NICHOLAS SCHOOL OF THE ENVIRONMENT

Duke Forest Carbon

An Analysis of the Potential for Using Forest Management to Achieve Emissions Reductions

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Duke University is dedicated to achieving climate neutrality by 2024. With over 7,000 acres of sustainably managed forest land, the Duke Forest has great potential for generating "in house" carbon offsets to help reach this goal. In this project we quantified the carbon represented in Duke's forest holdings and analyzed the potential for generating emissions-reducing offsets based on Climate Action Reserve (CAR) and American Carbon Registry (ACR) protocols. Throughout the process we focused on three varieties of forest offsets: Avoided Conversion, Improved Forest Management, and Afforestation/Reforestation, comparing the relative advantages and disadvantages of each under CAR and ACR carbon accounting systems. After completing these carbon calculations we conducted a financial analysis of results and made recommendations to the Duke Carbon Offsets Initiative concerning how they might apply these forests offsets towards the University's carbon neutrality goal.

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Introduction

Duke University Climate Neutrality

The development of carbon offsets is a crucial component of Duke University's plan to achieve climate neutrality by 2024. Increased efficiency alone cannot meet this goal, especially while the school relies on fossil fuels for its energy needs. However, in the development and selection of offsets the school has an opportunity to take a leadership role in the burgeoning field of environmental markets. With the resources it has available, and in keeping with the goals of Duke's Climate Action Plan, the University is in a position to play a key part in the development of forest carbon offset projects locally and across the region. The 7,091-acre Duke Forest represents not only carbon sequestration potential, but also a teaching tool for fostering better understanding of the mechanisms for developing forest offsets for land conservation organizations and private landowners. This project brings together stakeholders from the University with vested interests in each of these areas, with the goal of producing a carbon inventory of the Duke Forest that can benefit the University's climate neutrality goals while enhancing the development of the local carbon offset market through outreach and education.

Since its establishment in the early 1930s the Duke Forest has provided invaluable opportunities for the study of forestry and ecology to generations of students. As the voluntary carbon market grows, along with a range of ecosystem services markets, professional resource managers along with graduate students from Duke's Nicholas School of the Environment are seeking to develop the necessary skills to succeed in these areas. With this in mind it seems a vital time to undertake an account of the carbon sequestered by the Forest, with an additional emphasis on the potential educational benefits to be gained.

While an accurate measure of the current carbon sequestration in the Duke Forest will be useful for its future management and for assessing Duke's carbon footprint, the benefits will extend well beyond the boundaries of the forest. We recognize that the opportunity to develop the skills necessary to assess the quantity of carbon and the carbon sequestration potential of forested lands may be even more valuable for future students. Moreover there is substantial potential to support climate change mitigation through terrestrial carbon sequestration by promoting these skills among land conservation organizations, private landowners, and resource managers. Through taking such a leadership role, Duke can encourage local and regional involvement in forest carbon markets while improving its own ability to effectively utilize its carbon assets.

Project Goals

The potential for Duke University to generate its own forest carbon offsets is of interest to numerous stakeholders within the Duke community. In this project we set out to quantify the carbon represented in Duke Forest, and a pair of neighboring properties, based on forest carbon project protocols from two highly respected carbon registries (The Climate Action Reserve and The American Carbon Registry) in order to determine the Forest's potential for generating offset credits. By comparing protocol methods we hoped to gain a greater understanding of the variation in potential carbon values that one might find depending on the methodology employed in field analysis, forest carbon modeling, and carbon accounting. Our ultimate objective was to establish the potential quantity of current and future forest carbon offsets that could be developed on our study sites and asses the monetary value represented by these offsets.

After sharing these over-arching project goals with Sustainable Duke's Carbon Offsets Initiative (DCOI), the Duke Environmental Leadership (DEL) Program, and the Duke Forest, the three organizations agreed to jointly sponsor our work. Each of these groups was interested in different aspects of the project, and as such had specific requirements regarding additional deliverables we were to produce for them.

Carbon Offsets Initiative

Our assessment of the potential to develop certified carbon sequestration credits within the Duke Forest supports the Carbon Offsets Initiative's mission to secure carbon offsets to meet Duke's 2024 climate neutrality commitment. Our final analysis of the financial viability of developing local forest carbon offsets will be used to guide the further development of Duke's offset portfolio. Our analysis and recommendations cover the selection of a carbon protocol, the identification and prioritization of potential acquisitions, future project development, and the potential role for Duke University as a forest carbon offset buyer and developer. This final component will enable Duke to achieve its own climate objectives while also aiding conservation goals locally and further afield.

The DCOI expressed a particular interest in the role of Improved Forest Management on the Duke Forest, and the potential for quantifying reductions under this type of carbon offset project. Steps to meet Duke's goal of climate neutrality are being executed in accordance with the American College and University Presidents Climate Commitment (ACUPCC). In order for carbon offsets originating from university owned land to qualify under the ACUPCC these offsets need to meet the most rigorous industry standards.

DEL Program

The Duke Environmental Leadership program would like to offer a series of courses for professionals in a range of fields who need to understand climate change and carbon offsets in order to meet the requirements of changing markets and policies. Using the knowledge acquired and tools produced in the execution of our carbon analysis for the Duke forest, we have produced educational materials for a course titled *An Introduction to Forest Carbon Offsets*. The course will cover the general structure and goals of carbon markets, the role of forest carbon offsets locally and internationally, the procedure for collecting and processing field data, and the analysis of management techniques for carbon sequestration as a means of conserving forests.

Duke Forest

The Duke Forest is managed for research, education, and sustainable timber production. Duke Forest management emphasizes strict adherence to best management practices (BMPs) and for the past decade Duke has maintained forest certification under the Forest Stewardship Council (FSC) as a mark of its commitment to these principles. Our research will inform Duke Forest management as to the current and potential quantities of carbon represented within the forest. With this knowledge the Duke Forest will be prepared to comply with future FSC audit requirements, which will likely demand deeper engagement with climate change goals and potentially necessitate a full carbon inventory. Additionally, our work will serve as a model for current and future master's students with an interest in studying how to utilize carbon sequestration, along with a variety of other forest ecosystem services, to achieve the conservation goals of the 21st century.

Background

Why Forest Offsets?

In its comprehensive 2007 Fourth Assessment Report, The International Panel on Climate Change (IPCC) concluded that carbon-dioxide (CO_2) levels in the atmosphere should be reduced to below 350 ppm to avoid the worst effects of climate change[1]. Today CO_2 levels exceed 390 ppm and at the current rate of accumulation will reach 470 ppm by midcentury[2]. As deforestation and other forms of land use change account for ~36% of gross global greenhouse gas emissions(GHG)[3] - more than the entire global transport sector- forest carbon mitigation could play a significant role in stemming and ultimately reversing the trend in rising CO_2 levels. Recent studies also highlight the potential for forest offsets to be among the lowest-cost GHG offset mechanisms[4] and an investigation commissioned by the UN has suggested that without the inclusion of forest carbon offsets in climate change mitigation strategies, the international community's (Conference of the Parties 13, Bali 2009) goal of limiting global temperature increase to a maximum of 2 degrees-Celsius, will not be attainable[5].

In addition to carbon sequestration, forests provide a wide variety of ecosystem services that contribute substantially to global society[6]. These services include: providing *provisioning* (food, fresh water, wood/fiber, and fuel), supporting *social values* (atheistic, spiritual, recreational, and educational), improving *health* (reduction of vector-borne disease transition[7] and production of compounds used in drug manufacture), and sustaining *biodiversity*[8] (flora, fauna, micro-fauna, etc.). These additional values provided by forests create a double benefit to forest preservation/conservation activities.

What makes a high-quality Forest Carbon Offset?

Forest offsets have been a topic of considerable controversy over the last decade. This is because despite forests offering some of the greatest promise for low-cost GHG reductions[9], a number of outspoken individuals fear that the offsets generated by forests will be impermanent[10], illegitimate[11], or exploitative of local communities[8].

To address these concerns, a considerable body of work has been generated to establish how best to utilize the potential benefits of forest-carbon projects while avoiding the pitfalls that could render them ineffectual. While to date there is still no consensus on what is necessary to ensure forest offset projects fulfill their climate obligations without destabilizing the lives of forest peoples, several generally accepted principles for forest-carbon project legitimacy have become established through domestic and international dialogue. The following principles appear extensively in the offset literature and are represented in the framework outlined by the UN-REDD program[12] and the *decisions documentation* produced at COP 15 (Conference of the Parties, Copenhagen 2009) [13]:

- **Additionality** - All GHG reductions must exceed those that would have occurred in the absence of the project activity and under a business-as-usual scenario
- **Permanence** - Carbon associated with credited GHG reductions must remain recalcitrant into perpetuity (the practical time period represented by “perpetuity” is not explicitly defined)
- **Measurement, Reporting, and Verification** – GHG reductions must be accurately quantifiable, transparently reported, and verified by a responsible oversight body on a regular basis
- **Avoidance of leakage** – Projects must avoid any decrease in carbon sequestration or increase in emissions outside project boundaries as a result of project implementation
- **Incorporation of local stakeholders** - Project activities should provide net benefits to affected communities and the environment, and should not provide perverse incentives for the clearing of land to generate carbon offsets

- **General conservatism in carbon offset quantification** – Where doubt is present concerning the quantity of carbon credits to be attributed to a forest project, project developers should favor more conservative estimates of carbon sequestration benefits

Why CAR and ACR?

While over a dozen carbon registries currently certify forest carbon projects[14] we used The Climate Action Reserve (CAR) and The American Carbon Registry (ACR) in our analysis. Our decision to highlight these registries was based on the explicit nature of their individual project protocols, the scientific rigor of their carbon quantification methods, and industry support for their quality standards. The six key-principles for forest carbon offset integrity (listed in the above section) are also addressed by both CAR and ACR.

Since its establishment in 2008 CAR has gained considerable market share in the domestic voluntary carbon market and currently has over 300 officially listed projects[15]. CAR protocols serve as the bases for California's Air Resources Board (ARB) forest carbon offset standards[16] that are slated to be implemented in 2012 under California's groundbreaking *Global Worming Solutions Act* (AB32).

ACR was founded in 1996 as the first private voluntary GHG registry in the US and has issued over 31 million tonnes of certified carbon offsets since its inception[17]. ACR standards have been vetted by a team of industry leading scientists and the organization is an enterprise of Winrock International, an award-winning international non-profit.

Additionally, both CAR and ACR protocols are recognized by The International Carbon Reduction and Offset Alliance (ICROA), a not-for-profit group of leading carbon reduction and offset providers dedicated to advocating for strong industry standards in the voluntary carbon sector.

Methods

Overview

- Conducted field measurements on Duke forest land

- Determined which sites neighboring Duke Forest had the best potential for the establishment of forest carbon projects and conducted measurements on these sites
- Calculated current forest biomass and carbon figures for all sites under study
- Modeled growth of forests for *baseline*, *Avoided Conversion*, *Improved Forest Management*, and *Afforestation/Reforestation* scenarios under both protocols
- Calculated potential carbon offset disbursement schedules for all project types under both protocols
- Compared offset benefits and costs for all project types under both protocols

Field Sampling

Duke Forest Decadal Inventory

As the current and potential carbon value of the Duke Forest was the central focus of the project, these measurements were the most essential and also the largest portion of all data analyzed in the project. The Duke Forest decadal inventory, which began in the late summer of 2010 and ended in early summer 2011, supplied the majority of the data needed for the Duke Forest carbon assessment. The inventory consisted of 1,500 randomly generated sample points spread throughout the seven Forest divisions (appendix map 1). Four hundred of these sample points were "full-measurement plots", requiring the recording tree species, diameter at 4.5 feet above the ground (diameter at breast height, DBH) using diameter tape, and height using a clinometer (at 1 chain/66 feet distance) for all trees >4.5 inches DBH within the plot. The remaining 1,100 sample points were "non-measurement plots", which only recorded species and product class – either pulpwood or saw timber – for all trees within the sample plot. Pulpwood size trees were classified as all trees smaller than 4.5 inch DBH, and saw timber size trees as all those greater than 4.5 inch DBH. Sample points were located using a GPS unit. In accordance with Duke Forest inventory convention, variable radius plots were measured using a 10 basal area factor prism (Image 1) at each sample point location. Trees on the plot border were included every other instance.

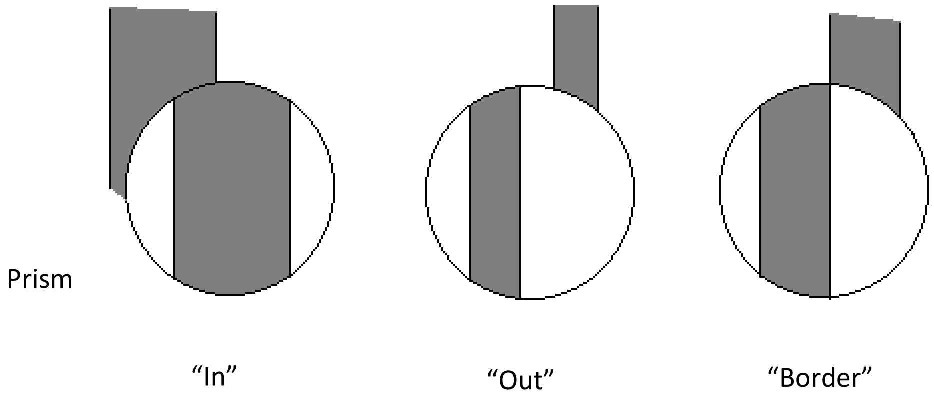


Image 1: *From Duke Forest Inventory Procedure*

Standing Deadwood

In addition to the data collected on live trees within the Duke Forest, data on standing deadwood within the Forest was also collected from 100 of the 400 full measurement plots. All standing dead trees with DBH greater than 4.5 inches within randomly selected plots were identified based on species (when possible) and measured for DBH, height and degree of decomposition. Decomposition was assessed subjectively by assigning dead trees to one of four classes. Class-1 trees were largely intact with well-preserved major and minor branches still holding twigs. Class-2 trees showed some bark loss and maintained fewer intact branches with no twigs. Class-3 trees displayed greater bole degradation and held only a few large branches. Class-4 trees exhibited considerable bole deterioration and possessed no branches whatsoever. These classes were used to apply biomass deductions to each dead tree which ultimately translated to deductions in gross carbon sequestration benefit.

In accordance with CAR protocols, each individual standing dead tree was given a specific biomass deduction based on species and decomposition class. Deduction factors were referenced from Harmon et al.[18], as specified within the protocol.

When applying ACR protocols, decomposition classes were assigned default biomass deductions. Class-1 trees receive no deduction (i.e. are treated the same as live trees), class-2 trees receive a 5% deduction, class-3 trees receive a 10% deduction, and class-4 trees receive a 15% deduction[19].

All live and standing deadwood data was then entered into spreadsheets and relational database tables for use in biomass/carbon calculations and Forest Vegetation Simulator (FVS) based tree growth prediction.

Properties Examined Outside Duke Forest Boundaries

Site selection & Sampling

In addition to assessing potential for generating carbon credits on Duke Forest property, we also explored options for carbon credit development on properties neighboring the Duke Forest. The idea being that if forest carbon offsets proved economical enough, it might benefit the University to consider acquiring properties that showed exceptional carbon offset development potential.

To this end we developed a prioritization rubric for selecting the most promising Avoided Conversion (AC), Afforestation/Reforestation (A/R), and Improved Forest Management (IFM) projects in areas surrounding the Duke Forest.

Metrics for initial parcel selection were developed through consultation with Duke Forest management to ensure the most realistic hypothetical acquisition parcels were identified[20]. Ultimately parcel size (greater than 100 acres), proximity to the Duke Forest border (within 3 miles), cost per acre, and current zoning were selected as the most important factors in identifying attractive hypothetical acquisition sites. Parcel and tax data for Durham, Orange, and Alamance Counties were obtained through county websites and communication with county representatives.

As the ACR protocol does not permit IFM projects on landholdings smaller than 1,000 acres, and no parcels of that size and suitable for an IFM project fell within our search radius, no hypothetical IFM project was conducted outside Duke Forest boundaries.

Unlike our IFM results, our initial selection process did yield several attractive potential sites for AC and A/R projects. The most attractive AC sites were those that were primarily forested, located within three miles of a developed area (e.g. residential communities), and zoned in a way that would allow future development. Of the half dozen sites that passed this second filter, the best sites were selected based on having the greatest total area of forest cover at the lowest cost per acre. The best A/R sites were selected by using Google Earth to decipher which of our potential sites had the largest portion of land that had been in an unforested condition for at least 10 years. This 10-year time frame was verified using historical Google Earth images from 1998 through 2010 (appendix map 2).

The final step in our AC and A/R site selection process was to gain permission from land owners to enter their respective properties and take forest measurements. Land owners' contact information was obtained through county websites and after extended telephone discussions, we were granted permission to execute our project on our highest ranking AC and A/R sites.

For each parcel surveyed, sample points were randomly generated, with roughly 18 acres per sample point. Sampling/measurement procedures carried out in these surveys were the same as those used in the Duke Forest inventory.

Modeling

Both CAR and ACR protocols require the project developer to model carbon stocks in the baseline and with-project scenarios across the entire timeline. The choice of model used for projecting carbon stocks can have a significant impact on the emissions reductions calculated for a project. Even more important are the choices made within the model. During the initial verification the model inputs and outputs along with any adjustments made to growth, density, or mortality relationships will be examined. For the purposes of this project we will describe the basic procedure we employed to produce our final CO_2e results and provide explanations for the important decisions we made within the model. Specific silvicultural choices will be described in the subsequent sections detailing the methodology of each project type.

The protocols grant approval to a number of empirical-based models. Selection of a model for use in the project was based on cost and the relative availability of resources to aid in the development of our projections. The Forest Vegetation Simulator (FVS) was developed by the US Forest Service to serve as a tool for the comparison of silvicultural regimes. Unlike other proprietary models, it is available at no cost. Developed in the early 1980s, the model now includes 22 unique variants, making it applicable across a wide range of forest types in the United States and Canada. It also contains the full suite of management options available to forest land managers. For these reasons it is commonly used for domestic project development. Communication with personnel at the FVS help desk and with professionals at Finite Carbon proved essential to this process.

FVS functions as an individual tree growth and yield model that creates projections based on standard inventory data. The species, height, and DBH of measured trees were input along with stand and plot information including longitude, latitude, slope, aspect, elevation, and the Ecological Unit Code (EUC). Plots were organized by strata based on their cover type using Duke Forest's classification. Based on this classification by age and species mix, these strata served as stands within the model. This stratification of the plots was recommended as a technique to reduce error within the dataset[21], while at the same time organizing the data by logical management units (i.e. mature pine stands or riverine mixed hardwoods). This organization by strata is particularly important for FVS, as the model treats the stand as the fundamental unit for the implementation of all management activities. Information from the survey design served as the basis to determine stand density, while the growth rates from tree cores taken at each plot were used to calibrate model growth relationships to local rates. The model processes each measured tree as a record which represents similar trees across the stand. Each tree record is assigned a specific tree per acre (TPA) expansion value. Thus an individual record from 2011 for a 50 foot tall loblolly pine with an 11 inch DBH might actually represent 0.6 trees per acre. These tree records form the basis for quantifying carbon across the projected time period.

Each projection is divided up into cycles, which in our case were 10 years long. Within each cycle silvicultural activities are executed as a series of keywords. All keywords in FVS are executed on the stand as a whole, with values calculated on a per acre basis. While FVS models individual growth and yield, with stand density calculated based on the survey design and data, it is not truly spatial in nature. Actual acreage does not exist within the model, and thus total values for standing timber or removals must be calculated outside the model by multiplying per acre values by the appropriate acreage.

Though FVS is capable of generating carbon projections in metric tonnes of CO_2e per acre, these outputs are currently not accepted by either registry. CAR requires the use of the

Component Ratio Method (CRM) to quantify carbon in the whole tree from measured height and DBH. In the interest of producing comparable carbon outputs under the two protocols we opted to employ this methodology for both CAR and ACR. In order to apply the appropriate series of equations to the thousands of tree records from FVS we built a relational database to process our model outputs and generate results in metric tonnes of CO_2e per acre. Volume was calculated for each individual tree using species-specific allometric equations based on height and DBH. These equations were provided by CAR and are accepted by ACR for use in determining tree volumes to be used in carbon calculations. For gross volume, all species except hop hornbeam (*Ostrya virginiana*) used the volume equation by McClure and Cost (2010), with each species having its own set of unique coefficients to be used for pulpwood and sawtimber sized trees. For pine species, pulpwood was defined as trees with a DBH smaller than nine inches, but greater than or equal to five inches, with all larger trees classified as sawtimber. For hardwood species, pulpwood was defined as trees with a DBH smaller than eleven inches, but greater than or equal to five inches, with all larger trees classified as sawtimber. Hop hornbeam used the volume equation by Hahn[18], which does not designate between pulpwood or sawtimber sized trees. After gross volume for each tree had been calculated, the percent sound volume was applied in order to obtain the total amount of sound wood to be used in deriving the quantity of CO_2e in each tree record. Based on FIA data for our sub-region, this cull factor represents the carbon deduction for rotten, missing, or damaged wood.

The CRM was used to calculate biomass in pounds for each component of the tree (stem bark, stem wood, branch wood, foliage, roots, etc.) [22]. Each separate component was then used to calculate a value for aboveground biomass, belowground biomass, and total biomass in pounds. Total pounds of biomass represented by individual tree records were then converted to metric tonnes of CO_2e per tree. This quantity was then multiplied by the TPA expansion factor for the record, producing the total quantity of carbon per acre represented by the tree, and allowing the total amount per acre to be summed.

