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Subsidizing carbon sequestration via forestry in Maryland: A cost-benefit assessment

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SUBSIDIZING CARBON SEQUESTRATION VIA FORESTRY IN MARYLAND: A COST-BENEFIT ASSESSMENT

A Thesis
Submitted to the Faculty
of
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by
Rachel C. Hettich

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of
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LIST OF ABBREVIATIONS

CARB	California Air Resources Board
CBA	Cost Benefit Analysis
CMS	Carbon Monitoring System
DICE	Dynamic Integrated Climate and Economy (IAM)
DNR	Department of Natural Resources
EPA	Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
FUND	Climate Framework for Uncertainty, Negotiation, and Distribution (IAM)
GHG	Greenhouse Gas
GHGRP	Greenhouse Gas Reduction Act Plan
GIS	Geographic Information Systems
IAM	Integrated Assessment Model
IPCC	Intergovernmental Panel on Climate Change
L2W	Lawn to Woodland
LEV	Land Expectation Value
MAI	Mean Annual Increment
MBF	Thousand Board Feet
MSY	Maximum Sustainable Yield
NASA	National Aeronautics and Space Administration
NLCD	National Land Cover Dataset
NPV	Net Present Value
NRCS	Natural Resources Conversation Service
PAGE	Policy Analysis of the Greenhouse Effect (IAM)
RGGI	Regional Greenhouse Gas Initiative
USDA	United States Department of Agriculture
WIP	Woodland Incentive Program

ABSTRACT

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Carbon sequestration by forestry is one way to mitigate climate change, and policy incentives are in place to encourage private investment in forestry. State and federal forestry cost-share programs subsidize the establishment of trees and the improvement of existing forested land. The objective of this research was to determine the effectiveness of such programs in Maryland and to compare the monetized benefits from permanently sequestered carbon with the current subsidies. To meet this objective, private and social cost-benefit analyses were conducted for three forestry investment scenarios in Maryland that coincide with the main cost-share programs available there. Sensitivity analysis considered a range of values for the social cost of carbon, the discount rate, and program implementation costs.

The first program considered was the state funded Woodland Incentive Program (WIP), which provides cost-share assistance for improving timber management. According to the cost-benefit analysis results, the program provides sufficient incentives to induce participation. For a discount rate of 5%, the investment in pre-commercial thinning with participation in WIP increases discounted returns by $60.62 per acre. However, the total program enrollment over the past eight years was only 24,443 acres, compared to GIS analysis results that show approximately 737,000 acres across Maryland are eligible for the program. The total cost share assistance provided by WIP for a timber management improvement practice of pre-commercial thinning was $81.34 per acre, while from society’s view, the discounted carbon sequestration benefits provided by the improved timber stand were $146.82 per acre. By basing the cost-share assistance on the

carbon benefits, and so increasing the subsidies, potential and actual program participation may converge.

Two land conversion programs were considered: the federally funded Environmental Quality Incentives Program (EQIP) and the state funded Lawn to Woodland (L2W) Initiative. The cost-benefit analysis results show that the conversion from cropland to forest through EQIP does not provide enough incentive to induce program participation. Cropland rents generate income far greater than the benefits from forestry conversion, even when carbon benefits are included. In this case, the program is already providing subsidies larger than the carbon sequestration benefits, and the actual participation of only 344 acres between 2009 and 2013 is still very low. However, when using the pastureland rent, which is about half of the cropland rent, the conversion to forest is much more likely. There are around 750,000 acres of pastureland in Maryland that could be converted to forest to increase carbon sequestration across the state.

The conversion from lawn to forest through L2W provided contrasting results. Since timber harvest is unlikely following the conversion from lawn to forest, the carbon benefits are much higher. The cost-share assistance was $335.91 per acre, and the discounted carbon benefits from the conversion were $1,245.87 per acre. Cost-share assistance based on the benefits from permanently sequestered carbon could justify increasing the incentive to participate by almost four times. Since neither land use in this scenario provides financial returns to the owner, the investment decision depends largely on the aesthetic values of lawn versus forest that the landowner possesses, which are difficult to estimate. GIS analysis estimated that approximately 230,000 acres are eligible for this new program across Maryland.

Maryland is at the forefront when compared to other states, supplementing federal cost-share programs with its own resources to combat climate change. This analysis suggests the state financed initiatives may exhibit the potential to enhance carbon sequestration more than the federal programs, and for each state program there was scope to increase subsidies given the value of carbon benefits realized.

CHAPTER 1. INTRODUCTION

1.1 Motivation

Increasing greenhouse gas (GHG) emissions and their impact on climate change have emerged as key political and economic topics in the United States and around the world. The impact of GHG emissions on climate change depends on several factors, including land use allocation and natural resource management (National Research Council, 2010). For example, maintaining existing forests and establishing new forests are two ways to mitigate the negative effects of GHG emissions because forests can sequester and store carbon.

Forests provide many co-benefits in addition to carbon sequestration, such as improved water quality, improved air quality, wildlife habitat, recreational opportunities, and aesthetics. The value of these non-market benefits can be estimated, but private forest owners do not receive full financial compensation equal to the benefits they provide to society. In other words, the positive externalities that the forest owner provides to society are not fully internalized. Subsidies offered by government sponsored forestry cost-share programs help make it less costly for landowners to plant and maintain trees. However, it is not evident whether the subsidies are adequate to overcome the opportunity costs from investing in forestry. Moreover, social benefits from the positive externalities provided by forestry may justify larger subsidies that would elicit greater program participation.

Through cost-benefit analysis (CBA), this research compares the profitability of owning forestland, including the possibility of participating in a government cost-share program, with other land use alternatives such as agriculture or lawn space. Further, a CBA from society's perspective[1], including the internalization of carbon sequestration

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[1] I did not attempt to fully internalize the social value of all co-benefits from forestry investments. Prior literature does not provide good estimates of the value of these benefits in mostly rural areas

benefits, was conducted to compare current cost-share assistance with the societal carbon benefits. The focus is on forestry cost-share programs implemented in the state of Maryland.

Maryland is at the forefront in addressing climate change on a broad scale, and especially when it comes to dedicating time and money to conserving its forests and providing incentives for landowners to do the same. 40% of Maryland's land is currently forested, and the state Department of Natural Resources (DNR) has implemented many measures to maintain or expand this forest cover. For example, the Woodland Incentive Program (WIP) provides cost sharing to private woodland owners for planting new trees and implementing practices that improve existing timber stands (Maryland Forest Service, 2008). Another new program in Maryland is the Lawn to Woodland Initiative (L2W), which offers private landowners the opportunity to convert their existing lawn to trees at no cost to them (Maryland Forest Service, 2014).

These state forestry cost-share programs, along with federal programs administered by the United States Department of Agriculture (USDA), serve as part of a larger GHG Emissions Reduction Act Plan (GHGRP), passed in 2012, which established an overall goal to reduce GHG emissions by 25% (using 2006 as the base year) in Maryland by 2020 (Department of the Environment, 2013). The forestry and sequestration efforts are projected to result in a reduction of 4.56 million metric tons of carbon, which is 8.2% of the total reduction goal.

1.2 Research Objectives

The aim of this study is first to evaluate whether landowners will invest in forestry with and without participation in a cost-share program. In other words, the analysis attempts to answer the question of whether the current subsidies are large enough to elicit program participation from private landowners. Next, this research evaluates whether larger subsidies would be justified by internalizing the carbon sequestration benefits the public receives from the forestry investments. Larger subsidies may be required to achieve greater program participation and carbon sequestration. Third, this research will assess the potential for these forestry efforts to make a difference in the fight against climate change in Maryland.

The analysis conducted consists of three forestry investment scenarios that align with the three main forestry cost-share programs available to private landowners in Maryland. The first investment scenario is a landowner that owns a loblolly pine stand that is at the appropriate age to be pre-commercially thinned. Pre-commercial thinning is a timber management improvement practice that is eligible for WIP, which is the forestry cost-share program for this scenario. The next two scenarios are similar in that they both consider converting land to forest. One investigates the conversion of agricultural land to an oak/hickory forest, and the other looks at the conversion of lawn to a red oak forest. Tree establishment on cropland is a conservation practice that is eligible for the Environmental Quality Incentives Program (EQIP), which is administered by the USDA Natural Resources Conservation Service (NRCS), and tree establishment on lawns is the purpose of the new L2W program in Maryland.

The net present value (NPV), which is the discounted value of a stream of annual net revenues, is calculated for a base case in each scenario, which is the case without the forestry investment in question. Next, the NPV is calculated assuming the landowner makes the forestry investment under two cases: with participation in a forestry cost-share program and without participation. Each of the NPVs are then calculated including potential financial compensation for the value of permanently sequestered carbon that results from the forestry investment. Sensitivity analyses are conducted to address uncertainty in the appropriate discount rate, carbon prices, social cost of carbon estimates, and scenario-specific elements.

To provide an idea of the scope of forestry cost-share programs in Maryland, geographic information systems (GIS) analysis was also conducted, which ties in with another motivation for this research. The National Aeronautics and Space Administration (NASA) provided funding for this research as part of its Carbon Monitoring Systems (CMS) program. Dubayah, Hurtt, Huang, and Swatantran (2013) participated in the CMS program and developed several GIS data layers for the state of Maryland that report the tree cover, tree height, and aboveground biomass present. From these data layers and a combination of other analyses, carbon sequestration potential of the land in Maryland was also calculated. There are various uses of the data produced by Dubayah et al. (2013), including using the data to monitor the success of forestry cost-share programs or to target eligible landowners. For this research, the data were used in the GIS analysis to estimate the total land in Maryland that is eligible for the forestry cost-share programs included in this research and the carbon sequestration potential should full program participation be achieved. The results of the GIS analysis provide another element to compare the actual and predicted program participation with the overall program potential.

1.3 Highlights of Main Conclusions

For the improving timber management scenario, pre-commercial thinning accelerates stand growth, which also accelerates carbon sequestration. For these reasons, the investment is definitely positive from a societal view, and it is positive from a private view if the additional timber benefits outweigh the pre-commercial thinning costs. At a discount rate of 5% (a typical private discount rate) and no participation in WIP, the benefits from pre-commercial thinning do not outweigh the costs. However, with cost-share assistance from WIP, the investment in pre-commercial thinning is worth it, even at a discount rate of 5%. WIP seems to be providing enough incentive for landowners to choose to improve timber management, and investing more in this program could increase carbon sequestration. The results of the GIS analysis estimate that around 737,000 acres of land in Maryland are eligible for WIP. However, from 2007 to 2014, only 814 landowners have participated in the program for improved management practices on 24,443 acres. Using the constant social cost of carbon estimate at a discount rate of 2.5% (a typical social discount rate), the carbon benefits provided by the improved timber management over the investment horizon are worth $146.82 per acre, while the current cost-share assistance is only $81.34 per acre. While the program already appears to provide the correct incentives to induce landowner participation, the actual participation may be increased by basing the cost-share assistance on benefits from permanently sequestered carbon.

For the conversion from cropland to forest scenario, the NPVs with annual collection of cropland cash rent are significantly higher than those of converting to forest, even with the cost-share assistance from EQIP. The NPVs are positive in all cases when the land is converted to forest, but they are not large enough to cover the opportunity cost of converting from agriculture. Even with the inclusion of carbon benefits, the landowner would likely not choose to convert their land to forestry. When the pastureland rent is used instead of the cropland rent, the NPVs from converting and participating in EQIP are higher than those without conversion for discount rates of both 2.5% and 3%. From 2009 to 2013, tree stand establishments have been conducted on 344 acres in Maryland, which is a small number as predicted by the analysis results. Perhaps by targeting marginal cropland or pastureland, the program would have greater participation for tree establishment practices.

For the conversion from lawn to forest scenario, the NPVs from converting to forest are substantially higher than those of maintaining lawn, even without harvesting any timber. The costs of managing a forest are much lower than those of managing a lawn. The decision of the landowner to participate in L2W and establish trees on their lawn space is largely determined by the aesthetic values of the landowner. Since it seems unlikely that the landowner would choose to harvest timber from one acre of trees, neither land use provides market benefits to the landowner, making the aesthetic benefits very important. The internalization of public benefits from carbon sequestration would make the investment in converting to forest even more attractive to the landowner. Using the constant social cost of carbon estimate discounted at 2.5%, the discounted carbon benefits provided by the conversion are worth $1,245.87 per acre when no timber is harvested, which is substantially higher than the current cost-share assistance of $335.91 per acre. The GIS analysis results estimate that around 230,000 acres of land in Maryland are eligible for L2W, which is much lower than the one million acre estimate set forth when the program was first launched. Since the program is new, no conclusions can be made regarding actual versus potential program participation, but the initial enrollment appears to be slow. Because the carbon sequestration potential is high for land that has not already been forested, investing more in L2W could accelerate Maryland's progress towards its GHG reduction goals.

Overall, several cases resulted where the NPV from the forestry investment did not exceed the opportunity costs using only private benefits and a typical private discount rate of 5%, but with a discount rate of 2.5% and carbon benefits included, the opportunity costs were exceeded. This represents a situation where the forestry investment is valuable to society, but from a private perspective, the landowner would likely not make the investment. The question of whether the government should make up the difference in order to induce the private landowner to invest and ultimately better society is raised from these results. Further, this question arises only with the internalization of one of the co-benefits (carbon sequestration), and in reality, the social benefits from forestry would be much more extensive.

1.4 Organization

The next chapter provides a review of climate change and forestry economics. The chapter includes topics such as the state of carbon prices around the globe, forestry's role in the carbon cycle, and land use alternatives. Chapter Three presents an in-depth explanation of Maryland's climate change initiatives and the role that forestry plays. Further, a detailed description of the forestry cost-share programs used for this analysis is laid out, including the results of the GIS analysis conducted to determine program eligibility across Maryland. Chapter Four discusses elements of CBA that are particularly important to analyzing forestry investments such as discounting and optimal timber rotations. Chapters Five, Six, and Seven explain the implementation of the three forestry investment scenarios and the results from each. Specifically, Chapter Five presents the improving timber management scenario and evaluates WIP, Chapter Six presents the conversion from agricultural land to forest scenario and evaluates EQIP, and Chapter Seven presents the conversion from lawn to forest scenario and evaluates L2W. Lastly, Chapter Eight provides a synthesized set of conclusions that use the CBA results, observed program participation, and the GIS analysis results. It also includes a discussion of the analysis limitations, future research, and policy recommendations.

CHAPTER 2. CLIMATE CHANGE AND FORESTRY ECONOMICS REVIEW

2.1 Summary of Topics

According to the International Panel on Climate Change’s (IPCC) most recent assessment report, concentrations of carbon dioxide in the atmosphere have increased by 40% compared to pre-industrial levels, which is just one of many statistics that brings to light the global carbon problem our world is currently facing (IPCC, 2013). Preventing the problem from escalating and searching for a global solution have been important topics in the political arena for over 20 years. A working group consisting of several agencies, including the Environmental Protection Agency (EPA), has been conducting ongoing research since 2010 to estimate the social cost of carbon, which is used to measure the benefits of carbon reductions in regulatory impact analyses (Interagency Working Group on Social Cost of Carbon, 2013). Further, economies around the world have implemented carbon pricing approaches to internalize the external costs of carbon emissions, which is an important step towards mitigating climate change (World Bank & ECOFYS, 2014).

One way that carbon in the atmosphere can be decreased is by sequestration, which is the process of capturing and storing carbon.. Sequestration by forests plays an important role in the carbon cycle, and increasing forested land is another component of the fight against climate change (Richardson & Macauley, 2012). However, since several alternative land uses to forestry exist, the costs and benefits that play a part in private land use decisions must be considered (Liu, Merrill, Gold, Kellogg, & Uchida, 2013). These topics will be covered in the following literature review to provide context for the analysis that follows.

2.2 Social Cost of Carbon

Estimates of the social cost of carbon vary immensely in the literature, depending on what model is used and what assumptions are made. According to the interagency working group discussed previously that includes the EPA, the definition of the social cost of carbon is the “estimate of the economic damages associated with a small increase in carbon emissions, conventionally one metric ton, in a given year.” Some of the damages it includes are “changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change” (Interagency Working Group on Social Cost of Carbon, 2013). The interagency group establishes four values for the social cost of carbon, which are based on the average results of three well-known integrated assessment models (IAMs). The three models are the Dynamic Integrated Climate and Economy (DICE) model, first presented by Nordhaus (1994), the Policy Analysis of the Greenhouse Effect (PAGE) model, first presented by Hope, Anderson, and Wenman (1993), and the Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) model, first presented by Tol (1997).

Pindyck (2013) defined IAMs as models that combine a climate science model with an economic model. There are six main elements to the common IAMs (DICE, PAGE, and FUND): future carbon emissions projections, future atmospheric carbon projections, projections of climate changes as a result of higher carbon concentrations, economic impacts from higher temperature projections, abatement cost estimates, and utility and time preferences. The modeler has freedom to specify key components of the model, generally requiring strong assumptions regarding the functional forms and parameter values, which is why the models produce differing results.

The models vary in how temperature changes are translated into economic damages (Greenstone, Kopits, & Wolverton, 2013). PAGE includes damages in three broad categories, while FUND and DICE include damages in several narrower categories. PAGE and DICE both include the possibility of catastrophic higher temperatures, while FUND does not. Another variation between the three models is in how they account for adaptation as a response to climate change. FUND induces adaptation practices in certain sectors, PAGE imposes adaptation exogenously, and DICE does not explicitly account for adaptation. Overall, PAGE and DICE produce similar estimates of the social cost of carbon, while FUND estimates are generally much lower.

Table 2.1 below shows the most recent estimates of the social cost of carbon from 2010 to 2050 using three different discount rates (2.5%, 3%, and 5%). These estimates are used by the United States government in project and policy assessments. As Table 2.1 shows, the social cost of carbon estimates increase over time. This is the case because “future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climate change” (Interagency Working Group on Social Cost of Carbon, 2013, p. 14).

Table 2.1 Annual Social Cost of Carbon Estimates, 2010-2050
(2007 $/ton)

Discount Rate Year	5.0%	3.0%	2.5%
2010	11	32	51
2015	11	37	57
2020	12	43	64
2025	14	47	69
2030	16	52	75
2035	19	56	80
2040	21	61	86
2045	24	66	92
2050	26	71	97

(Interagency Working Group on Social Cost of Carbon, 2013)

As one can see in Table 2.1, the discount rate chosen has quite an impact on the social cost of carbon. The discount rate reflects the marginal rate of substitution between consumption now and consumption in the future, and it used to calculate the net present value of a stream of future damages (Greenstone et al., 2013). The common discount rates used by government agencies are 2.5%, 3%, and 5%. The two higher discount rates are determined by historical interest rates. Since there is a popular concern that interest rates are uncertain in the future, the low discount rate is included as well. As the discount rate increases, the future becomes less important in the calculation. For example, the social cost of carbon in 2010 is $11 per ton using 5% as the discount rate and $51 per ton using 2.5%, which is a difference of $40. The power of discounting can make a drastic difference in calculating the damage caused by carbon emissions.

Which discount rate to use causes a lot of disagreement about which social cost of carbon is accurate. Further, the limitations of IAMs are believed to underestimate the true damage caused by increased carbon emissions (Stern, 2013). Overall, the models have remained mostly the same since their development. For example, weak damage functions have continued to prevail as the models have evolved despite advancements in research about the impacts of climate change. Greenstone et al. (2013) pointed out that the IAMs do not include inter-sectoral or inter-regional relationships. For example, the damages in one region on a neighboring region are not captured. Further, the IAMs do not account for changes in technology that will decrease the costs of adaptation practices over time. Moore and Diaz (2015) recently published the results of their modified DICE model, which was altered to include the impact of increasing temperature on long-run GDP growth. They concluded that the social cost of carbon is actually as high as $220 per ton. Several limitations to IAMs can be discussed, but the important takeaway is that researchers are continually working to increase the accuracy of the social cost of carbon estimates and lower the discrepancy between estimates.

2.3 Carbon Markets

Carbon markets exist to internalize the externality of carbon emissions (MacKenzie, 2009). Without them, emitters do not have to bear the full cost of the external damage they cause to society. Carbon pricing instruments include carbon taxes and cap-and-trade schemes, and carbon markets use one of these approaches or a combination of both. The majority of carbon prices that have recently emerged from carbon markets are much lower than the social cost of carbon estimates discussed in the previous section. The social cost of carbon estimates the damage from future carbon emissions. In contrast to the social cost of carbon, carbon prices that have emerged from carbon markets are signals of the costs of mitigation now. In other words, the social cost of carbon is the damage if we do nothing, and the carbon price is the cost to do something now. The relatively low carbon prices are an indication of the value of mitigating now to avoid the higher cost of damages in the future.

Cap-and-trade starts with the government setting a ‘cap,’ which is a maximum amount of aggregate total emissions (MacKenzie, 2009). A corresponding number of permits is distributed, either by giving them away or selling them at an auction. The ‘trade’ part comes in when firms buy and sell permits with each other depending on how much it costs them to reduce emissions compared to other firms. The price of carbon depends on how severe the cap is and it reflects to some extent the cost of reducing carbon. As the cap increases, allowing more emissions, the price of carbon decreases. Similarly, as the cap tightens, the price of carbon increases. Another important part of emissions trading schemes is the inclusion of offset credits. Offset credits are given for projects that reduce carbon emissions in one area in order to allow emissions in another area. Examples are the development of renewable energy, increased energy efficiency, and land-use change. An offset project of specific importance to this research is that of forestry offsets.

Using a carbon tax allows the carbon price to be set by the government through policy at a certain amount (World Bank & ECOFYS, 2014). Using the well-known Pigouvian approach, the optimal carbon tax should be set equal to its marginal social damage (Cremer, Gahvari, & Ladoux, 1998). This would mean that the carbon tax should be set to equal the governmental social cost of carbon estimate, but this has not happened because of uncertainty in markets and the social cost of carbon estimates themselves. Carbon taxes are often used in areas where there are not a large enough number of emitters to have a successful trading scheme. They are also used in conjunction with emissions trading approaches. For example, carbon taxes are combined with offset credits in South Africa and Mexico. Unique carbon market designs that blend different pricing approaches are essential for finding the most effective and efficient way to run a carbon market.

