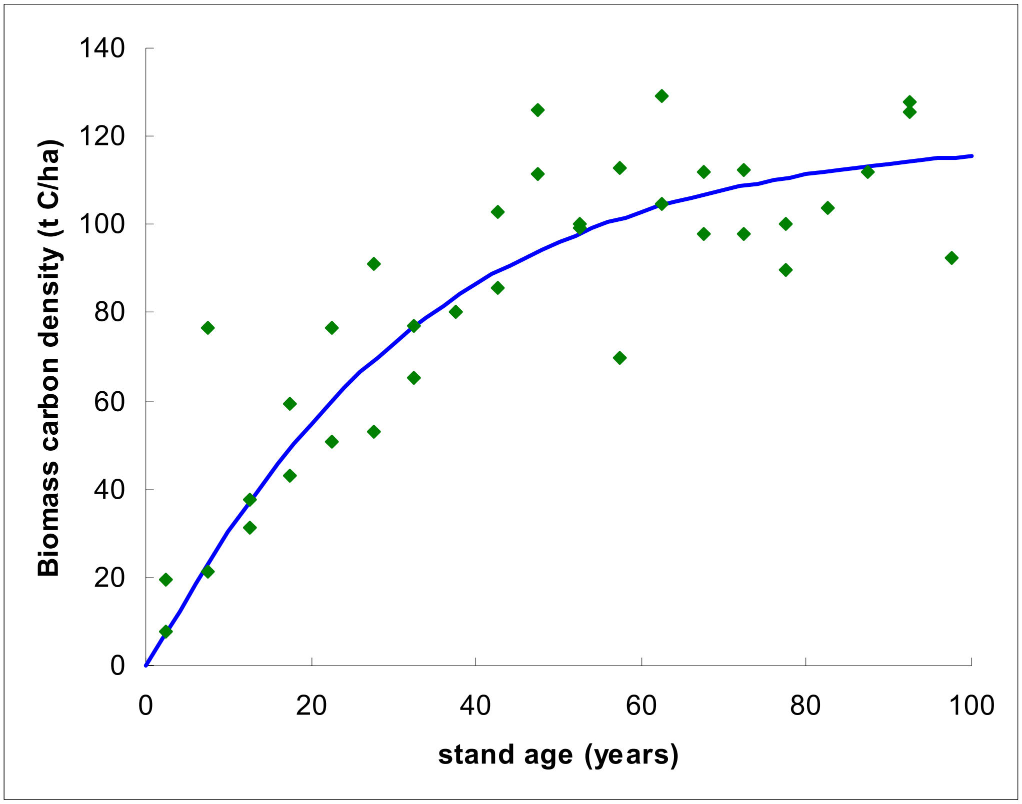


Figure 3. Fitted Chapman Richard's curve to oak-pine/oak-hickory stands (raw data from Virginia Department of Forestry). Aboveground biomass carbon (mg/ha) = 120*(1-EXP(-0.034*stand age (years)))^1.11 (R-squared = 0.72)



Economic potential

The cash-flow financial analysis applied the following assumptions:

- discount rate of 5% (reflects long term treasury bond yield)
- inflation rate of 1.5%
- 100 year term of financial analysis
- 100 acre project
- loblolly pine site prep and planting cost is $115 per acre
- loblolly pine is managed on a 40 year rotation (2,793 ft3 felled, 2,772 ft3 harvested) with thinnings at 16 (524 ft3 felled, 322 ft3 harvested) and 24 years (1,036 ft3 felled, 990 ft3 harvested)
- hardwood site prep and planting cost is $140 per acre
- timber sold as stumpage
- stumpage prices (buyer pays harvest and thinning costs): pulp $15/cord, chip-n-saw $30/cord, and sawtimber $150/MBF (thousand board feet)
- cost to establish a conservation easement is $500/acre
- representative cost of land acquisition is $2,000/acre

- monitoring cost is $135 per acre (present value of 100 years monitoring at 5-year intervals), targeting 10% project error, 90% confidence interval, 100 acre project size (derived from Mooney 2003)
- timber yields based on site index 55