A similar process was also applied to “cut lists” produced by FVS, wherein the tree records actually represent harvested trees, thus allowing us to model carbon in removals from harvests. This produced the total carbon in trees harvested for wood products, but not the amount that would remain sequestered. The amount of wood that would remain sequestered in wood products was determined based on the output from the dry bole biomass equation within the CRM, as this represents the "merchantable" portion of the tree. This pound value was converted to CO_2e and multiplied by the TPA expansion factor to produce tonnes of CO_2e in the merchantable portions of removed trees. Production efficiency of milling was then taken into account, based on prescribed efficiencies for four general wood categories: hardwood pulpwood, hardwood sawtimber, softwood pulpwood, and softwood sawtimber[23]. Different classes of timber products were accounted for by the registries, including softwood lumber, hardwood lumber, plywood, oriented strand board, non-structural building materials, paper, and miscellaneous. Each product class had an associated fraction that could be expected to remain sequestered for at least 100 years, though these varied by registry[24]. Within each product class, CO_2 is stored long-term in two different forms: in long-lived wood products and in landfills. The proportion of each product class that 'survives' in each form was calculated, thus producing CO_2e values sequestered in wood products for each projection that included harvesting.

In order to have a visual representation of carbon stocks in the Duke Forest, the CO_2e per acre value calculated for each tree record was related back to the plot where the tree was measured. Plot level CO_2e was then linked to the original data points in GIS, and through interpolation the CO_2e per acre across the forest could be represented (appendix map 3).

Carbon Protocol Execution

All three project types (Avoided Conversion, A/R, and IFM) were carried out under both CAR and ACR protocols to allow for comprehensive comparisons to be drawn regarding the methodologies of the two carbon accounting registries. The following sections outline the steps in each registry's approach to implementation of the three project types and their methods for addressing the risk of project reversal. Under the subsections for each project type we describe the method by which we arrived at the total number of credits generated. Not all of these credits are awarded to the project proponent due to the need for buffer contributions to account for the possibility of project reversal. This important component is addressed in the final subsection.

Afforestation/Reforestation (A/R)

Afforestation/Reforestation projects involve the establishment or restoration of forest cover on land that currently has no, or minimal, tree cover. In order for any A/R project to meet additionally requirements, it must be demonstrated that the site of interest would be expected to remain unforested in the absence of the project.

CAR:

The first step towards establishing an A/R project under CAR protocol requires a qualitative characterization of the likely vegetative conditions and activities that would have occurred onsite in the absence of the project. This characterization is based on an onsite inventory used to generate the project baseline against which the with-project scenario is compared. This was relatively straightforward in our case as the Afforestation/Reforestation hypothetical site was a cattle pasture with very few trees (only one within our randomly generated sample plots) and no significant underbrush. As the land owner had confirmed that active cattle grazing had been occurring on the property for over a decade and was likely to continue indefinitely into the future, we generated our baseline carbon by simply modeling future growth of the single tree inventoried and applying the trees per acre expansion factor calculated by FVS. As we had concluded that the baseline carbon represented in underbrush and standing deadwood was negligible under the protocol standards there was no further consideration of these pools. Due to the lack of tree cover on the project area, no harvested wood products were expected to result from the business as usual scenario, and therefore no harvested wood product carbon was attributed to the baseline.

For the with-project scenario we elected to plant 262.5 loblolly pines, 56.25 Virginia pines, and 56.25 shortleaf pines per acre over the extent of the 106-acre deforested portion of the Afforestation/Reforestation hypothetical site. Survival rate for planted species was modeled at 80% based on expert recommendation[20]. These species and planting quantities were selected based on regional forest makeup and CAR's recommended species mix within *the South East Middle Mixed Forest Piedmont Supersection*[25]. Loblolly pine was selected as the primary planted species due to its advantageous growth rate and the ease of planting. We limited its planting rate in compliance with CAR's requirement that no species make up more than 70% of the species mix for this super section[26]. Forest growth for the newly planted stand was then modeled over a 100-year period. The carbon sequestration in the baseline scenario for each year of the projection was then subtracted from the amount of additional carbon sequestered in each year in the with-project scenario to get preliminary carbon offset figures. These figures then needed to be reduced by the secondary effects attributed to the project. Secondary effects for A/R projects under CAR are based on two emissions sources: combustion emissions associated with machinery use in site preparation, and the shifting of cropland or grazing activities to forestland outside the project area. As no significant brush clearing was necessary for our project site, the combustion emissions could be assumed to be zero based on CAR prescribed equations[24]. Shifting of grazing activities was a legitimate concern for our project and it was determined using CAR's *Activity Shifting ("Leakage") Risk Assessment* flow chart[24]. This leakage required a deduction of 50% of the project's net carbon benefit. After accounting for this 50% reduction in tonnes of sequestered carbon, we arrived at our final CO_2e offset figures.

ACR:

ACR requires that A/R projects demonstrate additionality through the *ACR three-prong test*[27] by employing the *CDM "Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities" [28]*. This tool outlines a five-step process through which it can be established that A/R project activities under consideration meet the following requirement: not required by any existing laws, go beyond common practice in the project region, and face either financial, technological, or institutional barriers to implementation. Using this guidance document we were able to confirm that the Afforestation/Reforestation hypothetical site was eligible under ACR for an A/R project. After confirming the site's eligibility we modeled the baseline carbon scenario over a 40-year period. As was the case with the A/R simulation under CAR, carbon sequestration in our pools of interest (live trees and standing deadwood) was minimal due to the lack of woody vegetation cover on the site and no carbon storage could be attributed to harvested wood products.

For the with-project scenario we chose to plant 375 trees per acre of loblolly pine. For this projection we also employed the same 80% survival rate we used under the CAR scenario. Unlike CAR, ACR does not require A/R projects to have a forest makeup representative of *natural forest management*[24]. We planted purely loblolly pine due to its faster growth rate, a trait that was borne out in our modeling trials. After generating the with-project carbon stocks we calculated the yearly change in tonnes of carbon sequestered over the project life and subtracted the change in the baseline scenario from this amount in each year.

Leakage, under ACR's A/R protocol, is only deducted for GHG emissions due to "activity displacement," defined as the relocation of the agricultural or grazing practices from areas of land located within the project boundary to areas of land located outside the project boundary. Livestock grazing was the activity displaced from our project implementation. To assess the expected leakage from converting our site's pastureland into forest we utilized the CDM's tool for *"Estimation of the increase in GHG emissions attributable to displacement of pre-project agricultural activities in A/R CDM project activity"* called for by ACR [29]. After incorporating the leakage deduction into our preliminary carbon offset figures we arrived at our final quantity of carbon offsets generated.

Avoided Conversion or REDD

Avoided Conversion projects consist of specific actions that prevent the conversion of forestland to any non-forest land use. Common non-forest land uses leading to forest conversion include: residential, commercial or industrial development, agricultural expansion, pasture establishment, and mining activity.

For our purposes we examined the potential carbon offset generation that would result from the establishment of an Avoided Conversion project on all Duke Forest holdings not explicitly prohibited from sale or development by the Board of Trustees (appendix map 4), and on the 700-acre hypothetical acquisition property selected based on the prioritization described earlier in this document (appendix map 2).

CAR:

In any Avoided Conversion project, baseline carbon levels are calculated by projecting the onsite forest carbon losses that would have occurred within the project area if the forest were to be converted to a non-forest land use. Under CAR this is accomplished by identifying the highest-value land use alternative based on an appraisal by an accredited real-estate professional. The appraisal is based on zoning regulations, proximity to metropolitan areas, proximity to groceries and fuel stations, and population growth in the surrounding area. To execute this appraisal while maintaining compliance with CAR requirements, it was necessary to engage a local appraisal agent. Dawn Talton of Appraise This, Inc.[30] was kind enough to help us in this capacity (though it should be noted that her participation was based on an understanding that her appraisal would be considered completely hypothetical and would not be used for any official or legal purpose). Ms. Talton's work established that all of our sites of interest fell within one of three potential conversion categories: *commercial*, *low-density residential*, or *medium-density residential*.

Based on this information we then determined how much of each stratum would be converted on the Duke Forest. Conversion rates for each land-use category were based on CAR's default avoided conversion table (appendix 1). The fraction of each stratum that fell into each type of use was calculated in GIS. We then applied the conversion rates to these areas and produced an average conversion rate for each stratum of 78%. The hypothetical acquisition for Avoided Conversion was identified as having only one most likely conversion category, medium density residential, with an associated conversion percentage of 85%. In accordance with CAR standards the modeled carbon loss due to conversion was amortized over the first ten years of the simulation. Furthermore, CAR requires that carbon stocks be held constant following conversion, for the remaining 90 years of the projection. We then discounted for any uncertainty of conversion probability by comparing our proposed alternative land use to CAR's prescribed *Avoided Conversion Discount Factor*[24].

As not all tree biomass removed from the site preceding land use conversion would result in an immediate carbon release, it was necessary to account for the carbon sequestered in harvested wood products in order to avoid overestimating the project's net carbon benefit. Carbon stored in wood products was calculated by modeling the average amount of carbon in standing live carbon stocks that would have been harvested in each year of the conversion period. These harvest figures were then separated into wood-product classes (e.g. paper, softwood lumber, plywood, etc.) using default percentages provided in CAR's *Assessment Area* data file and discounted based on regional mill efficiencies specified by CAR[31]. Ultimately, standard 100-year decay rates were applied for each product type to establish our final wood product carbon figures[24] (appendix 2).

Baseline carbon figures were then compared to modeled carbon stocks on the project area under the with-project scenario. CAR requires that Avoided Conversion projects be placed under a strict, qualified conservation easement. Therefore, the projected carbon stocks in the with-project scenario represent the composition of the forest assuming no future timber removals over the life of the project. Limited timber harvest activity is permitted under some easements, but for the purpose of this analysis and to maximize potential carbon credits, timber harvests are assumed to be zero. The difference between the baseline and the with-project scenario over 100 years represents the potential net carbon benefit of the Avoided Conversion project. However, accepting this figure as the ultimate carbon benefit of the project would neglect the potential for "secondary effects." These effects represent unintended changes in carbon stocks or GHG emissions caused by the project itself. The secondary effect of most concern in the case of Avoided Conversion projects is the risk that the loss of forest cover due to conversion for the type of land use that was intended for the project site will be shifted to another forested area. This would serve to negate the carbon benefit of the project. CAR accounts for secondary effects by requiring a standard deduction of 3.6% from the total carbon calculated when carbon in the baseline case is subtracted from the with-project scenario. After completing this calculation for both the Duke Forest and the Avoided Conversion hypothetical site we were able to complete CAR's *Annual GHG Reduction/Removal Calculations Worksheet*[24] and produce our final carbon offset figures.

ACR:

The first step in developing a REDD (ACR's preferred terminology instead of Avoided Conversion) project under ACR protocols is to establish the likely *agent*, or *class of agent*, of deforestation within the project area. Then, in order to justify the additionality of the project, ACR requires that project proponents establish the following: the project site is suitable for the proposed alternative land use, conversion is legally permissible on the site, there is a legitimate threat of the forest site being converted, and without carbon market-related revenues the project area would be more financially attractive under a non-forest land use type. To meet these requirements we consulted further with Dawn Talton, who confirmed the legality of the potential conversion activities and helped identify "private commercial developers" as the likely *class of deforestation agent*. To establish the legitimacy of the threat of conversion on our sites we reviewed publically accessible zoning and land use records for Durham and Orange Counties and documented the transition of land out of the *Forest-Use* tax designation over the last decade. To do this we made a series of maps highlighting all properties in the *Forest Use* tax designation in 2000 and those still under the *Forest-Use* designation in 2010. Our results revealed that of the acres listed under *Forest-Use* in 2000, only ~55% in Durham County (appendix map 5) and 83% in Orange Country (appendix map 6) remained under the *Forest Use* designation by 2010. The financial incentive to convert our project sites to non-forest land-use was demonstrated by comparing the average listed value, per acre, of *Forest Use* designated properties to the county appraiser's listed *market* value, per acre, if that land were to be sold out of *Forest Use*. This data for Durham County was provided by Durham Tax Administration staff, but was unavailable for Orange County. Through this investigation we found that lands listed under the *Forest Use* designation, in Durham, are valued at a ~90% discount per acre when compared to properties without the *Forest Use* designation.

After establishing additionality, ACR requires that the project proponent calculate the average annual area of project land to be deforested. ACR's methods for calculating this conversion rate are considerably different than those used by CAR, which prescribe a standard conversion based on the highest alternative use established by a registered appraiser. The ACR protocol calls for an examination of the time period over which a series of proxy sites have been deforested in the past decade to establish a likely deforestation rate for the project area itself. To establish this rate we selected five proxy sites from the pool of former *Forest-Use* designated properties from our "legitimacy of threat" analysis described in the preceding paragraph. The five proxy sites were selected based on their similarity to the project areas defined by four categories: proximity, soil types, slope, and elevation (appendix map 7). Review of the conversion rates on these sites, using time sequenced satellite imagery, revealed that on average the properties had been 60% deforested over a five-year period. This percentage of deforestation was applied to both the Duke Forest and hypothetical Avoided Conversion projects.

With this average conversion rate we were then able to model the baseline carbon levels for the project area over the 40-year commitment. As was done under the CAR protocol, ACR requires that carbon stocks in the baseline be held constant after the period of conversion. It was also necessary to account for carbon stored in wood products that would be generated by the conversion activity to avoid overestimating the carbon benefit of the REDD project. Wood product carbon was calculated using prescribed equations from *the ACR Tool for Calculating Emissions and Sources*[32] and the associated product decomposition factors from Winjum *et al*. 1998[33]. This quantity of carbon was then subtracted from the net carbon stock changes in the baseline to reflect the actual changes on a per acre level.

With-project carbon stocks were modeled using the same parameters as the CAR scenario, but with a 40-year timeline. From these stocks the yearly net carbon change in the area to be deforested is calculated. This quantity represents the additional sequestration that would occur in each year as a result of the project activity. Baseline carbon changes in each year, with wood products taken into account, were then subtracted from this amount. The result of this calculation was then discounted to account for "leakage," the ACR equivalent of secondary effects. Under ACR leakage comes in two forms: *Activity Shifting Leakage* and *Market Effects Leakage*. *Activity Shifting Leakage* accounts for market demand for the good that would have been produced within the project area (in our case, housing or commercial development), instead being produced on other forested lands that would otherwise have remained undisturbed. This was calculated using the ACR *leakage factor* (~13%) applicable to our site based on the ability of alternative lands to accommodate the development that would otherwise have taken place in the project area. This *leakage factor* was applied in conjunction with ACR's provided *Activity Shifting Leakage* equation to get final *Activity Shifting Leakage* figures[34]. *Market Effects Leakage* accounts for any shifting of timber harvest activities to new sites in order to compensate for the reduced timber supply caused by the REDD project activity. The magnitude of this leakage is determined by assessing the relative productivity of the areas likely to make up for the supply shortage. This was calculated using another ACR prescribed leakage factor (40%) based on the timber productivity of likely replacement timberlands in comparison to that of the project area. This leakage factor was then applied in conjunction with ACR's provided *Market Effects Leakage* equation[34] to establish final *Market Effects Leakage* figures. With these leakage figures established, we subtracted them from our total project carbon sequestration value and further discounted for uncertainties related to the quantification of GHG emission reductions using an ACR prescribed equation[34]. With these discounts accounted for we arrived at our final total of carbon offsets generated in each project.

Improved Forest Management (IFM)

IFM projects involve management activities that increase carbon stocks on forested land relative to baseline carbon levels. Typical IFM activities include, but are not limited to: conversion from conventional logging to reduced impact logging, conversion of managed forests to protected forests, extending rotation lengths in managed forest, conversion of low-productive forests to high-productive forests, increasing forest productivity by thinning diseased or suppressed trees, managing competing brush and short-lived forest species, increasing the stocking of trees on under-stocked areas, increasing carbon stocks in harvested wood products, improving harvest or production efficiency, and shifting from shorter to longer-term wood products.

For both CAR and ACR projects we needed to establish a baseline management scenario against which to compare our IFM activities. Under ACR this baseline is defined as the legally permissible harvest scenario that would maximize net present value (NPV) of perpetual wood products harvests. CAR allows project developers some latitude in how they model their baseline, but enforces a Minimum Baseline (MBL) that will supersede any baseline with average stocks below the common practice. We developed this scenario through consultation with industry professionals[20, 35] and examination of silvicultural prescriptions recommended in scholarly journals and state/federal agency publications. A variety of harvest regimes were modeled in FVS using the Economic Analysis Extension[36]. Ultimately an NPV projection was created depicting the cash flows resulting from our baseline timber management practices.

The most significant feature of this NPV scenario is the clear-cutting of most of Duke Forest's stands in the first year and the conversion of the entire area to loblolly pine. This is because most of the timber on Duke Forest is already mature, and the greatest value could be generated by harvesting these stands and replanting in pine. Harvesting was only delayed in the young pine stands. The only areas that remained unharvested in this projection were those that fell within a stream management zone, defined by a 50 foot buffer calculated in GIS. Though this is not a strict legal requirement by the state of North Carolina, it serves as a reasonably conservative means to ensure that the NPV scenario would still be in compliance with laws regulating sediment and logging debris entering streams[37]. A real discount rate of 6% was utilized in the cash flow model in accordance with ACR requirements. Inputs for the creation of our NPV model included: our timber inventory of the project lands, wood product pricing over the last decade, logging costs, reforestation costs, silvicultural treatment costs (fertilization, controlled burning, stand thinning, pesticide treatment, etc.), road maintenance costs, and other forest management fees[20]. For both projects carbon in wood products was calculated separately, as the registries use different mill efficiencies, product categories, and fraction of CO_2 expected to remain stored long-term in each category.

For the with-project scenario under both registries we modeled Duke's current management practices. Duke Forest already employs much of what would be considered Improved Forest Management. It is certified by the Forest Stewardship Council (FSC) with a management regime that is characterized by longer timber rotations and smaller harvest areas. Certification by FSC, the Sustainable Forestry Initiative (SFI), or the Tree Farm System is a requirement for ACR, and serves as one of three potential mechanisms for demonstrating sustainable harvesting practices under CAR. In defining current harvests and operations Duke Forest management was consulted to ensure all legally binding timber contracts were accounted for and all timber removals were consistent with North Carolina Best Management Practices (BMPs).

Records of Duke Forest management and timber sales served as an important resource in our effort to accurately model current practices. The area of annual harvest was based on average harvests over the last 10 years[38]. Initial harvesting took place in the mature pine strata (pine 40 years and older). Here the spatial limitations of FVS became a serious complication. As the fundamental unit of management, the strata/stand could be harvested or left to grow, but the model cannot process a clear-cut on only a fraction of a stand. We developed a technique in consultation with experts at the Forest Service and professionals at Finite Carbon to create "pathways" for harvested areas that could be tracked in a spreadsheet outside of the model where the acreage associated with each pathway could be applied. Each pathway came to represent the area harvested within a particular stratum during a 10-year cycle. The carbon outputs from the modeled pathway were multiplied by the area harvested during that cycle, with that number of acres being subtracted from the total acreage remaining unharvested in the strata. Once the total area for the strata had been subject to harvesting, timber removals shifted to the next younger pine strata. Acreages for each stratum reflected only the area outside of stream management zones, as calculated by placing a 50 foot buffer around perennial and intermittent streams.

For the purposes of this scenario harvesting took place only in the loblolly pine stands. Though in reality some harvesting does take place in hardwood or mixed pine/hardwood stands on the Duke Forest, FSC regulations place severe restrictions on the conversion of natural hardwood stands to planted pines[39]. Similarly we did not harvest in the mixed pine stands. Accounting for less than 300 acres, these are areas that contain some of the more rare or unique stands of pine in the Duke Forest, including mature stands of shortleaf and longleaf pine. These choices lead to slightly more conservative rates of carbon assimilation across the Duke Forest as a whole because the mature hardwood and mixed pine/hardwood stands that remain unharvested have slower growth rates than would have been seen if some of these areas had been clear-cut and regenerated.

CAR:

Our initial plan to model a baseline for use with the project under both registries proved untenable based on the specific restrictions that CAR places on modeled baseline scenarios. Under CAR protocols the modeled above-ground standing live carbon stocks for the IFM baseline cannot fall below a minimum baseline (MBL). The MBL is determined based on whether the current stocks are above or below the average level for standing carbon stocks within the project's FIA-designated *Assessment Area(s)* (CAR Eq. 6.5 and 6.6) [24]. This local average serves as the "common practice" for the purpose of carbon stock comparison. To identify the appropriate common practice stocks we first had to determine the geographic *Supersection* within which our project areas were located. Using maps provided on the CAR website[21] we established that our project fell within the *South East Middle Mixed Forest Piedmont Supersection*. Then by referencing tree species lists[25] associated with our *Supersection* we were able to identify the four *Assessment Areas* applicable to our sites and, based on site-index figures, the associated common practice carbon stocks. We then compared these common practice stocks to our own carbon figures based on our forest inventory. Our carbon levels were above the common practice, so we were required to use that value as our baseline. This provides an added measure of conservatism to IFM activities because projects with particularly aggressive harvesting regimes in their baseline scenario would be limited in the amount of credits they could claim for their more carbon-conscious practices.