Different approaches produce vastly different carbon prices internationally. For example, the Tokyo cap-and-trade price is $95 per ton, while the Regional GHG

Initiative (RGGI) in the Northeastern United States sells carbon credits for around $3 per ton (World Bank & ECOFYS, 2014). The carbon prices from the 2014 World Bank Group Report for different economies around the world are included in the Table 2.2 and Table 2.3 below. Table 2.2 shows the carbon taxes set by governments, some of which have lower and upper limits as shown. Table 2.3 shows the carbon prices that have emerged from cap-and-trade schemes. The carbon price in Japan of $95 per ton is an outlier, which is attributed to the fact that no excess credits were sold when the market was implemented, so no trading was possible.

Table 2.2 Carbon Taxes around the World
($ per ton of carbon)

Region	Carbon Tax
Sweden	168
Norway	4-69
Switzerland	68
Finland	48
Denmark	31
British Columbia, Canada	28
Ireland	28
Australia	22
United Kingdom	16
France	10
Iceland	10
South Africa	5
Mexico	1-4
Japan	2

(World Bank & ECOFYS, 2014)

Table 2.3 Carbon Prices from Cap-and-Trade Programs around the World
($ per ton of carbon)

Region	Carbon Price
Tokyo	95
California, United States	11
Shenzhen, China	11
Guangdong, China	10
Quebec, Canada	10
Beijing, China	9
European Union	9
Shanghai, China	5
Tianjin, China	4
RGGI, United States	3
New Zealand	1

(World Bank & ECOFYS, 2014)

The two emissions trading schemes within the United States are in California and in the Northeastern region (RGGI). The California Cap-and-Trade Program was established in 2012, and the first compliance period began on January 1, 2013 (World Bank & ECOFYS, 2014). Carbon offsets are sold within the continental United States and Quebec. Carbon permits were initially allocated by the government to large entities based on production and efficiency, and the rest are auctioned off periodically. The original emissions cap was set 2% below the 2012 forecast of emissions, and it was set to decline 2% in 2014 and 3% in 2015 (Kossoy & Guigon, 2012). The carbon price at the beginning of 2012 was $15.40, which spiked at the end of July and then steadily decreased to around $11 by the end of 2012 (Climate Policy Iniative, 2015). In 2013, the price increased to $16.40 at the beginning of January but decreased back to around $11 by the end of the year. At the beginning of 2015, the carbon price was $13.02, and has remained steady since then. The GHG Reduction Fund in California receives the auction proceeds, which are used to reach three main goals: sustainability in communities, clean and efficient energy, and improved waste diversion.

RGGI, launched in 2009, is a market-based program designed to reduce carbon emissions from power plants in the following nine states: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont (World Bank & ECOFYS, 2014). In 2014, a new emissions cap of 91 million tons of carbon was implemented, which is 45% less than the previous cap set in 2012. The cap was lowered so substantially because the actual emissions had consistently been about 35% lower than the earlier cap. The cap will decline by 2.5% annually from 2015 to 2020. Most emission allowances are sold through auctions, and the proceeds are invested to promote energy efficiency and renewable energy. The clearing price for the first auction in September of 2008 was $3.07, which steadily decreased to around $1.90 by the end of 2009 and stayed about the same until the end of 2012 (RGGI Inc., 2015). At the beginning of 2013, the price started to increase, and the most recent auction in March of 2015 cleared at $5.41.

Both the RGGI and the California Cap-and-Trade Program incorporate forestry offsets into their initiatives, which the next section discusses.

2.4 Forestry in the Carbon Process

While the main focus of climate change legislation tends to be the reduction of new emissions, forestry plays a unique role in that it reduces carbon that is already in the atmosphere. Forested lands possess the ability to sequester carbon from the atmosphere, making them a valuable resource in the climate change arena. “Carbon sequestration is the process of capture (through photosynthesis) and long-term storage of atmospheric carbon dioxide” (Sedjo & Sohngen, 2012, p. 128).

The carbon sequestration process in forests takes place within tree biomass, which is defined as “any part of living or nonliving tree tissue, for example, the trunk, branches, leaves, or roots” (Sedjo & Sohngen, 2012, p. 128). The walls of plant cells are comprised of cellulose or lignin, and carbon is needed to build these fibers. Plants sequester carbon for this purpose through photosynthesis, which is critical for plant growth. Carbon is also sequestered by the soils of forestland through two processes: humification and microphotosynthesis. Humification occurs when plants die and their biomass decomposes into the soil, and microphotosynthesis occurs when photosynthetic bacteria in the soil itself sequesters carbon from the atmosphere. Existing forests can be managed to increase carbon sequestration in several ways such as extending harvest rotations or ensuring that carbon storage is maintained in wood products after harvest (Cunha-e-Sa, Rosa, & Costa-Duarte, 2013).

It is important to note that some of the sequestered carbon is released back into the atmosphere during harvest or when the tree dies and starts to decompose. Exactly how the forestry carbon cycle works depends on the tree species, the management practices used, the rotation length, and the use for harvested wood. If the timber is burned for fuel, the carbon will be released back into the atmosphere, but if it is used for building furniture or houses, the carbon remains sequestered. Figure 2.1 shows a simplified version of how vegetation sequesters and releases carbon through different facets.

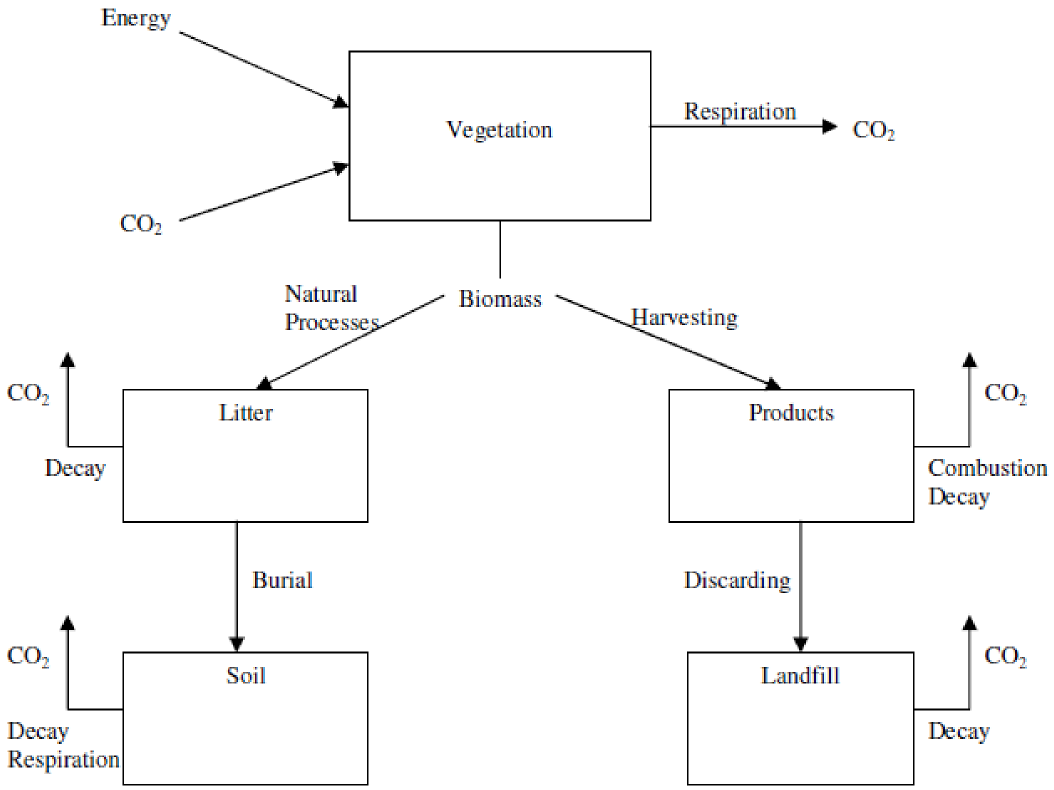

Figure 2.1 Simplified Carbon Process (Wieland & Strebel, 2008)

Since forestry is an important carbon sink, it makes sense that it would be included in carbon markets as an offset option. RGGI allows forest offset projects in the form of reforestation, improved forest management, avoided conversion, and afforestation (RGGI Inc., 2013). Reforestation is when trees are established on land that had recently been forested, and afforestation is when trees are established on land that was not previously forested. All offset projects must be in one of the nine RGGI states, but afforestation is only eligible in Connecticut and New York. Offset credits are awarded based on the net additional tons of carbon sequestered within the project boundary for each period. The California Cap-and-Trade Program allows the following forest offset projects: reforestation, improved forest management, and avoided conversion (Air Resources Board, 2011). The forestry projects can be located anywhere within the United States. Like RGGI, the offset credits are awarded based on any carbon sequestered in addition to a “business-as-usual” scenario. Protocols exist to establish the amount of carbon sequestered as a result of the various forestry offsets.

Even though forestry offsets are included in many carbon markets, many challenges have arisen in their implementation. The first is additionality, which is the requirement that the emissions reductions (sequestration) would not have taken place if it were not for the offset project (Chomitz, 2000). A common example of a project where additionality is questionable is one where the project makes money and would be implemented with or without the offset program. The second challenge is determining the baseline “business as usual” scenario because so many different scenarios could take place in absence of the project. Similarly, the third challenge is the measurement of carbon sequestered with the project. Monitoring the progress of the offset project can become very costly. Finally, permanence is of concern because of the possibility of carbon sequestration being reversed, whether it is accidental or deliberate. Even though the challenges seem great, forestry cannot be ignored as valuable offset option and an integral piece in combating climate change.

2.5 Forestry and Alternative Land Uses

As discussed above, forestland is valuable in the fight against climate change, but that does not guarantee that it is a profitable land use choice for a private landowner. One must consider alternative land uses such as agriculture and urban development. Urbanization in the eastern United States is causing a decline in agricultural and forest lands (Liu et al., 2013). With the loss of agricultural and forest lands also comes losses in ecosystem services like water filtration, wildlife habitat, and carbon storage. Private landowners have an incentive to provide private goods such as crops and timber, but they do not necessarily have incentives to preserve ecosystem services that benefit society since the positive social externalities are not internalized by the landowner.

One way to incentivize private landowners to provide ecosystem services is by public policy. In the design of public policy, it is important to consider tradeoffs between alternative land uses when thinking of ways to preserve ecosystem services (Liu et al., 2013). For example, conversion to forestland improves water quality and sequesters carbon, but it also takes land away from development and other agricultural uses. Urbanization and crop production play an important role in regional economic growth, which cannot be ignored. Decision-makers need to have an assessment of the tradeoffs between multiple land uses and land management scenarios.

Private landowners make land use decisions based on the net present value (NPV) of the future revenue streams from all land use options (Nelson & Hellerstein, 1997). Output quantities, input and output prices, and the discount rate are all part of determining the NPV for each land use. Plantinga, Mauldin, and Miller (1999) estimated land use shares by solving an individual landowner’s profit maximization problem in three states: Maine, South Carolina, and Wisconsin. They then used an econometric model to predict the estimated land use shares using rents from agriculture and forestry, land quality measures, and transportation costs as explanatory variables. Rents from forestry were measured as the NPV of future timber revenues per acre, and rents from agriculture were measured as the NPV of future crop or pasture revenues per acre. They used population density measures to explain the share of land that was developed. As expected, their results showed that when forest rent increases, the share of agricultural land relative to forestland decreases, all else equal. The opposite is also true. Interestingly, changes in forest and agricultural rents did not appear to have a significant effect on the allocation of land to urban development.

Since this research has a focus on forestry, the rest of this section further explains the costs and benefits associated with forestry ownership.

2.5.1 Private Costs of Forestry

There are two types of forest owners: industrial and nonindustrial. Industrial forest lands are managed for timber production, and they are typically owned by wood processing facilities (Newman & Wear, 1993). Owners of nonindustrial private forest (NIPF) land are likely to value non-timber benefits, such as hunting, aesthetics, and wind breaks, as highly as the timber production benefits. Newman and Wear (1993) compared the behavior of industrial and nonindustrial forest owners, and they find that nonindustrial owners still practice profit maximizing behavior. Both types of forest owners will be treated equally in this research, and the NPV that maximizes profit will be used to predict landowner decisions.

Most of the private costs of forest ownership are incurred at the time of forest establishment. Site preparation includes clearing past logging residue, preparing seedbeds, and controlling for weeds (Bair & Alig, 2006). Planting costs include seedlings, shelters, stakes and other equipment. Seedlings can be planted by hand or with machines, which makes labor and fuel prices important factors for forest landowners as well. Costs besides those incurred during forest stand establishment depend on the intermediate management strategies chosen. Some examples of intermediate management costs are fire protection, thinning costs, boundary maintenance, management plans, herbicide and fertilizer treatments, pruning, harvesting costs, and surveying (Bair & Alig, 2006). Certain costs can depend on the tree species. For example, seedling costs and fertilizer recommendations vary amongst species. The United States Department of Agriculture (USDA) and several land grant university extension services publish periodic estimates of these costs. For this analysis, the extension services of the University of Maryland, Pennsylvania State, Virginia Tech, the University of Arkansas, and the University of Florida are used as data sources.

Private landowners who want to dedicate their land to forestry may have access to government cost-share programs. Such programs are in place to provide incentives for landowners to dedicate their land to forestry because governments recognize the benefits that forests provide, including those that help in the fight against climate change (Kooten, Binkley, & Delcourt, 1995). This has a significant impact on the private costs of owning forest. In some cases, 100% of the establishment costs are covered by the cost-share program, making it much less costly for landowners. However, there are often constraints to participating in such programs, such as long-term time commitments and eligibility requirements. Details on the current forestry cost-share programs available to Maryland landowners are included in the next chapter.

2.5.2 Private Benefits of Forestry

The main benefit that arises from forestry is the revenue from harvesting timber, which can come from a commercial thinning or a final harvest. In estimating the benefits from timber harvest, it is important to understand the distinctions between different grades of timber and the prices associated with each. As a tree grows, its grade shifts from pulpwood to sawtimber to veneer (Jacobson, 2008). However, certain species will never reach the veneer grade, so that needs to be taken into account. Further, the species is important in determining what the timber will likely be used for, which drastically impacts the benefits from carbon sequestration. Tree growth data for this analysis was obtained from the Forest Research Group, which is a private research organization in Massachusetts, and from the United States Forest Service, which will be discussed in detail in later chapters. Prices are commonly given in terms of volume, which could be board feet, cords, or cubic feet. The most recent analysis of timber prices in the United States conducted by the USDA includes real price projections to 2050 for hardwood and softwood timber of different grades from different regions, which will be used in this analysis (Haynes, 2003). While this publication may seem outdated, comparisons between the price predictions and more recently observed prices provided some validation for the predictions, which is discussed in more detail in the implementation chapters.

Another private benefit from forestry ownership is the aesthetic value of trees. The Forest Service conducts a National Woodland Owner Survey every year, which acts as a census of forest owners across the United States. When asked the question of the importance of owning trees to enjoy their beauty or scenery, approximately 70% of the forest owners that were surveyed answered “important” or “very important” (United States Forest Service, 2014). McPherson, Simpson, Peper, Maco, and Xiao (2005) included aesthetic benefits in their analysis of trees in five United States cities. They calculated aesthetic benefits based on the contribution of a large tree in the front yard to a house sale price in each city. Also, they take the distribution of street trees and the tree growth rates into account for each city. Annual aesthetic benefits per tree range from $21 in Bismarck to $67 in Berkeley. These estimates are for urban trees, and this analysis is focused on rural trees, for which aesthetic values are more difficult to quantify. While timber revenues are much easier to monetize, aesthetic benefits are an important private benefit as well. Several other co-benefits from forestry are presented in the next section.

2.5.3 Social Benefits of Forestry

Public, or social, benefits from forestry ownership are extensive. Besides carbon sequestration, forests provide several co-benefits such as improved water quality, improved air quality, increased shade and reduction of building temperatures, energy savings, flood control, wildlife habitat preservation, and recreation opportunities. This section discusses the valuation techniques that have been used in the literature for carbon sequestration, improved air quality, and improved water quality as a result of forestry.

As already discussed, trees can sequester carbon from the atmosphere and store it in their roots, trunks, branches and leaves over their lifetime. Nowak (1994b) conducted a valuation of the reduction in atmospheric carbon by urban forests in Chicago. First ground samples were collected for 8,996 trees in the study area including diameter at breast height (dbh), tree height, and species. Allometric equations, which are equations that relate the easily quantified characteristics of trees (such as height and species) with more difficult properties (such as biomass), were used to calculate biomass for each tree. Then, tree-growth was estimated based on measurement of growth increments. The growth increments came from a sample of 543 trees removed in Chicago in the early

1990's that were measured to determine average annual growth for major tree species. The result estimated that 5.6 million tons of carbon is stored in Chicago's trees. The total carbon storage can be monetized using the social costs of carbon estimates previously discussed. Nowak's study illustrates the fact that estimating the benefits from carbon sequestration requires a large amount of ground sampling and historical growth data, which can be costly and difficult to obtain. However, governments rely on such measures for regulatory analysis, so these types of studies continue to be conducted.

Trees improve air quality in several ways. First, they can lower building temperatures by shading, which can in turn lower building energy use (Nowak, 1994a). This decrease in energy use can decrease power plant emissions. Trees can also intercept particles from the atmosphere and absorb pollutants. Besides reducing carbon dioxide, trees can also help decrease carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, and other particulate matter in the atmosphere. To estimate the removal of air pollutants by trees, one must know the rate at which the surface of a tree cleans a given pollutant from the air. Once the pollution removal by trees is known, the monetary value of the pollutants removed is calculated by using the costs for emission control. In other words, the cost of preventing the emission of the pollution by using control strategies is used as the value of the pollutant removal by trees. Nowak uses the following 1990 dollar values per metric ton of pollutant removed from the California Energy Commission: $490 for ozone, $920 for carbon monoxide, $1,307 for particulate matter, $1,634 for sulfur dioxide, and $4,412 for nitrogen dioxide. For an acre of trees in Chicago, the estimated annual monetary value of pollution removal was $61 in 1991.

Improved water quality as a result of trees is often measured by the amount of stormwater runoff reduction and monetized by using the costs for controlling stormwater runoff. Stormwater runoff is the "second most common source of water pollution for lakes and estuaries and the third most common source for rivers nationwide (Xiao, McPherson, Simpson, & Ustin, 1998). Trees are capable of intercepting and storing stormwater, which reduces runoff volumes. One way to monetize the costs for controlling stormwater runoff is to sum the total money spent to store water in a basin instead (McPherson et al., 2005). The costs would include acquiring retention basin land, maintenance, operations, and construction. McPherson et al. (2005) calculated a stormwater reduction benefit ranging from $31 per tree in Glendale to $89 per tree in Berkeley. Improved water quality also arises when forests filter pollutants such as nitrogen and phosphorus that come from agricultural activities (Norton & Fisher, 2000).

The co-benefits from forestry are vast but very difficult to quantify and especially to monetize, which becomes a limitation to evaluating forestry investments. Further, many of the attempts to quantify co-benefits from forestry in the literature have been for urban forests, as was presented in this section. Since this analysis considers rural forestry investments, the estimates from the literature are not directly applicable. It is important to note that only the benefits from permanently sequestered carbon are included in this analysis, so the total social benefits from the forestry investments in question are likely higher than the ones calculated.

2.6 Forestry Investment and Policy Literature

Econometric studies that explain the behavior and management decisions of forest landowners and try to identify the determinants of certain forestry investments have been conducted in the literature. Additionally, researchers have investigated the impacts of government forestry programs on private landowner investment decisions.

Beach, Pattanayak, Yang, Murray, and Abt (2005) combined results from 39 econometric studies through a meta-analysis with the goal of identifying the determinants of forest management by nonindustrial private forest owners. The meta-analysis technique used was vote-counting, which is the process of categorizing the findings from each study (significantly positive, significantly, negative, or not significant for each variable) and the category with the most “votes” for each variable is determined to be the best representation. Most of the studies used in their meta-analysis were from the United States, with a few from other countries. The majority of the models were either binary choice models that estimated the probability of a forest landowner making a certain management decision (timber stand improvements, reforestation, or harvesting) or ordinary least squares regressions that estimated the influence of the independent variables on the amount of a management activity that took place (measured by acres).

They used the following categorization of the determinants of forest management decisions: market drivers, policy variables, owner characteristics, and plot conditions. The main market driver that most studies included was timber prices, and surprisingly, the percentage of studies that found a significantly positive effect on forest management investment was lower than they expected. Plot size seemed to have a consistently positive and significant effect on forest management investment, but owner characteristics did not provide conclusive results across management practices. This suggests that forestry cost-share programs might receive higher acreage participation if they were targeted towards large landowners

The policy variables are of special importance to this analysis. Tax incentives, cost-share programs, and technical assistance are typical examples of policy variables included in the analysis of forestry investments. Beach et al. (2005) found that policy variables were rarely included in harvesting studies, which makes sense since the purpose of such programs is usually to incentivize reforestation and timber stand improvements, not necessarily harvesting. The results regarding the impact of policy variables on the decision to reforest or improve timber stands are shown in Table 2.3 and 2.4. A total of 16 reforestation studies and five timber stand improvement studies were used

Overall, they concluded that more empirical analyses found that landowners respond to government programs than found that landowners respond to other factors, such as market prices. However, the results showed that the frequency of significance was higher for reforestation than for timber stand improvement. This may indicate that cost-share assistance for reforestation would result in higher participation than for timber stand improvements.