Reforestation/management model outcomes

Model 1: Hardwood planting to old-growth forest

At 100 years over 100 acres, this model would sequester 17,131 metric tons of CO2 in living tree aboveground biomass (equivalent to 115.4 Mg C/ha or 171.3 metric tons of CO2 per acre). This value is actually higher than the loblolly pine working forest model, which results in 15,632 metric tons of CO2 sequestered in living tree aboveground biomass and long-lived wood products, despite faster growth of loblolly relative to hardwoods (e.g. at 16 years, loblolly biomass carbon is 57 Mg/ha, compared with 46 Mg/ha for hardwood biomass carbon). The difference arises due to inefficiencies in harvest and processing to convert tree biomass to long-lived wood products, as well as the 1% per year retirement rate of long-lived wood products.

With establishment of a conservation easement, present value cost to produce one metric ton CO2 (i.e. break-even carbon price, NPV = 0) for this alternative is $4.50 (total present value cost $77,500 / 17,131 tCO2), while with outright land acquisition, cost to produce one metric ton CO2 for this alternative is $13.28 (total present value cost $227,500 / 17,131 tCO2) (Table 5).

Model 2: Loblolly pine working forest buffer with hardwood old-growth core

At 100 years over 100 acres, this model would sequester 16,110 metric tons of CO2 (equivalent to a mean of 108.5 Mg C/ha or 161.1 metric tons of CO2 per acre across the hardwood and managed loblolly pine strata). With establishment of a conservation easement, cost to produce one metric ton CO2 for this alternative is $3.63 (total present value net cost $58,420 / 16,110 tCO2). Total net cost includes planting, monitoring, and conservation easement establishment costs (present value $77,180) as well as revenues from stumpage sales from thinnings and end of rotation harvests on the 50 acres of loblolly pine working forest buffer (present value $18,760).

With outright land acquisition, present value cost to produce one metric ton CO2 for this alternative is $12.94 (total present value cost $208,420 / 16,110 tCO2), which is the break-even carbon price (i.e. NPV = 0) (Table 5).

Model 3: Loblolly pine working forest

At 100 years over 100 acres, this model would sequester 15,090 metric tons of CO2 (equivalent to 101.7 Mg C/ha or 151.0 metric tons of CO2 per acre). With establishment of a conservation easement, cost to produce one metric ton CO2 for this alternative is $2.61 (total present value net cost $39,340 / 15,090 tCO2). Total net cost includes planting, monitoring, and conservation easement establishment costs (present value $76,860) as well as revenues from stumpage sales from thinnings and end of rotation harvests (present value $37,520).

With outright land acquisition, present value cost to produce one metric ton CO2 (i.e. break-even carbon price, NPV = 0) for this alternative is $12.55 (total present value cost $189,340 / 15,090 tCO2) (Table 5).

Table 5. Carbon sequestration and economic potential of 3 reforestation/management models for a 100 acre candidate site, 100 year term.

		Break-even price ($ per ton) (i.e. NPV = 0)	
Afforestation/forest management model	**Mg CO2/acre at 100 years**	**with conservation easement**	**with land purchase**
1) Hardwood planting to old-growth forest	171.3	4.5	13.28
2) Loblolly pine working forest buffer with hardwood old-growth core	161.1	3.63	12.94
3) Loblolly pine working forest	151	2.61	12.55

Discussion of land protection costs

In addition to costs associated with planting trees and monitoring, costs associated with protecting land through and beyond the project term are incorporated into the feasibility assessment. The Nature Conservancy would prefer to protect lands not just for the term of the carbon sequestration contract, but in perpetuity. The outcome of the financial analysis is sensitive to the land acquisition/conservation easement cost, which represents the most significant, and also most highly variable, cost involved. This cost will be substantial where the full fair market value is sought, hence the advantage of establishing a conservation easement which represents only a partial interest in property, and should be sufficient to protect the candidate tracts for the purposes of the project.