For both the baseline and the IFM scenario we estimated carbon stored in wood products. The baseline scenario was calculated by determining the average amount of carbon in standing live carbon stocks that would have been harvested in each year of the project term based on our modeled removals. These removals were reduced by 9% to account for the increase in carbon left onsite after we modified our baseline to match the common practice level. Carbon in wood products in the IFM scenario was based on the exact quantities of modeled removals. For both scenarios we then separated harvest figures into wood-product classes (e.g. paper, softwood lumber, plywood, etc.) using default percentages provided in CAR's *Assessment Area* data file and discounted based on regional mill efficiencies specified by CAR[31]. Then we applied standard 100-year decay rates for each product type to establish our final wood product carbon figures[24].

The last step before calculating the total additional carbon sequestered in our IFM scenario was to deduct for secondary effects. CAR only requires that IFM projects account for secondary effects that occur when reduced harvesting on the project area results in an increase in harvesting on other properties. We accounted for this harvest shifting by multiplying the difference between the baseline average harvest and the IMF harvest by 0.2 in any year the baseline harvest exceeds that of the IFM scenario, as was prescribed in the CAR protocol[24]. With secondary effects thus addressed we were able to complete CAR's *Annual GHG Reduction/Removal Calculations Worksheet*[24] and establish the total estimated offset benefit of our IFM project.

ACR:

The first step in executing an ACR IFM project is to establish the projects additionality. We did this by carrying out ACR's *three-prong additionally test*[40] demonstrating that our project exceeded currently effective laws and regulations; exceeded common practice in the forestry sector and geographic region; and faced a financial implementation barrier.

After modeling baseline carbon stocks under a maximum NPV scenario, we then averaged these stocks over the two 20-year periods that make up the project timeline. Next, wood products produced as result of harvest activities were calculated. This was achieved in two steps. First, we calculated the annual biomass of the total volume extracted from within the project boundary, classifying harvested material as hardwood sawtimber, hardwood pulpwood, softwood sawtimber, or softwood pulpwood and then converted biomass to carbon using specific gravity for each species. Second, the proportion of these wood products that would not be emitted into the atmosphere within 100 years (and hence would be considered sequestered for the purposes of the protocol) was determined by referencing Table 1.6 from the *Forestry Appendix* of the *Technical Guidelines of the US department of Energy's Voluntary Reporting of Greenhouse Gases Program* (known as Section 1605b) [41]. This quantity of carbon was then averaged across the two 20-year periods and added to the average standing stocks. Uncertainty in all baseline measurements was accounted for using equations prescribed by ARC's *IFM Methodology for Quantifying GHG Removals and Emission Reductions through Increased Forest Carbon Sequestration on U.S. Timberlands* [19].

After completing all baseline calculations we turned to the with-project IFM scenario. Once again we used the carbon stocks we modeled based on Duke Forest's current practices. The ACR protocol requires project developers to model harvests under a perpetual harvest regime, so the 40-year project horizon used by ACR did not impact the rotation ages for the stands. We then accounted for carbon stored in wood products and measurement uncertainty in the same manner described in the baseline scenario. The with-project scenario utilizes the actual stocks and removals each year rather than the average value calculated for the baseline.

Preliminary emissions reductions were then calculated by subtracting the average baseline carbon stocks from the IFM figures for each year of the project. ACR strictly prohibits *Activity Shifting Leakage* to other lands owned or under management by any IFM project proponent. This type of leakage covers the intensifying of timber harvests on other areas of forestland owned by the project proponent to compensate for the reduced harvests on the with-project area. As a result of this we made no deductions to our carbon stock totals for this variety of leakage. We did however make deductions for *Market Leakage*, defined as reductions in product outputs due to project activity that are compensated for by increased production by other entities in the marketplace. These deductions were assessed using the default values prescribed by ACR's IFM protocol[19]. After completing our leakage deductions we arrived at our final quantity of carbon offsets generated as result of the IFM project.

Risk and the Buffer Pool

Both protocols recognize the risk of project reversals as a real and material threat to forest carbon offset permanence and viability. To address this issue and uphold a standard of offset conservatism, both registries maintain a buffer pool - a holding account for Forest Project offsets used as a general insurance mechanism against unavoidable reversals for all forest types. Any time a Forest Project experiences an unavoidable reversal of GHG reductions the registries retire a number of offset credits from the buffer pool equal to the amount of carbon that was reversed. Under both protocols a Forest Project's contribution to this pool is determined by a project-specific risk rating.

CAR:

CAR provides standardized worksheets to help forest owners derive the appropriate reversal risk rating for their particular projects. These worksheets were utilized to establish risk ratings and associated buffer contributions for each of our project scenarios (appendix 4). Though risk ratings may be adjusted at each 6-year project verification interval, we assume the risk rating will remain constant over the life of the project. This assumption is based on the strength of Duke Forest Management's established risk mitigation practices and thorough historic records of regional environmental threats.

ACR:

ACR requires risk and the associated buffer contribution to be calculated using the Verified Carbon Standard's *AFOLU Non-Permanence Risk Tool*. This tool provides detailed instructions on how to calculate risk for all forest carbon offset projects, and was utilized in our analysis of project risk for each of our ACR project scenarios (appendix 5). ACR allows for projects to update their risk rating at every 5-year project verification interval, but as we did in the CAR scenario, we assume risk to remain constant throughout the project life.

Financial Modeling

To fully evaluate the potential for carbon offset generation in each of our project scenarios, financial modeling was conducted to address the feasibility of project development and execution. To do this, cumulative net present value (NPV) charts were generated to show the comparative financial benefits of using CAR and ACR protocols for conducting each project type. NPV was calculated by summing the value of all offsets issued to a project at a given time (based on projected over the counter pricing on the voluntary offset market) and then subtracting the cumulative cost of developing the project.

Voluntary market pricing shifts over time and prices can be difficult to identify as there is no central marketplace to publically list the going rates of offset sales. To overcome this hurdle we consulted with experts at the Nicholas Institute, the Climate Action Reserve, and Green Assets Inc. (a North Carolina based forest offset project development company) and determined that a reasonable credit price was between $8 and $10 dollars. Ultimately we elected to use $8 for the sake of conservatism. Once this price was established we modeled NVP both with and without a 3% annual price increase.

A 6% real discount rate was applied to all project types. We decided upon this rate as it was required under ACR's IFM protocol and was consistent with conservative rates used by practicing professionals in the forest carbon industry[42].

Costs considered included:

- Forest Inventory
- Forest Verification
- Reserve Account Start-up Fees
- Annual Reporting Fees
- Annual Reserve Membership Fees
- Credit Issuance Fees (CAR only)
- Seedling purchase and planting expenses
- Site prep expenses
- Monitoring expenses
- Mortgages (Acquisition sites only)

To better address the needs of the CAR and ACR protocols it would be advantageous to spread the inventory out over several years rather than the current Duke practice of conducting the entire inventory in a single year every decade. To adjust for this we evenly distribute the cost of inventory over 10 years for all ACR projects and 12 years for all CAR projects (CAR requires that a full forest inventory be completed every 12 years instead of 10). Inventory costs were calculate by applying the per-acre cost of the official Duke Forest inventory ($4) to the total project acreage on each site. It should be noted that forest inventory costs were not included in the financial calculus on the two Duke Forest projects because the current forest inventory process (which is already figured into the forest budget) is sufficiently rigorous and happens at regular enough intervals to satisfy both CAR and ACR inventory requirements.

Monitoring and reporting costs following the final year of credit issuance were calculated for both registries by continuing the forest inventory schedule and supplanting the cost of on-site verification (occurring every 5 years under ACR and every 6 years under CAR) with the cost of a desk audit.

In order to fairly assess the net potential carbon offset value for acquiring land outside the duke forest it was necessary to include the cost of a 30-year mortgage in the expenses associated with project development. 30-year mortgage fees were calculated for both of the hypothetical acquisition sites. Total site value (land value and building value) was found through the Orange and Alamance Counties' tax assessment website, with the listed values based on a 2010 tax assessment. Using the online Yahoo Real Estate tool, the mortgage rates for each property for a 30 year fixed-rate mortgage were determined (the rates used here were obtained in early November 2011 and may have changed since that time)[43]. The mortgage rate was based on county trends and total property value. For the Avoided Conversion hypothetical site, the 30 year fixed-rate mortgage is 4.153% for a loan of $4,484,382. By the time of repayment of the mortgage, $3,365,979 in interest will have been paid over the life of the loan. For the Afforestation/Reforestation hypothetical site, the 30 year fixed-rate mortgage is also 4.153% for a loan of $535,926. By the time of repayment of the mortgage, $402,266 in interest will have been paid over the life of the loan.

The addition of these mortgages made both Hypothetical Acquisition Projects infeasible (appendix 3). As result in the remainder of this document the Hypothetical Acquisition projects will be considered with the mortgage values omitted for the purpose of analyzing the cost effectiveness of conducting such projects as a non-land owning carbon project developer.

Results

The following graphs and tables represent the results of our carbon analysis. Carbon graphs (Figures 1-24) depict the cumulative and annual carbon offset quantities generated by each registry under the various project scenarios, while Net Present Value (NPV) graphs depict the cumulative and annual financial benefit represented in these offsets. All financial graphs are presented twice, once with the $8 price of carbon offsets being held constant and a second time with a 3% annual price increase. In each graph ACR outcomes are portrayed by two lines, one representing a scenario in which 10% of a project's cumulative buffer contributions are refunded every 5 years, and a second in which no refunds are issued. This first line accounts for ACR's unique buffer contribution system, allowing for periodic credit refunds in the absence of carbon loss on the project site. CAR is represented by a single line as it has no mechanism for issuing buffer refunds.

Carbon and Financial Summary Tables (Tables 1-2, 5-6, 9-10, 13-14) display cumulative offset totals and their value at three key points in time. The highlighted time periods, year 13 (2024), year 40, and year 100, represent the deadline for the DCOI's climate neutrality pledge, the conclusion of the ACR project commitment, and the conclusion of the CAR project commitment, respectively. The final column in each table identifies which registry performed better at each time during a given project scenario and indicates the percentage by which the superior registry outperformed its competitor. As was the case with the Carbon and Financial graphs, all financial tables appear twice, to represent project outcomes with and without the 3% annual price increase. All figures pertaining to ACR within the tables refer to the scenario with bi-decadal buffer refunds.

The detailed Decadal Carbon Tables (Tables 3-4, 7-8, 11-12) are designed to be read top to bottom and left to right, with figures at the top representing basic carbon stocks and figures at the bottom representing emissions reductions (offset credits) issued. The tables are broken up into four categories:

1. Onsite Carbon Stocks – Depicting the raw GHG reductions due to project implementation
2. Wood Products – Calculating the quantity of removed wood material that will be sequestered in products or landfills for 100 years or more
3. Secondary Effects – Accounting for potential leakage as result of deforestation activities that would have occurred on the project area being shifted to other forests
4. Calculation of Credit Generation – Accounting for project risk and buffer pool contributions

Within these categories, rows are color coded with orange representing carbon stocks in trees and wood material, green representing GHG reductions, and blue representing factors that lessen GHG offsets issued.

The CAR and ACR Decadal Carbon Tables mirror each other as closely as possible but, given the technical differences in the registries' carbon accounting systems, some notable differences can be seen. One such difference is the order in which the *confidence deduction* or *project uncertainty deduction* is subtracted from the running GHG reduction total. This deduction accounts for statistical uncertainty to ensure that estimates of GHG reductions are conservative. In the CAR tables this deduction is calculated based on, and deducted directly from, the *Project Scenario Carbon Stock* projections. In the ACR tables this deduction is calculated after leakage is determined, and therefor includes leakage uncertainty along with uncertainty in onsite carbon stock enhancements in its calculus.

It should be noted that the *Wood Products* section is omitted in the A/R scenarios under both CAR and ACR as no wood was projected to be harvested on the site over the lifetime of the project. Additionally, because ACR requires carbon stored in wood products be factored into the initial *Onsite Carbon Stock* calculations for IFM projects, the *Wood Products* section does not appear in the ACR IFM table.

Another important difference can be seen in the last row of the ACR tables, labeled "Cumulative ERTs Issued to Account Holder if No Reversals Occur." This row is not present in the CAR tables and represents ACR's bi-decadal reimbursements for up to 10% of a project's cumulative credit contributions to the buffer pool, provided reversals has not occurred. These credit reimbursements continue indefinitely provided carbon stocks on the project area are not diminished.

A final significant differentiating factor between the registries' results tables can be seen in their chronological progression. As CAR requires a minimum 100-year project commitment, its tables extend for ten full decades. ACR projects are bound to a 40-year minimum project commitment and only extend decadally until year 40, before jumping to year 100. Though no new offsets will be issued to the project after age 40, the jump is included to capture the additional offset value represented in the potential reimbursements from the ACR buffer pool if no reversals were to occur over the 60 years following project completion.

For the remainder of this document the ACR scenario with no buffer reimbursements will be referred to as the "conservative scenario," while the scenario without reversals will be referred to as the "reimbursement scenario."

A/R Hypothetical Acquisition

Our selected hypothetical A/R plot was a 215-acre calf ranch on the boarder of Orange and Alamance counties. Our reforestation effort was targeted towards 106 virtually tree-bare acres of the property that had been dedicated exclusively to calf pasture for several decades.

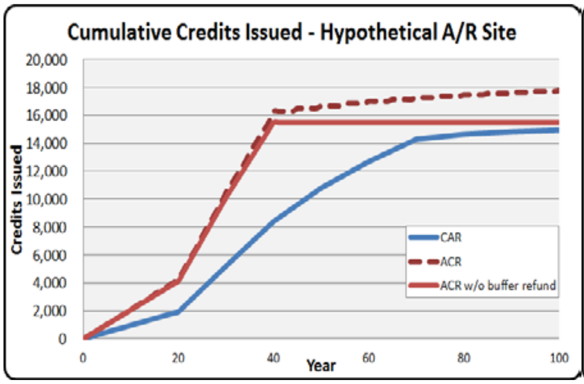


Figure 1: Cumulative Credits, equaling tonnes CO_2-e

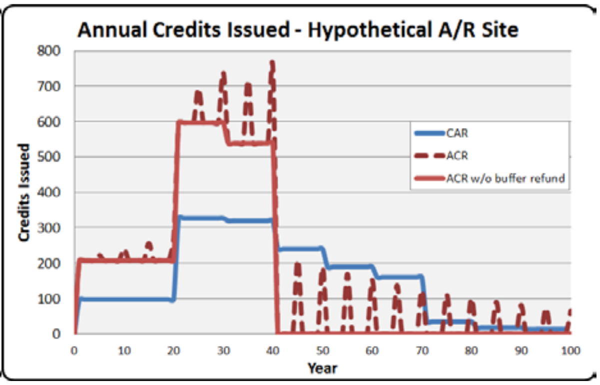


Figure 2: Annual credits, equaling tonnes CO_2-e

Hypothetical A/R Site

Cumulative Carbon Credits Issued

Year	CAR	ACR	Advantage
13 (2024)	1,260	2,740	ACR 117%
40	8,399	16,284	ACR 94%
100	14,949	17,787	ACR 19%

Table 1: Numerical comparison of cumulative credits issued for each protocol, in key years

Both ACR scenarios produce more than double the quantity of offset credits generated by CAR over the first 40 years of the project. Following the conclusion of the ACR project commitment in year 40 the ACR reimbursement scenario continues to provide nearly 20% more cumulative credits than CAR through year 100.

Both CAR and the conservative ACR scenario reach their peak annual credit issuance at around 600 t CO_2e between year 20 and 30 when the young trees are putting on new biomass most vigorously. After year 30 CAR's offset generation declines in varying stair-step increments eventually reaching annual production of less than 50 t CO_2e by year 71. The reimbursement ACR scenario reaches its peak issuance of 750 t CO_2e in year 40 due to the combined effects of a large buffer refund and high stand growth levels. After year 40 the conservative ACR scenario ceases to issue credits while the reimbursement ACR scenario receives declining spikes in annual credit levels every five years due to buffer refunds.

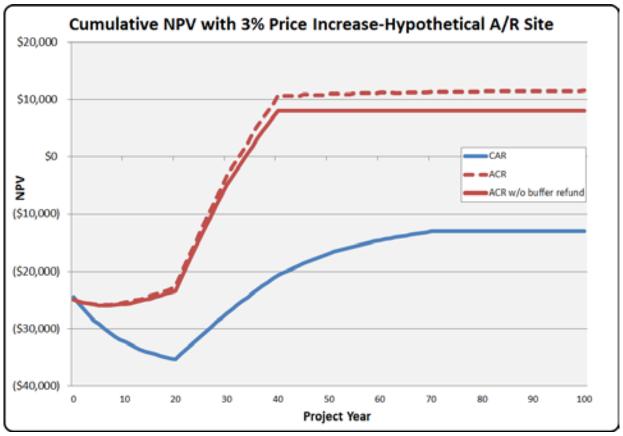


Figure 3: Cumulative Net Present Value, with 3% price increase

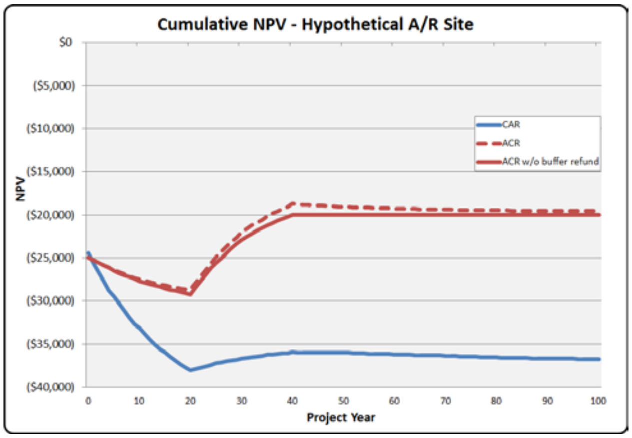


Figure 4: Cumulative Net Present Value, constant price

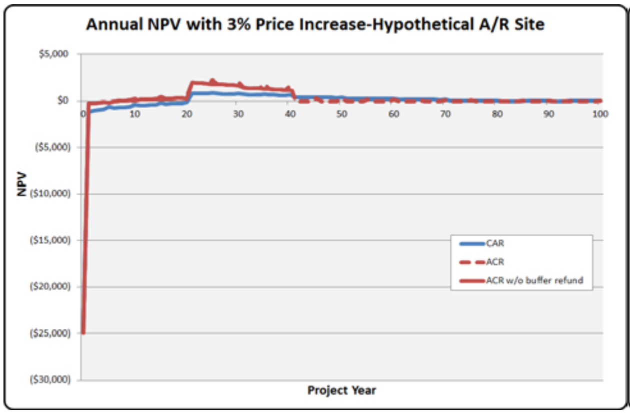


Figure 5: Annual Net Present Value, with 3% price increase

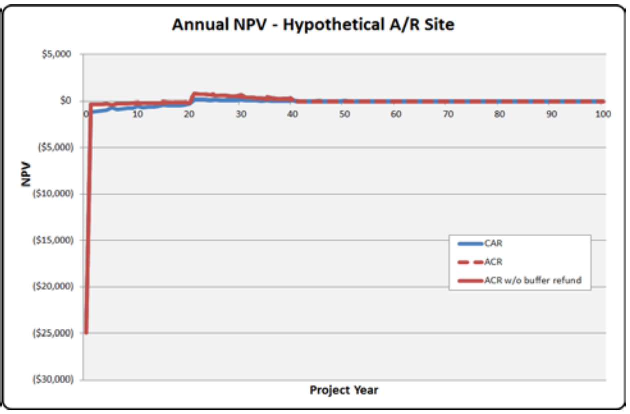
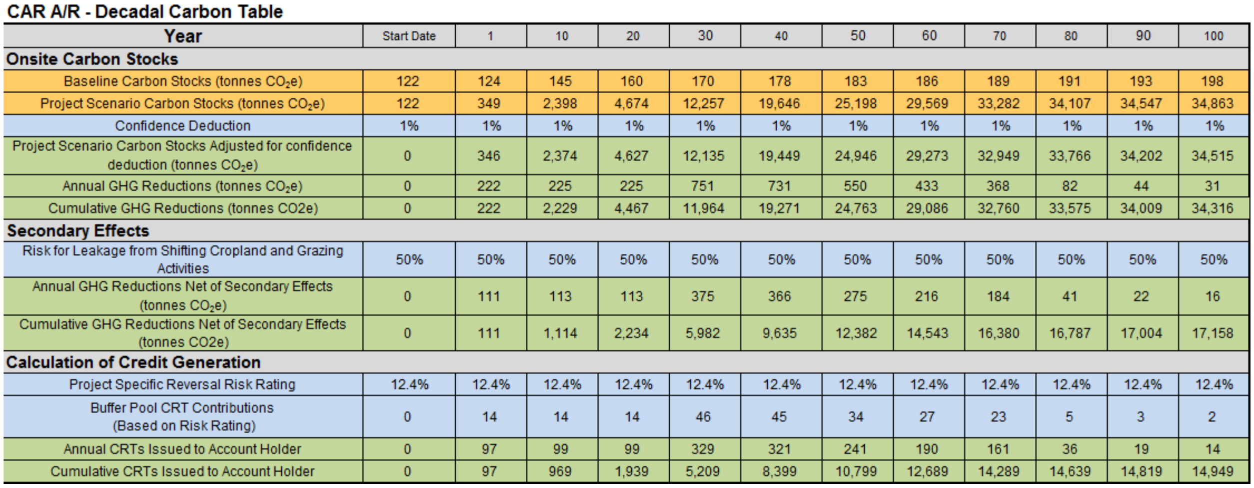