Table 2.4 Impact of Policy Variables on Reforestation Behavior

Policy Variables	Frequency of Inclusion in Studies	Frequency of Positive Significance (Out of total studies that included each variable)
Cost-Share	80%	100%
Technical Assistance	29%	100%
Tax Incentives	18%	67%

(Beach et al., 2005)

Table 2.5 Impact of Policy Variables on Timber Stand Improvement Behavior

Policy Variables	Frequency of Inclusion in Studies	Frequency of Positive Significance (Out of total studies that included each variable)
Cost-Share	50%	50%
Technical Assistance	60%	67%
Tax Incentives	20%	100%

(Beach et al., 2005)

Most agree that government cost-share programs have a positive impact on the forestry industry since timber production is a long-term commitment and incentives may be required to encourage investment by landowners. However, some argue that such programs do not induce additional investments in such activities as reforestation and improved timber management, but instead, they replace the private capital that would have been invested anyway. de Steiguer (1984) examined data from the participation of 10 states in two federal government forestry cost-share programs, the Federal Incentives Program and the Agricultural Conservation Payments Program, to determine whether these programs induced additional investments in forestry. Using regression analysis, he estimated total private autonomous investment in tree planting as a function of personal income, expected stumpage prices, expected interest rates, and total cost-share money available for tree planting from the two cost-share programs mentioned above. He found no evidence of capital substitution, and therefore, concluded by saying that the opponents of forestry cost-share may not have a valid argument.

The majority of the past research focuses on landowners who have already invested in forestry to try to explain and predict their behavior, some including government cost-share programs and others without. This research analyzes the perspective of a private landowner facing an investment decision to either establish new forestland or improve existing forestland, and investigates the differences in investment decisions with and without cost-share programs. The results will contribute to the question of whether cost-share programs are only substituting capital that would have been invested in forestry even in the absence of the program. Further, this analysis will explore the possibility of compensating private landowners not only by covering the costs of investing in forestry, but also by subsidizing the carbon sequestration that results from their forestry investment. The analysis is set in the state of Maryland, and the next chapter will present an in-depth look at the cost-share programs currently available to landowners there and their role in Maryland’s climate change policy.

CHAPTER 3. THE ROLE OF FORESTRY PROGRAMS IN MARYLAND'S CLIMATE CHANGE INITIATIVES

3.1 Maryland's Climate Change Initiatives

Maryland's GHGRP, passed in 2012, established an overall goal to reduce GHG emissions by 25% (using 2006 as the base year) by 2020 (Department of the Environment, 2013). According to the Maryland Department of the Environment (Air and Radiation Management Administration, 2011), Maryland has one of the longest tidal coastlines (behind Florida, California, and Louisiana), which makes it one of the states that is most vulnerable to rising sea levels that result from climate change. There have been 20 states, including Maryland, that have implemented GHG emissions targets (Center for Climate and Energy Solutions, 2015). The reduction goals across states cannot be directly compared because they have different baseline years and target years. However, for some perspective on Maryland's progressive goals, the state of Connecticut has a reduction target of 10% (using 1990 as the base year) by 2020. This is clearly a much more conservative goal than the one Maryland has in place.

Maryland passed several pieces of legislation that led up to the GHGRP of 2012 (Air and Radiation Management Administration, 2011). The Healthy Air Act, passed in 2006, included a plan for Maryland to join RGGI. The Maryland Clean Cars Act, passed in 2007, implemented stringent emissions standards, and EmPOWER Maryland, passed in 2008, was designed to reduce electricity use by providing incentives for homeowners to increase their energy efficiency. Further, the Maryland Renewable Energy Portfolio Standard, amended in 2008, requires that 20% of the electricity used in Maryland must be from renewable sources by 2022.

The GHGRP plan describes various programs in place to either reduce emissions or for offsetting reductions. The programs are divided into the following categories: energy, transportation, agriculture and forestry, zero waste, buildings, innovative initiatives, land use, and other. Specific to forestry, the action plan focuses on managing forests to capture carbon, planting new forests, protecting wetlands to capture carbon, using biomass for energy production, and increasing urban trees. The forestry and sequestration efforts are projected to result in a reduction of 4.56 million metric tons of carbon dioxide emissions in Maryland by 2020, which is 8.2% of the total reduction goal. In order to reach the projected carbon emissions reduction from forestry and sequestration efforts, the DNR in Maryland, with help from federal agencies such as the NRCS, has many forestry cost-share programs in place.

Maryland’s land is currently around 40% forested, and in 2011, 89.4 million tons of carbon was stored by forests in Maryland (Department of the Environment, 2013). Figure 3.1 shows the three physiographic regions in Maryland, which are determined by major geologic landforms. Pine species are common in the Coastal Plain region and a mix of northern hardwoods species are common in the Mountain and Piedmont regions (Highfield and Sprague 2011).

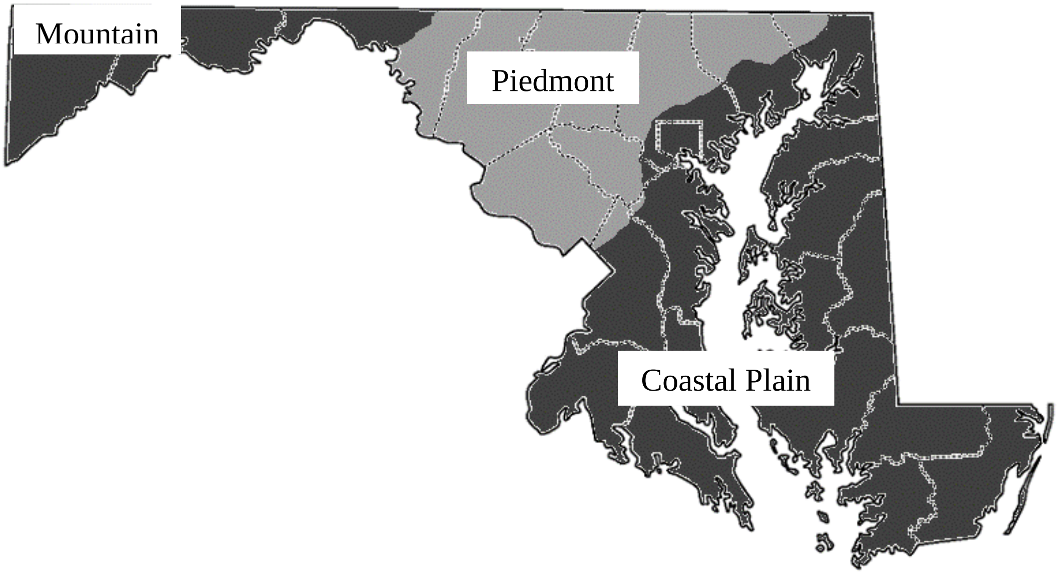

Figure 3.1 Maryland’s Physiographic Provinces (Highfield & Sprague, 2011)

3.2 United States Forestry Cost-Share Programs

Forestry practices that are eligible for federal cost-share assistance are a subset of a longer list of agricultural conservation practices. The federal conservation programs are often intertwined, and this is by no means a comprehensive summary of all programs available. This section presents the main program that offers cost-share assistance for forestry practices to landowners in Maryland. Other programs such as the Conservation Reserve Enhancement Program and the Agricultural Management Assistance Program allow some forestry practices, but not nearly as extensively.

The Environmental Quality Incentives Program (EQIP), administered by the NRCS, is a conservation program that provides financial assistance to agricultural landowners, including forest landowners, to reduce pollution and improve the state of natural resources in Maryland (Natural Resources Conservation Service, 2015). The program helps landowners plan and implement conservation practices, such as structural changes or management changes, on agricultural or forested land. One of the national priorities for EQIP is to increase biological carbon storage and sequestration, which is directly relevant for forestry and climate change. The financial assistance is based on the average cost to undergo the agreed upon conservation practices. Participants can have varying contract lengths depending on the conservation practice, but total assistance is limited to $300,000 per person over a six-year period. Examples of eligible conservation practices that deal with forests are forest stand improvement, riparian forest buffers, forest management plans, and tree and shrub site preparation and establishment. The conservation practices must be maintained for the life span of the specific practice, according to NRCS standards, which is 15 years for the forestry practices.

From 2009 to 2013, forest stand improvements have been conducted on 1,698 acres in Maryland (Morgart, 2014). Tree and shrub establishments have taken place on 344 acres, and 24 forest management plans have been executed through EQIP in Maryland. These seem like small numbers, but it is important to remember that EQIP focuses on many other conservation practices besides forestry. For the 2015 EQIP participants, there are 98 eligible practices, with only five of them dealing with forestry.

The average EQIP costs for forestry options relevant to this analysis will be included in a later chapter that discusses data.

3.3 Maryland Forestry Cost-Share Programs

Maryland is perhaps one of the more progressive states when it comes to providing cost-share assistance to landowners in order to incentivize forestry investments. A detailed description of Maryland's forestry cost-share programs is presented in this section, followed by the results of a Geographic Information Systems (GIS) analysis that was conducted to shed some light on how much land in Maryland meets the eligibility requirements for each program and what the carbon sequestration potential of that land is.

3.3.1 Woodland Incentive Program

The Woodland Incentive Program (WIP), administered by the Maryland DNR, provides cost sharing to private woodland owners for planting new trees, site preparation, and timber stand improvement (Maryland Forest Service, 2008). Anyone who owns between 5 and 1,000 acres of woodland and agrees to uphold forestry practices for 15 years is eligible for this program. The program covers up to 65% of the costs incurred by the private landowner for forest management, not to exceed $5,000 per year or $15,000 in a 3-year period. The 65% payment is made only after the costs have been incurred by the landowner. Eligible costs to improve woodland are thinning, pruning, prescribed burning, crop tree release, site preparation for reforestation, herbicide treatments, and seedling plantings. The program was put in place as a way of incentivizing the development and management of private nonindustrial forests because they provide environmental benefits, aesthetic benefits, and habitats for wildlife. From 2007 to 2014, 814 landowners have participated in the program for management practices on 24,443 acres (Rider, 2014). The total cost-share assistance for these 814 participants was $834,803, which is an average of $104,350 annually.

GIS Analysis was used to isolate any patches of land that meet the eligibility requirements for WIP[2]. The data used for this analysis were from the Maryland Carbon

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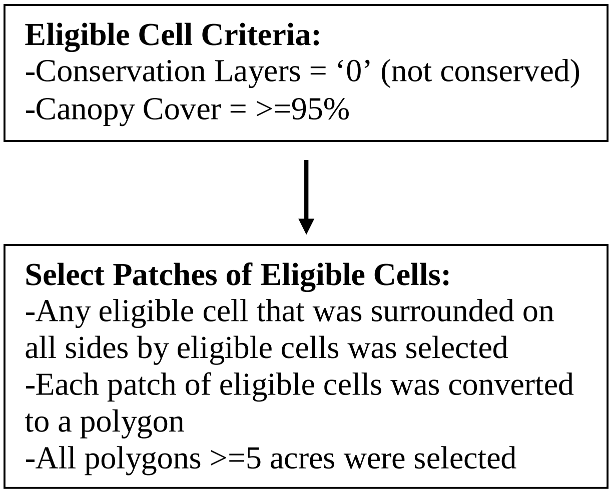
[2] Refer to the appendix for a detailed description of the GIS analysis

Monitoring System (CMS) Database (Dubayah et al., 2013) and the Maryland Protected Lands Map Server (Maryland iMAP, 2014). The CMS data layers used were a statewide 30 meter resolution canopy cover raster layer, which reports the percentage of canopy cover for each cell and a statewide 90 meter resolution carbon sequestration potential raster layer, which reports the difference between the total lifetime carbon sequestration potential and the current aboveground biomass for each cell. The total lifetime carbon sequestration potential was calculated using an ecosystem demography model, which assumed that the entire state was restored to its natural vegetation of trees. The iMap data layers used were a combination of layers showing land in Maryland that has already been conserved in some way, including land that DNR owns and land under easements.

The process used to determine the patches of land that are eligible for WIP is shown in Figure 3.2. First, the cells that were not already in a conservation program and had a canopy cover of at least 95% were selected as eligible cells for WIP participation. From the eligible cells, polygons of at least 5 acres were selected, and the carbon sequestration potential statistics were calculated within the eligible polygons.



Eligible Cell Criteria:
-Conservation Layers = ‘0’ (not conserved)
-Canopy Cover = >=95%

Select Patches of Eligible Cells:
-Any eligible cell that was surrounded on all sides by eligible cells was selected
-Each patch of eligible cells was converted to a polygon
-All polygons >=5 acres were selected

Figure 3.2 WIP Eligibility According to GIS Criteria

The results showed a total of 736,761 acres of land in Maryland is eligible for WIP, and the carbon sequestration potential (excluding current aboveground biomass) on this land is approximately 138.8 million metric tons. To provide some context for these results, the size of Maryland is approximately 8 million acres, of which about 3 million acres are forested, and Maryland emitted approximately 97 million metric tons of carbon in 2013. In other words, about a year and a half's worth of total emissions could be sequestered on eligible WIP land.

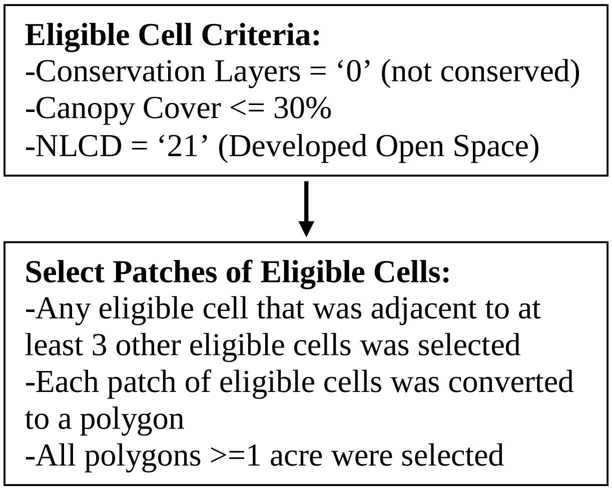
The eligible land for WIP is much larger than the program participation that has been observed. Perhaps, private landowners observe negative net present values of improving timberland management, even with the cost-share assistance. The question of whether it is due to the size of the cost-share assistance not being large enough will be addressed in this analysis.

3.3.2 Lawn to Woodland

The L2W Initiative is a new program primarily aimed at afforestation, which is the establishment of new forest cover. The program is a joint effort of Maryland DNR and the Arbor Day Foundation. According to the advertisement materials for this new program, Maryland has nearly one million acres of lawn that could potentially be converted to forests (Maryland Forest Service, 2014). This program seeks to plant trees on land that is currently lawn, and it fully funds the trees, tree planting, and monitoring assistance. Any private landowner with more than one acre of turf qualifies for the program. The program was launched in 2104 in four pilot counties, Montgomery, Howard, Carroll, and Baltimore, and it is being extended statewide in 2015. In 2014, a total of 4,300 trees were planted on 12 sites that totaled 14.6 acres in size (Feldt, 2014).

Again, GIS analysis was used to isolate patches of lawn that are eligible for this program in Maryland, with a specific goal to see where the one million acres of lawn estimate came from. The data used for this analysis were the same as for the WIP analysis, with the addition of data from the National Land Cover Dataset (NLCD) (Jin et al., 2013). The NLCD layer reports the land cover classification for each cell (total of 16 classifications).

The process used to determine the patches of land that are eligible for L2W is shown in Figure 3.3. First, the cells that were not already in conservation programs, had less than or equal to 30% canopy cover, and were classified as '21' in the NLCD layer were selected as eligible cells for L2W participation. Originally, 0% canopy cover was used as the eligibility criteria, but the resulting eligible acres was only around 28,000. In reality, most lawn space would have a few trees on it, so 30% canopy cover was chosen to account for that. The land cover classification of ‘21’ indicates ‘developed, open space,’ which is what most large lawn spaces in the Maryland imagery layer were classified as. It is by no means a perfect choice though because the ‘developed, open space’ classification also includes land that is not lawn, such as baseball fields and golf courses. However, a choice needed to be made in order to move forward with the analysis. From the eligible cells, polygons of at least 1 acre were selected, and the carbon sequestration potential statistics were calculated within the eligible polygons.



Eligible Cell Criteria:
-Conservation Layers = ‘0’ (not conserved)
-Canopy Cover <= 30%
-NLCD = ‘21’ (Developed Open Space)

Select Patches of Eligible Cells:
-Any eligible cell that was adjacent to at least 3 other eligible cells was selected
-Each patch of eligible cells was converted to a polygon
-All polygons >=1 acre were selected

Figure 3.3 L2W Eligibility According to GIS Criteria

The results showed a total of 230,450 acres of land in Maryland is eligible for L2W, and the carbon sequestration potential (excluding aboveground biomass) on this land is approximately 301.6 million metric tons, which is equivalent to about three years of Maryland’s annual emissions. You can see that this result is much lower than the one million acre estimate, which could be due to differences in the GIS analyses approaches. However, the enormous difference in estimates raises some concerns. Perhaps the state overestimated the amount of eligible land for this new program. However, the great effort that the state of Maryland makes to promote new forest cover and improve management on existing forest cover is undeniable, regardless of the discrepancies in estimated eligible land.

CHAPTER 4. COST-BENEFIT ANALYSIS APPLIED TO FORESTRY INVESTMENTS

4.1 Components Critical to Forestry Investments

Cost-Benefit Analysis (CBA) is a well-known method for evaluating alternative investments and can be used to analyze forestry investment scenarios. This research will use CBA to evaluate forestry investments, specifically focusing on the differences in returns with and without participation in a government cost-share program. There are a few aspects of CBA that are critical to forestry investments, which will be the focus of this chapter. Specifically, since forestry is an abnormally long term investment, discounting plays a very important role in the analysis. We already saw the role that discounting plays in estimating the social cost of carbon as well. Also, there are different methods for determining the optimal rotation length, which can change the results. A brief description of the scenarios and sensitivity analysis conducted in this research is in order as well.

4.2 Discounting and its Impact on Forestry Investments

As previously stated, the discount rate reflects the marginal rate of substitution between consumption now and consumption in the future. It is used to calculate the net present value of a stream of future costs and benefits (Greenstone et al., 2013). The further the benefits and costs occur in the future, the lower their present value today. This becomes especially important for forestry investments because the majority of the costs, such as establishment costs and fertilizer treatments, are incurred towards the beginning of the time horizon and the benefits from harvesting timber occur much later. When a landowner is faced with the decision to invest in something that has substantial upfront costs and no benefits until year 20, it does not seem very appealing. However, people continue to invest in forestry, which could be attributed to the co-benefits that forestry provides, such as aesthetic value, lower pollution levels, and carbon storage.

Choosing the appropriate discount rate for forestry investments is a somewhat controversial matter. As the discount rate increases, the less the future is valued. Kula (1988) pointed out that discounting easily wipes away the future benefits from harvesting timber, even though the risk that forestry investments will become worthless someday in the future is very low. Because of this, some argue that forestry investments should be discounted at an especially low rate. However, choosing a specific discount rate just to make an investment look appealing does not seem like the best approach, especially since one could also argue that investing in forestry can come with substantial risks. Such risks might include fluctuating future prices of timber, fire damage, wildlife damage, invasive species, and wind or other weather damage. Perhaps forestry investments should be discounted the same as any other investment. Moreover, discounting is about the opportunity cost of investing elsewhere, and such alternatives are relevant for forestry investments as well

The damages from GHG emissions occur over several decades and the same concerns about the longevity of the analysis are evident for estimating the social cost of carbon as estimating the private returns from a forestry investment. Consequently, it makes sense that the discount rates chosen for this analysis are based on those used by an interagency working group consisting of several agencies including the EPA and the USDA to estimate the social cost of carbon (2.5%, 3%, and 5%) (Greenstone et al., 2013). The two higher discount rates (3% and 5%) were chosen to represent historically observed interest rates. The 2.5% discount rate was chosen to represent the concern that interest rates over time are uncertain and to incorporate the common environmentalist view that future outcomes matter.

Recent low interest rates suggest that 2.5% may actually be the most accurate discount rate for social CBA. The interest rate on a 30-year treasury bill on March 13th, 2015 was 2.7% (United States Department of the Treasury, 2015). However, private discount rates are likely higher than social discount rates because interest rates on private investments such as land and home mortgages are higher. Further, private interest rates include a risk premium in addition to valuing current versus future consumption. GreenStone Farm Credit Services, which is one of the largest rural lenders in the United States, currently offers an interest rate between 4.3% and 6.8% for 30-year fixed mortgages on rural homes (GreenStone Farm Credit Services, 2015). The interest rate offered on a 30-year fixed loan for a parcel of land over 10 acres is between 5.3% and 7.8%. These higher values suggest that the 5% discount rate may be the best rate for the private CBA, and it might actually be a lower bound for the actual private discount rate depending on the risk preferences of the landowner. The concept of private impatience becomes evident when discussing the difference between the social and private discount rates. From a social planner's point of view (government's point of view), the time horizon in consideration is much longer than that of a private individual. Because of this, private individuals are less patient than social planners and therefore their discount rate is higher.

Results of this research will be presented using all three discount rates (2.5%, 3%, and 5%), which will also serve as an illustration for how much discounting impacts the analysis of forestry investments. The distinction between typical private and social discount rates will also be used to interpret the analysis results. Specifically, 2.5% will represent a typical social discount rate, and 5% will represent a typical private discount rate. For each discount rate, an NPV will be calculated with and without the forestry investment in question. Equation 1 shows the NPV formula used for a typical forestry investment, which is the basis for the private CBA conducted in this research.

$$\boldsymbol{NPV} = -Establishment\ Costs + \sum_{t=1}^{harvest\ year} \frac{Timber\ Revenue_t - Maintenance\ Costs_t}{(1 + discount\ rate)^t} \tag{1}$$

Equation 2 shows the inclusion of benefits from carbon sequestration that result from the forestry investment, which is the basis for the social CBA conducted in this research.

$$\boldsymbol{NPV} = -Establishment\ Costs + \sum_{t=1}^{harvest\ year} \frac{Timber\ Revenue_t + Carbon\ Benefits_t - Maintenance\ Costs_t}{(1 + discount\ rate)^t} \tag{2}$$

4.3 Determining the Optimal Rotation Length

The decision on when to harvest timber depends first on the optimization objective of the landowner. The two objectives that a landowner can have are to maximize long-run growth (a biological optimum) or to maximize long-run net revenue (an economic optimum). Another way of looking at the differing objectives is to think of the biological optimum as maximizing carbon sequestration and the economic optimum as maximizing timber harvest net returns. Economic maturity of forests generally occurs sooner than biological maturity because the economic optimum accounts for the concept of earning interest on the forest investment (Jacobson, 2008). In other words, calculating the biological optimum rotation does not take into consideration that you could invest your money elsewhere. Different rotation lengths result depending on which optimization objective is used. However, you will see in the analysis results that the difference between the biological and economic rotations depends heavily on the species and growth rates of the stand.