Even so, the purchase of a conservation easement on conservation sites may cost more than what is economically feasible (i.e. what the voluntary or retail carbon market will pay). However, if carbon sequestration funding provided only a portion of the total funding for a land protection project, The Nature Conservancy could seek complementary financing to leverage revenue derived from carbon sequestration.

Land values in the Chesapeake Rivers study area vary from county to county. Average land values are listed in Table 6. Conservation easements vary by location and by restrictions.

Table 6. Average per acre land values in the study area by property class (from TNC-reviewed appraisals)

Property class	Value per acre
Waterfront Acres	$25,700
Homesite Acres	$5,200
Tillable Acres	$2,600
Pond Acres	$6,300
Cut-over Acres	$650
Swamp/Wasteland Acres	$260
Conservation Easements (vary by restrictions and location)	$400 - $1,200 / acre

Leakage

There are two main types of leakage that can be generated by a carbon sequestration project: activity-shifting and market-shifting leakage. Each category of leakage can be either positive or negative in the scope of the project. Activity-shifting leakage occurs when the change in land use (e.g. reforestation of agricultural lands) causes the displacement of other resources (e.g., clearing of forest land for agriculture). Positive activity-shifting leakage may occur if the reforestation of some lands leads to the establishment, protection or enhancement of adjacent forest resources.

Market-based leakage may occur if a reforestation project changes the dynamics of the local or regional forest or agricultural markets. For example, a large reforestation project could result in depressed prices in forest products due to a large influx of supply on the market, potentially shifting incentives among landowners to engage in forest management.

The local and regional agricultural sector is facing declines in productivity and strong competition in a global market, thus the risk of activity-shifting leakage from reforestation of agricultural lands is low, although further quantitative analysis is needed to precisely define and project impacts within a county, watershed or region. Regarding market-based leakage, data from the Virginia Department of Forestry's IMPACT analysis, which evaluates both direct and indirect impacts of the timber industry on local markets, suggests that only a very large (>50,000 acres) project would disrupt the local timber markets, and potentially accelerate timber liquidation.

Leakage could be managed through leakage contracts. Leakage contracts would stipulate that the landowner may not clear forestland for agricultural uses inside or outside of the project area, and cannot farm land that has been cleared within the past 12 years or during the project period, or lands that would have been reforested. Additional strategies may be identified in a more comprehensive study of the interaction between farming and forestry.

Additionality

Additionality measures whether or not an activity would have occurred in the absence of the project and relates to the net effect the activity has on atmospheric CO_2, and serves to answer the question: would this project have occurred without the investment or initiative of the groups involved?

The reforestation models explored here all require a substantial upfront investment prior to the generation of carbon benefits. Specifically, high land values represent a significant barrier to reforestation projects in the study area, and it is precisely these economic constraints that demonstrate the economic additionality of any carbon benefits produced via reforestation – these are outcomes over and above what is currently possible given existing market opportunities. This is reflected and further substantiated in the results of the forest cover change analysis, which demonstrates a decline in area of land in forest use in the study area for the 1987/88-2001 period.

CONCLUSION

The project team collected data necessary to identify sites for reforestation in the study area, environmental data for the determining site suitability for a range of reforestation alternatives and has identified and addressed potential leakage and additionality issues associated with implementing a carbon sequestration project in the Chesapeake Rivers Conservation Area. Furthermore, carbon emissions reductions generated would have strong potential for recognition in existing reporting systems such as the U.S. Department of Energy 1605(b) voluntary reporting requirements and the Chicago Climate Exchange.

This study identified 384,398 acres on which reforestation activities could potentially be sited. Of these candidate sites, sites totaling 26,105 acres are an appropriate size for management (> 100 acres) and located in priority conservation areas identified by The Nature Conservancy. Total carbon sequestration potential of reforestation in the study area, realized over a 100 year timeframe, ranges from 58 to 66 million tons of carbon dioxide equivalent, and on the priority sites alone, potential for carbon sequestration approaches or exceeds 4 million tons of carbon dioxide equivalent. In the absence of concerted reforestation efforts, coupled with policy strategies (Commonwealth of Virginia 2005), the region will likely face continued declines in forest land.

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