Figure 6: Annual Net Present Value, constant price

Cumulative NPV - Hypothetical A/R Site			
With 3% Price Increase			
Year	CAR	ACR	Advantage
13 (2024)	$ (33,606)	$ (24,855)	ACR
40	$ (20,616)	$ 10,761	ACR
100	$ (12,951)	$ 11,540	ACR
With Constant Price			
Year	CAR	ACR	Advantage
13 (2024)	$ (35,035)	$ (27,973)	ACR
40	$ (35,944)	$ (18,719)	ACR
100	$ (36,739)	$ (19,554)	ACR

Table 2: Numerical comparison of cumulative net present values (with and without price increase) between the two protocols

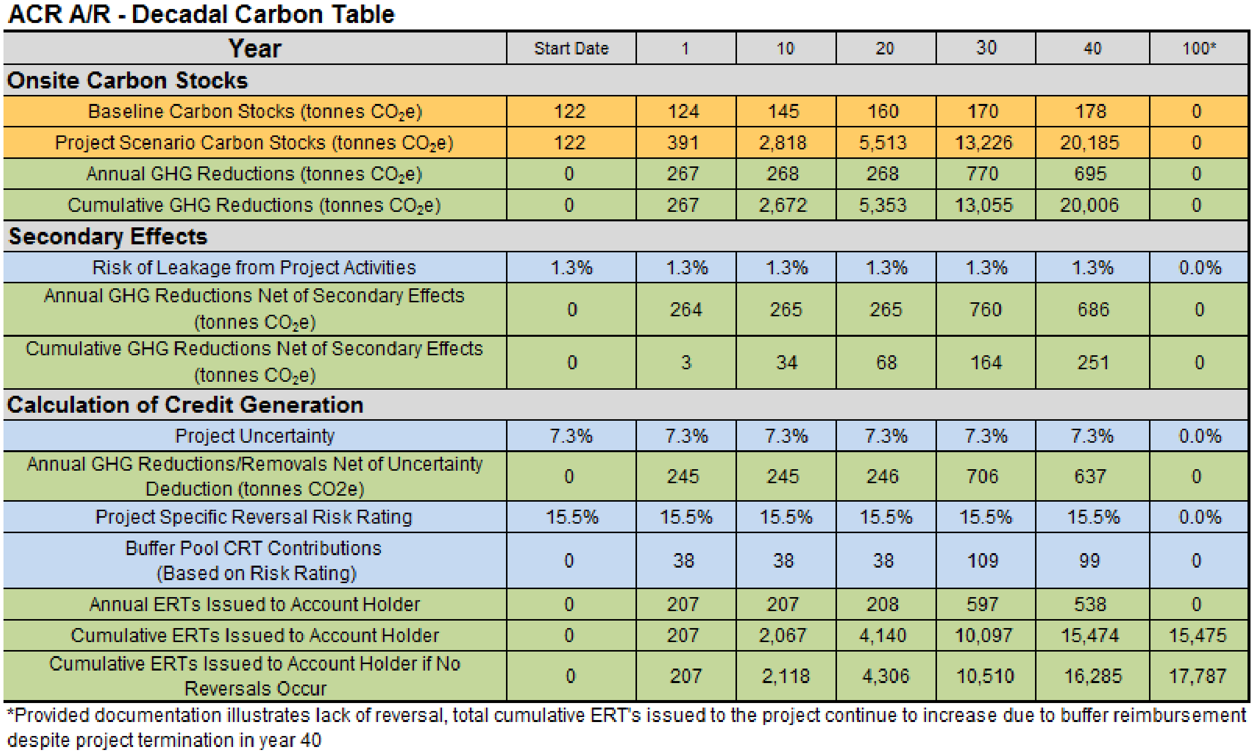
Neither CAR nor ACR provide a positive financial return when the $8 per tonne CO_2e price is held constant, with CAR and ACR accumulating net losses of nearly $37,000 and $20,000, respectively, by year 100. Both the conservative and reimbursement ACR scenarios provide positive bottom-lines by year 34 when the 3% annual price increase is taken into account, but even with the added benefit of rising carbon offset prices, CAR ends up with nearly $13,000 of losses by the end of the project commitment. Annual financial NPV levels in the 3% price increase model never value more than $900 under CAR and never surpass $2,250 under either ACR scenario.



CAR A/R - Decadal Carbon Table

Year	Start Date	1	10	20	30	40	50	60	70	80	90	100
Onsite Carbon Stocks												
Baseline Carbon Stocks (tonnes CO_2e)	122	124	145	160	170	178	183	186	189	191	193	198
Project Scenario Carbon Stocks (tonnes CO_2e)	122	349	2,398	4,674	12,257	19,646	25,198	29,569	33,282	34,107	34,547	34,863
Confidence Deduction	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Project Scenario Carbon Stocks Adjusted for confidence deduction (tonnes CO_2e)	0	346	2,374	4,627	12,135	19,449	24,946	29,273	32,949	33,766	34,202	34,515
Annual GHG Reductions (tonnes CO_2e)	0	222	225	225	751	731	550	433	368	82	44	31
Cumulative GHG Reductions (tonnes CO2e)	0	222	2,229	4,467	11,964	19,271	24,763	29,086	32,760	33,575	34,009	34,316
Secondary Effects												
Risk for Leakage from Shifting Cropland and Grazing Activities	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Annual GHG Reductions Net of Secondary Effects (tonnes CO_2e)	0	111	113	113	375	366	275	216	184	41	22	16
Cumulative GHG Reductions Net of Secondary Effects (tonnes CO2e)	0	111	1,114	2,234	5,982	9,635	12,382	14,543	16,380	16,787	17,004	17,158
Calculation of Credit Generation												
Project Specific Reversal Risk Rating	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%
Buffer Pool CRT Contributions (Based on Risk Rating)	0	14	14	14	46	45	34	27	23	5	3	2
Annual CRTs Issued to Account Holder	0	97	99	99	329	321	241	190	161	36	19	14
Cumulative CRTs Issued to Account Holder	0	97	969	1,939	5,209	8,399	10,799	12,689	14,289	14,639	14,819	14,949

Table 3: Overview table of Climate Action Reserve figures for Afforestation/Reforestation



ACR A/R - Decadal Carbon Table

Year	Start Date	1	10	20	30	40	100*
Onsite Carbon Stocks							
Baseline Carbon Stocks (tonnes CO_2e)	122	124	145	160	170	178	0
Project Scenario Carbon Stocks (tonnes CO_2e)	122	391	2,818	5,513	13,226	20,185	0
Annual GHG Reductions (tonnes CO_2e)	0	267	268	268	770	695	0
Cumulative GHG Reductions (tonnes CO_2e)	0	267	2,672	5,353	13,055	20,006	0
Secondary Effects							
Risk of Leakage from Project Activities	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	0.0%
Annual GHG Reductions Net of Secondary Effects (tonnes CO_2e)	0	264	265	265	760	686	0
Cumulative GHG Reductions Net of Secondary Effects (tonnes CO_2e)	0	3	34	68	164	251	0
Calculation of Credit Generation							
Project Uncertainty	7.3%	7.3%	7.3%	7.3%	7.3%	7.3%	0.0%
Annual GHG Reductions/Removals Net of Uncertainty Deduction (tonnes CO2e)	0	245	245	246	706	637	0
Project Specific Reversal Risk Rating	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%	0.0%
Buffer Pool CRT Contributions (Based on Risk Rating)	0	38	38	38	109	99	0
Annual ERTs Issued to Account Holder	0	207	207	208	597	538	0
Cumulative ERTs Issued to Account Holder	0	207	2,067	4,140	10,097	15,474	15,475
Cumulative ERTs Issued to Account Holder if No Reversals Occur	0	207	2,118	4,306	10,510	16,285	17,787

*Provided documentation illustrates lack of reversal, total cumulative ERT's issued to the project continue to increase due to buffer reimbursement despite project termination in year 40

Table 4: Overview table of American Carbon Registry figures for Afforestation/Reforestation

Avoided Conversion - Hypothetical Acquisition

Our chosen hypothetical avoided conversion project was a 700 acre forest property in Orange County. This large tract of forest had been managed for softwood timber for generations and was undergoing a small timber harvest to help the family cope with financial needs while we were taking measurements on the site. As property values in the surrounding area have skyrocketed since the family first purchased the land in the late eighteenth century and, according to our appraisal consultant, zoning policies for the region would likely be amenable to sale of the property out of the *Forest-Use* designation, this property provided a good example of a potential land conversion site.

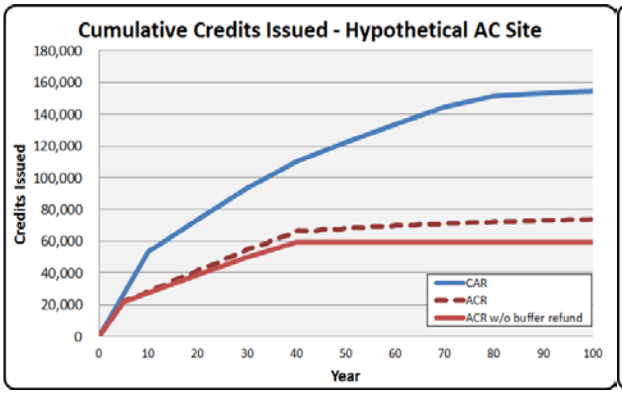


Figure 7: Cumulative credits issued, equaling tonnes CO_2-e

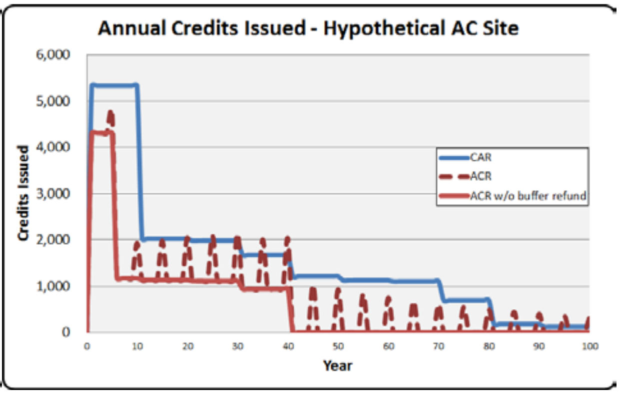


Figure 8: Annual credits issued, equaling tonnes CO_2-e

Hypothetical AC Site

Cumulative Carbon Credits Issued

Year	CAR	ACR	Advantage
13 (2024)	59,408	32,043	CAR 85%
40	110,140	66,416	CAR 66%
100	154,480	73,799	CAR 109%

Table 5: Numerical comparison of cumulative credits issued for each protocols, in key years

The CAR protocol provided considerably higher quantities of carbon credits under this project scenario. By year 13 CAR has produced 85% more offsets than either ACR scenario and, due to the consistently steep trajectory of its *Cumulative Credits Issued* curve, by year 100 CAR has amassed over 154,480 credits, more than doubling the number produced by the ACR reimbursement scenario.

Both Car and the conservative ACR scenario peak in annual offsets generated in year one, with 5,333 t CO_2e and 4,307 t CO_2e, respectively. In the CAR scenario this maximum annual rate of credit generation persists for 10 years before plummeting by over 50% to 2,026 t

CO_2e in year 11. In the conservative ACR scenario the peak annual offset generation is only maintained for five years, at which point it drops by over 70% to 1,172 t CO_2e. The reimbursement ACR scenario peaks at year 5 with 4,779 t CO_2e generated due to buffer refunds but falls to 1,172 t CO_2e the following year. After the severe drop in year 11 the CAR scenario has moderate offset generation declines in years 30, 40, 70, and 80, after which offset yield is minimal until the project period terminates in year 100. The annual offset output from the conservative ACR scenario remains relatively constant around 1000 t CO_2e from year six until year 40 at which point it drops to zero. The reimbursement ACR scenario mimics the conservative ARC scenario's pattern with the exception of declining pulses of offsets from buffer refunds extending out beyond year 100.

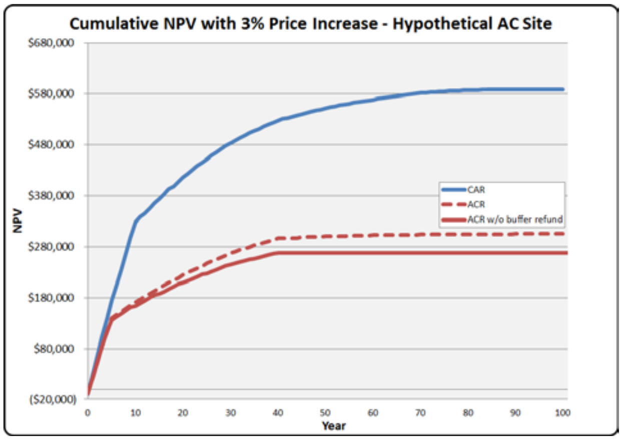


Figure 9: Cumulative Net Present Value, with 3% price increase

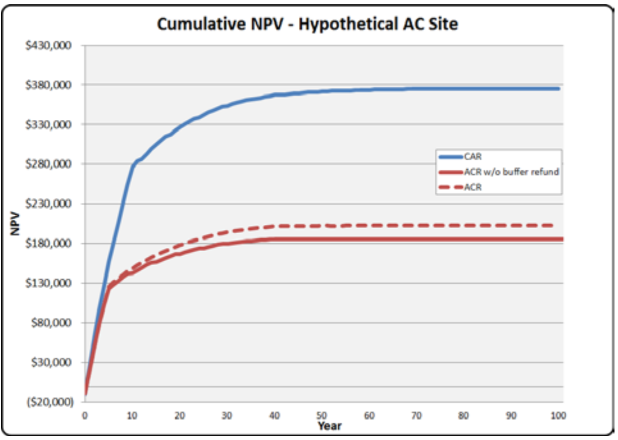


Figure 10: Cumulative Net Present Value, constant price

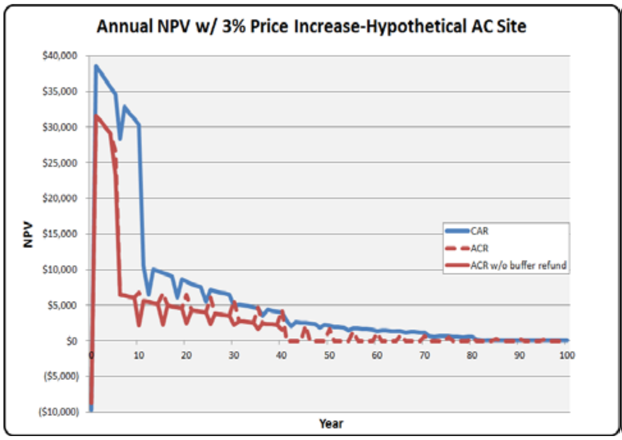


Figure 11: Annual Net Present Value, with 3% price increase

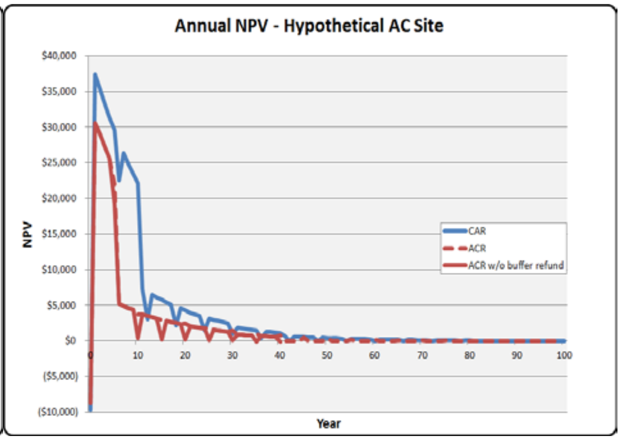


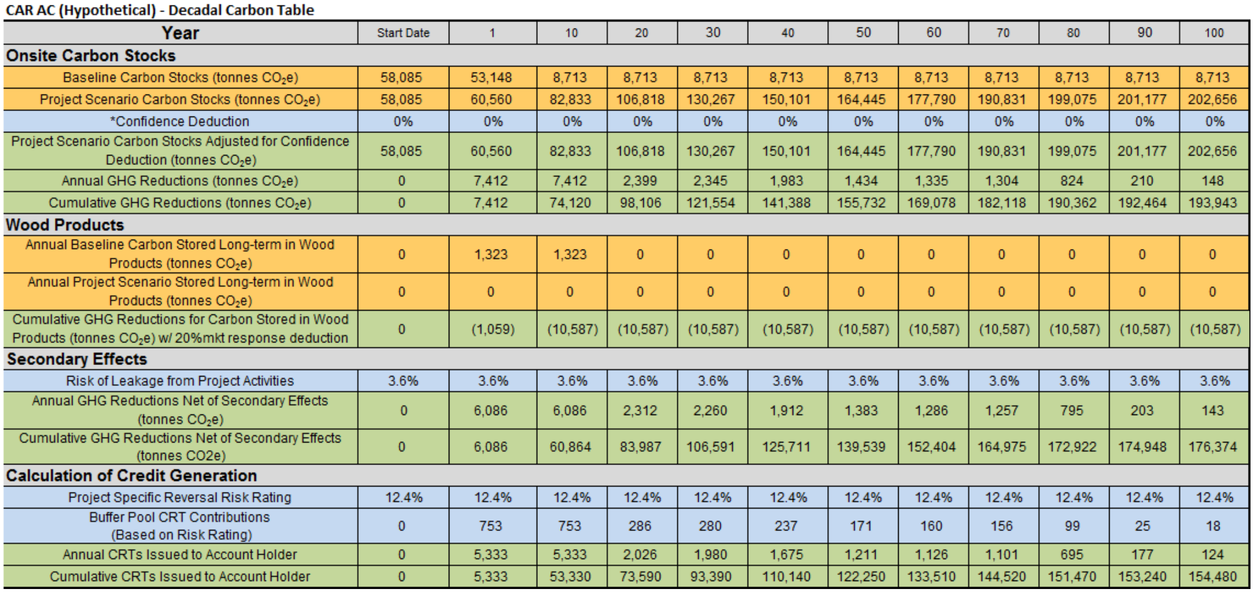
Figure 12: Annual Net Present Value, constant price

Cumulative NPV - Hypothetical AC Site			
With 3% Price Increase			
Year	CAR	ACR	Advantage
13 (2024)	$ 354,892	$ 187,527	CAR 89%
40	$ 527,925	$ 296,883	CAR 78%
100	$ 588,678	$ 305,283	CAR 93%
With Constant Price			
Year	CAR	ACR	Advantage
13 (2024)	$ 293,071	$ 159,314	CAR 84%
40	$ 367,337	$ 201,897	CAR 82%
100	$ 374,996	$ 202,502	CAR 85%

Table 6: Numerical comparison of cumulative price increases (with and without price increases) between the two protocols

The financial returns from the CAR project are superior to those from either of the ACR scenarios. This advantage is slightly more pronounced in the 3% annual price increase model, with the CAR project reaching comparative advantages as high as 93% above that of the reimbursement ACR project, but the advantages are clear in the static price model as well, with CAR showing a consistent 80%+ value premium over ACR for the majority of the 100-year project period. In fact, in both the with and without price increase models the CAR project reaches a higher value in year 13 than the reimbursement ACR scenario can attain in the entire 100-year period.

Annual NPV peaks in year-one of all three project scenarios in both the 3% price increase and constant price models. Under the 3% price increase model CAR peaks around $38,000 then declines steadily by ~$1,000 a year before dipping sharply in year six as result of the cost of the first on-site verification. Following this dip in NPV CAR rebounds in year seven and resumes its steady $1,000 annual decline until year 11 when NPV suddenly plummets to a level ~66% below that seen in year 10. After this point CAR experiences consistent annual NPV drops punctuated by the costs of onsite verification every six years, eventually flattening out after year 80 at an NPV around $100. CAR’s annual NPV pattern under the constant price model is virtually the same as that seen in the price increase model with the exception that all declines in NPV are more dramatic, causing price to reach a near flat-line state sooner. The pattern of annual NPV change in the ACR scenarios mimics that seen under CAR but the dips representing the onsite inventory expenditures occur in every fifth year rather than every sixth and are counterbalanced by buffer refunds in the reimbursement scenario. Additionally the precipitous dip in annual NPV that occurred in year 11 under CAR occurs in year six under ACR.