4.3.1 Biological Rotation

Forest stand growth is commonly expressed in terms of volume per acre per year. Growth is not constant over the lifetime of a tree. Rather, it grows at an increasing rate for a period of time and slows to a decreasing growth rate, producing an S-shaped graph. The point when the growth rate is zero is called the biological maximum age. This concept is illustrated in Figure 4.1.

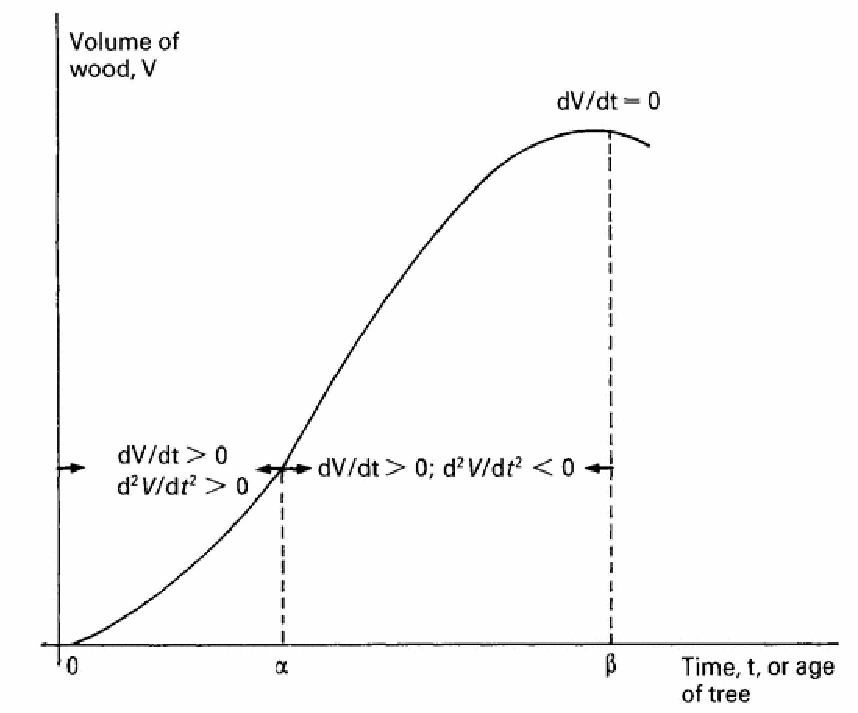


Figure 4.1 Representative Tree Growth Cycle (Kula, 1988)

Between 0 and α, the tree is growing at an increasing rate; between α and β, the tree is growing at a decreasing rate; and at β, the biological maximum is achieved because the growth rate is zero. When volume growth per acre is averaged over the life of the stand, the result is called the mean annual increment (MAI). The MAI is calculated each year by taking the total volume of the stand divided by the age of the stand. The year in which the MAI is maximized is the optimal biological rotation, and the yield that year is called the maximum sustained yield (MSY) (Jacobson, 2008). No costs or benefits are taken into account when calculating the optimal biological rotation. Because of this, harvesting at the biological rotation definitely maximizes the physical harvest volume, but it might result in lower returns than the economically optimal rotation.

4.3.2 Economic Rotation

Financial maturity of a forest stand usually occurs earlier than biological maturity (Jacobson, 2008). The difference between the optimal biological rotation and the optimal economic rotation depends on the growth rate of the timber and the alternative rate of return. When these two rates equal each other, it is the optimal time to harvest timber.

This method of solving for the optimal rotation age is also known as maximizing the land expectation value (LEV), which was first proposed by Faustmann (1849). The LEV is the net present value (NPV) of a stream of net revenues from an infinite series of optimal timber rotations. This optimal economic rotation is commonly known as the Faustmann rotation. Figure 4.2 illustrates the difference in rotation length between the optimal biological rotation and the optimal economic or “financial” rotation.

The optimal economic rotation will be the primary rotation used for this analysis, but a discussion of how the biological and economic rotations differ will be included as well. In Figure 4.2, the difference between the two rotation lengths looks quite substantial, which is not always the case (as mentioned earlier). In one of the analysis scenarios, the optimal rotations are only one year apart, but in the other scenario the economic optimum occurs 20 years before the biological optimum. The difference lies in the varying growth rates of the tree species.

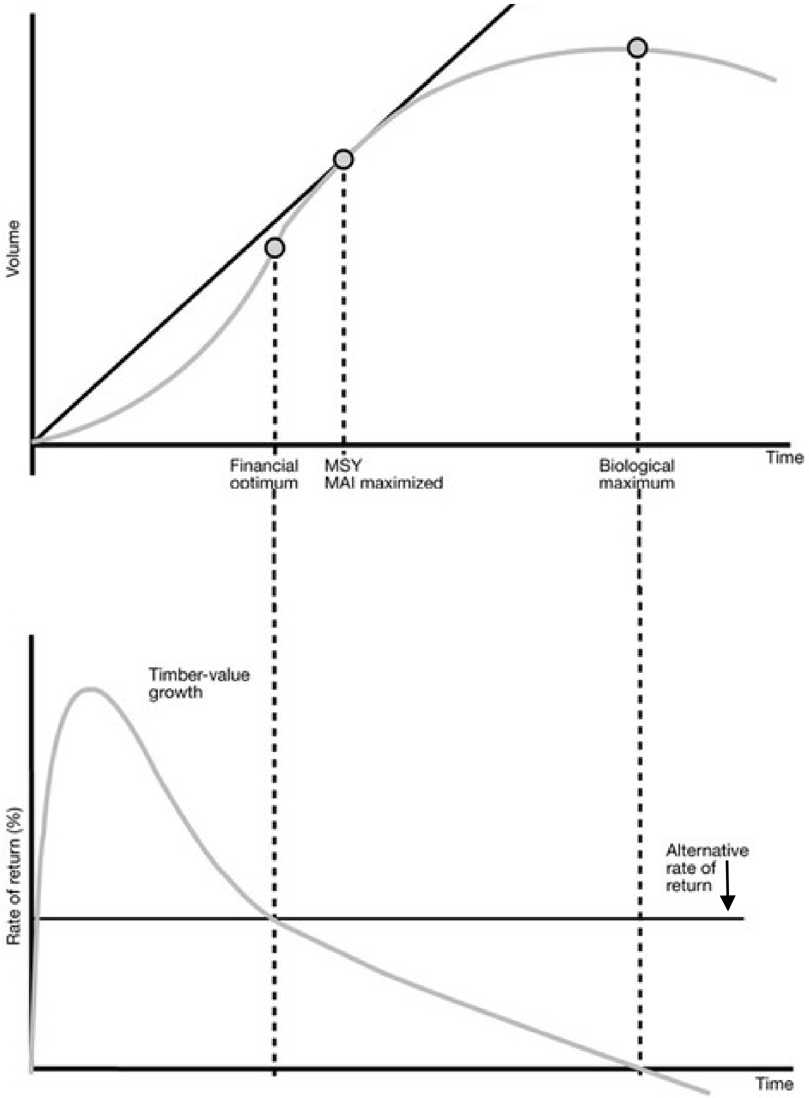


Figure 4.2 Tree Volume Growth and the Optimal Rotations (Jacobson, 2008)

4.4 The With and Without Analysis Process

The costs and benefits associated with making a forestry investment vary significantly based on the investment in question. An overview of the important costs and benefits to consider was presented already in the section on forestry and alternative land uses. This section presents an overview of the steps involved in using CBA to analyze forestry investment scenarios. An explanation of how our data are used to implement the relevant costs and benefits for our scenarios is discussed in the next chapter.

One of the basic approaches to the benefit-cost analysis process is the with-and-without approach (Campbell & Brown, 2003). This approach includes opportunity costs, which are an important concept in cost-benefit analysis. Undertaking an investment in forestry means you are giving up the opportunity to do something else with your land. The opportunity cost is quantified in the 'without' portion of this approach. If the investment benefits from the 'with' analysis are greater than the investment opportunity costs in the 'without' analysis, the investment should be made. In this research, a third result is added to the traditional with-and-without approach. For each investment, there will be two results for the 'with' analysis: one assuming that the landowner participates in a forestry cost-share program and one where they do not participate. For each of the three scenarios, there is an appropriate forestry cost-share program that the landowner would be eligible for. An overview of the three scenarios follows.

4.5 Forestry Investment Scenarios and Sensitivity Analysis

The next three chapters present a detailed description of how CBA was used to assess the three forestry investment scenarios presented in Table 4.1. Each scenario coincides with one of the forestry cost-share programs discussed earlier.

To test how sensitive the investment decisions are to the discount rate chosen, results will be presented using the three discount rates discussed in a previous section (2.5%, 3%, and 5%). In addition, sensitivity analysis of the carbon price used to calculate benefits from carbon sequestration will be conducted. Specifically, results will be presented using the actual carbon price from the California Cap-and-Trade Program to calculate the benefits from carbon sequestration. These results will be compared to results using the social cost of carbon estimates, as calculated by the Interagency Working Group discussed earlier, to calculate the benefits from carbon sequestration. The appropriate social cost of carbon will be used for each discount rate, since the choice of discount rates for this analysis was based off the rates used to report the social cost of carbon estimates. Scenario specific sensitivity analysis is conducted as well. For example, sensitivity analysis on the cost of pre-commercial thinning in the improving timber management scenario is conducted due to the large variability in costs.

Table 4.1 Overview of Forestry Investment Scenarios

Forestry Investment	Overview of Scenario
Improving Timber Management	• 30 acres • 4-year-old loblolly pine stand • Participate in WIP: Pre-commercially thin pine stand at age 4 (year 0 in this scenario), 65% of thinning costs covered • Timber sold as pulpwood • Carbon sequestration calculated using conversion factors for softwoods in the Northeastern United States
Conversion from Agricultural Land to Forest	• 17 acres • Cropland and pastureland separately considered • Oak/hickory stand establishment • Participate in EQIP: Cost-share based on average costs for high density, mechanical tree planting • Timber sold as sawtimber • Carbon sequestration calculated using conversion factors for hardwoods in the Northeastern United States
Conversion from Lawn to Forest	• 1 acre • Oak/Hickory stand establishment • Participate in L2W: 100% of establishment costs covered • Timber sold as sawtimber • Carbon sequestration calculated using conversion factors for hardwoods in the Northeastern United States

CHAPTER 5. IMPROVING TIMBER MANAGEMENT: IMPLEMENTATION AND RESULTS

5.1 Scenario Overview

The setting for this scenario is a private landowner in Wicomico County, Maryland who owns 30 acres of loblolly pine that was naturally regenerated following a seed tree harvest four years earlier. Naturally regenerated stands utilize the seeds from existing trees leftover from the previous harvest (Cunningham, Barry, & Walkingstick, 2008). The landowner is facing the decision of whether or not to improve management of the stand by pre-commercially thinning. Pre-commercial thinning of loblolly pine stands is recommended to be conducted in the first three or four years of growth for the best results (Williams, Bohn, McKeithen, & Demers, 2011), which is the basis for assuming the investment occurs in year four.

Pre-commercial thinning is an eligible practice for WIP, which is a program in Maryland that provides cost-share assistance for the improvement of existing timber stands. Historical data showing participation in WIP between 2007 and 2014 reports that the average number of acres amongst program participants is 29.78 (Rider, 2014).

The base case for this scenario, also called the ‘without’ case, assumes that the landowner does not pre-commercially thin the stand. Two ‘with’ cases result from this scenario: one assuming the landowner pre-commercially thins without receiving cost-share assistance from WIP and one assuming the landowner pre-commercially thins and participates in WIP. Each piece of individual data needed for the CBA is presented in detail, followed by the results showing the NPVs of net revenue streams under different assumptions, from the year the pre-commercial thinning investment is made to the year of the economically optimal timber harvest.

5.2 Loblolly Pine Growth Function

Loblolly Pine is a common species in the Coastal Plain of Maryland (Highfield & Sprague, 2011). Refer back to Figure 3.1 for an illustration of Maryland's physiographic regions (defined by major geologic landforms).

According to a University of Maryland extension publication about forest thinning, the main benefit from pre-commercial thinning is improved timber quality (Stewart & Dawson, 2013). Improved timber quality arises because pre-commercial thinning removes the inferior trees, which leaves the remaining trees with more resources, allowing them to grow faster and larger. Pre-commercial thinning is especially important for naturally regenerated loblolly pine stands because it is common for pine stands to produce seeds at a very high rate, which leads to overstocked stands (Williams et al., 2011). Growth curves illustrating the concept that pre-commercially thinned loblolly pine stands result in greater timber volumes at harvest are presented next.

5.2.1 Growth without Pre-commercial Thinning

The growth function for a loblolly pine stand that has not been pre-commercially thinned was taken from a Forest Research Group publication (Lutz, 2011). The annual volume in tons per acre for the first 40 years was reported. The growth estimates were developed by averaging several growth curves from different forest owners. It is specified that no thinnings were applied on this hypothetical stand. For different stages of the analysis, the timber volume needs to be in cubic feet per acre (to convert to carbon per acre) and cords per acre (to sell as pulpwood). The appropriate volume conversion factors are shown below (Nix, 2015). A common measurement for timber volume is board feet, which is a board that is one foot in length, one foot wide, and one inch thick. One thousand board feet is abbreviated as MBF. It was necessary to convert tons per acre into MBF per acre first because of the available conversion factors.

$$\left(\frac{tons}{acre} \div \frac{7.5\ tons}{MBF}\right) \times \frac{183\ cubic\ feet}{MBF} = \frac{cubic\ feet}{acre} \qquad (3)$$

$$\left(\frac{tons}{acre} \div \frac{7.5\ tons}{MBF}\right) \times \frac{2.8\ cords}{MBF} = \frac{cords}{acre} \qquad (4)$$

5.2.2 Growth with Pre-commercial Thinning

The growth function for a loblolly pine stand that has been pre-commercially thinned was taken from a Forest Service publication that reports regional cost information for different timberland management practices, as well as justifications for investing in timberland management, such as pre-commercial thinning (Bair & Alig, 2006). The volume in cubic feet per acre in five year increments for a pine stand that had been pre-commercially thinned was reported, and a fitted equation was used to fill in the annual volume measures. Since the volume measures were already in cubic feet per acre, they only had to be converted to cords per acre (using equation 2 above).

Table 5.1 shows the volume measures in cords per acre with and without pre-commercial thinning that are used in this analysis, and Figure 5.2 shows the plotted volume curves for the values in Table 5.1.

Table 5.1 Loblolly Pine Volume Measures Used
(cords/acre)

Year	Without Pre-Commercial Thinning	With Pre-Commercial Thinning
1	0	0
2	2.6	0
3	3.6	0.5
4	4.8	2.7
5	6.3	6.0
6	8.2	10.0
7	10.8	14.7
8	14.0	19.8
9	17.2	25.1
10	20.3	30.7
11	23.3	36.2
12	26.3	41.6
13	29.2	46.9
14	31.9	52.0
15	34.6	56.7
16	37.1	61.2
17	39.5	65.2
18	41.9	68.9
19	44.1	72.2
20	46.2	75.1
21	48.2	77.6
22	50.2	79.7

Adapted from Lutz (2011) and Bair and Alig (2006)

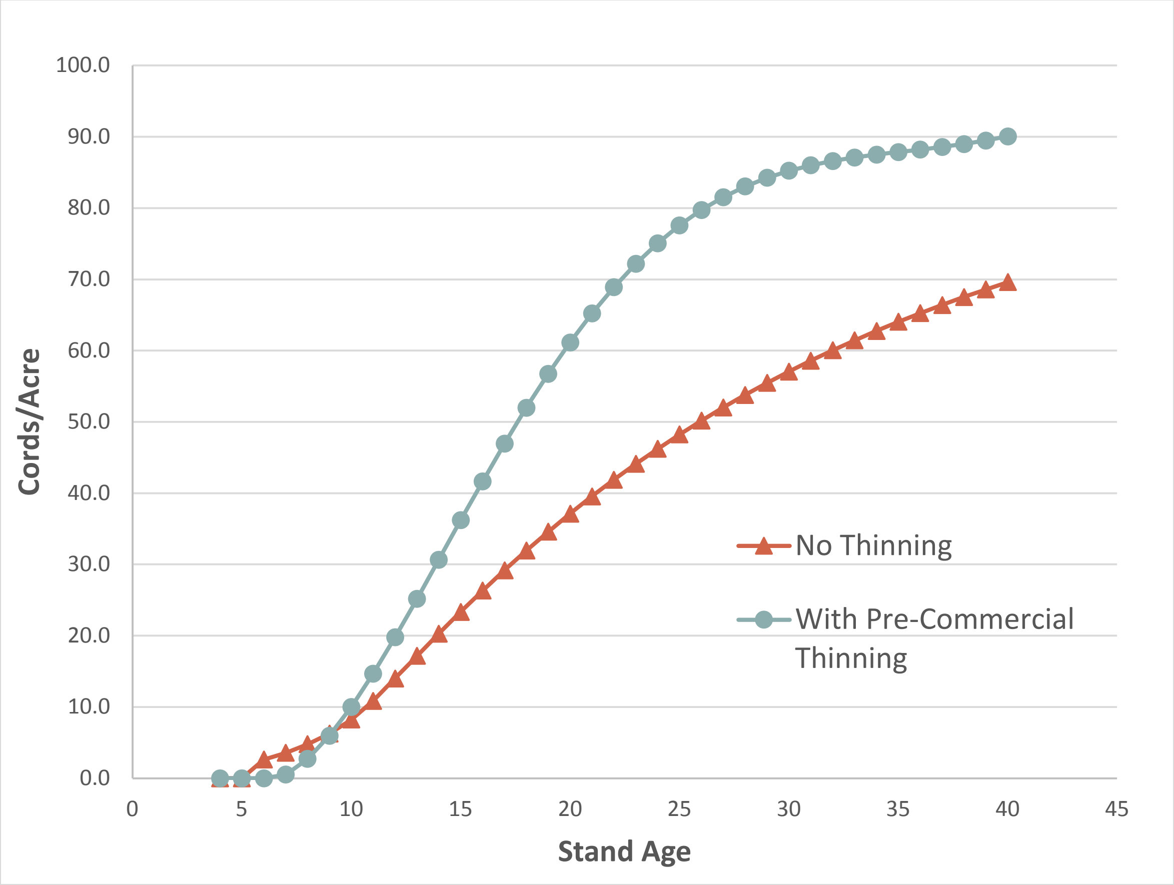


Figure 5.1 Volume Curves for Loblolly Pine Stands: With and Without Pre-commercial Thinning

Adapted from Lutz (2011) and Bair and Alig (2006)

5.3 Management Costs

The only management cost that is different between the 'with' and 'without' cases in this scenario is the inclusion of pre-commercial thinning cost. Other management costs including fertilizer, herbicide, and miscellaneous management costs would also be incurred by the landowner, but those would not change with the decision to pre-commercially thin. Since the investment in question is pre-commercial thinning, that is the only cost that needs to be considered in the analysis. The analysis is done in real 2010 dollars, so all of the costs and benefits are converted according to the Producer Price Index (PPI) for all commodities (United States Bureau of Labor FRED Economic Data, 2015). The Producer Price Index measures average changes in over one thousand commodity prices including prices of sawtimber, pulpwood, and other wood products, which makes it suitable for forestry analyses (Gunter & Haney Jr, 1984).

The Alabama Cooperative Extension System (Alabama A&M University and Auburn University) conducts a survey of forest landowners in the Southern United States every two years, in which respondents are asked to report their major forestry costs (Dooley & Barlow, 2013). Maryland is included in the states that are surveyed. The most recent published survey results are from 2012, from which the average pre-commercial thinning cost per acre was taken. The authors noted a large variance in responses for pre-commercial thinning costs, from $38 to $236 per acre. I used the average of these two values, which is $137 per acre ($125. 14 per acre in 2010 dollars). Since the range of pre-commercial thinning costs is so large, sensitivity analysis is conducted using the two extremes. The cost is incurred in year zero (stand is four years old) for the 'with' cases.

5.4 Optimal Rotation and Timber Benefits

The difference between the optimal biologic and economic rotations was previously discussed. The biologically optimal rotation maximizes the mean annual increment (MAI) in tree volume, and it does not take any costs or benefits into consideration. The maximized MAI in this scenario occurs when the stand is 26 years old without pre-commercial thinning and at 23 years old with pre-commercial thinning. The difference in rotation lengths is attributed to the accelerated growth that follows pre-commercial thinning, which leads to a shorter rotation length.

For the analysis, the economically optimal rotation lengths were used since the landowner's objective is to maximize timber profits. Faustmann's formula (below) that calculates the land expectation value (LEV) was used to determine the optimal economic rotation lengths with and without pre-commercial thinning (Faustmann, 1849). The LEV is an estimate of the net present value (NPV), using continuous discounting, of a stream of net revenues from rotations to infinity.

$$LEV = -C + [(V(t) - C]\left[\frac{1}{e^{rt}} + \frac{1}{e^{r2t}} + \frac{1}{e^{r3t}} \dots\right] \qquad (5)$$

Equation 5 simplifies to Equation 6:

$$LEV = -C + \frac{V(t) - C}{e^{rt} - 1} \qquad (6)$$

C in the equation above is the stand regeneration cost, which was obtained from the same Forest Service publication as the loblolly pine growth with pre-commercial thinning data (Bair & Alig, 2006). This publication reports regional cost estimates, which were produced by combining current and past prices, as well as prices for labor and fuel. For the Northeast region, the stand establishment costs for naturally regenerated softwood stands was estimated to be $92 per acre ($129.61 per acre in 2010 dollars).