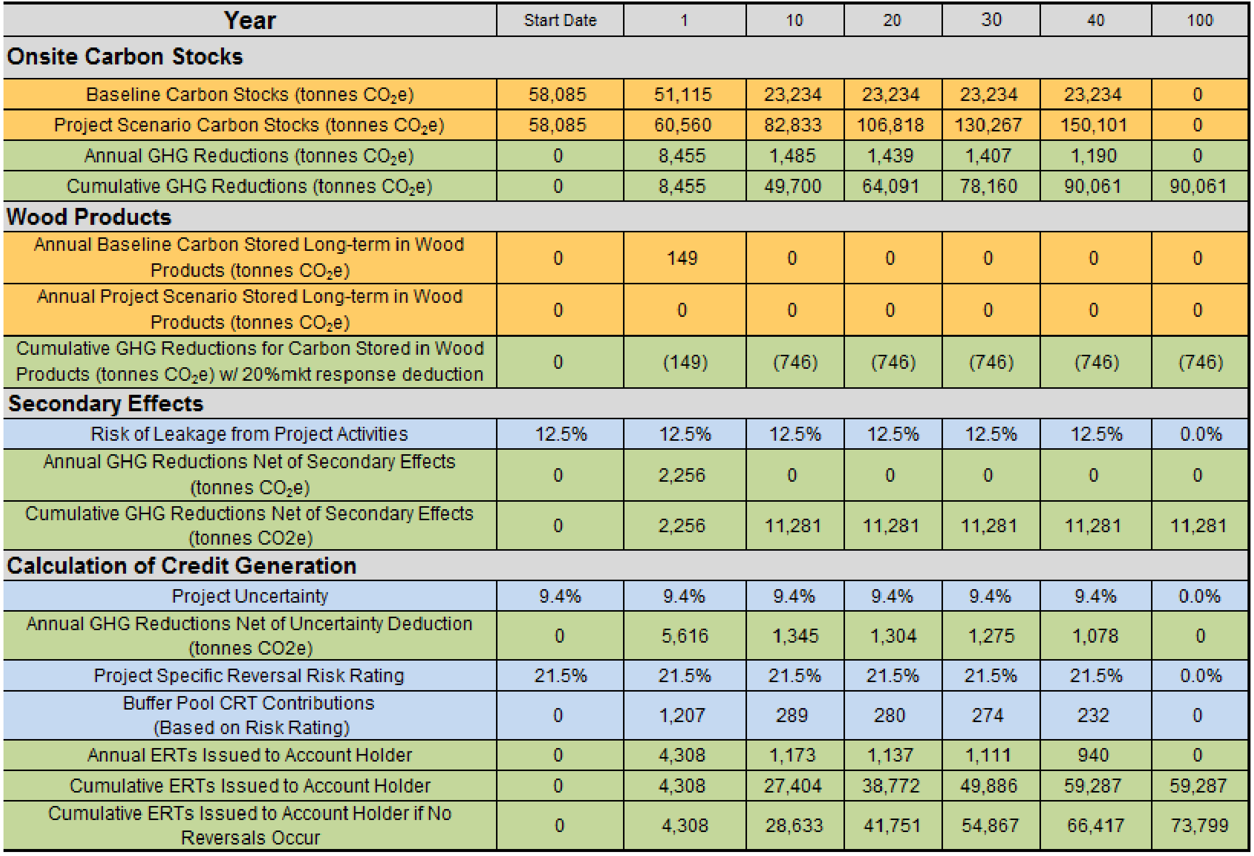


CAR AC (Hypothetical) - Decadal Carbon Table

Year	Start Date	1	10	20	30	40	50	60	70	80	90	100
Onsite Carbon Stocks												
Baseline Carbon Stocks (tonnes CO_2e)	58,085	53,148	8,713	8,713	8,713	8,713	8,713	8,713	8,713	8,713	8,713	8,713
Project Scenario Carbon Stocks (tonnes CO_2e)	58,085	60,560	82,833	106,818	130,267	150,101	164,445	177,790	190,831	199,075	201,177	202,656
*Confidence Deduction	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Project Scenario Carbon Stocks Adjusted for Confidence Deduction (tonnes CO_2e)	58,085	60,560	82,833	106,818	130,267	150,101	164,445	177,790	190,831	199,075	201,177	202,656
Annual GHG Reductions (tonnes CO_2e)	0	7,412	7,412	2,399	2,345	1,983	1,434	1,335	1,304	824	210	148
Cumulative GHG Reductions (tonnes CO_2e)	0	7,412	74,120	98,106	121,554	141,388	155,732	169,078	182,118	190,362	192,464	193,943
Wood Products												
Annual Baseline Carbon Stored Long-term in Wood Products (tonnes CO_2e)	0	1,323	1,323	0	0	0	0	0	0	0	0	0
Annual Project Scenario Stored Long-term in Wood Products (tonnes CO_2e)	0	0	0	0	0	0	0	0	0	0	0	0
Cumulative GHG Reductions for Carbon Stored in Wood Products (tonnes CO_2e) w/ 20%mkt response deduction	0	(1,059)	(10,587)	(10,587)	(10,587)	(10,587)	(10,587)	(10,587)	(10,587)	(10,587)	(10,587)	(10,587)
Secondary Effects												
Risk of Leakage from Project Activities	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%
Annual GHG Reductions Net of Secondary Effects (tonnes CO_2e)	0	6,086	6,086	2,312	2,260	1,912	1,383	1,286	1,257	795	203	143
Cumulative GHG Reductions Net of Secondary Effects (tonnes CO2e)	0	6,086	60,864	83,987	106,591	125,711	139,539	152,404	164,975	172,922	174,948	176,374
Calculation of Credit Generation												
Project Specific Reversal Risk Rating	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%
Buffer Pool CRT Contributions (Based on Risk Rating)	0	753	753	286	280	237	171	160	156	99	25	18
Annual CRTs Issued to Account Holder	0	5,333	5,333	2,026	1,980	1,675	1,211	1,126	1,101	695	177	124
Cumulative CRTs Issued to Account Holder	0	5,333	53,330	73,590	93,390	110,140	122,250	133,510	144,520	151,470	153,240	154,480

Table 7: Overview table of Climate Action Reserve figures for Avoided Conversion project

ACR AC (Hypothetical) - Decadal Carbon Table



Year	Start Date	1	10	20	30	40	100
Onsite Carbon Stocks							
Baseline Carbon Stocks (tonnes CO_2e)	58,085	51,115	23,234	23,234	23,234	23,234	0
Project Scenario Carbon Stocks (tonnes CO_2e)	58,085	60,560	82,833	106,818	130,267	150,101	0
Annual GHG Reductions (tonnes CO_2e)	0	8,455	1,485	1,439	1,407	1,190	0
Cumulative GHG Reductions (tonnes CO_2e)	0	8,455	49,700	64,091	78,160	90,061	90,061
Wood Products							
Annual Baseline Carbon Stored Long-term in Wood Products (tonnes CO_2e)	0	149	0	0	0	0	0
Annual Project Scenario Stored Long-term in Wood Products (tonnes CO_2e)	0	0	0	0	0	0	0
Cumulative GHG Reductions for Carbon Stored in Wood Products (tonnes CO_2e) w/ 20%mkt response deduction	0	(149)	(746)	(746)	(746)	(746)	(746)
Secondary Effects							
Risk of Leakage from Project Activities	12.5%	12.5%	12.5%	12.5%	12.5%	12.5%	0.0%
Annual GHG Reductions Net of Secondary Effects (tonnes CO_2e)	0	2,256	0	0	0	0	0
Cumulative GHG Reductions Net of Secondary Effects (tonnes CO2e)	0	2,256	11,281	11,281	11,281	11,281	11,281
Calculation of Credit Generation							
Project Uncertainty	9.4%	9.4%	9.4%	9.4%	9.4%	9.4%	0.0%
Annual GHG Reductions Net of Uncertainty Deduction (tonnes CO2e)	0	5,616	1,345	1,304	1,275	1,078	0
Project Specific Reversal Risk Rating	21.5%	21.5%	21.5%	21.5%	21.5%	21.5%	0.0%
Buffer Pool CRT Contributions (Based on Risk Rating)	0	1,207	289	280	274	232	0
Annual ERTs Issued to Account Holder	0	4,308	1,173	1,137	1,111	940	0
Cumulative ERTs Issued to Account Holder	0	4,308	27,404	38,772	49,886	59,287	59,287
Cumulative ERTs Issued to Account Holder if No Reversals Occur	0	4,308	28,633	41,751	54,867	66,417	73,799

Table 8: Overview table of American Carbon Registry figures for Avoided Conversion project

Avoided Conversion Duke

In 1995 the Duke Forest Supervisory Board declared more than half of the Duke Forest as permanently off-limits for sale or development [20] (appendix map 4), leaving approximately 2,870-acres eligible for conversion should circumstances necessitate such action. Acknowledging that the University is not currently planning on taking steps that would lead to the conversion of this area, we based our Duke Avoided Conversion scenario on these 2,870 acres for demonstrative purposes. It should be noted however, that based on our consultations with Dawn Talton, if the University's interests were otherwise aligned, the area would fall into a category of high conversion risk based on its location and its potential residential and commercial value.

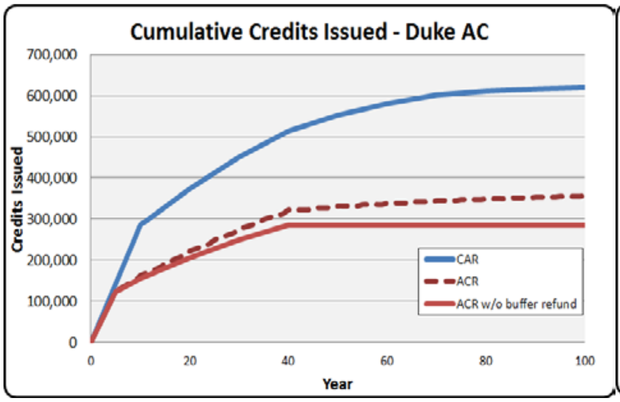


Figure 13: Cumulative credits issued, equaling tonnes CO_2-e

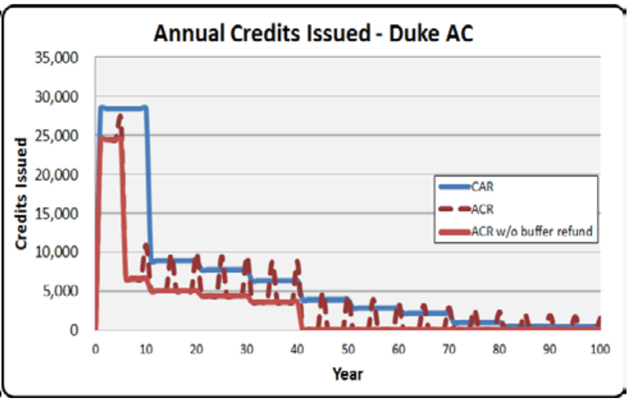


Figure 14: Annual credits issued, equaling tonnes CO_2-e

Duke AC - Cumulative Carbon Credits Issued			
Year	CAR	ACR	Advantage
13 (2024)	311,213	177,267	CAR 76%
40	513,820	322,117	CAR 60%
100	619,960	356,550	CAR 74%

Table 9: Numerical comparison of cumulative credits issued by protocol, at key years

The variance in cumulative credits issued to the project under CAR vs. the two ACR scenarios is similar to the results seen in the Hypothetical Acquisition Avoided Conversion Project. The use of CAR accounting methods leads to considerably more carbon offsets being generated on the project site. This advantage is established in the early years of the project, with CAR generating 76% more offsets than the reimbursement ACR scenario by year 13, and persists through year 100.

As was seen in the Hypothetical Acquisition Avoided Conversion project, the CAR and conservative ACR scenarios both peak in quantity of annual offset tonnes produced in year one. In this case the CAR scenario produces 28,454 offset tonnes for a full decade and then drops precipitously to 8,891 tonnes in year 11, while the conservative ACR scenario produces 24,471 tonnes of offsets for five years before dramatically dropping to 6,560 tonnes in year six. The reimbursement ACR scenario peaks at 27,152 offset tonnes generated in year five and then falls in line with the conservative ACR scenario in year six generating 6,650 tonnes. After its steep decline in annual offset yield in year 11, the CAR scenario falls in offset productivity decadally in a stair step fashion until year 80 where it levels out at around 400 tonnes per year until the conclusion of the project period in year 100. The annual production of offsets in the conservative ACR scenario drops to 5,045 tonnes in year 11 and then hovers at approximately that level until dropping to zero at the projects end date in year 40. Annual offset generation in the reimbursement ACR scenario mimics the pattern seen in the conservative ACR scenario with the exception of the declining buffer refund tonnes it receives bi-decadally up to and beyond year 100.

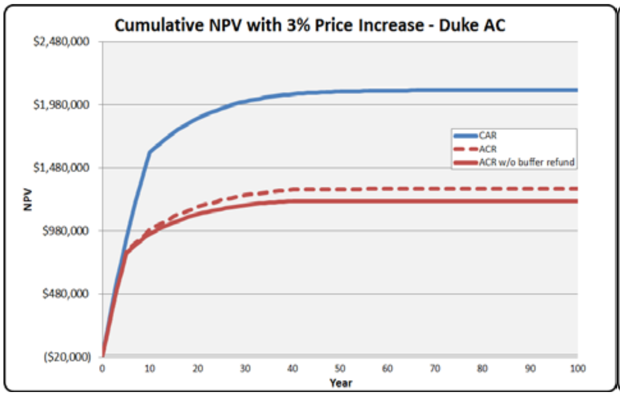


Figure 15: Cumulative Net Present Value, with 3% price increase

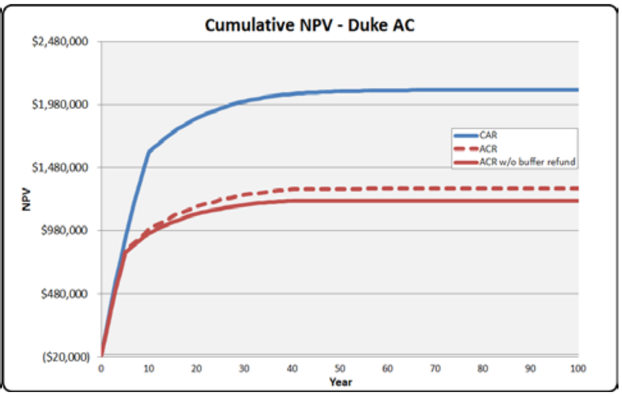


Figure 16: Cumulative Net Present Value, constant price

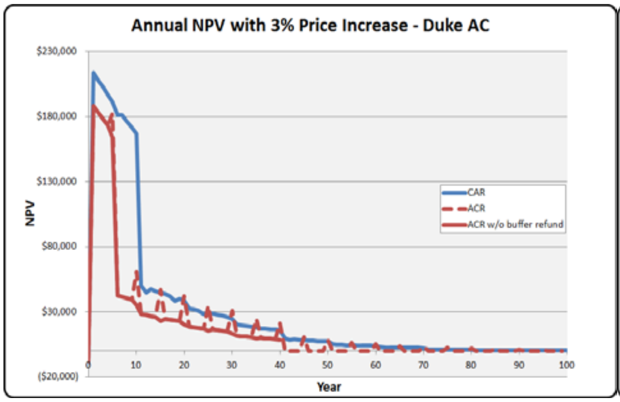


Figure 17: Annual Net Present Value, with 3% price increase

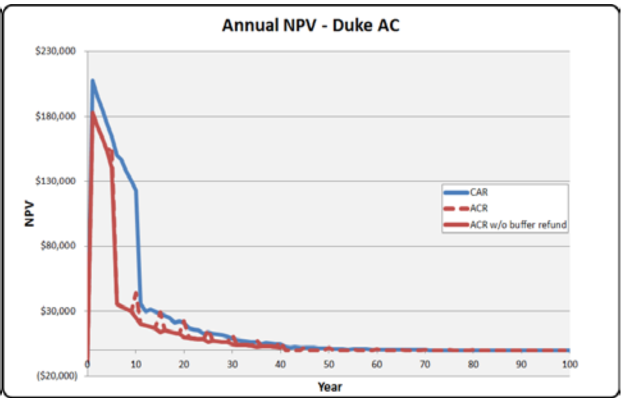


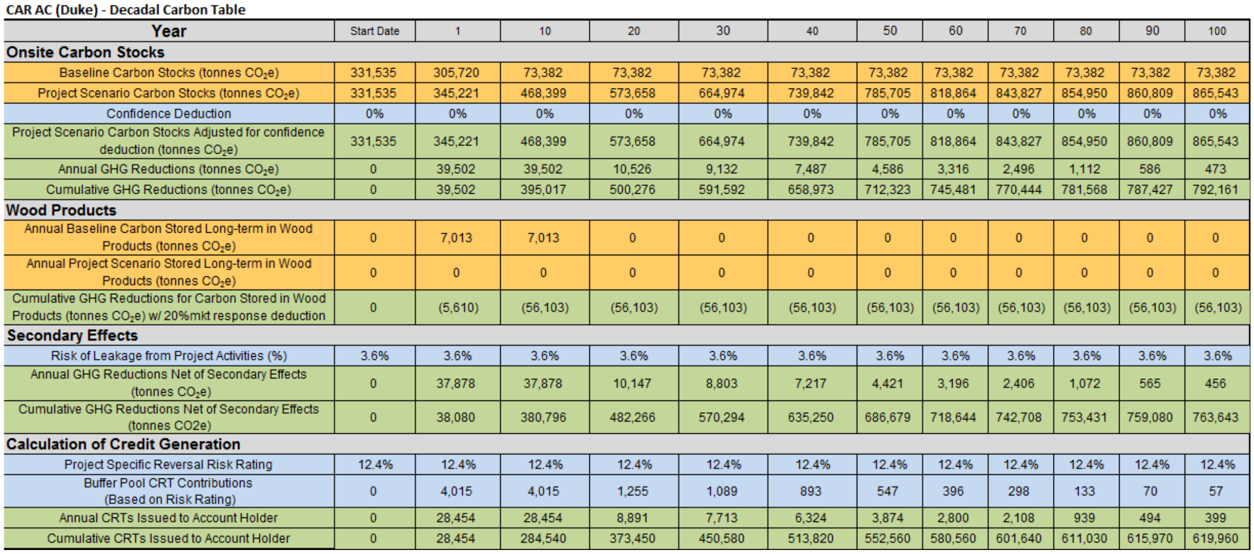
Figure 18: Annual Net Present Value, constant price

Cumulative NPV - Duke AC			
With 3% Price Increase			
Year	CAR	ACR	Advantage
13 (2024)	$ 2,021,624	$ 1,204,417	CAR 68%
40	$ 2,780,060	$ 1,741,820	CAR 60%
100	$ 2,943,771	$ 1,785,387	CAR 65%
With Constant Price			
Year	CAR	ACR	Advantage
13 (2024)	$ 1,701,509	$ 1,052,003	CAR 64%
40	$ 2,065,485	$ 1,308,066	CAR 60%
100	$ 2,095,620	$ 1,315,276	CAR 62%

Table 10: Numerical comparison of cumulative net present value (with and without price increase) at key years

Under CAR protocols the cumulative NPV of the project is at least 60% above that of the ACR scenarios for the entire 100 year period in both pricing models. The ACR reimbursement scenario slightly reduces the gap in cumulative NPV around year 40 in both price models but loses most progress made by year 100.

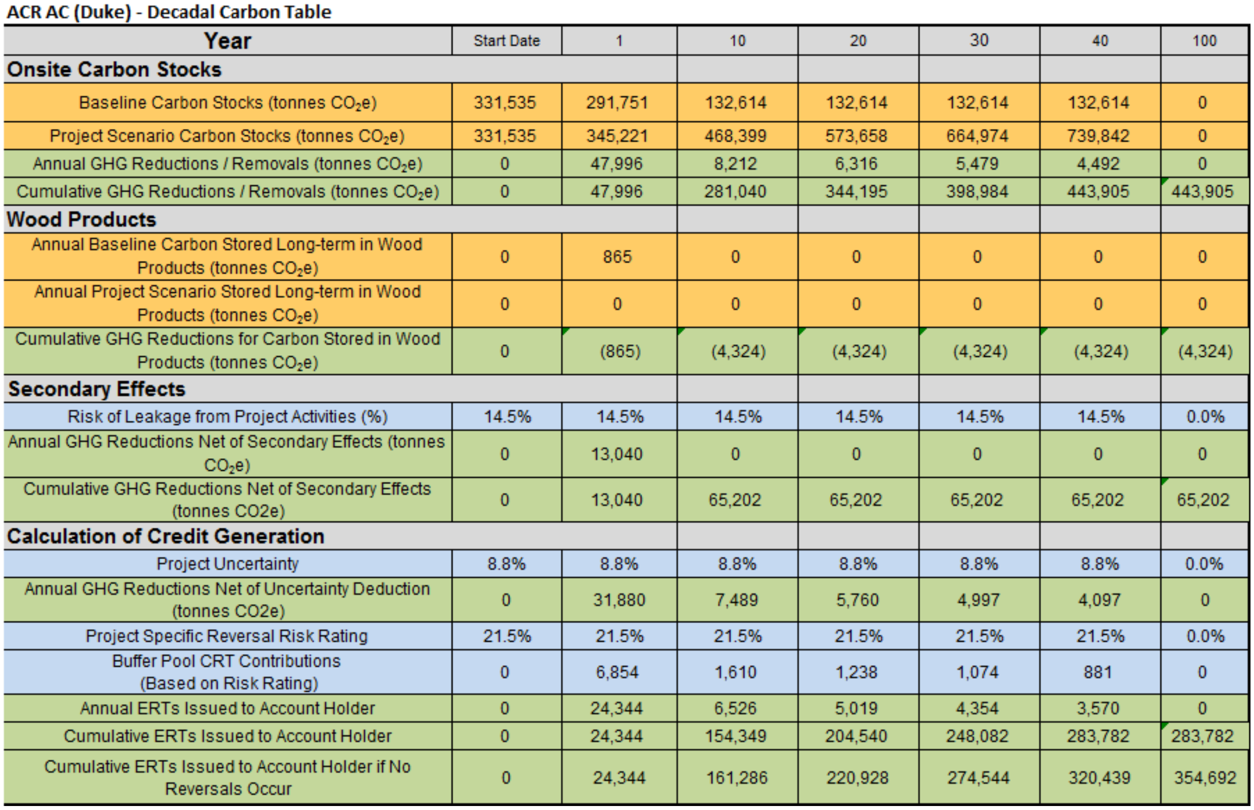
As was seen in the Hypothetical Acquisition Avoided Conversion Project, annual NPV peaks in year-one of all three project scenarios in both the 3% price increase and constant price models. Under the 3% price increase model CAR peaks $213,934 then declines steadily by ~$7,000 a year before dipping in year six due to on-site verification costs. The consistent verification cost dips are less severe for the Duke Forest than those seen in the Hypothetical Acquisition Avoided Conversion Project as the costs of verification is significantly less per acre for larger project sites. Following this dip NPV levels recover in year seven and resume their ~$7,000 annual decline until year 11 when NPV falls by 70% from its level at year 10. After this point CAR experience consistent annual NPV drops punctuated by onsite verification expenses every six years, eventually flat-lining around year 70 and terminating in year 100 with an annual NPV of $175. CAR's pattern of annual NPV decline under the constant price model is similar to that seen in the price increase model but declines in NPV are more dramatic, causing price to reach a near flat-line state by year 40 and terminate at $3 in year 100. The annual pattern of NPV change in the ACR scenarios mimic that seen under CAR but the dips representing the onsite inventory expenditures occur in every fifth year rather than every sixth and are counterbalanced by buffer refunds in the reimbursement scenario. Additionally the severe dip in annual NPV that occurred in year 11 under CAR occurs in year six under ACR.