V(t) is the stumpage value when the stand is *t* years old. It is calculated by multiplying the stumpage price (in dollars per cord) by the timber volume in year *t* (in cords per acre). Stumpage prices are the prices that a logging company pays a landowner for the right to harvest their standing trees (J. S. Kays & Bittenbender, 2012). Harvesting costs such as cutting and hauling are already accounted for in stumpage prices. A Forest Service publication that analyzes the United States timber situation from 1952 to 2050 reports historic stumpage prices by region and estimates price projections to 2050 (Haynes, 2003). The 2003 publication is the most recent comprehensive Forest Service report of stumpage prices, which may seem outdated. However, since stumpage prices are determined on a case by case basis by logging companies, they are difficult to report on a frequent basis. The University of Maryland extension service no longer reports stumpage prices (as of 2006), and the closest extension services that do are Penn State and West Virginia University. When looking at their most recent stumpage prices reports, the number of observations raised some concerns. For example, in the most recent West Virginia price report (December 2014), the stumpage price for softwood pulpwood in the region closest to Maryland was $10.71 per cord ($9.63 per cord in 2010 dollars), but it is only based on the results of one survey (Appalacian Hardwood Center, 2014). I decided to use the 2003 Forest Service publication because it combined the results of small surveys such as the one in West Virginia to produce more robust stumpage price estimates. In addition, the price used from Haynes (2003) for softwood pulpwood was $9.24 per cord, which is actually very close to the one survey observation from West Virginia.

Loblolly pine is the primary tree species used by the paper industry, so I assumed that the harvested timber is sold as pulpwood (Cubbage et al., 2009). Real stumpage price increases are predicted to be quite substantial. The softwood pulpwood stumpage price is predicted to increase in real terms from \$9.24 per cord in 2010 to \$36.94 per cord in 2050 (in 2010 dollars). The drastic increases are estimated to happen between 2030 and 2050 due to a projected tightening supply of pulpwood. However, since real increases in other components such as regeneration and management costs are not considered in this analysis, I will assume that there are no real increases in stumpage prices. I used the 2010 real softwood pulpwood stumpage price of \$9.24 per cord to calculate $V(t)$. This equation was also used to calculate timber benefits from harvesting. In reality, a few trees per acre would be left to provide seed trees for natural regeneration, but that was not accounted for in the calculation of timber benefits since the difference would be minimal.

r is the discount rate, which in the base case is 3%. The discount rate of 3% was chosen because it is the middle value of the three discount rates considered in this analysis (2.5%, 3%, and 5%).

The LEV using Equation 6 was calculated for each year (with and without pre-commercial thinning), assuming the harvest occurred in that year. The year with the highest LEV was chosen as the optimal economic rotation length. The resulting optimal economic rotation lengths were age 25 without pre-commercial thinning and age 22 with pre-commercial thinning. Both economic rotation lengths are one year less than the respective biological rotation lengths. Since loblolly pine stands grow so quickly, the difference between the economic and biological rotations is minimal. However, in the case of an oak/hickory stand, which is presented in the next scenario, the difference is much larger.

5.5 Woodland Incentive Program Participation

Thinning is one of the eligible improved management practices that receives cost-share assistance from WIP. WIP covers up to 65% of the costs of the improved management, so I assumed that 65% of the pre-commercial thinning costs were reimbursed to the landowner in the case with WIP participation. The total WIP cost-share assistance per acre is $81.34 when the average pre-commercial thinning cost of $125.14 per acre is used. The WIP cost-share assistance is adjusted to be 65% of the two extreme pre-commercial thinning costs used for sensitivity analysis as well. The resulting cost shares are $22.56 per acre using the minimum pre-commercial thinning cost and $140.12 per acre using the maximum. The WIP cost-share assistance was adjusted because the amount of cost-share the landowner receives is determined after the costs are incurred, and it is based on the payment receipts for the management practice undergone as part of the program.

5.6 Carbon Sequestration Benefits

The benefits from carbon sequestration were calculated using a sequence of conversions that result in the metric tons of carbon per acre that remain permanently sequestered in harvested wood products. The first step was to convert merchantable timber volume (in cubic feet per acre) into total above and below ground volume. The ratio of total above and below ground volume to merchantable volume for softwood species in the Northeast region is 2.193 (Birdsey, 1992). The second step was to convert the total volume (in cubic feet per acre) to pounds of carbon per acre. The factor to convert loblolly pine in the Northeast region from total volume to carbon is 15.28 (Birdsey, 1992). The common measurement for carbon is metric tons, which is the unit that the social cost of carbon is reported in. To convert carbon from pounds to metric tons, pounds are multiplied by 0.00045359 (Environmental Protection Agency, 2004).

The next step was to calculate the percentage of the carbon that actually remains sequestered in the harvested wood products. The process in California Cap-and-Trade Program’s forest offset protocol was used to estimate carbon in wood products (Air Resources Board, 2011). To account for carbon that is lost during harvest and in the processing of wood products, mill efficiency measures were calculated by the California Air Resources Board (CARB) for each state. The mill efficiency factor for softwood pulpwood in Maryland is 51.3%, which means 48.7% of the original carbon sequestered is lost before it can be transferred to wood products. The mill efficiency factors vary from about 50% to 70% across states. Any carbon that remains sequestered in in-use wood products or in landfills for at least 100 years is considered to be permanent by CARB. Examples of in-use wood products are furniture, paper products, and wood used in construction. Smith, Heath, Skog, and Birdsey (2006) estimated the average carbon disposition patterns for saw logs and pulpwood for the United States by regions. For softwood pulpwood in the Northeast region, 0.6% remains in in-use wood products after 100 years, and 8.4% remains in landfills after 100 years. A total of 9% of the original carbon sequestered by the loblolly pine stand remains permanently sequestered, so that is what was used to calculate the carbon benefits.

The equation below shows the process of converting timber volume in cubic feet per acre to metric tons of carbon permanently sequestered per acre.

$$\begin{aligned}\frac{cubic\ feet}{acre} \times 2.193 \times 15.28 &= \frac{pounds\ of\ carbon}{acre} \times 0.00045359 \\ &= \frac{metric\ tons\ of\ carbon}{acre} \times 51.3\% \times 9\% \\ &= \frac{metric\ tons\ of\ permanently\ sequestered\ carbon}{acre} \qquad (7)\end{aligned}$$

As previously discussed, the inclusion of carbon benefits using the Interagency Working Group’s social cost of carbon estimates will be compared to the inclusion of carbon benefits using the carbon price from the California Cap-and-Trade Program. The 2015 social cost of carbon estimates in 2010 dollars using 2.5%, 3%, and 5% as discount rates are $60.96, $39.57, and $11.76 per metric ton respectively (Interagency Working Group on Social Cost of Carbon, 2013). As mentioned earlier, these social cost of carbon estimates increase over time (see Table 2.1). The carbon benefits are quantified here using both constant social cost of carbon estimates with the 2015 values and increasing social cost of carbon benefits with the corresponding annual value each year. The California carbon price on March 9th, 2015 was $12.63 per metric ton, which is $12.14 per metric ton in real 2010 dollars (Climate Policy Iniative, 2015).The California carbon price is very similar to the social cost of carbon estimate using the highest discount rate, which is illustrated in the results.

The tons of carbon sequestered per acre each year were adjusted to determine how much would remain permanently sequestered based on the conversion factors in Equation

7. The social cost of carbon estimates and the carbon price were multiplied by the annual incremental metric tons of permanently sequestered carbon per acre to calculate the annual carbon benefit, which is then discounted appropriately in the final NPV calculation for each case. In other words, the annual carbon benefit is only based on the carbon that remains permanently sequestered, and the temporary carbon sequestration is not valued. The debate about whether temporary carbon sequestration should be viewed as a way of mitigating climate change is ongoing. Kirschbaum (2006) claimed that temporary carbon sequestration achieves very little impact on mitigating climate change and should therefore not be incentivized by policy. In response to Kirschbaum's paper, Dornburg and Marland (2008) argued that temporary carbon sequestration reduces carbon in the atmosphere in the short run, which helps "buy time" to pursue long term mitigation strategies. Since California's forestry offset protocol does not value temporary carbon sequestration, I chose to do the same.

5.7 Base Case Results

The net revenue each year was calculated by subtracting the annual costs from the annual benefits. There are no quantified private benefits until the harvest year, so the net revenues are negative up to that point. The NPV is the discounted value of the stream of net revenues from the year of the investment (year zero in this case) to the harvest year (year 21 without pre-commercial thinning and year 18 with pre-commercial thinning). It is important to remember that the loblolly pine stand is already four years old in year zero of this scenario, so the optimal rotation lengths are four years longer than the number of years between the pre-commercial thinning investment and the harvest.

It should be noted that net revenues from timber are taxed using capital gains tax rates since timber is a long-term investment. The results shown here are before taxes are subtracted, since including taxes would not alter any investment decisions. The results would decrease proportionately depending on which tax bracket the landowner falls into.

The base case results are shown in Table 5.2.

Table 5.2 Improving Timber Management Results: Base Case NPVs
($/acre)

Discount Rate	Without Pre-Commercial Thinning	With Pre-Commercial Thinning	With Pre-Commercial Thinning & WIP
2.5%	$265.25	$282.74	$364.09
3%	$239.49	$248.54	$329.88
5%	$159.91	$139.20	$220.54

It is important to note that the NPVs in Table 5.2 only include the pre-commercial thinning costs, so the actual net returns to the landowner would be different than these since they would pay the establishment and management costs as well. However, the investment in question is pre-commercial thinning, not the question of whether to allocate land to forest. The landowner had already decided to forest the land four years ago. As expected, the NPV with pre-commercial thinning and participation in WIP is higher. Even though all of the NPVs are positive, the interesting question is whether the NPVs with pre-commercial thinning are greater than those without pre-commercial thinning. This will differ depending on which discount rate is used.

5.8 Discount Rate Sensitivity Results

The difference between the ‘with’ and ‘without’ cases are reported in Table 5.3.

Table 5.3 Improving Timber Management Results: Difference in NPVs
($/acre)

Discount Rate	Additional NPV from Pre-Commercial Thinning	Additional NPV from Pre-Commercial Thinning & WIP
2.5%	$17.49	$98.93
3%	$9.05	$90.39
5%	($20.72)	$60.62

One can see that the discount rate makes a substantial difference in the landowner’s decision of whether to pre-commercially thin. With a discount rate of 5% and no participation in WIP, the NPV without pre-commercial thinning is higher than the NPV with pre-commercial thinning. As discussed earlier, 2.5% is expected to be the best representation of a social discount rate, and 5% is closer to a private discount rate. With that assumption, private forest landowners would not choose to invest in pre-commercial thinning without cost-share assistance from WIP. With participation in WIP, the returns per acre from pre-commercial thinning are greater than those without thinning for all discount rates. The program seems to provide enough for the landowner to invest in pre-commercial thinning, but it may depend on the pre-commercial thinning costs.

5.9 Pre-Commercial Thinning Cost Sensitivity Results

The survey results reporting the per acre pre-commercial thinning costs used for this analysis ranged from $38 per acre to $236 per acre ($34.71 and $215.57 per acre in real 2010 dollars) (Dooley & Barlow, 2013). For the base case, the average of $125.14 per acre was used, but the wide uncertainty in pre-commercial thinning costs raises some concerns. Table 5.4 reports the difference between the ‘with’ and ‘without’ cases for the two extremes of the pre-commercial thinning cost per acre. The pre-commercial thinning costs are labeled minimum ($34.71 per acre), average ($125.14 per acre), and maximum ($215.57 per acre) in Table 5.4.

Table 5.4 Improving Timber Management Results: Difference in NPVs for Different Pre-Commercial Thinning Costs
($/acre)

Discount Rate	Pre-Commercial Thinning Cost Per Acre	Additional NPV from Pre-Commercial Thinning	Additional NPV from Pre-Commercial Thinning & WIP
2.5%	Minimum	$107.92	$130.48
	Average	$17.49	$98.83
	Maximum	($72.94)	$67.18
3%	Minimum	$99.48	$122.04
	Average	$9.05	$90.39
	Maximum	($81.38)	$58.74
5%	Minimum	$69.71	$92.28
	Average	($20.72)	60.62
	Maximum	($111.15)	$28.97

As expected the minimum reported pre-commercial thinning cost per acre yielded the highest NPVs and the maximum reported pre-commercial thinning cost per acre yielded the lowest NPVs. With the maximum pre-commercial thinning cost and no cost-share assistance from WIP, the NPV is negative for all three discount rates. However, for a discount rate of 5%, participation in WIP just barely outweighs the high per-commercial thinning cost with an NPV of just $28.97 per acre. Even with cost-share assistance from WIP, the landowner may choose not to invest in pre-commercial thinning if the costs are at the maximum. The variability in pre-commercial thinning costs definitely makes a different in the investment decision.

5.10 Carbon Price Sensitivity Results

The results below include potential compensation for carbon that remains permanently sequestered as a result of investing in pre-commercial thinning. The NPVs reported in Table 5.5 and 5.6 are the difference between the NPVs with pre-commercial thinning and carbon benefits and the ones without pre-commercial thinning in Table 5.2. The carbon benefits in Table 5.5 were calculated using the California carbon price, and those in Table 5.6 were calculated using both the constant and increasing social cost of carbon estimates for all three discount rates.

Table 5.5 Improving Timber Management Results: Difference in NPVs Including Carbon Benefits based on California Carbon Price
($/acre)

Discount Rate	Additional NPV from Pre-Commercial Thinning & Carbon Benefits	Additional NPV from Pre-Commercial Thinning, WIP, & Carbon Benefits
2.5%	$46.73	$128.08
3%	$36.80	$118.15
5%	$1.93	$83.27

Table 5.6 Improving Timber Management Results: Difference in NPVs Including Carbon Benefits based on Social Cost of Carbon Estimates
($/acre)

Discount Rate	Inclusion of the Social Cost of Carbon Estimates	Additional NPV from Pre-Commercial Thinning & Carbon Benefits	Additional NPV from Pre-Commercial Thinning, WIP, & Carbon Benefits
2.5%	Constant	$164.31	$245.65
	Increasing	$197.70	$279.04
3%	Constant	$99.49	$180.83
	Increasing	$125.57	$206.91
5%	Constant	$1.22	$82.57
	Increasing	$7.89	$89.23

The interpretation of Table 5.5 and Table 5.6 depends largely on the initial goals for WIP. If the original goal when implementing the program was to increase carbon sequestration, then the cost-share assistance would already be based on the carbon benefits. This would mean that the last column in Table 5.5 and Table 5.6 would be double counting the carbon benefits. The main goal of WIP was to "foster and encourage the development, management, and protection of the nonindustrial private woodlands" (Maryland Forest Service, 2008). The co-benefits of forestry such as environmental, wildlife, and aesthetic benefits are cited in the program information as well, but they are not at the forefront. This may indicate that the last column is not double counting anything, since the current cost-share assistance is likely not based on societal benefits from carbon sequestration.

For the 2.5% and 3% discount rate results, the carbon benefits using the social cost of carbon are much higher than those that use the California carbon price. However, the 5% discount rate results are almost identical. This is a clear illustration of the importance of discounting in both the calculation of the social cost of carbon and in the calculation of the discounted net returns for this scenario. With the inclusion of carbon benefits, the NPVs with pre-commercial thinning are all positive, even without participation in WIP. However, at a discount rate of 5% and no participation in WIP, the NPVs are less than

$2.00 per acre, which highlights the extent of private impatience in this scenario. Looking at the 2.5% discount rate results when carbon benefits are included, the investment in pre-commercial thinning is definitely worth it from society's perspective. It seems like there might be a gap between what is best from society's point of view and what the landowner will actually choose. Perhaps the cost-share assistance should be increased in order to encourage private landowners to invest and therefore better society. Table 5.7 shows the current cost-share assistance compared with the amount if the cost-share assistance were based on the carbon benefits. The values in Table 5.7 are the NPVs of only the annual carbon benefits from pre-commercial thinning.

Table 5.7 Improving Timber Management Results: Comparison of Cost-Share Assistance based on Carbon Benefits

($/acre)

Discount Rate	Current WIP Cost-Share	California Carbon Price	Constant Social Cost of Carbon Estimate	Increasing Social Cost of Carbon Estimate
2.5%	$81.34	$29.25	$146.82	$180.21
3%	$81.34	$27.75	$90.44	$116.52
5%	$81.34	$22.65	$21.94	$28.61

If the cost-share assistance were based on the 2.5% constant social cost of carbon estimate, the assistance per acre would be $146.82, compared to the current assistance of only $81.34 per acre. An even higher cost-share assistance would result if it were based on the increasing social cost of carbon estimates. The actual subsidies of $81.32 per acre are not as large as the carbon benefits provided to society. Further, the values in Table 5.7 only illustrate what happens when the societal benefits from carbon sequestration are used to calculate subsidies, when in reality, many more social benefits arise from the forestry investments.

The 5% discount rate results in Table 5.7 provide an interesting illustration of private impatience once again. If the cost-share assistance were based on the valuation of carbon benefits from the private point of view, the subsidies would actually be lower than they currently are. The internalization of the carbon benefits from a private perspective and a social perspective result in very different values. If the cost-share assistance were based on the avoided damages from society’s perspective (using the 2.5% social cost of carbon estimate), the issue of private impatience may be fixed.

Overall, in all cases where the landowner participates in WIP, the NPVs are positive and greater than the comparable NPVs without pre-commercial thinning. This indicates the success of WIP in incentivizing landowners to invest in a management practice such as pre-commercial thinning that leads to increased timber benefits to the landowner and carbon benefits to society. However, basing the cost-share assistance on the carbon benefits may lead to higher program participation and acceleration towards Maryland’s GHG reduction goals.

CHAPTER 6. CONVERSION FROM AGRICULTURAL LAND TO FOREST: IMPLEMENTATION AND RESULTS

6.1 Scenario Overview

The setting for this scenario is a private landowner in Harford County, Maryland who is considering converting 17 acres of cropland into an oak/hickory forest stand. The landowner currently collects cropland cash rent for the acreage and is wondering whether investing in forestry with the goal of harvesting timber in the future would provide a greater return. Another alternative considered is that the land is of lower quality, for which the pastureland cash rent is collected instead of cropland cash rent.

Tree stand establishment is one of the eligible practices for EQIP, which is a federal conservation program that provides cost-share assistance based on the average costs of eligible practices. Historical data showing EQIP participation from 2009 to 2013 reports that the average number of acres that landowners enrolled for tree establishment was 17.04 acres (Morgart, 2014).

The base case for this scenario, also referred to as the ‘without’ case, assumes that the landowner continues to collect cropland or pastureland cash rent for the 17 acres. Two ‘with’ cases result from this scenario: one assuming the landowner converts to forest without participating in EQIP and one assuming the landowner converts to forest and receives cost-share assistance from EQIP for the tree establishment costs.

6.2 Oak/Hickory Growth Function

Oak/hickory mixed forests are the most common forest type in the state of Maryland (Highfield & Sprague, 2011). These forests contain a mix of many species, including northern red oak, white oak, chestnut oak, and pignut hickory, and they are common in the Piedmont region of Maryland (refer back to Figure 3.1).

The Forest Service conducted a survey of 409 plots of fully stocked, even-aged oak/hickory stands across a study region extending from Illinois eastward through New York that included plots in Maryland (Schnur, 1937). Field measurements were obtained from the plots and yield curves were produced for five different site indices: 40, 50, 60, 70, and 80. A site index is a term used by the Forest Service to indicate the growth potential for trees at a specific location. It is most commonly reported as the height of the average dominant and co-dominant tree when the stand is 50 years old. In Harford County, Maryland the site indices range from 64 to 79, so I used the yield curve for the site index of 70 for this analysis (Maryland Watershed Services & Maryland Forest Service, 2003).

The volume per acre in cubic feet was given in five year increments for 100 years of stand growth. A fitted polynomial equation was used to fill in the annual volume measures. For the purpose of selling hardwood timber, the volume measures needed to be converted from cubic feet per acre to MBF per acre to be sold as sawtimber. The appropriate volume conversion factors are shown in Equation 8 (Nix, 2015).

$$\frac{cubic\ feet}{acre} \div \frac{183\ cubic\ feet}{MBF} = \frac{MBF}{acre} \qquad (8)$$

Table 6.1 shows the volume measures used for this analysis, and Figure 6.1 shows the plotted volume curve for the values in Table 6.1. Since oak/hickory stands are slower growing, the first volume measure reported is for year 17.

Table 6.1 Oak/Hickory Volume Measures Used
(MBF/acre)

Year	Volume Measures
17	1.2
18	1.5
19	1.9
20	2.3
21	2.7
22	3.1
23	3.5
24	3.9
25	4.4
26	4.8
27	5.3
28	5.8
29	6.2
30	6.7
31	7.2
32	7.7
33	8.1
34	8.6
35	9.1
36	9.6
37	10.0
38	10.5
39	11.0
40	11.4

Adapted from Schnur (1937)

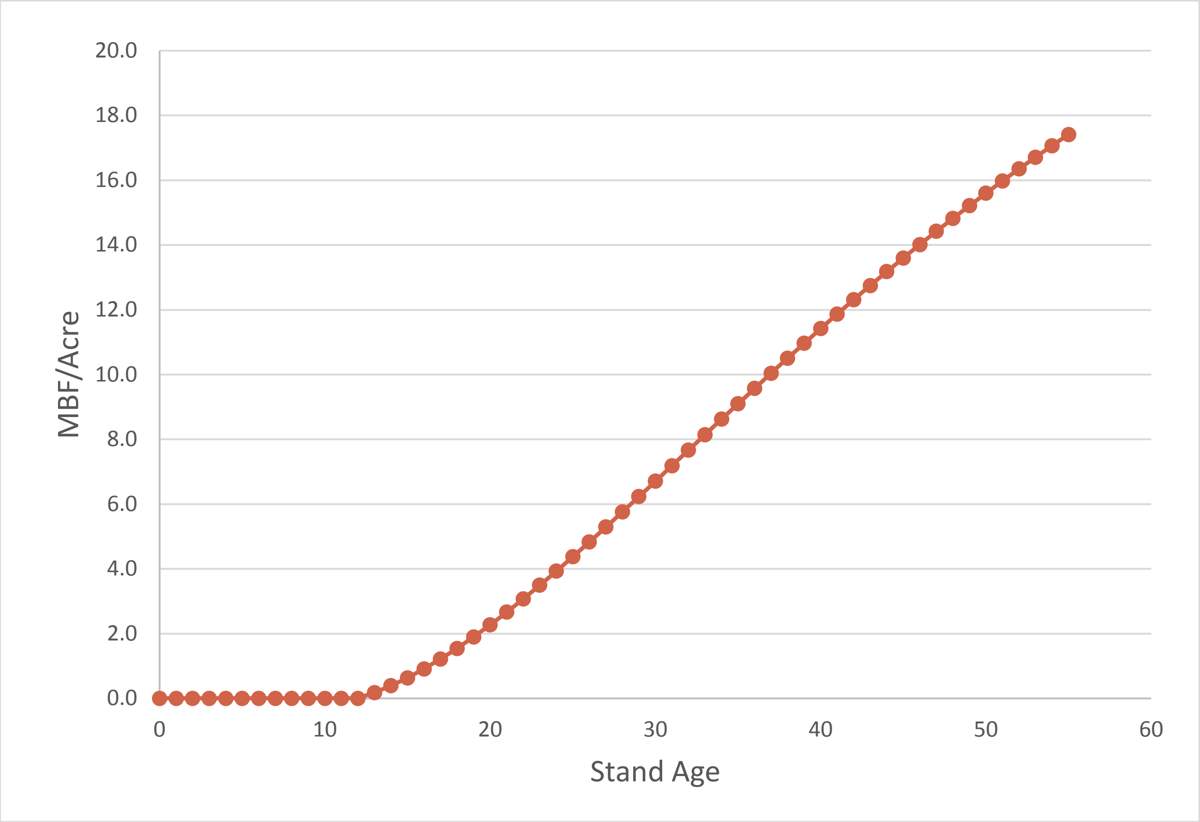


Figure 6.1 Volume Curve for Oak/Hickory Stand (Schnur, 1937)

6.3 Land Conversion and Management Costs

Costs to convert agricultural land to forest include site preparation and planting. Bair and Alig (2006) reported regional cost estimates, which were also used in the previous scenario. Maryland is included in the Northeast region, but some of the costs are not reported for every region individually. In cases where the cost was not reported for the Northeast region, the Southeast region estimate was used. The Southeast region extends north up to Virginia, which borders Maryland. The hardwood site preparation cost to convert cropland to forest for the Southeast region was $81.16 per acre ($114.34 per ace in 2010 dollars). Further, the planting cost for hardwood species in the Southeast region was $135.42 per acre ($190.79 per acre in 2010 dollars). The establishment costs are incurred in year zero of the investment time frame.

Management and other costs for this scenario include herbicide treatments, fertilizer treatments, miscellaneous management costs, and property taxes. Herbicide, fertilizer, and miscellaneous management costs were obtained from the Forest Service publication previously discussed (Bair & Alig, 2006). The herbicide cost per acre for hardwood species in Southeast region was $58.48 per acre ($82.39 per acre in 2010 dollars). Planted oak seedlings are susceptible to weeds in the first few years after establishment, so in this scenario, the herbicide treatment costs are incurred in year one of the investment time frame (Boozer, 2013). The fertilizer cost per acre for hardwood species in the Southeast was $14.82 ($20.88 per acre in 2010 dollars). Fertilizing an established oak stand every five years is recommended, so the fertilizer treatment cost is incurred every five years in this scenario, beginning in year five of the time frame (Boozer, 2013). The miscellaneous management cost category includes forest management plans, boundary maintenance, fire protection, and surveying, and it is estimated on a 10-year basis. For the Southeast region, the miscellaneous management estimate for hardwood species was $16.71 per acre ($23.54 per acre in 2010 dollars). This estimate is divided by 10 and included on an annual basis beginning in year one ($2.35 per acre annually).

In the state of Maryland, any forested land that is under a certified forest management plan is assessed at a land value of $187.50 per acre, which is significantly less than the average agricultural use assessment value (J. Kays & Schultz, 2002). Since I am including the miscellaneous management estimate, which includes a cost for management plans, I assumed that the landowner has a certified forest management plan. The Harford County property tax rate is 1.042 per $100 in assessed value, and the Maryland state property tax rate is 0.112 per $100 in assessed value (Maryland Department of Assessments & Taxation, 2015). With an assessment value of $187.50, the total county and state property tax per acre is $2.16, which is included annually in the ‘with’ case. In the base case without conversion to forest, the land would be assessed using the average agricultural assessment value of $312.50 per acre. The total county and state property tax based on the assessment value of $312.50 per acre for cropland is $3.61, which is included annually in the ‘without’ case.

A summary of the establishment and management costs and the timing of their inclusion in the analysis is presented in Table 6.2.

Table 6.2 Summary of Costs for Converting Agricultural Land to Forest

Cost	$/Acre (Real 2010 Dollars)	Inclusion in ‘Without’ Case	Inclusion in ‘With’ Case
Site Preparation	$114.34	-	Year 0
Planting	$190.79	-	Year 0
Herbicide	$82.39	-	Year 1
Fertilizer	$20.88	-	Years 5, 10, 15, 20, 25, 30, 35, 40
Miscellaneous Management	$2.35	-	Annually Beginning in Year 1
Forest Property Tax	$2.16	-	Annually Beginning in Year 0
Agricultural Land Property Tax	$3.61	Annually Beginning in Year 0	-

(Bair & Alig, 2006) and (Maryland Department of Assessments and Taxation, 2015)

6.4 Optimal Rotation and Timber Benefits

The maximized MAI in this scenario occurs when the stand is 60 years old, which is the biologically optimum rotation for the oak/hickory stand. For the analysis, the economically optimal rotation length, which maximizes the LEV, was used since the landowner’s objective is to maximize timber profits (refer to Equation 6 in the previous chapter).

C in Equation 6 is the stand regeneration cost, which is the establishment cost in this scenario. The site preparation and planting costs discussed in the previous section were used as the establishment costs in the LEV equation. Again, the hardwood site preparation cost for the Southeast region was $114.34 per acre, and the planting cost for hardwood species in the Southeast region was $190.79 per acre (Bair & Alig, 2006). The total value for *C* in the LEV calculations was $305.13.

V(t) is the stumpage value when the stand is *t* years old. Oak is commonly sold as sawtimber, so I assumed that the harvested timber from this oak/hickory stand is all sold as such (Szymanski & Pelkki, 2001). Real hardwood sawtimber stumpage prices are not predicted to increase as dramatically as the softwood pulpwood prices (Haynes, 2003).

The hardwood sawtimber stumpage price is predicted to increase in real terms from \$387.87 per MBF in 2010 to \$439.59 per MBF in 2050 (in 2010 dollars). Again, I will not include any real price increases in this scenario. I used the 2010 real hardwood sawtimber stumpage price of \$387.87 per MBF to calculate *V(t)*. This equation was also used to calculate timber benefits from harvesting.

The maximized LEV occurs in year 40, which is the economically optimal rotation length used for this scenario. This is twenty years sooner than the optimal biologic rotation length, which is a substantial difference. The slower growing the trees are, the more spread out the biologic and economic rotations are, which is why there is more of a difference in rotation lengths in the oak/hickory stand than for the loblolly pine stand discussed previously.

6.5 Environmental Quality Inventive Program Participation

Tree stand establishment is one of the eligible conservation practices that receives cost-share assistance from EQIP. The cost-share assistance is based on the average cost to undergo the agreed upon conservation practices. Every year, the NRCS releases the eligible practices and payment rates. The 2015 payments rates were used in the calculation of benefits from EQIP to the landowner in this scenario (Natural Resources Conservation Service, 2015).

There are several tree establishment practices that have varying costs. For example, costs for low density hand planting, high density hand planting, and high density mechanical planting are reported. The hand planting costs are much higher than the mechanical costs. The high density hand planting cost is \$2595.81 per acre, as compared to the high density mechanical planting cost of \$309.43 per acre. Since 17 acres are being planted with trees, hand planting seems unlikely, and the cost-share assistance is based on what is actually done. For this reason, I assumed the landowner receives cost-share assistance based on the cost for high density mechanical planting of \$309.43 per acre in 2015 (\$297.51 per acre in 2010 dollars) because this is very close to the actual establishment costs incurred by the landowner of \$305.13 per acre as calculated earlier.

The total EQIP cost-share assistance per acre in the case where the landowner participates in the program is $297.51.

6.6 Agricultural Land Rent Benefits

The average cropland cash rent for the state of Maryland was used to calculate the benefits to the landowner in the first ‘without’ case. In 2014, the average cropland cash rent in Maryland was $94.50 per acre, which is $84.98 per acre in 2010 dollars (National Agricultural Statistics Service, 2014). In reality, a parcel of lesser quality cropland would more likely be converted to forest, but the rent values reported are not quality specific. In the second ‘without’ case, the average pastureland rent for the state of Maryland was used, which was $43.50 per acre in 2014 ($39.12 in 2010 dollars).

6.7 Carbon Sequestration Benefits

Similar to the previous scenario, the benefits from carbon sequestration were calculated using a sequence of conversions that result in the metric tons of carbon per acre that remain permanently sequestered in harvested wood products (shown in Equation 7). The first step was to convert the tree growth from cubic feet per acre to metric tons of carbon per acre. The next step was to calculate the percentage of the carbon that actually remains sequestered in the harvested wood products. The process from California Cap-and-Trade Program’s forest offset protocol was explained earlier. The estimated mill efficiency for hardwood saw timber is 61.4%. For hardwood sawtimber harvested in the Northeast region, 3.5% is estimated to remain in in-use wood products after 100 years, and 28.1% remains in landfills after 100 years. A total of 31.6% of the original carbon sequestered by the oak/hickory stand remains permanently sequestered, so that is what was used to calculate the carbon benefits. The annual carbon benefits were calculated the same way as the previous scenario using both constant and increasing social cost of carbon estimates and the California carbon price.

$$
\begin{aligned}
&\frac{cubic\ feet}{acre} \times 2.14 \times 19.76 = \frac{pounds\ of\ carbon}{acre} \times 0.00045359 \\
&= \frac{metric\ tons\ of\ carbon}{acre} \times 61.4\% \times 31.6\% \\
&= \frac{metric\ tons\ of\ permanently\ sequestered\ carbon}{acre} \qquad (8)
\end{aligned}
$$

6.8 Base Case Results

The base case results for the conversion from cropland to forest are shown in Table 6.3 below. Again, the NPVs reported here are before capital gains and income taxes are subtracted.

Table 6.3 Conversion from Cropland to Forest Results: Base Case NPVs
($/acre)

Discount Rate	Without Conversion	With Conversion	With Conversion & EQIP
2.5%	$2124.08	$1,048.91	$1,346.42
3%	$1962.31	$775.30	$1072.81
5%	$1,477.67	$101.08	$398.59

All of the base case NPVs are positive, but one can tell by looking at Table 6.3 that the returns from receiving cropland rent are much higher than those from conversion. At a discount rate of 5%, the returns from converting to forest without cost-share assistance are only around $100 per acre, which is a significant decrease from the same result at a 2.5% discount rate. Since 5% represents a typical private discount rate, the landowner would never find it profitable to convert average cropland to forest. As discussed earlier, 5% may actually be a lower bound to an actual private discount rate, which makes it even less likely that the landowner would ever choose to make the conversion in reality.

6.9 Discount Rate Sensitivity Results

All of the NPVs are positive, but the ‘without’ case has significantly higher returns. Table 6.4 shows the difference in NPVs between the ‘with’ cases and the ‘without’ case at all three discount rates.

Table 6.4 Conversion from Cropland to Forest Results: Difference in NPVs
($/acre)

Discount Rate	Additional NPV from Conversion	Additional NPV from Conversion & EQIP
2.5%	($1075.17)	($777.66)
3%	($1,187.01)	($889.50)
5%	($1,376.59	($1,079.08)

Converting the cropland in this scenario to forest results in much lower returns than leaving the land in its original agricultural use. The discount rate definitely makes a difference in NPVs, but the returns from cropland are higher in all cases. Participation in EQIP lessens the difference in NPVs between the ‘with’ and ‘without’ cases, but the landowner would still choose to leave the land as cropland. The cropland cash rent would need to be as low as $9.17 per acre to make the NPV with conversion equal to the NPV without conversion (using 5% as the discount rate). Similarly, if the landowner participates in EQIP, the cropland cash rent would have to be $25.56 per acre for the NPV with conversion to equal the NPV without conversion. The same results using 2.5% as the discount rate are $43.79 per acre (without EQIP participation) and $55.19 per acre (with EQIP participation). In reality, a landowner would never convert cropland to forest unless it was marginal land. As a proxy for the returns from marginal cropland, the average pastureland cash rent in Maryland in 2010 dollars of $39.12 per acre can be used. The results using pastureland rent in place of cropland rent are presented next.

6.10 Pastureland Rent Sensitivity Results

Table 6.5 shows the difference in NPVs between converting the land to forest and keeping it as pastureland.

Table 6.5 Conversion from Pastureland to Forest Results: Difference in NPVs
($/acre)

Discount Rate	Additional NPV from Conversion	Additional NPV from Conversion & EQIP
2.5%	$122.01	$419.52
3%	($81.01)	$216.50
5%	($534.74)	($246.23)

At a discount rate of 2.5%, the conversion to forest results in a higher NPV than continuing to collect pastureland rent on the land. However, at a 3% discount rate, the conversion is only worth it with cost-share assistance from EQIP. Further, at a 5% discount rate, the conversion results in lower NPVs even with participation in EQIP. Again, the personal discount rate of the landowner makes a big difference in the investment decision, and the private impatience is evident in this scenario when looking at the 5% discount rate results. Even though the conversion would be worth it from society's point of view when dealing with pastureland, it would never be worth it from a private perspective. However, the conversion from pastureland or marginal land to forest is overall more likely than the conversion from cropland to forest.

6.11 Carbon Price Sensitivity Results

The results below include compensation for carbon that remains permanently sequestered as a result of investing in the conversion of agricultural land to forest. The NPVs reported in Table 6.6 and 6.7 are the difference between the NPVs with conversion and carbon benefits and the base case results without conversion in Table 6.3. Again, Table 6.6 calculates carbon benefits based on the California carbon price, and Table 6.7 calculates carbon benefits based on both the constant and increasing social cost of carbon estimates.

Table 6.6 Conversion from Cropland to Forest Results: Difference in NPVs Including Carbon Benefits based on California Carbon Price
($/acre)

Discount Rate	Additional NPV from Conversion & Carbon Benefits	Additional NPV from Conversion, EQIP, & Carbon Benefits
2.5%	($1,027.01)	($729.50)
3%	($1,144.67)	($847.16)
5%	($1,350.79)	($1,053.28)

Table 6.7 Conversion from Cropland to Forest Results: Difference in NPVs Including Carbon Benefits based on Social Cost of Carbon Estimates
($/acre)

Discount Rate	Inclusion of Social Cost of Carbon Estimates	Additional NPV from Conversion & Carbon Benefits	Additional NPV from Conversion, EQIP, & Carbon Benefits
2.5%	Constant	($833.44)	($535.93)
	Increasing	($703.64)	($406.13)
3%	Constant	($1,049.04)	($751.53)
	Increasing	($954.40)	($656.89)
5%	Constant	($1,351.59)	($1,054.08)
	Increasing	($1,328.07)	($1,030.56)

One can see that even with the inclusion of carbon benefits, the conversion from cropland to forest would never overcome the opportunity costs. As before, the interpretation of Table 6.6 and Table 6.7 depends on whether the original goal of EQIP was to increase carbon sequestration. One of the seven national priorities for EQIP is to increase biological carbon storage and sequestration, which may indicate that last column in Table 6.6 and Table 6.7 is double counting the carbon benefits. However, even if double counting is an issue here, the conversion would still never be worth it to the landowner. Similar to the pre-commercial thinning scenario, at a discount rate of 5%, the resulting NPV from the inclusion of carbon benefits using the California carbon price are almost identical to those using the social cost of carbon estimates.

The same results using pastureland rent instead of cropland rent are shown in Table 6.8 and Table 6.9 below.

Table 6.8 Conversion from Pastureland to Forest Results: Difference in NPVs Including Carbon Benefits from California Carbon Price
($/acre)

Discount Rate	Additional NPV from Conversion & Carbon Benefits	Additional NPV from Conversion, EQIP, & Carbon Benefits
2.5%	$170.16	$467.67
3%	($38.67)	$258.84
5%	($517.94)	($220.43)

Table 6.9 Conversion from Pastureland to Forest Results: Difference in NPVs Including Carbon Benefits from Social Cost of Carbon Estimates
($/acre)

Discount Rate	Inclusion of Social Cost of Carbon Estimates	Additional NPV from Conversion & Carbon Benefits	Additional NPV from Conversion, EQIP, & Carbon Benefits
2.5%	Constant	$363.74	$661.25
	Increasing	$493.54	$791.05
3%	Constant	$56.96	$354.47
	Increasing	$151.59	$449.10
5%	Constant	($518.75)	($221.23)
	Increasing	($495.22)	($197.71)

The only case where the inclusion of carbon benefits leads to a different investment decision by the landowner is the case of a 3% discount rate and no participation in EQIP. For discounts rate of 2.5% and 3%, the inclusion of carbon benefits when the landowner participates in EQIP increases the returns from conversion significantly, but the landowner would choose to participate without carbon benefits as well. Assuming 5% is the most realistic private discount rate, the landowner would likely not choose to convert to forestry, regardless of whether the land was in crops or pasture. The comparison of basing the cost-share assistance on the carbon benefits to society instead of the current cost-share assistance are shown in Table 6.10.

Table 6.10 Conversion from Agricultural Land to Forest Results: Comparison of Cost-Share Assistance based on Carbon Benefits
($/acre)

Discount Rate	Current WIP Cost-Share	California Carbon Price	Constant Social Cost of Carbon Estimate	Increasing Social Cost of Carbon Estimate
2.5%	$297.51	$48.15	$241.73	$371.53
3%	$297.51	$42.34	$137.97	$232.61
5%	$297.51	$25.80	$25.00	$81.66

When the cost-share assistance is based on the 2.5% increasing social cost of carbon estimate, the cost-share would be larger than it currently is. However, in all other cases, even when the cost-share assistance is based on the constant 2.5% social cost of carbon estimate, the cost-share is actually higher in its current state. This suggests that the cost-share assistance is close to the value of carbon benefits already. In this scenario, basing the cost-share assistance on the societal benefits may not induce any greater participation. Overall, the program may be more successful by targeting pastureland or marginal cropland because the difference in NPVs are positive in some cases when pastureland rent is used and always negative when average cropland rent is used.

CHAPTER 7. CONVERSION FROM LAWN TO FOREST: IMPLEMENTATION AND RESULTS

7.1 Scenario Overview

The setting for this scenario is a private homeowner in Montgomery County, Maryland who is considering converting one acre of lawn into a red oak forest stand. This scenario provides insights on homeowners' preferences for lawn versus forest. The new L2W Initiative in Maryland covers all of the costs to establish trees on any patches of lawn that are at least one acre in size. All of the seedling and equipment purchases and planting are done by the Maryland DNR and the Arbor Day Foundation, so the landowner never has to incur any establishment costs. The program was launched in four pilot counties in 2014, including Montgomery County. The four species planted in 2014 as part of this program were red oak, red bud, hazelnut, and persimmon (Feldt, 2014).

For simplicity, the same volume measures used in the conversion from cropland scenario for an oak/hickory stand are used here. 79.7% of the 409 fully stocked, even-aged oak/hickory plots surveyed by the Forest Service included red oak (Schnur, 1937). I assumed that the annual volume measures for the red oak stand established in this scenario would be the same as the oak/hickory stand established in the previous scenario. The economically optimal rotation length was calculated in the previous chapter as 40 years, which is used here as well.

The base case for this scenario, also referred to as the 'without' case, assumes that the homeowner leaves the one acre as lawn. Two 'with' cases result from this scenario: one assuming the homeowner converts the lawn to forest without participating in L2W and one assuming the homeowner converts the lawn to forest and receives cost-share assistance from L2W for the tree establishment costs. The results for the two 'with' cases are calculated both with and without timber harvest. The homeowner would likely not harvest timber from one acre of trees, but calculating the revenue from timber harvest represents the maximum potential private benefits of establishing forest.

7.2 Establishment and Management Costs

The establishment costs used for this scenario are mostly the same as those used in the establishment of the oak/hickory stand in the previous scenario. The only difference is that the hardwood site preparation cost to convert pastureland to forest for the Southeast region was used in place of the cost to convert cropland to forest. The cost per acre to convert pastureland to forest in the Southeast region was $103.01 per acre ($145.13 per ace in 2010 dollars). The planting, herbicide, fertilizer, and miscellaneous management costs are identical to the previous scenario: $190.79 per acre, $82.39 per acre $20.88 per acre, and $2.35 per acre respectively (Bair & Alig, 2006).

The property taxes on lawn space would be based on the assessed value of the home in reality, but it is difficult to calculate an average assessed value for a home. For simplicity, I assumed the one acre of land was assessed as average agricultural land in the 'without' case and forested land under a certified management plan in the 'with' cases. The Montgomery County property tax rate is 0.732 per $100 in assessed value, and the Maryland state property tax rate is 0.112 per $100 in assessed value (Maryland Department of Assessments and Taxation 2015). With an assessment value of $187.50 for forested land, the total county and state property tax per acre is $1.58, which is included annually in the 'with' case. The total county and state property tax based on the average agricultural land assessment value of $312.50 per acre for cropland is $2.64, which is included annually in the 'without' case.