CAR AC (Duke) - Decadal Carbon Table

Year	Start Date	1	10	20	30	40	50	60	70	80	90	100
Onsite Carbon Stocks												
Baseline Carbon Stocks (tonnes CO_2e)	331,535	305,720	73,382	73,382	73,382	73,382	73,382	73,382	73,382	73,382	73,382	73,382
Project Scenario Carbon Stocks (tonnes CO_2e)	331,535	345,221	468,399	573,658	664,974	739,842	785,705	818,864	843,827	854,950	860,809	865,543
Confidence Deduction	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Project Scenario Carbon Stocks Adjusted for confidence deduction (tonnes CO_2e)	331,535	345,221	468,399	573,658	664,974	739,842	785,705	818,864	843,827	854,950	860,809	865,543
Annual GHG Reductions (tonnes CO_2e)	0	39,502	39,502	10,526	9,132	7,487	4,586	3,316	2,496	1,112	586	473
Cumulative GHG Reductions (tonnes CO_2e)	0	39,502	395,017	500,276	591,592	658,973	712,323	745,481	770,444	781,568	787,427	792,161
Wood Products												
Annual Baseline Carbon Stored Long-term in Wood Products (tonnes CO_2e)	0	7,013	7,013	0	0	0	0	0	0	0	0	0
Annual Project Scenario Stored Long-term in Wood Products (tonnes CO_2e)	0	0	0	0	0	0	0	0	0	0	0	0
Cumulative GHG Reductions for Carbon Stored in Wood Products (tonnes CO_2e) w/ 20%mkt response deduction	0	(5,610)	(56,103)	(56,103)	(56,103)	(56,103)	(56,103)	(56,103)	(56,103)	(56,103)	(56,103)	(56,103)
Secondary Effects												
Risk of Leakage from Project Activities (%)	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%
Annual GHG Reductions Net of Secondary Effects (tonnes CO_2e)	0	37,878	37,878	10,147	8,803	7,217	4,421	3,196	2,406	1,072	565	456
Cumulative GHG Reductions Net of Secondary Effects (tonnes CO2e)	0	38,080	380,796	482,266	570,294	635,250	686,679	718,644	742,708	753,431	759,080	763,643
Calculation of Credit Generation												
Project Specific Reversal Risk Rating	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%	12.4%
Buffer Pool CRT Contributions (Based on Risk Rating)	0	4,015	4,015	1,255	1,089	893	547	396	298	133	70	57
Annual CRTs Issued to Account Holder	0	28,454	28,454	8,891	7,713	6,324	3,874	2,800	2,108	939	494	399
Cumulative CRTs Issued to Account Holder	0	28,454	284,540	373,450	450,580	513,820	552,560	580,560	601,640	611,030	615,970	619,960

Table 11: Overview table of Climate Action Reserve figures for Avoided Conversion in Duke Forest



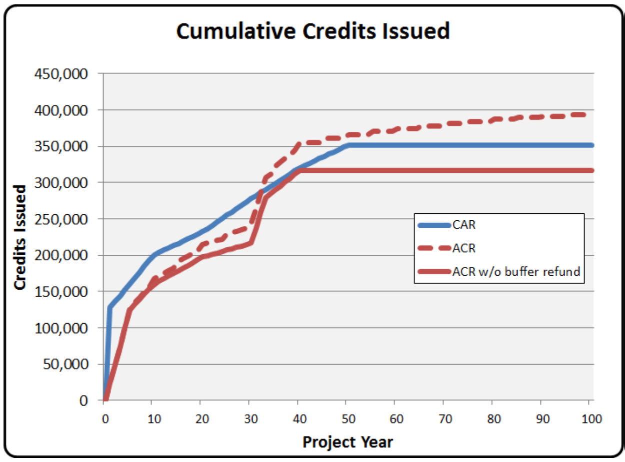
ACR AC (Duke) - Decadal Carbon Table

Year	Start Date	1	10	20	30	40	100
Onsite Carbon Stocks							
Baseline Carbon Stocks (tonnes CO_2e)	331,535	291,751	132,614	132,614	132,614	132,614	0
Project Scenario Carbon Stocks (tonnes CO_2e)	331,535	345,221	468,399	573,658	664,974	739,842	0
Annual GHG Reductions / Removals (tonnes CO_2e)	0	47,996	8,212	6,316	5,479	4,492	0
Cumulative GHG Reductions / Removals (tonnes CO_2e)	0	47,996	281,040	344,195	398,984	443,905	443,905
Wood Products							
Annual Baseline Carbon Stored Long-term in Wood Products (tonnes CO_2e)	0	865	0	0	0	0	0
Annual Project Scenario Stored Long-term in Wood Products (tonnes CO_2e)	0	0	0	0	0	0	0
Cumulative GHG Reductions for Carbon Stored in Wood Products (tonnes CO_2e)	0	(865)	(4,324)	(4,324)	(4,324)	(4,324)	(4,324)
Secondary Effects							
Risk of Leakage from Project Activities (%)	14.5%	14.5%	14.5%	14.5%	14.5%	14.5%	0.0%
Annual GHG Reductions Net of Secondary Effects (tonnes CO_2e)	0	13,040	0	0	0	0	0
Cumulative GHG Reductions Net of Secondary Effects (tonnes CO2e)	0	13,040	65,202	65,202	65,202	65,202	65,202
Calculation of Credit Generation							
Project Uncertainty	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%	0.0%
Annual GHG Reductions Net of Uncertainty Deduction (tonnes CO2e)	0	31,880	7,489	5,760	4,997	4,097	0
Project Specific Reversal Risk Rating	21.5%	21.5%	21.5%	21.5%	21.5%	21.5%	0.0%
Buffer Pool CRT Contributions (Based on Risk Rating)	0	6,854	1,610	1,238	1,074	881	0
Annual ERTs Issued to Account Holder	0	24,344	6,526	5,019	4,354	3,570	0
Cumulative ERTs Issued to Account Holder	0	24,344	154,349	204,540	248,082	283,782	283,782
Cumulative ERTs Issued to Account Holder if No Reversals Occur	0	24,344	161,286	220,928	274,544	320,439	354,692

Table 12: Overview table of American Carbon Registry figures for Avoided Conversion in Duke Forest

IFM

Our improved forest management scenario was conducted on the ~7,000 acres of managed land within the Duke Forest.



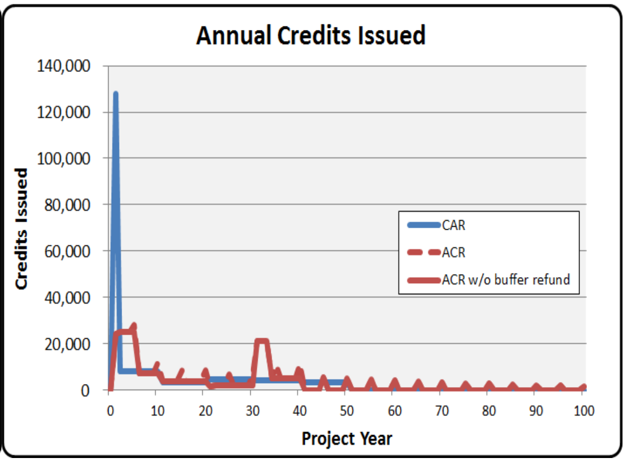


Figure 19: Cumulative credits issued, equaling tonnes CO_2-e

Figure 20: Annual credits issued, equaling tonnes CO_2-e

IFM - Cumulative Carbon Credits Issued			
Year	CAR	ACR	Advantage
13 (2024)	210,115	178,912	CAR 17%
40	320,289	355,050	ACR 11%
100	351,809	395,236	ACR 12%

Table 13: Numerical comparison of cumulative credits issued, at key years

The quantity of carbon credits issued by the CAR and ACR protocols have more parity in the context of the IFM project than in any of the other project scenarios examined. In the first decades of the IFM project, the CAR protocols lead to quicker accumulation of offset credits, giving CAR a 17% advantage over the reimbursement ACR scenario by year 13. However, by year 33 the ACR reimbursement scenario surpasses CAR, eventually gaining a 12% advantage by year 100.

Much greater variation between the protocols is apparent in the schedule of annual credit issuance. CAR's credits are extremely front loaded, with over 36% of its total credits being issued in year one and the remaining 64% all being issued by year 50. ACR credits are issued in waves, peaking first with around 26,000 credits a year between years one and six and then again with over 21,000 credits a year between years 31 and 33. These waves coupled with the bi-decadal buffer refund give the ACR reimbursement scenario the advantage in overall credits in the long run.

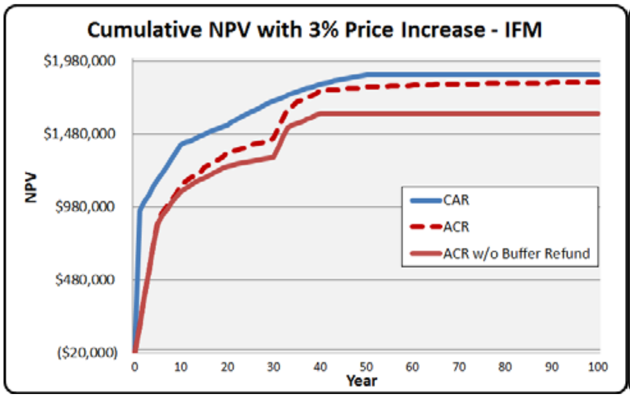


Figure 21: Cumulative Net Present Value, with 3% price increase

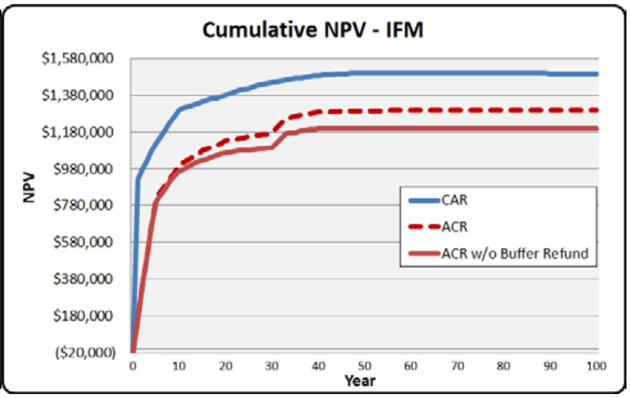


Figure 22: Cumulative Net Present Value, constant price

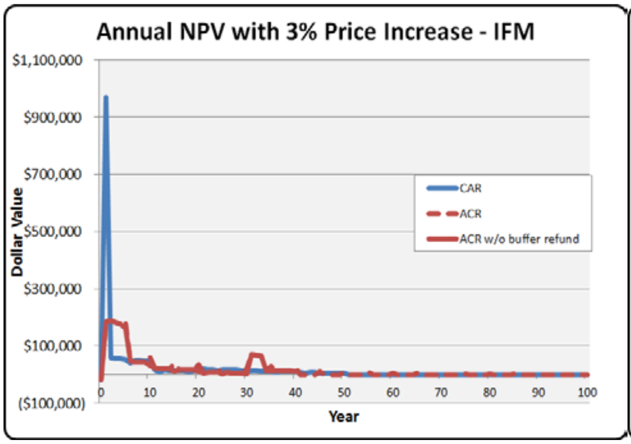


Figure 23: Annual Net Present Value, with 3% price increase

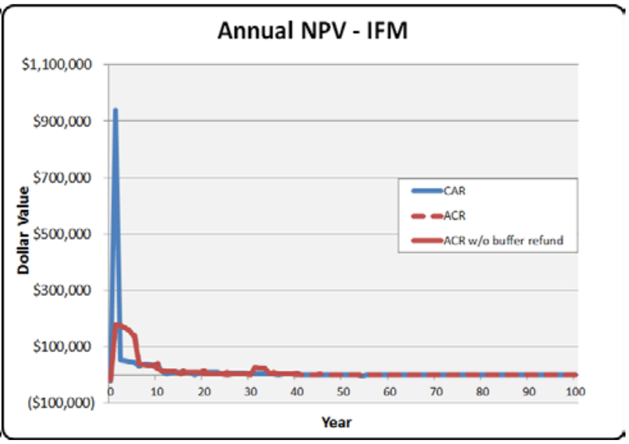


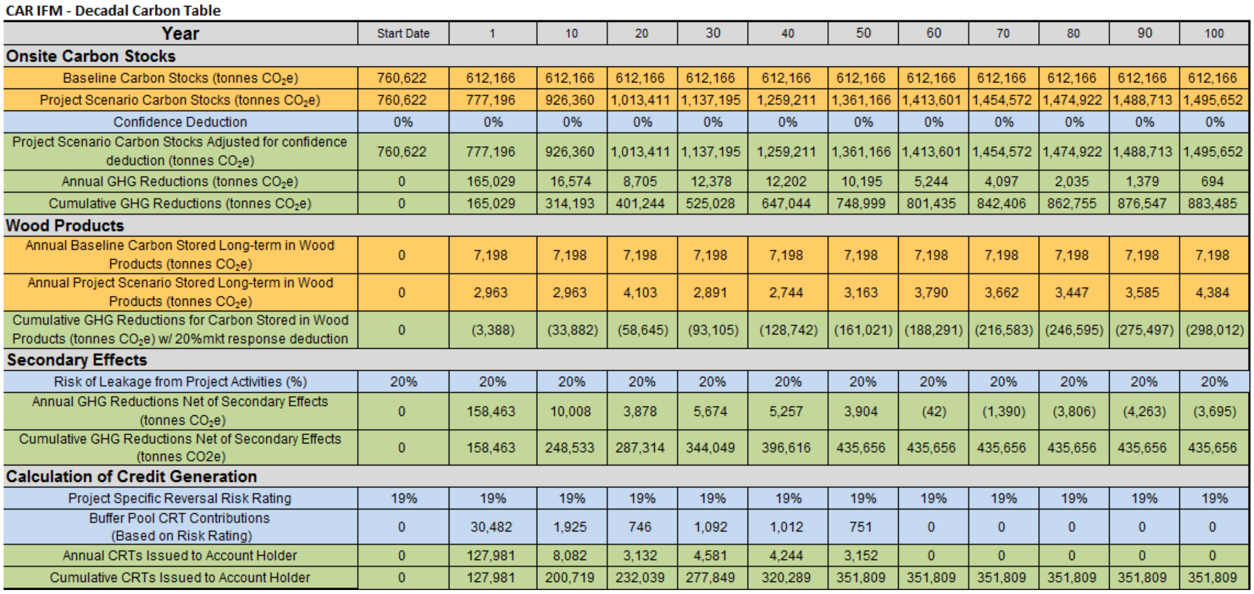
Figure 24: Annual Net Present Value, constant price

Cumulative NPV - IFM			
With 3% Price Increase			
Year	CAR	ACR	Advantage
13 (2024)	$ 1,448,779	$ 1,196,511	CAR 21%
40	$ 1,824,202	$ 1,782,672	CAR 2%
100	$ 1,884,368	$ 1,834,510	CAR 3%
With Constant Price			
Year	CAR	ACR	Advantage
13 (2024)	$ 1,326,133	$ 1,044,481	CAR 27%
40	$ 1,487,130	$ 1,291,308	CAR 15%
100	$ 1,496,817	$ 1,299,958	CAR 15%

Table 14: Numerical comparison of cumulative net present value (with and without price increase) at key years

Despite the ACR reimbursement scenario's greater quantity of overall offset credits generated, the CAR protocol maintains a higher cumulative NVP for the entire period. CAR's advantage is greater in the $8 fixed offset price model, where it maintains a cumulative NPV 15% higher than that of the ACR reimbursement scenario, while in the increasing offset price model it only narrowly maintains its advantage of 2-3% after year 40.

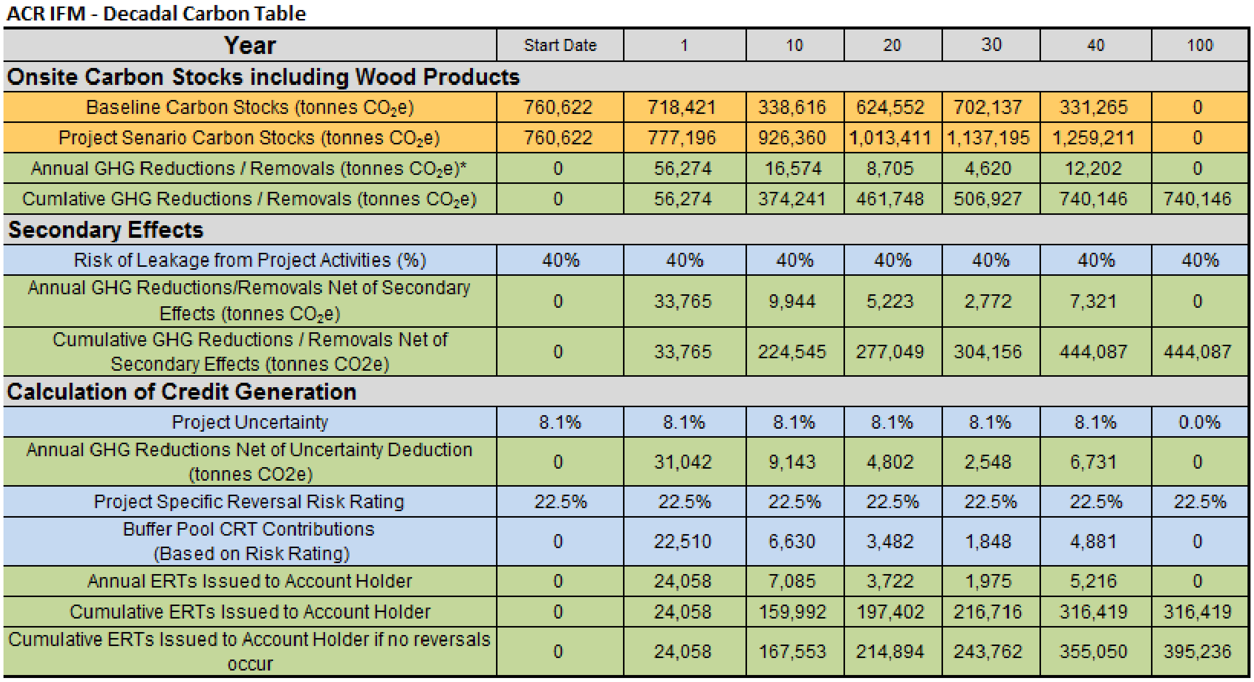
The annual NPV pattern follows that of annual credit disbursement, with CAR experiencing its highest annual NPV in year one and then falling dramatically (~95%) in year two, while the ACR protocol experiences two distinct waves of high annual NPV periods between year one and five and between year 31 and 33. The heights of the ACR waves are greater in the 3% price increase model as the annual rise in prices adds value to the credits issued later in the project's life.