Zhou, Troy, Morgan Grove, and Jenkins (2009) conducted an econometric study to predict lawn-care expenditures based on demographic and socioeconomic indicators. In the process, they collected lawn care expenditures for Baltimore city and Baltimore County, Maryland. The average annual total lawn care expenditures were $319.71 in 2003 ($427.59 in 2010 dollars). The total lawn care expenditures included spending on lawn care services, lawn care supplies, equipment repair and rentals, and purchases of new yard machinery. The average lawn size used to produce these cost estimates is not reported, so this is a rough estimate to include for this scenario. One acre of lawn seems to be on the larger end of lawn size, so in reality, the expenditures may be more than these. However, I assumed that the annual lawn care maintenance cost is $427.59 per acre.

A summary of the establishment and management costs and the timing of their inclusion in the analysis is presented in Table 7.1.

Table 7.1 Summary of Costs for Converting Lawn to Forest

Cost	$/Acre (Real 2010 Dollars)	Inclusion in 'Without' Case	Inclusion in 'With' Case
Site Preparation	$145.13	-	Year 0
Planting	$190.79	-	Year 0
Herbicide	$82.39	-	Year 1
Fertilizer	$20.88	-	Years 5, 10, 15, 20, 25, 30, 35, 40
Miscellaneous Management	$2.35	-	Annually Beginning in Year 1
Forest Property Tax	$1.58	-	Annually Beginning in Year 0
Cropland Property Tax	$2.64	Annually Beginning in Year 0	-
Lawn Care Costs	$427.59	Annually Beginning in Year 0	-

(Bair and Alig 2006) (Maryland Department of Assessments and Taxation, 2015) and (Zhou et al. 2009)

7.3 Lawn to Woodland Participation

As previously discussed, the L2W Initiative covers 100% of the establishment costs. In the case where the homeowner participates in L2W, the site preparation and planting costs are zero. In other words, the total cost-share assistance per acre is $335.91. The landowner is still responsible for the management costs with participation in L2W.

7.4 Carbon Sequestration Benefits

The calculation of the carbon that remains permanently sequestered in harvested wood products for this scenario follows the same steps as the conversion from cropland to forest scenario. The process used to include carbon benefits in the ‘with’ cases that account for timber harvest is identical to the process used in the previous chapter. However, the ‘with’ cases in this scenario are also calculated without a timber harvest. Without harvesting any timber, the carbon that remains permanently sequestered as a result of the conversion to forest is much higher since none of it is released by harvesting. To calculate the carbon benefits in the ‘with’ cases that do not account for timber harvest, the total metric tons of annual carbon sequestration per acre (refer to equation 8 in the previous chapter) were multiplied by the appropriate carbon values. This calculation was done every year until the same year as the economically optimal rotation (year 40) to make the NPVs with and without timber harvest comparable.

7.5 Base Case Results

The net revenue each year was calculated by subtracting the annual costs from the annual benefits. In the ‘without’ case where the homeowner decides to keep the lawn as is, the net revenues in every year are negative since the aesthetic benefits from owning lawn are not monetized. Similar to the ‘without’ case, the ‘with’ cases that do not account for timber harvest have negative net revenues every year before the inclusion of carbon benefits. The base case NPVs are shown in Table 7.2. Lawn to Woodland is abbreviated as L2W in the result tables.

Table 7.2 Conversion from Lawn to Forest Results: Base Case NPVs
($/acre)

		Without Timber Harvest		With Timber Harvest	
Discount Rate	Without Conversion	With Conversion	With Conversion & L2W	With Conversion	With Conversion & L2W
2.5%	($11,230.18)	($616.41)	($280.50)	$1,033.31	$1,369.22
3%	($10,374.88)	($599.38)	($263.47)	$758.54	$1,094.45
5%	($7,812.57)	($548.35)	($212.44)	$80.86	$416.77

The base case results show how much more costly lawn is to maintain than forest. Conversion to forest also comes with costs, but they are much lower than the lawn maintenance costs. In reality, forest management costs would likely be higher than what is included in this scenario, but they would likely still be less than the lawn maintenance costs. Even without harvesting timber, converting to forest has a higher NPV than keeping it in lawn. Without participating in L2W, the homeowner still has enough incentive to invest in forestry if they plan on harvesting timber. Overall, on such a small piece of land as one acre, the investment decision likely depends more on the aesthetic values of lawn versus forest that the homeowner possesses. Large lawn space provides numerous benefits such as space for outdoor games and gatherings which cannot be estimated. In order for the landowner to decide not to convert to forest, their aesthetic value of lawn must be high enough to account for the large difference in NPVs between the 'with' and 'without' cases. Preference for lawn might limit participation in L2W and likely varies between landowners.

7.6 Discount Rate Sensitivity Results

The results in Table 7.3 show the difference in NPVs between the 'with' cases and the case without conversion to forest.

Table 7.3 Conversion from Lawn to Forest Results: Difference in NPVs
($/acre)

	Without Timber Harvest		With Timber Harvest	
Discount Rate	Additional NPV from Conversion	Additional NPV from Conversion & L2W	Additional NPV from Conversion	Additional NPV from Conversion & L2W
2.5%	$10,613.77	$10,949.68	$12,263.49	$12,599.40
3%	$9,775.50	$10,111.41	$11,133.42	$11,469.33
5%	$7,264.22	$7,600.14	$7,893.43	$8,229.34

In all cases, the homeowner could earn more by converting the lawn to forest. These results highlight how costly lawn maintenance is compared to forest maintenance. Again, even if the maintenance costs of the conversion to forest ended up being higher than the ones included in this analysis, they would likely never be high enough to be more expensive than the lawn maintenance costs. This is especially true since the lawn maintenance cost included here is likely an underestimate as well. The values in Table 7.3 can be thought of as the aesthetic value of lawn that the landowner would need in order to choose not to invest in forestry.

7.7 Carbon Price Sensitivity Results

The NPVs reported in Table 7.4 (using the California carbon price) and Table 7.5 (using the constant and increasing social cost of carbon estimates) are the difference between the NPVs with carbon benefits and the ones in Table 7.2 without conversion to forest. The issue of double counting may be present again here when both the cost-share assistance from L2W and the carbon benefits are included. The program information cites cleaner water, cleaner air, cooler temperatures, and wildlife diversity as reasons why one should participate in the program (Maryland Forest Service, 2014). Since carbon sequestration is a component of the cleaner air benefit, the subsidies may already be accounting for the carbon benefits. However, the NPVs with conversion to forest were already substantially higher than the 'without' case, so the possible double counting does not impact the investment decision.

Table 7.4 Conversion from Lawn to Forest Results: Difference in NPVs Including Carbon Benefits based on California Carbon Price
($/acre)

	Without Timber Harvest		With Timber Harvest	
Discount Rate	Additional NPV from Conversion & Carbon Benefits	Additional NPV from Conversion, L2W, & Carbon Benefits	Additional NPV from Conversion & Carbon Benefits	Additional NPV from Conversion, L2W, & Carbon Benefits
2.5%	$10,861.95	$11,197.86	$12,311.64	$12,647.55
3%	$9,993.72	$10,329.63	$11,175.76	$11,511.67
5%	$7,397.22	$7,733.13	$7,919.23	$8,255.14

Table 7.5 Conversion from Lawn to Forest Results: Difference in NPVs Including Carbon Benefits based on Social Cost of Carbon Estimates
($/acre)

		Without Timber Harvest		With Timber Harvest	
Discount Rate	Inclusion of Social Cost of Carbon Estimates	Additional NPV from Conversion & Carbon Benefits	Additional NPV from Conversion, L2W, & Carbon Benefits	Additional NPV from Conversion & Carbon Benefits	Additional NPV from Conversion, L2W, & Carbon Benefits
2.5%	Constant	$11,859.65	$12,195.56	$12,505.22	$12,841.13
	Increasing	$12,528.64	$12,864.55	$12,635.02	$12,970.93
3%	Constant	$10,486,60	$10,822.52	$11,271.39	$11,607.30
	Increasing	$10,974.35	$11,310.26	$11,366.03	$11,701.94
5%	Constant	$7,393.07	$7,728.98	$7,918.43	$8,254.34
	Increasing	$7,514.32	$7,850.23	$7,941.95	$8,277.86

Since the NPVs with conversion were already so much higher than without conversion in all cases, it is difficult to tell how much difference the carbon benefits make by looking at Table 7.4 and Table 7.5. In this case, it makes sense to show the actual NPVs including carbon benefits, without comparing them to the NPV without conversion.

Table 7.6 Conversion from Lawn to Forest Results: NPVs Including Carbon Benefits based on California Carbon Price
($/acre)

	Without Timber Harvest		With Timber Harvest	
Discount Rate	With Conversion & Carbon Benefits	With Conversion, L2W, & Carbon Benefits	With Conversion & Carbon Benefits	With Conversion, L2W, & Carbon Benefits
2.5%	($368.23)	($32.32)	$1,081.46	$1,417.37
3%	($381.16)	($45.25)	$800.88	$1,136.79
5%	($415.35)	($79.44)	$106.66	$442.57

Table 7.7 Conversion from Lawn to Forest Results: NPVs Including Carbon Benefits based on Social Cost of Carbon Estimates
($/acre)

		Without Timber Harvest		With Timber Harvest	
Discount Rate	Inclusion of Social Cost of Carbon Estimates	With Conversion & Carbon Benefits	With Conversion, L2W, & Carbon Benefits	With Conversion & Carbon Benefits	With Conversion, L2W, & Carbon Benefits
2.5%	Constant	$629.47	$956.38	$1,275.03	$1,610.95
	Increasing	$1,298.46	$1,634.37	$1,404.84	$1,740.75
3%	Constant	$111.72	$447.63	$896.51	$1,232.42
	Increasing	$599.47	$935.38	$991.14	$1,327.05
5%	Constant	($419.50)	($83.59)	$105.86	$441.77
	Increasing	($298.25)	$37.66	$129.38	$465.29

When the carbon benefits are based on the 2.5% and 3% social cost of carbon estimates, the conversion from lawn to forest results in a positive NPV, even without cost share from L2W. At a discount rate of 5% and including the carbon benefits based on the increasing social cost of carbon estimates, the conversion also results in a positive NPV without timber harvest. However, it is only when both the current L2W cost-share assistance and the carbon benefits are included, which may be double counting.

Table 7.8 shows the cost-share assistance based on the discounted carbon benefits provided by the conversion when no timber is harvested. Table 7.9 shows the cost-share assistance based on the carbon benefits and timber harvest.

Table 7.8 Conversion from Lawn to Forest Results: Comparison of Cost-Share Assistance based on Carbon Benefits without Timber Harvest
($/acre)

Discount Rate	Current WIP Cost-Share	California Carbon Price	Constant Social Cost of Carbon Estimate	Increasing Social Cost of Carbon Estimates
2.5%	$335.91	$248.18	$1,245.87	$1,914.87
3%	$335.91	$218.22	$711.10	$1,198.85
5%	$335.91	$133.00	$128.85	$250.10

Table 7.9 Conversion from Lawn to Forest Results: Comparison of Cost-Share Assistance based on Carbon Benefits with Timber Harvest
($/acre)

Discount Rate	Current WIP Cost-Share	California Carbon Price	Constant Social Cost of Carbon Estimate	Increasing Social Cost of Carbon Estimates
2.5%	$335.91	$48.15	$241.73	$371.53
3%	$335.91	$42.34	$137.97	$232.61
5%	$335.91	$25.80	$25.00	$48.52

Cost-share assistance based on the 2.5% and 3% social cost of carbon estimates would be substantially higher than the current cost-share assistance. From society's perspective the conversion is very valuable, but again, the private impatience at a discount rate of 5% might stop the private landowner from investing. The current cost-share assistance at a 5% discount rate is already higher than the carbon benefits from a private perspective. Again, the question of whether the government should make up the difference by offering larger subsidies in order to increase program participation and better society as a whole arises. Since the investment decision in this scenario depends largely on the aesthetic values of the landowner, larger subsidies could help outweigh a potentially high aesthetic value of lawn.

CHAPTER 8. CONCLUSION

8.1 Overview of Conclusions

For each scenario, conclusions can be made by comparing the results of the CBA with the observed forestry cost-share program participation and the GIS analysis results. Further, the results can provide insights on how realistic the goals set forth by Maryland’s GHGRP are in regards to the forestry efforts. Figure 8.1 shows how the analysis results feed into the big picture of what is really happening in Maryland.

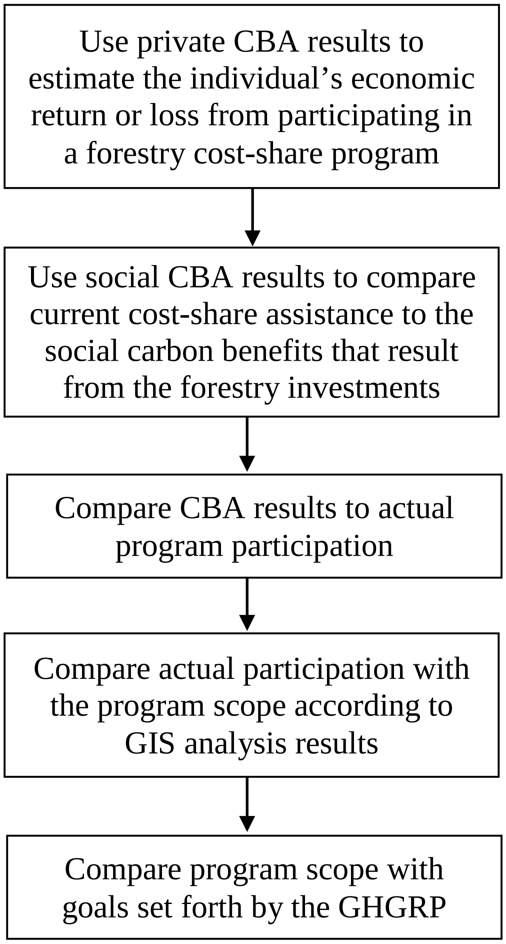


Figure 8.1 Progression of Results

A discussion of how the results for each scenario fit together using the flow diagram in Figure 8.1 will be presented in the next three sections.

8.2 Improving Timber Management: Synthesis of Results

The results of the CBA on improving timber management provide some insights on the observed WIP participation and the scope of land that is eligible for WIP. The timber management improvement in question was pre-commercial thinning of a four-year-old loblolly pine stand. With a pre-commercial thinning cost of $125.14 per acre, the resulting NPVs are positive in every case except the case with a discount rate of 5% and no participation in WIP. Since 5% is likely a representation of a private discount rate, this is an indicator that WIP should be successful in inducing improved timber management that would not have happened in the absence of the program. Even after adjusting for the uncertainty in pre-commercial thinning costs, the NPVs were positive with participation in WIP for all discount rates. Cost-share assistance from WIP is enough to result in a positive NPV from pre-commercial thinning, even at a discount rate of 5%. From these results, one could predict that forest owners would be willing to participate in WIP.

The average number of acres annually enrolled in WIP, based on data from the past eight years, is 3,055 (Rider, 2014). This is actually above the projected goal set forth as part of the original program information of enrolling 1,500 to 2,000 acres annually (Forest Service, 2008). According to the GIS analysis conducted, there are 736,761 acres of land that meet the eligibility requirements for WIP. Participation in WIP has exceeded the original program scope, but the number of eligible acres in Maryland greatly exceeds the observed enrollment.

Perhaps landowners are improving timber management without the help of cost-share programs or they are not specifically managing their forests for maximized timber growth. Landowners can pay DNR or other private forest industry firms to assist in developing forest stewardship plans, examining planting sites, marking areas in need of timber stand improvement, and renting forestry equipment. The extent of participation in such services was not gathered as part of this research, so no conclusion can be made on the number of acres of forest land in Maryland that is managed intensively. However, for landowners interested in improving timber management, WIP definitely provides the right incentives to induce participation.

The permanently sequestered carbon is greater with pre-commercial thinning due to accelerated growth following the thinning. WIP is cited as one of the programs in the Maryland GHGRP that will help the state meet the 2020 GHG reduction target of 25% below 2006 levels by increasing carbon sequestration by forests (Department of the Environment, 2013). The CBA results definitely support the claim that pre-commercial thinning leads to greater carbon sequestration than in similar stands without thinning. According to the GIS analysis, the lifetime carbon sequestration potential of the land that is eligible for WIP is about 139 million tons of carbon, which is 188 tons of carbon per acre. This is far above the estimated 4.56 million tons of carbon emissions reductions from forestry efforts in the GHGRP. However, those two numbers cannot really be compared because the estimate from the GHGRP only accounts for reductions between 2012 and 2020, while the carbon sequestration potential is over the entire plant lifetime. If anything, the GIS results provide evidence that the GHGRP estimate of carbon reductions due to forestry is reachable through increased participation in WIP.

When the cost-share assistance is based on the carbon benefits provided to society by the investment in pre-commercial thinning, the decision of whether or not to participate in WIP does not change. However, it does increase the returns for the landowner, which could increase program participation if that benefit accrued to the landowner. Cost-share assistance based on the constant 2.5% social cost of carbon estimate would be $146.82 per acre, compared to the current cost-share assistance of $81.34 per acre. Subsidizing carbon sequestration that results from WIP participation would potentially accelerate Maryland’s progress towards the goals laid out by the GHGRP.

8.3 Conversion from Agricultural Land to Forest: Synthesis of Results

The CBA results of the decision to convert cropland to forest are largely in favor of leaving the land as cropland. EQIP, administered by the NRCS, provides cost-share assistance for a large number of conservation practices, including several forestry practices. The conservation practice in question here was establishing new trees on cropland. Even with participation in EQIP, the NPVs from conversion to forest are around $1,000 per acre less than those of collecting cropland rent at all three discount rates (2.5%, 3%, and 5%). Based on these results, one would estimate that participation in EQIP for tree establishment would be relatively low.

From 2009 to 2013, tree establishment through EQIP has only been implemented on 344 acres in Maryland, which is as expected based on the CBA results (Morgart, 2014). According to the national land cover data that was used for the GIS analyses, there are around 1.2 million acres of cultivated cropland in Maryland (Jin et al., 2013). 344 acres is miniscule compared to the total eligible land for EQIP. In reality, lower value cropland would be much more likely enrolled in EQIP, but the cropland rent used here was an average value. The cropland would have to be worth around 40% less than the average cash rent of approximately $85 per acre (2010 dollars) for the landowner to establish trees as part of EQIP and not lose money. Perhaps EQIP would be more successful if it targeted marginal lands.

As a proxy for marginal cropland, the average pastureland rent of $39.12 per acre was used instead of the cropland rent. There are around 747,000 acres of pastureland in Maryland that could potentially be converted to forest. The NPVs with conversion of pastureland and EQIP participation were higher for discount rates of 2.5% and 3% than those without conversion. However, at a 5% discount rate, the conversion still results in lower NPVs even with participation in EQIP. Again, the personal discount rate of the landowner makes a big difference in the investment decision. However, the conversion from pastureland to forest is definitely more likely than the conversion from cropland to forest.

EQIP is also cited as one of the programs in the Maryland GHGRP that will help the state meet the 2020 GHG reduction target by increasing carbon sequestration in forests. When carbon benefits are included in the CBA, the NPVs from conversion to forest are still significantly lower than those of leaving the land as is. Even in the case of using pastureland rent, at a 5% discount rate, the inclusion of carbon benefits still does not outweigh the NPV without conversion. This indicates that from society's view, at a

2.5% discount rate, the pastureland should be converted to forest, but the private landowner will likely not make the investment. There may be potential for greater EQIP participation if the subsidies were increased to make the conversion from pastureland to forest a worthwhile investment at a 5% discount rate. Overall, larger subsidies are needed to induce landowners to convert any agricultural land to forest. Perhaps targeting land that is not committed to agriculture is a better option, which is discussed in the next section.

8.4 Conversion from Lawn to Forest: Synthesis of Results

According to the CBA results, targeting lawn for conversion to forest should yield much better results than targeting cropland. In all cases, the NPVs from converting to forest are greater than those from caring for lawn, even without harvesting any timber or participating in L2W. This is due to the large annual lawn maintenance costs. The aesthetic values that the landowner possesses for lawn versus forest become the determining factor for participation in a program like L2W because neither land use results in large returns to the landowner.

According to the GIS analysis results, there are 230,450 acres of eligible land for L2W, which is much lower than the one million acre estimate set forth as part of the program announcement (Forest Service, 2014a). Since the program is new, there is only one year of participation data to compare this to. In 2014, around 15 acres were enrolled in the program, which seems very small even though the program is new. The seemingly slow start to the program could be for a number of reasons. For example, it could be a program budget constraint, limited program administration resources, poor advertisement, or simply because private landowners do not want to convert their lawn to forest.

The GIS analysis results estimate that the total lifetime sequestration potential of the eligible land is about 300 million tons of carbon, which is approximately 1,300 tons per acre. This is significantly higher than the carbon sequestration potential per acre on the WIP land of 188 tons. This makes sense since the carbon sequestration potential only accounts for additional sequestration beyond what is already there. The land eligible for

WIP is already forested, so the potential for further sequestration is lower than that of land that has not been forested yet.

The inclusion of carbon benefits in this scenario is enough to outweigh the initial negative NPVs from conversion to forest without harvesting timber when the carbon benefits are calculated using the 2.5% and 3% social cost of carbon estimates. However, for a discount rate of 5%, which is likely more similar to a private discount rate, the carbon benefits do not outweigh the negative NPV of investing in forestry without harvesting timber, which illustrates the concept of private impatience. When the cost-share assistance is based on the constant 2.5% social cost of carbon estimate, it is $1245.87 per acre, compared to the current cost-share assistance of $335.91 per acre. Since the conversion is so valuable from society's perspective, increasing the cost-share assistance to fully internalize the positive external social benefits could increase program participation. Overall, from the three scenarios, it appears like increasing investment in the L2W program would make the greatest impact on reducing atmospheric carbon.