CAR IFM - Decadal Carbon Table

Year	Start Date	1	10	20	30	40	50	60	70	80	90	100
Onsite Carbon Stocks												
Baseline Carbon Stocks (tonnes CO_2e)	760,622	612,166	612,166	612,166	612,166	612,166	612,166	612,166	612,166	612,166	612,166	612,166
Project Scenario Carbon Stocks (tonnes CO_2e)	760,622	777,196	926,360	1,013,411	1,137,195	1,259,211	1,361,166	1,413,601	1,454,572	1,474,922	1,488,713	1,495,652
Confidence Deduction	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Project Scenario Carbon Stocks Adjusted for confidence deduction (tonnes CO_2e)	760,622	777,196	926,360	1,013,411	1,137,195	1,259,211	1,361,166	1,413,601	1,454,572	1,474,922	1,488,713	1,495,652
Annual GHG Reductions (tonnes CO_2e)	0	165,029	16,574	8,705	12,378	12,202	10,195	5,244	4,097	2,035	1,379	694
Cumulative GHG Reductions (tonnes CO_2e)	0	165,029	314,193	401,244	525,028	647,044	748,999	801,435	842,406	862,755	876,547	883,485
Wood Products												
Annual Baseline Carbon Stored Long-term in Wood Products (tonnes CO_2e)	0	7,198	7,198	7,198	7,198	7,198	7,198	7,198	7,198	7,198	7,198	7,198
Annual Project Scenario Stored Long-term in Wood Products (tonnes CO_2e)	0	2,963	2,963	4,103	2,891	2,744	3,163	3,790	3,662	3,447	3,585	4,384
Cumulative GHG Reductions for Carbon Stored in Wood Products (tonnes CO_2e) w/ 20%mkt response deduction	0	(3,388)	(33,882)	(58,645)	(93,105)	(128,742)	(161,021)	(188,291)	(216,583)	(246,595)	(275,497)	(298,012)
Secondary Effects												
Risk of Leakage from Project Activities (%)	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Annual GHG Reductions Net of Secondary Effects (tonnes CO_2e)	0	158,463	10,008	3,878	5,674	5,257	3,904	(42)	(1,390)	(3,806)	(4,263)	(3,695)
Cumulative GHG Reductions Net of Secondary Effects (tonnes CO2e)	0	158,463	248,533	287,314	344,049	396,616	435,656	435,656	435,656	435,656	435,656	435,656
Calculation of Credit Generation												
Project Specific Reversal Risk Rating	19%	19%	19%	19%	19%	19%	19%	19%	19%	19%	19%	19%
Buffer Pool CRT Contributions (Based on Risk Rating)	0	30,482	1,925	746	1,092	1,012	751	0	0	0	0	0
Annual CRTs Issued to Account Holder	0	127,981	8,082	3,132	4,581	4,244	3,152	0	0	0	0	0
Cumulative CRTs Issued to Account Holder	0	127,981	200,719	232,039	277,849	320,289	351,809	351,809	351,809	351,809	351,809	351,809

Table 15: Overview table of Climate Action Reserve figures for Improved Forest Management



ACR IFM - Decadal Carbon Table

Year	Start Date	1	10	20	30	40	100
Onsite Carbon Stocks including Wood Products							
Baseline Carbon Stocks (tonnes CO_2e)	760,622	718,421	338,616	624,552	702,137	331,265	0
Project Senario Carbon Stocks (tonnes CO_2e)	760,622	777,196	926,360	1,013,411	1,137,195	1,259,211	0
Annual GHG Reductions / Removals (tonnes CO_2e)*	0	56,274	16,574	8,705	4,620	12,202	0
Cumlative GHG Reductions / Removals (tonnes CO_2e)	0	56,274	374,241	461,748	506,927	740,146	740,146
Secondary Effects							
Risk of Leakage from Project Activities (%)	40%	40%	40%	40%	40%	40%	40%
Annual GHG Reductions/Removals Net of Secondary Effects (tonnes CO_2e)	0	33,765	9,944	5,223	2,772	7,321	0
Cumulative GHG Reductions / Removals Net of Secondary Effects (tonnes CO2e)	0	33,765	224,545	277,049	304,156	444,087	444,087
Calculation of Credit Generation							
Project Uncertainty	8.1%	8.1%	8.1%	8.1%	8.1%	8.1%	0.0%
Annual GHG Reductions Net of Uncertainty Deduction (tonnes CO2e)	0	31,042	9,143	4,802	2,548	6,731	0
Project Specific Reversal Risk Rating	22.5%	22.5%	22.5%	22.5%	22.5%	22.5%	22.5%
Buffer Pool CRT Contributions (Based on Risk Rating)	0	22,510	6,630	3,482	1,848	4,881	0
Annual ERTs Issued to Account Holder	0	24,058	7,085	3,722	1,975	5,216	0
Cumulative ERTs Issued to Account Holder	0	24,058	159,992	197,402	216,716	316,419	316,419
Cumulative ERTs Issued to Account Holder if no reversals occur	0	24,058	167,553	214,894	243,762	355,050	395,236

Table 16: Overview table of American Carbon Registry figures for Improved Forest Management

Discussion

General Protocol Differences

Though both CAR and ACR maintain rigorous standards for forest carbon quantification, several differences are apparent in the design and implementation of their forest offset protocols. Most salient among these are CAR and ACR's differing requirements for project length, types of forest carbon pools permitted for offset generation, and stringency of management practices on project land.

The concept of perpetuity is central to any discussion of forest carbon sequestration. If carbon emissions reductions are produced by sequestering carbon in planted trees or avoiding emissions from the deforestation of existing stands, the climate mitigating effects of these activities should be "permanent." However, true permanence is impossible to guarantee. Therefore protocol designers are tasked with defining the scope of perpetuity in the context of their climate mitigation strategies. To this end CAR defines a permanent project as one that is bound to a minimum project commitment of 100 years plus a minimum monitoring and reporting period of 100 additional years following the last offset credit issued to the project. In effect this could mean a 200 year legally binding commitment if any credits were issued to the project in year 100. This multi-generational commitment period reflects CAR's philosophy that perpetuity should be interpreted as literally as feasibly possible. ACR takes a considerably different view of the issue, requiring a minimum project commitment of only 40 years, with post project monitoring and reporting incentivized through buffer reimbursements rather than required by mandate. This policy reflects ACR's philosophy that forest based climate mitigation strategies should be a "bridge strategy to achieve near-term reductions cost-effectively over the period from now through 2050 – the timeframe over which U.S. legislative frameworks and international negotiations propose effective de-carbonization of major emitting sectors, with reductions of around 80% below current GHG emissions[40]." These differences in project timeline requirements have serious ramifications when considering which forest offset protocol is the best fit for a given organization's emissions reduction goals.

In addition to having more demanding time commitment requirements, CAR is also more restrictive in terms of the types of forest materials from which they will allow carbon offsets to be generated. As there is currently considerable debate about the accuracy of soil, duff, and downed-wood carbon quantification methods, CAR has postponed issuance of any offset credits based on these pools until further accuracy can be ensured[44]. In contrast ACR will issue credits based on these carbon pools provided the methodology utilized is deemed acceptable by an ACR verifier.

Though both registries attempt to encourage sustainable forest management on project lands, CAR is more explicit in regard to what types of actions are forbidden on verified project sites. One example of this can be seen in CAR's requirement that all Avoided Conversion Projects be placed under a strict conservation easement upon project commencement. ACR encourages similar action by reducing buffer requirements if an easement is undertaken, but does not go as far as to require them for project enrollment with the registry. CAR also mandates that all forest projects employ specifically prescribed "natural forest management[24]" practices designed to promote and maintain diversity of native species across multiple age classes within project stands. ACR has no such stipulations, but does require official certification under FSC, SFI, or ATF for the enrollment of IFM projects. Lastly CAR prohibits the use of broadcast fertilization on any forest project, while fertilization is not under ACR project regulations.

It should be noted that ACR's acceptance of broadcast fertilization creates increased carbon sequestration potential as the addition of moderate levels of nitrogen fertilizer have been known to increase the productivity of loblolly growth in the southern US[45]. Unfortunately we were not able to account for this potential benefit in our growth simulations because FVS models for the southeastern US have not yet been calibrated for the effects of fertilization. While understanding fertilization's potential carbon benefit would have been helpful from the standpoint of illuminating differences between the two protocols, the effects do not have significant implications for Duke Forest, as the forest does not practice fertilization in any of its management activities.

Discount Rates

As mentioned in the methods section of this document, the 6% discount rate applied in all financial models utilized in this analysis was chosen based on the requirements of ACR's IFM protocol and the advice of industry professionals. It is important to consider that this discount rate is only mandatory for ACR's IFM project, leaving all other project scenarios open to choose alternate rates. Though the 6% rate was maintained to allow for a more controlled comparison of the registries' various protocols, it could be argued that a lower discount rate could be justified for long-term forest investments. The chosen discount rate has a profound effect on the financial performance of each carbon project and if altered could dramatically change the NPV outcomes seen in our results section. For example, if the IFM project under CAR was given a discount rate of 5% in the price increase model, its cumulative NPV would increase ~10% by the last year of the project. If that discount rate was reduced one percent further to 4%, the project's new cumulative NPV would be nearly 22% higher than that seen under the original rate by year 100.

Afforestation / Reforestation

The A/R project was the only scenario in which ACR protocols lead to the generation of decisively higher quantities of offset credits and improved NVP levels than those seen under

CAR. ACR's superior performance can be almost completely attributed to the substantially higher leakage deductions required by CAR under the particular circumstances of the project.

Calculating leakage under the CAR protocols requires accounting for the shifting of cropland or grazing activities to forestland outside the Project Area. To due this CAR provides a flow chart (appendix 4) with a series of questions that eventually lead to an ultimate leakage deduction percentage based on the characteristics of the given A/R site. Because our site was being managed for commercial grazing, a massive 50% deduction was required to compensate for what CAR protocol designers perceived would be the amount of forest land cleared to support new grazing activity that would supplant the grazing which once took place on the project area. ACR's leakage deductions are not nearly as severe in the case of grazing land, and only required a deduction of a 1.3%. This number was calculated based on the number of cattle present on the area to be reforested, in conjunction with the percentage of forest cover in Alamance and Orange counties[28].

From a financial standpoint neither of these projects performed well in either the static or increasing price model. This is due to the effect of high project execution cost in relation to the size of the total project area. Projects of all sizes must pay the same annual reserve fees and the cost of verification per acre is considerably higher for small projects than large ones[42]. The need to reach a certain scale for forest projects to become cost effective is one of the reasons why project aggregation is desirable for many small land owners interested in developing forest carbon projects on their land. Costs are particularly damaging to afforestation projects because a large portion of the project expenses must be paid up front for project development, while carbon returns are slow in coming as project proponents must wait for trees to grow in order to recognize offsets benefits. Due to these collective challenges, the CAR project never achieves a positive NPV during the entire 100 year period under both price schemes, while the ACR reimbursement scenario manages to achieve only a humble cumulative NPV post year 32 under the price increase model (Figures 3-6).

Avoided Conversion / REDD

In both the Duke forest and the Hypothetical Acquisition Project CAR protocols resulted in considerably higher carbon offsets and financial benefits. This performance advantage can be attributed to three factors: the difference in the way CAR and ACR calculate the percentage of a given site that is eligible for conversion, the amount of leakage required for each project, and the longer life of CAR projects.

When assessing the baseline carbon stocks on a potential AC site (i.e. the proportion of the land that will be left forested after conversion occurs) it cannot be assumed that 100% of the project area will be cleared and shifted to non-forest use. The two registries have dramatically different methods for assessing this cleared portion of the site (which we describe in greater detail in the methods section of this document) which lead to significant difference in the quantities of offsets each generates.

CAR prescribes default percentages based on the type of conversion activity most likely to occur on the site (appendix 4). On the Duke Forest this conversion activity was deemed to be a mix of commercial and low-to-medium density residential development that qualified for permanent clearing of 78% of the total forested area. On the Hypothetical Project area the conversion activity was identified as purely medium density development and qualified for permanent clearing of 85% of the forest cover.

ACR determines the percentage of the project that can be converted based on the amount of forested land cleared on “proxy sites” (sites with similar characteristics) in the region that have been converted to non-forest use in the last decade. In this process, five sites are identified and the proportion of conversion seen on each is averaged to determine the conversion percentage allowable in the project area. This resulted in an allowable conversion rate of only 60% for both the Duke Forest and the Hypothetical Project, as the same proxy sites were used in both cases. This low conversion rate allowed CAR’s Duke Forest and Hypothetical Acquisition projects to generate offsets on 18% and 25% more land than could be utilized under ACR (Figures 7 & 13).

CAR’s comparative advantage over ACR was increased with the consideration of leakage, as CAR protocols required around 10% less leakage deductions than ACR for both projects. Lastly CAR’s 100-year project period allows for the issuance of new credits for 60 years after ACR project completion. These combined advantages led to differences of 74% greater offset generation in the case of Duke Forest and 109% greater offset generation in the case of the Hypothetical Project when compared to their ACR counterparts over the 100 year period (Tables 5 & 9).

The financial results reflect CAR's superior credit generation, but financial outcomes are somewhat muted as a result of the $0.20 fee CAR charges for the issuance of every offset tonne. ACR charges no such fee and thereby reduces the gap between itself and CAR in terms of cumulative NPV levels. Both CAR projects recognize proportionately higher cumulative NPV levels under the price increase model with the Duke Forest and Hypothetical Acquisition Project terminating with 65% and 75% higher cumulative NPVs than their ACR counterparts (Tables 6 & 10).

Improved Forest Management

While the reforestation and avoided conversion projects we analyzed remain largely hypothetical at this time, our analysis of Improved Forest Management has real and significant implications for offsetting Duke's carbon footprint. Our decision to model Duke's current management practices as the "with-project" scenario under CAR and ACR means that the credits calculated can be considered applicable to offsetting Duke's carbon footprint immediately. The credit disbursement schedule, the total number of credits issued over the length of the project, and the NPV for a registered project should all be considered before a protocol can be selected and the resulting credits applied to offsetting Duke's carbon footprint. To do this it is necessary to examine some of the most significant features of the two IFM protocols: the establishment of a baseline for comparing CO_2e reductions in the with-project scenario and the impact of leakage calculations on the total number of credits issued. After an analysis of these aspects final consideration must be given to the disbursement schedule that these differences lead to and the effect that discounting will have on the NPV for each project.

The most significant feature that determined the total number of emissions reductions under each registry was the calculation of the baseline. The apparent flexibility for the procedure under CAR turned out to be more restricted once the average standing carbon stocks under the common practice for our area was established. As baseline carbon stocks can never fall below common practice in areas where they started out above that level, utilizing the more aggressive harvesting regime modeled as our highest NPV scenario was not possible. As a result, the average baseline carbon stocks for ACR were 11% lower than under CAR. This led to ACR producing greater emissions reductions in the short term and over the life of the project (Figures 19 & 20).

Despite the proportionally larger number of emissions reductions calculated under ACR, the project did not produce a similarly advantageous number of credits. These emissions reductions were tempered by the leakage calculations required under the protocol. The reduction in the net benefit from project activity in both protocols is based on the anticipated displacement of timber activity from areas under IFM to other forested areas as a response to the decrease in harvesting. Each protocol provides a leakage factor to account for this effect. CAR requires that only 20%[24] of the reduction in carbon removals be leaked, while ACR requires project developers to use 40%[19]. By requiring project developers to deduct so much of the carbon benefit of reduced removals in the project area, ACR significantly diminishes the relative advantage the protocol provided by allowing projects to set their own baseline as a highest NPV scenario.

The mechanism for credit disbursement under the two registries has consequences both for the availability of credits to meet the University's offset needs, and also for the NPV of the project in each scenario. CAR awards the bulk of its credits in the first year, as the largest quantity of emissions reductions is calculated based upon the difference between the carbon stocks in the first year of the project and the carbon stocks in the baseline. ACR amortizes these reductions over five years in this project. With the 6% discount rate we used in both projects, this slower disbursement has a significant effect on the NPV of the ACR project. Largely as a result of this difference the 17% advantage in credits issued under CAR translated into a 21% advantage in cumulative NPV under the increasing price model in the in year 2024 (Table 14). This difference is even greater under the constant price model, where CAR possesses a 27% advantage. As a consequence of discounting and the steady decline in credits issued to both projects, the ACR project never surpasses the cumulative NPV of the CAR project, even though it passes CAR in cumulative credits issued by year 33, with an 11% advantage by year 40 and a 12% advantage by year 100 (Table 13).

In addition to the stark impact of discounting on future credits issued, the two projects experience the same slowing rate of carbon assimilation. This is a reflection of the choices made in modeling Duke Forest's current management. Much of the Duke Forest is not actively managed for timber and thus remained unharvested in our IFM projections. These sections of the Duke Forest include: research areas, stream management zones, aesthetic management zones, significant cultural areas, Natural Heritage Areas on the North Carolina Registry, and other significant natural areas[46]. Harvesting in hardwood stands is very limited as FSC restricts the conversion of hardwood stands to planted pine and the Duke Forest is interested in promoting the natural development of these areas into old growth[39]. With the goal of not overestimating the rate of carbon assimilation across the Duke Forest we chose to model harvests in the pine stands exclusively. As a result the unharvested areas assimilate carbon at a rate that continues to slow over the lifetime of the project. This reduces the overall average rate of assimilation for the Duke Forest and has a significant effect on the number of emissions reductions quantified against the baseline in the later years of the project. The effect of this reduction in credits generated is not as acute under ACR, where the project continues to receive buffer refunds based on earlier emissions reductions. However, the impact of discounting on the value of these credits still prevents ACR from exceeding the cumulative NPV of the CAR project.

Conclusions & Recommendations

Our analysis clearly establishes that the Duke Forest has the potential to produce significant amounts of high quality carbon offsets at a cost considerably below that of purchasing them on the voluntary market. Developing these offsets can provide the University with the dual benefit of helping fulfill its climate neutrality commitment while establishing itself as a pioneering institution in the field of carbon-conscious forest management.

While both the AC and IFM projects yielded strong results in terms carbon and financial benefits, it is our recommendation that the University pursue an IFM-based carbon offset strategy. We came to this conclusion because, despite the higher quantity of carbon offsets that could be generated by the AC project (figure 13) the University has no current plans to sell or develop any of its forest land. While the lack of existing intent to convert this land does not completely eliminate the possibility of developing an AC project, it brings the additionality of the project into sufficient enough question to warrant favoring other forest mitigation strategies. The IFM strategy presents no barriers to immediate execution, and requires minimal adjustment of current forest practices to generate substantial tonnes of carbon offset (figure 19).

Given that the IFM strategy is better suited for application on the Duke Forest, the question shifts to which of the carbon protocols will best serve the University's emission reduction goals. This answer is less clear-cut as CAR produces greater quantities of carbon offsets in the short term while ACR provides superior offset generation beginning in year 33 of the project (figures 19 & 20). This difference in offset distribution schedule could influence the University to side with either protocol, depending on the time sensitivity of their offset demands. However, when the cost of project execution is taken into account CAR becomes the clear choice as it maintains a higher cumulative NPV throughout the entire 100 year project period (figures 21 &22).

By executing the IMF project under the CAR protocol Duke Forest could generate 358,109 offset credits by 2061, saving the university $1.5 million in comparison to the purchase of those credits at $8 per tonne on the voluntary market. Based on the disbursement schedule modeled in our analysis, the credits gained prior to 2024 would be sufficient to offset the University's entire carbon footprint in that year and nearly 16% of the footprint in 2025. After that date the forest would continue to generate credits through 2061, offsetting progressively higher proportions of Duke's annual offset needs as the yearly demand for offsets declines (Figure 25).

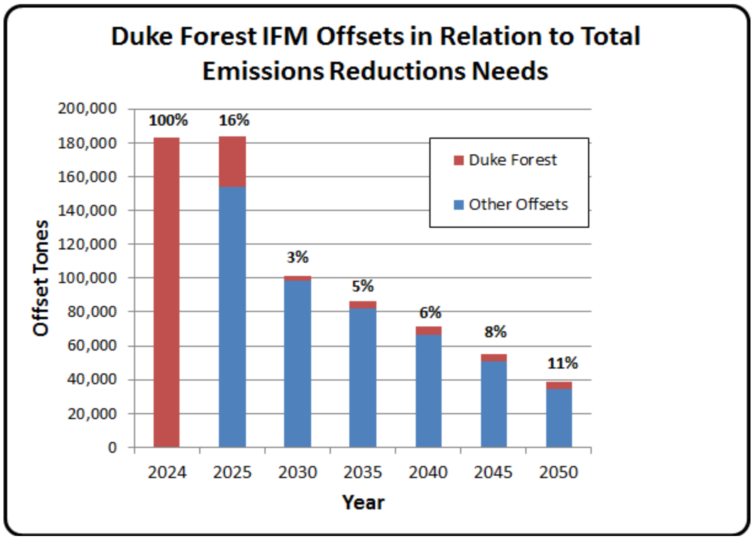


Figure 25: Duke Forest offsets generated, as percentage of total emissions reductions required in a given year

Our final calculations of offsets generated under both protocols have produced results that meet the requirements of the ACUPCC for being additional, real, permanent, and verifiable. It is our hope that this project highlights the value of land conservation and multiple-use forestry by institutions like Duke University, provides greater incentive for expanded stewardship by such institutions, and produces a model for other colleges and universities who wish to create forest carbon offsets.

The results of our work have significant implications for the development of forest offset projects in the region. Duke University is in a unique position to serve as a carbon offset buyer and developer, as well as a resource for local land trusts and other institutions seeking to use carbon sequestration as a means to meet climate change and conservation goals. Though our analysis demonstrates that the cost of land acquisition in our area is too high to justify the outright purchase of land for the development of carbon projects, there remains the potential to use carbon offset value as a tool for conservation in partnership with local land trusts. With in-house resources for the initiation and development of similar offsets projects, Duke could work with local land trusts to assess the potential carbon value of land being considered for purchase. Through execution of a comprehensive forest inventory and the development of a carbon management plan the University would create value for the land trust while Duke could benefit from offsets generated.

As carbon and other ecosystem service markets continue to grow and develop, the opportunity for graduate students to study carbon accounting and management through practical application becomes more valuable. Future students at Duke's Nicholas School of the Environment will benefit from the opportunity to apply these skills in the development of other forest carbon projects. The ecological and societal co-benefits to be gained from Duke's role in research and education, as well as through facilitation of carbon offset generation in the region, underscore the value of this dynamic approach to climate change mitigation.