8.5 Comparison of Carbon Sequestration Potential and Abatement Costs

This section presents a discussion of the carbon sequestration potential of the forestry programs in Maryland and a comparison of the effective marginal abatement costs of forestry investments that qualify for each program. From Maryland's GHGRP, the forestry and sequestration efforts between 2012 and 2020 were projected to result in a reduction in emissions of 4.56 million metric tons. The GIS analysis results estimated the lifetime carbon sequestration potential of all eligible land for each program, which was divided into a per acre estimate. This per acre estimate was multiplied by the actual program participation over the past few years to estimate how much carbon will be sequestered over the lifetime of the land that is already enrolled in each program. Further, in the case of L2W, the program implementation materials estimated how much land was eligible for the program, so the per acre lifetime carbon sequestration potential estimate was also multiplied by the program potential according to DNR. Table 8.1 shows how these carbon sequestration estimates compare.

Table 8.1 Carbon Sequestration Potential of Maryland’s Forestry Programs
(millions of tons of carbon)

	Program Participation		
	Actual Realized Potential	GIS Estimated Potential	DNR/GHGRP Estimated Potential
WIP	4.61	138.82	N/A
EQIP Conversion of Cropland Conversion of Pastureland	0.45	1570.30 977.39	N/A
L2W	0.02	301.56	1308.89
Total Forestry Efforts	5.08	2988.07	4.56

One can see from Table 8.1 that the total lifetime carbon sequestration potential is not even close to being realized for any of the programs. Further, the DNR estimated carbon sequestration potential of L2W is much higher than the GIS analysis results. However, the GIS estimated lifetime carbon sequestration potentials for the three programs are still quite substantial. For perspective, the total 2013 Maryland GHG emissions was 96.8 million tons, so the total GIS estimated lifetime carbon sequestration potential for all three programs is the equivalent of about 30 years of annual emissions. Even though the lifetime potentials are far from being realized, the goal set forth by the 2012 GHGRP for the total forestry and sequestration efforts to result in a reduction of 4.56 million tons by 2020 appears to be doable. The total lifetime carbon sequestration potential for the land already enrolled in the programs is 5.08 million tons. Increasing participation in the forestry cost-share programs is definitely a climate change mitigation strategy that could be successful.

The important question is how the abatement costs from the forestry cost-share program participants compare to abatement costs from carbon markets. Table 8.2 compares the abatement costs of each forestry investment to the abatement costs from United States carbon markets (California and RGGI) and the marginal damages as estimated by the constant and increasing social cost of carbon estimates. The effective abatement costs were calculated by dividing the ‘with’ minus ‘without’ NPVs (in dollars per acre) for each scenario by the total permanently sequestered carbon (in tons per acre) that results from the forestry investment. The L2W abatement costs were also calculated using just the ‘with’ NPVs to provide a perspective of what happens when the lawn maintenance costs are not included as opportunity costs in the calculation. The timing of the carbon sequestration is not taken into account in these calculations.

Table 8.2 Effective Abatement Costs of Forestry Investments
(2010 $/ton)

	Discount Rate		
	2.5%	3%	5%
WIP - Pre-Commercial Thinning	($12.67)	($6.56)	$15.02
EQIP - Agricultural Land Conversion			
Conversion of Cropland	$138.24	$152.62	$176.99
Conversion of Pastureland	($15.69)	$10.42	$69.91
L2W - Lawn Conversion			
With Timber Harvest	($1,576.76)	($1,431.47)	($1,014.89)
Without Timber Harvest	($102.70)	($94.59)	($70.29)
Excluding Lawn Maintenance Costs			
With Timber Harvest	($132.86)	($97.53)	($10.40)
Without Timber Harvest	$5.96	$5.80	$5.31
Marginal Abatement Costs – Carbon Markets			
California Cap-and-Trade Program	$12.14	$12.14	$12.14
RGGI	$4.94	$4.94	$4.94
Marginal Damage - Social Cost of Carbon			
Constant	$54.54	$34.22	$11.76
Rising	$60.96	$39.57	$11.76

In many cases, the abatement costs for forestry investments are negative, which means that those investments are profitable for private landowners at a given discount rate. Hence, the existing incentives are enough for the landowner to be willing to make the forestry investment, even without extra incentives to sequester carbon. The lawn conversion scenarios result in very large negative numbers, which means that the potential private benefits are quite substantial from the conversion. Even when the opportunity costs of lawn maintenance are excluded from the calculations, the abatement costs are still very low. Large positive abatement costs indicate investments that are not privately profitable and therefore are not cost-effective mitigation strategies. The only cases where the abatement costs of forestry investments are higher than the California carbon price are the conversion from agricultural land cases. The only exceptions are the conversion from pastureland to forest at the 2.5% and 3% discount rates. Since the cropland cash rent is higher than the pastureland cash rent, the abatement costs are higher for cropland conversion than for pastureland conversion.

Table 8.3 shows what the carbon price (California or RGGI) would need to be for the private landowner to make the forestry investment in question and gain the monetized external benefits from the permanently sequestered carbon that results from the investment. In other words, Table 8.3 shows the break-even carbon prices of the three forestry investment scenarios. The break-even carbon prices were calculated by determining which carbon price sets the 'with' minus 'without' NPVs equal to zero for each forestry investment. The 'with' minus 'without' NPVs used for the calculations were those that include carbon benefits based on the California carbon price. The timing of the carbon sequestration is taken into account in Table 8.3, which is different from Table 8.2. The carbon sequestered further in the future is discounted back to the beginning of the investment, so it is not as valuable.

Table 8.3 Break-Even Carbon Prices of Forestry Investments
(2010 $/ton)

	Discount Rate		
	2.5%	3%	5%
WIP - Pre-Commercial Thinning	($23.55)	($12.80)	$35.64
EQIP - Agricultural Land Conversion			
Conversion of Cropland	$271.14	$340.44	$647.81
Conversion of Pastureland	($30.77)	$23.23	$255.88
L2W - Lawn Conversion			
With Timber Harvest	($3,092.67)	($3,193.13)	($3,714.57)
Without Timber Harvest	($519.33)	($543.98)	($663.27)
Excluding Lawn Maintenance Costs			
With Timber Harvest	($260.58)	($217.55)	($38.05)
Without Timber Harvest	$30.16	$33.35	$50.07

A positive break-even carbon price indicates that the current carbon price would have to increase to that level in order for the landowner to make the forestry investment. For example, in the case of conversion from cropland to forest at a typical private discount rate of 5%, the carbon price would need to increase to $647.81 per ton before the landowner would make the conversion and gain the monetized carbon benefits. Again, this illustrates how difficult it is to induce conversion of cropland to forest. In the case of conversion from pastureland to forest, the break-even carbon prices are much smaller. However, at a discount rate of 5%, the break-even carbon price for conversion from pastureland is $255.88, which is still quite large.

There are many cases where the break-even California carbon price is substantially lower than the current California price of around $12 per ton. The main example of this is the lawn to forest scenarios, especially when the landowner harvests timber. However, even the cases without timber harvest result in large negative break-even carbon prices. A negative break-even carbon price indicates that the forestry investment is not contingent on participation in the carbon market. The investment is privately profitable without any monetized external carbon benefits. Since it is so cheap to sequester carbon by converting lawn to forest, pursuing this as a mitigation strategy makes sense for the state of Maryland. Further, pre-commercial thinning is relatively cheap as well, especially at the 2.5% and 3% discount rates. These results suggest that increasing participation in the two state-funded programs (WIP and L2W) would be a cost-effective climate change mitigation strategy for Maryland.

8.6 Analysis Limitations

The analysis limitations are largely due to data imperfections and the need to condense the actual heterogeneity amongst land and forest stands in Maryland into three average case scenarios. The scenarios were region specific to Maryland, but not all of the data were region specific. For example, most of the costs taken from Bair and Alig’s (2006) regional cost publications were not reported for the Northeast region, so the costs for the Southeast region were used. Also, the volume growth measures for loblolly pine were not specific to a certain region. The growth rate could vary significantly based on locational features. Even within the Northeast region, costs may vary significantly between states, which is not accounted for in much of the data used. Further, while the lawn care maintenance cost was specific to Maryland, the estimate did not account for lawn size, so some uncertainty surrounds the NPVs from the base case in the L2W scenario. If anything, the lawn maintenance costs were likely lower than they would be in reality, since one acre of lawn is quite large. Also, the projected prices from Haynes (2003) are outdated even though they seemed like the best available estimates to use.

Uncertainty in the discount rate is another limitation that is common for most analyses of this type. Every landowner has a unique discount rate depending on their preferences for future consumption and risk, so assuming that every landowners' discount rate will fall into one of the discount rates I used is a limitation. I assumed that 2.5% was a representation of the social discount rate, and 5% represented a private discount rate. However, private landowners could just as easily have discount rates much higher than 5% in reality, which would make the forestry investments even less likely in all scenarios and further accelerate the problem of private impatience. This may explain the low program participation observed over the past few years.

The uncertainty in carbon valuation that was discussed in the review of climate change economics section also exposes a limitation of this analysis. Uncertainty in future damages from carbon emissions as predicted by the IAMs used to estimate the social cost of carbon result in estimates ranging from around $12 a ton to $60 a ton for 2010 (Greenstone et al., 2013). It has been argued by some that these values vastly underestimate the true damages from carbon emissions (Moore & Diaz, 2015). Further, the majority of carbon prices emerging from markets around the globe are on the low end of the social cost of carbon estimates. By using both the social cost of carbon estimates and the California carbon prices, some of the uncertainty was accounted for through sensitivity analysis.

Lastly, the inclusion of only the carbon sequestration benefits excludes many other important co-benefits from forestry. For example, water quality improvements, wildlife habitats, and recreational opportunities could have been included in a social cost benefit analysis as well. Since only the benefits from carbon sequestration were included in this analysis, the numbers resulting from the social CBA are only a lower bound of the actual benefits that forests provide to society. Further, the social benefits discussed here are global benefits, not just benefits for the state of Maryland. Regional programs are used in this analysis, and in reality, Maryland only realizes a portion of the benefits provided to society by the programs. To really deal with climate change problems, other states need to be doing what Maryland is doing. To suggest that Maryland needs to invest more in its forestry programs is one small piece of what needs to be done to solve the climate change problem.

8.7 Future Research and Recommendations

I plan to present the results of this analysis to employees of the Maryland DNR with hopes of providing a private landowner perspective on whether the forestry cost-share programs provide the right incentives to induce participation. I would like to provide guidance to the Maryland DNR on what to emphasize in pushing the programs forward. Further, since this research illustrates a potential use of GIS data produced by Dubayah et al. (2013) as part of NASA's CMS program, I hope to increase awareness of the value of such data. The GIS analysis provided considerable insights on the actual participation relative to the program scope and on the carbon sequestration potential. By illustrating the value of carbon monitoring data, the data is more likely to be updated in the future.

One of the main conclusions from this analysis is that even when the forestry cost-share programs provide enough incentive to induce participation, the actual participation is much less than the potential. Even in cases where the program seems to be providing enough incentive for landowners to participate, the uptake of the program seems slow. Perhaps there is a budget constraint or limited administrative resources for the program, which both could limit participation. One recommendation for the DNR in Maryland is to increase advertisement of their forestry cost-share programs. The new L2W program is difficult to find on the DNR website, and the WIP advertisement materials do not seem like they have been updated since the program was first implemented.

In addition to increasing program advertisement, if the cost-share assistance was adjusted to include greater compensation for carbon sequestration, program participation may be increased. The difference in investment decisions using the 2.5% discount rate and 5% discount rate illustrates the idea of private impatience in all scenarios. If the cost-share assistance fully internalized the external carbon sequestration benefits provided to society by the forestry investments, the problem of private impatience may decrease. Further work on what motivates program participation is warranted to fully understand what the Maryland DNR could do to increase participation.

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APPENDIX

APPENDIX

The purpose of this appendix is to present a detailed description of the GIS analysis discussed in Chapter 3, which describes the forestry cost-share programs available for landowners in Maryland. The GIS analysis was conducted to determine the eligible number of acres for WIP and for L2W. As a reminder, anyone who owns between five and 1,000 acres of woodland and agrees to uphold improved forestry management practices for 15 years is eligible for WIP. Further, any private landowner with at least one acre of lawn qualifies for L2W. The eligibility criteria were based on these program requirements. Table 1 shows the GIS data sources used in the analysis.

GIS data layers are reported in either raster or vector format. Both were used for this analysis. Raster data is organized in a matrix of cells, in which each cell has a unique value. Vector data is organized in one of the following formats: polygons, lines, or points. The first step in the GIS analysis was to convert the polygon layers to raster layers. The reason for the conversion was because the eligibility requirements for the cost-share programs were first applied to each cell individually, so all of the data needed to be in raster format. Once the eligible cells were selected, appropriately sized portions of eligible cells were isolated by converting the eligible patches of cells back into polygons and using the polygon areas.

Appendix Table 1. GIS Data Sources and Layers Used in Analysis

Data Source	Layers Used	Layer Format
Maryland Carbon Monitoring System (Dubayah et al., 2013)	Maryland Statewide Canopy Cover	30-meter raster
	Maryland Statewide Carbon Sequestration Potential	90-meter raster
National Land Cover Database (Jin et al., 2013)	Maryland Statewide Land Cover Classifications	30-meter raster
Maryland Protected Lands Map Server (Maryland iMAP 2014)	Maryland DNR Owned Properties and Conservation Easements	polygon
	Rural Legacy Properties	polygon
	Maryland Environmental Trust Easements	polygon
	Forest Conservation Act Easements	polygon
	Maryland Agricultural Land Preservation Foundation Easements	polygon
	Local Protected Lands	polygon
	Private Conservation Lands	polygon
	Protected Federal Lands	polygon

Once the polygon layers from the Maryland Protected Lands Map Server were converted to raster, they were combined into one layer. The reason for the combination of layers was to decrease the number of steps to select eligible cells for each program. In the combined layer, any cell with a value of ‘0’ was a piece of land that was not part of any of the original polygon layers. In other words, any cell with a value of ‘0’ was not owned by DNR or in some sort of conservation easement. The combined layer was named ‘Conservation Layers,’ which is how it is labeled in the rest of the analysis.

Model Builder in ArcMap was used to do the rest of the analysis. The WIP and L2W models are very similar. The first goal of the analysis was to calculate a raster layer that reported a ‘1’ for all cells of eligible land, according to the criteria for the two programs.

For the WIP model, the criteria were: Conservation Layers = 0 and Canopy Cover >= 95%. These criteria select all cells that are privately owned and contain a canopy cover of at least 95%.

For the L2W model, the criteria were: Conservation Layers = 0, Canopy Cover <= 30%, and NLCD = 21 (Developed, Open Space). Most large lawn spaces in the Maryland imagery were classified as ‘developed, open space,’ so that is how this criteria was chosen. These criteria select cells that are privately owned, covered by no more than 30% canopy cover, and classified as ‘developed, open space.’ Originally, an eligibility requirement of 0% canopy cover was chosen, but in reality, most lawn space has a few trees on it. For this reason, 30% canopy cover was used to represent lawn that may have some trees on it but would definitely be able to accommodate more trees from participation in the L2W program.

The second goal of the analysis was to select only the patches of eligible land that met the acreage requirements (5 acres for WIP and 1 acre for L2W). The first step was to isolate patches of eligible land since there were so many long strings of cells that passed the eligibility criteria but were not actually eligible for the programs. For example, long strings of road side trees passed the eligibility criteria for WIP, but they are not actually forest patches. This task was accomplished by using the ‘Focal Statistics’ tool. This tool calculates a statistic of the values within a specified neighborhood around each cell. By using a 3x3 rectangle as the specified neighborhood around each cell, any cell with a value of ‘9’ was eligible land that was surrounded on all sides by eligible land.

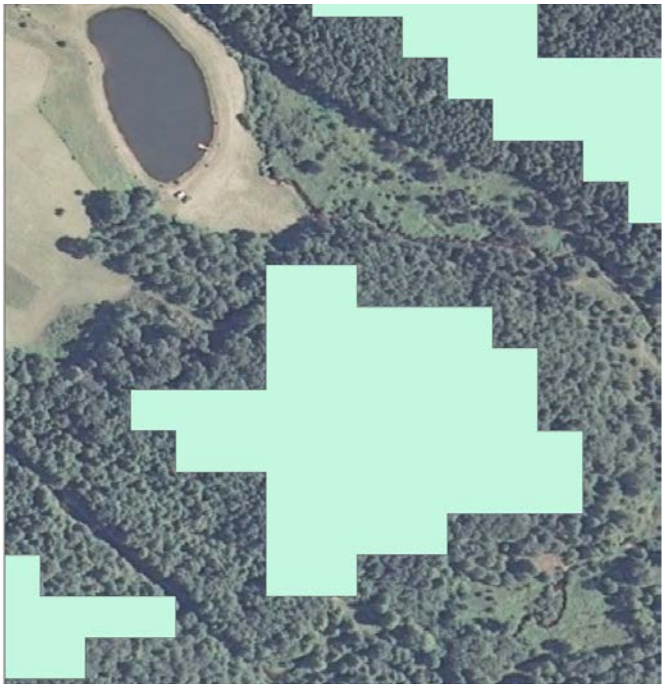
For the WIP model, a value of ‘9’ was used as the required criteria, and for L2W, any value >= ‘4’ was required. The reason why the L2W value is lower is because the acreage requirement is smaller, so it is not as important that a cell is surrounded on all sides by other eligible land.

The next step was to convert the eligible patches of land into polygons. As mentioned earlier, this conversion was made because the patches of eligible cells needed to be selected based on their acreage. The easiest way to calculate areas using GIS data is to have the data in a polygon format. For the WIP model, all polygons with an area >= 20,234.3 m^2 (5 acres) were selected, and for the L2W model, all polygons with an area >= 4,046.9 m^2 (1 acre) were selected. By adding the areas of all of the eligible polygons, the total number of eligible acres for each program was calculated.

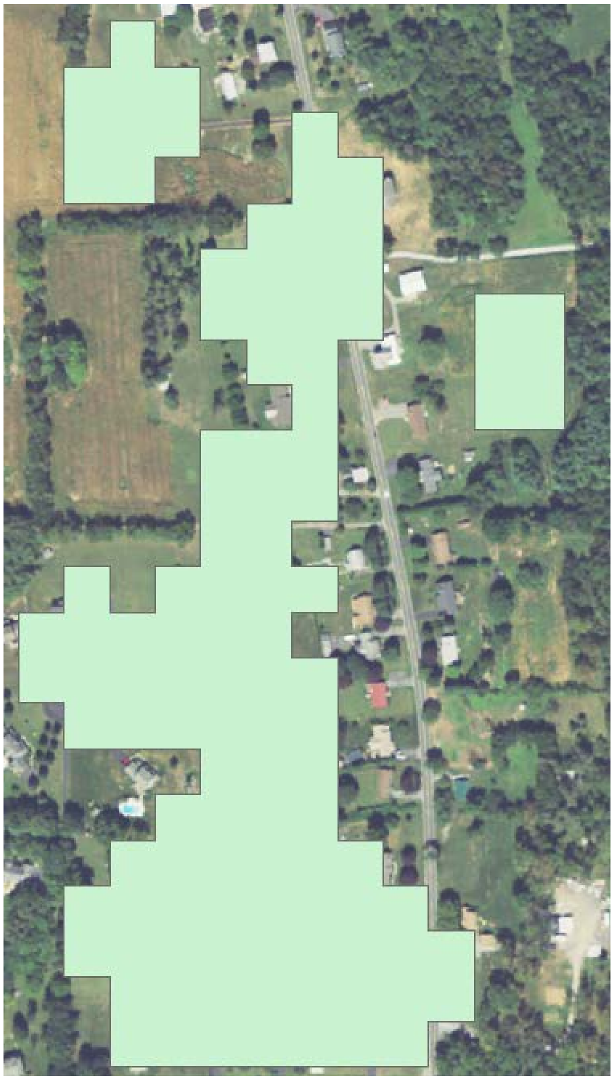
The third goal of the analysis was to calculate the carbon sequestration potential for the selected eligible polygons. This task was accomplished by using the 'Zonal Statistics' tool. This tool calculates statistics based on values of a raster, within the zones of another dataset. In this case, the raster layer used was the Carbon Sequestration Potential layer, and the zones were the selected eligible polygons for each program. In other words, the carbon sequestration potential values for each cell within each eligible polygon were added together in this step, resulting in a total carbon sequestration potential value for each polygon. By adding the carbon sequestration potential values for all of the eligible polygons, the total carbon sequestration potential was calculated for each program.

Example results are shown in Figure 1 and Figure 2. The resulting polygons are overlaid with Maryland imagery to illustrate that the analysis does in fact select polygons that look eligible according to the imagery. In Figure 1, the polygon is part of a large forested area (eligible for WIP), and in Figure 2 the polygons are in an urban fringe area where the houses are spread out enough to have large lawn space (eligible for L2W). A limitation of the L2W results is that certain areas of land meet all of the analysis requirements, but they are not actually lawn when they are compared with the imagery. For example, golf courses and baseball fields are included in the results.

The total acreage eligible for each program is 736,761.5 acres for WIP and 230,450 acres for L2W. The total carbon sequestration potential (excluding current aboveground biomass) for each program is 138,816,892 metric tons for WIP and 301,563,830 metric tons for L2W. These results indicate that the carbon sequestration potential of the land that could be enrolled in either WIP or L2W is quite substantial. It is important to remember that the carbon sequestration potential values are the sum of all carbon sequestered over the lifetime of the trees. In other words, these are not annual values. However, over 400 million metric tons could be sequestered on the eligible land, which is about four years' worth of total emissions for Maryland.



Appendix Figure 1. Example WIP Analysis Results



Appendix Figure 2. Example L2W Analysis Results