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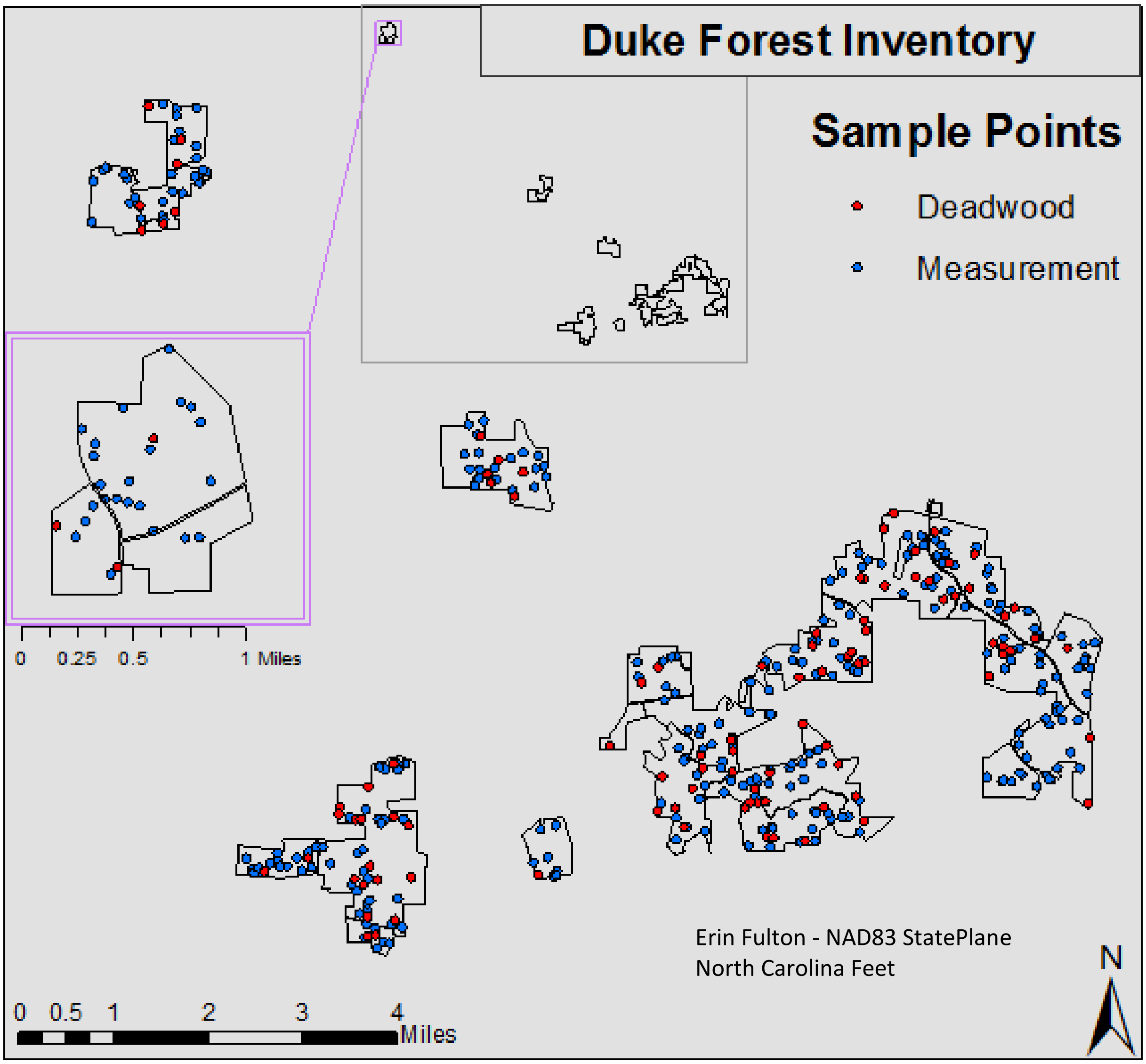
Appendices

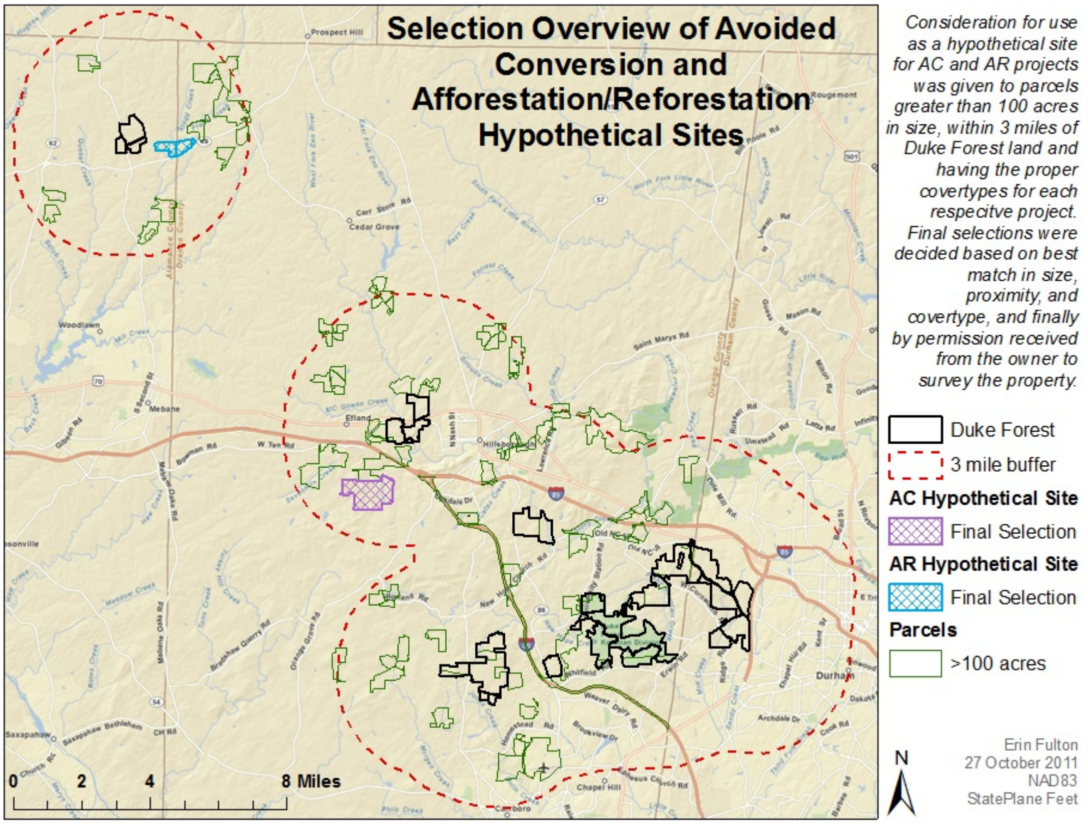
Maps

1. Duke Forest Inventory Sample points



Map 1: Locations of measurement points and additional deadwood measurement points used in the Duke Forest Inventory and this analysis.

2. Afforestation/Reforestation Hypothetical Site



Consideration for use as a hypothetical site for AC and AR projects was given to parcels greater than 100 acres in size, within 3 miles of Duke Forest land and having the proper covertypes for each respecitve project. Final selections were decided based on best match in size, proximity, and covertype, and finally by permission received from the owner to survey the property.

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27 October 2011
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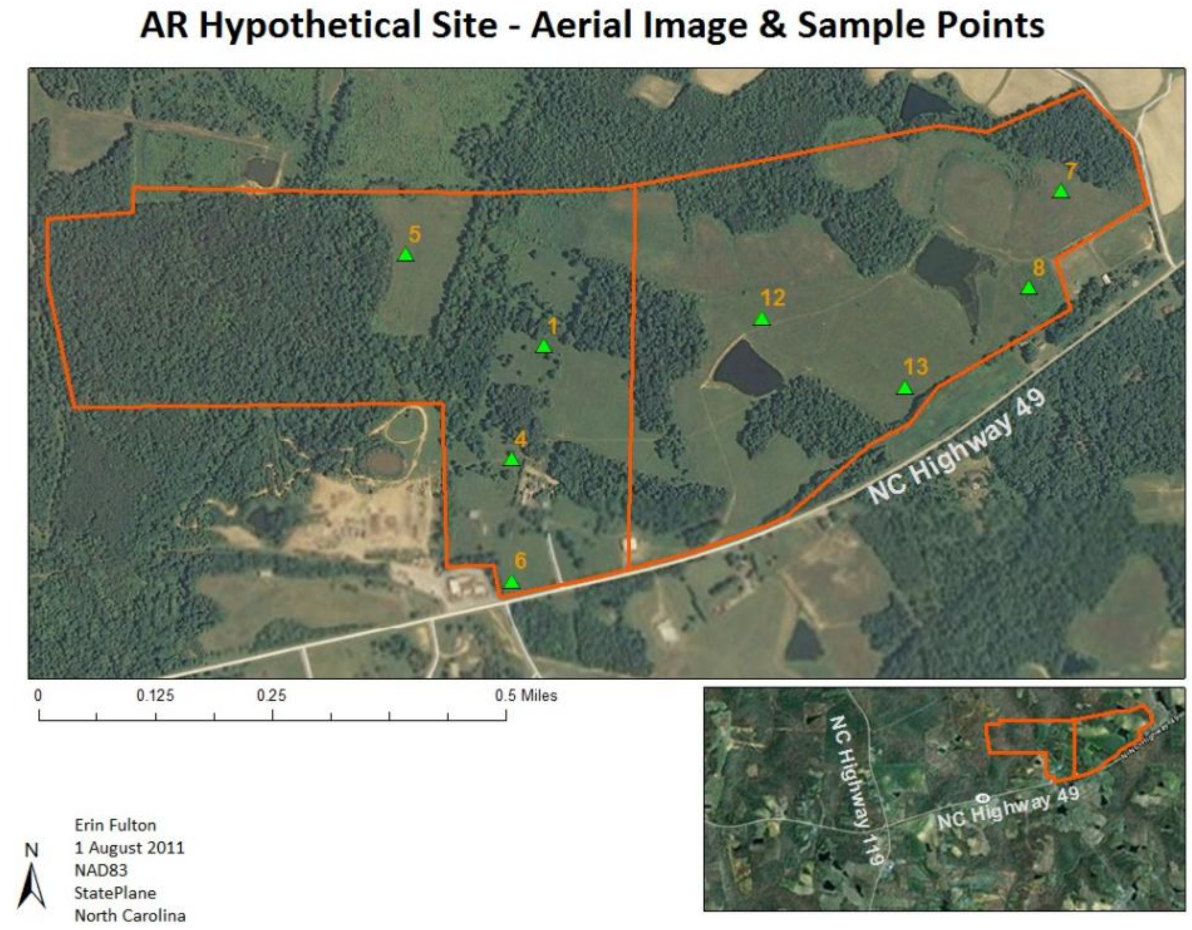
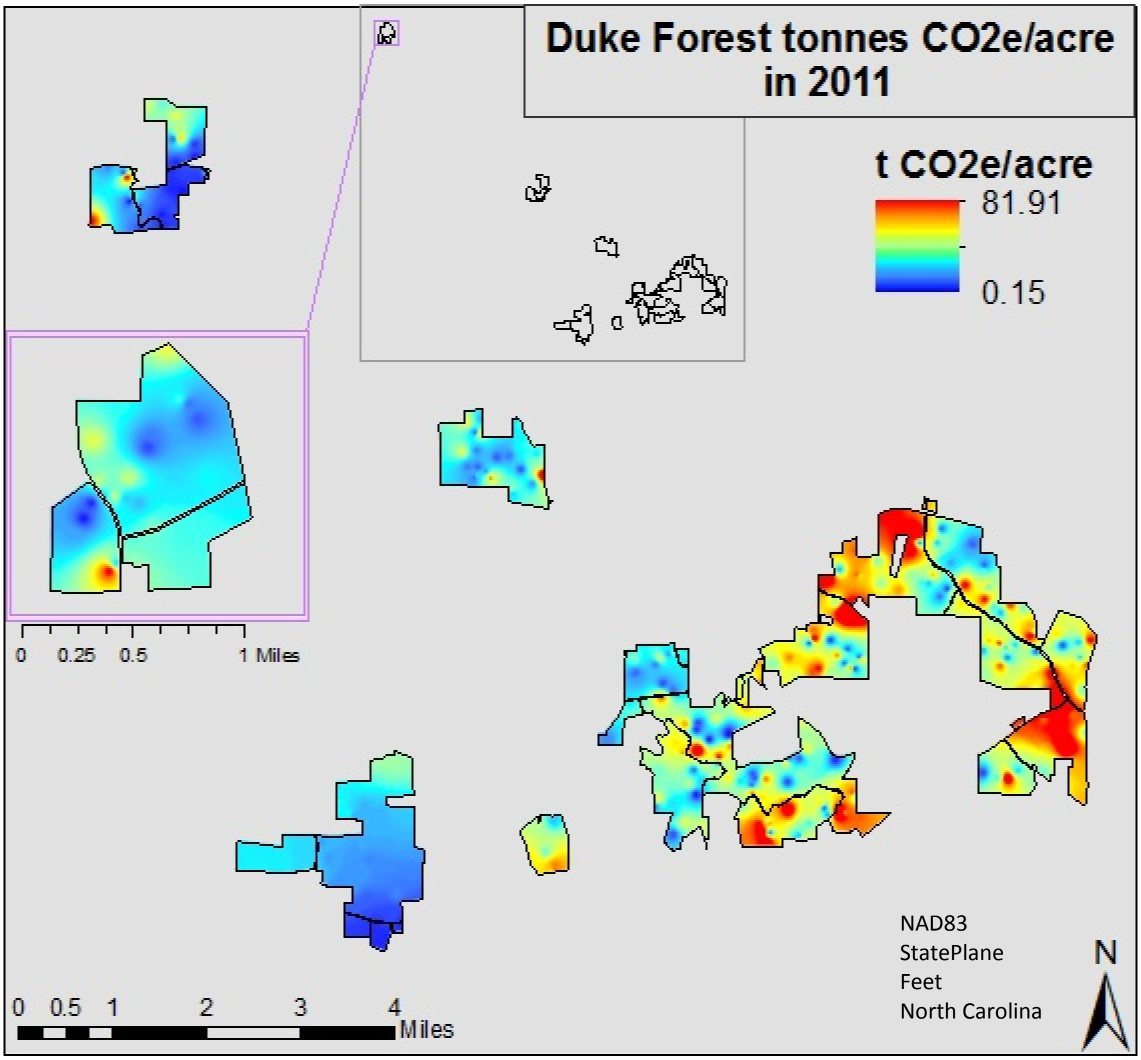
StatePlane Feet

Map 2a: Overview of selection process for hypothetical acquisition sites.



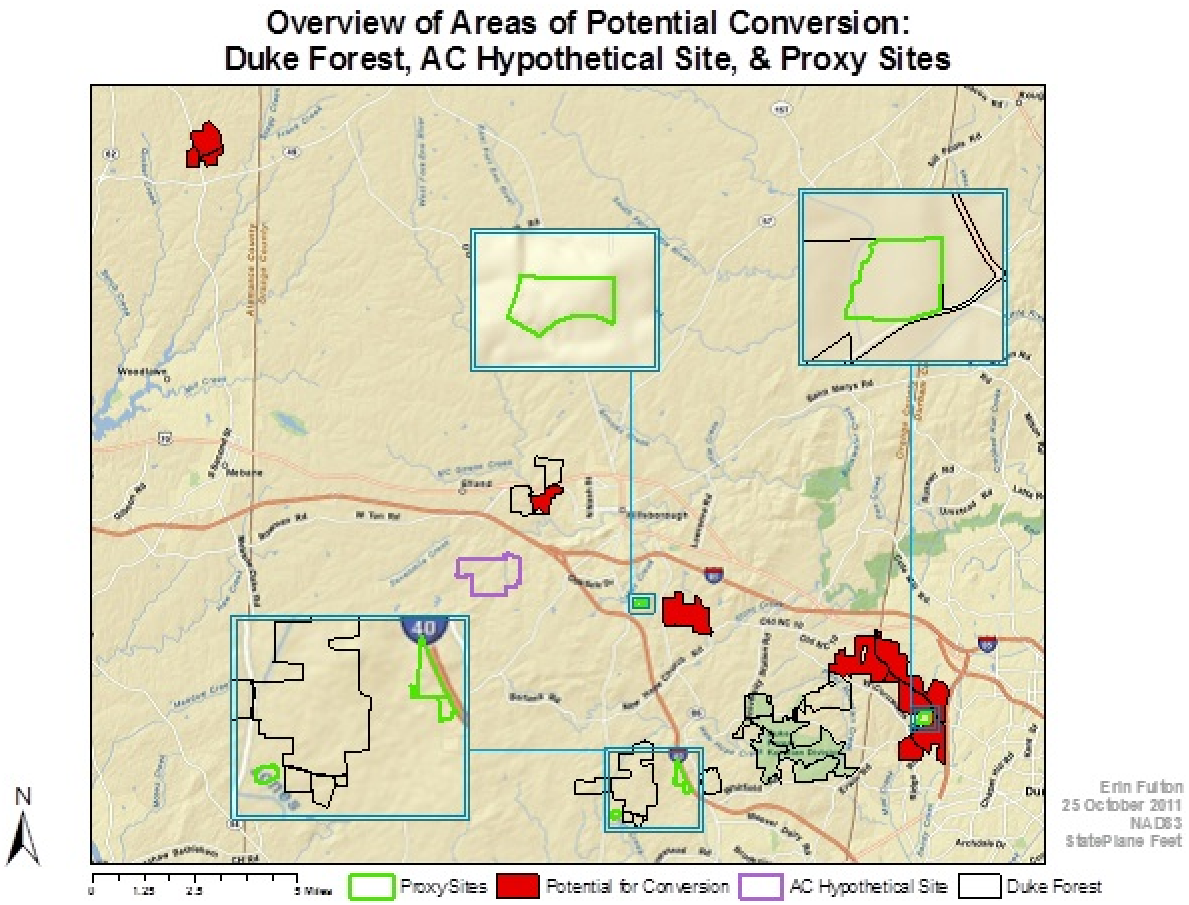
Map 2b: Aerial image of Afforestation/Reforestation hypothetical site, with sample points in light green.

3. Interpolated CO_2e per acre Across Duke Forest



Map 3: CO_2e per acre for 2011, interpolated from CO_2e values at each measurement point

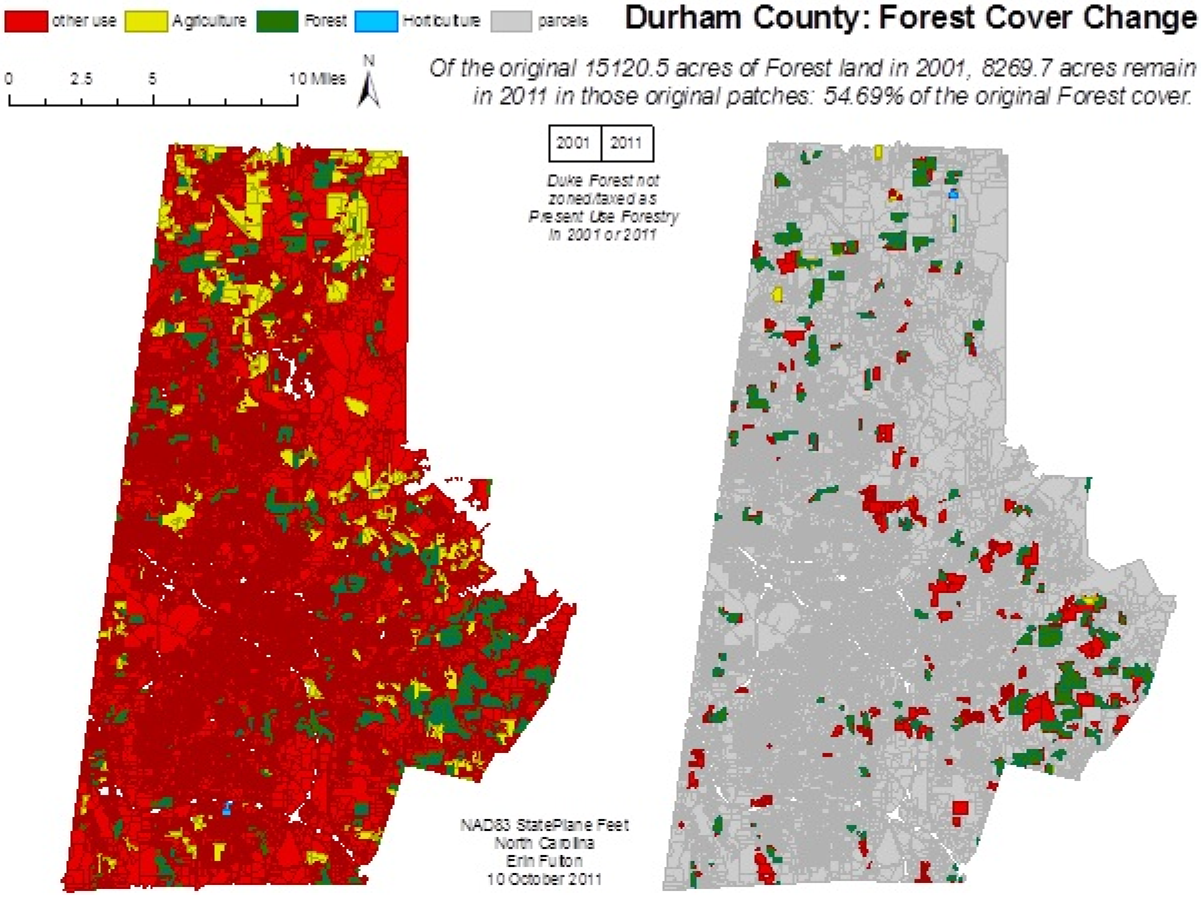
4. Avoided Conversion in Duke Forest


Overview of Areas of Potential Conversion:
Duke Forest, AC Hypothetical Site, & Proxy Sites

Erin Fulton
25 October 2011
NAD83
StatePlane Feet

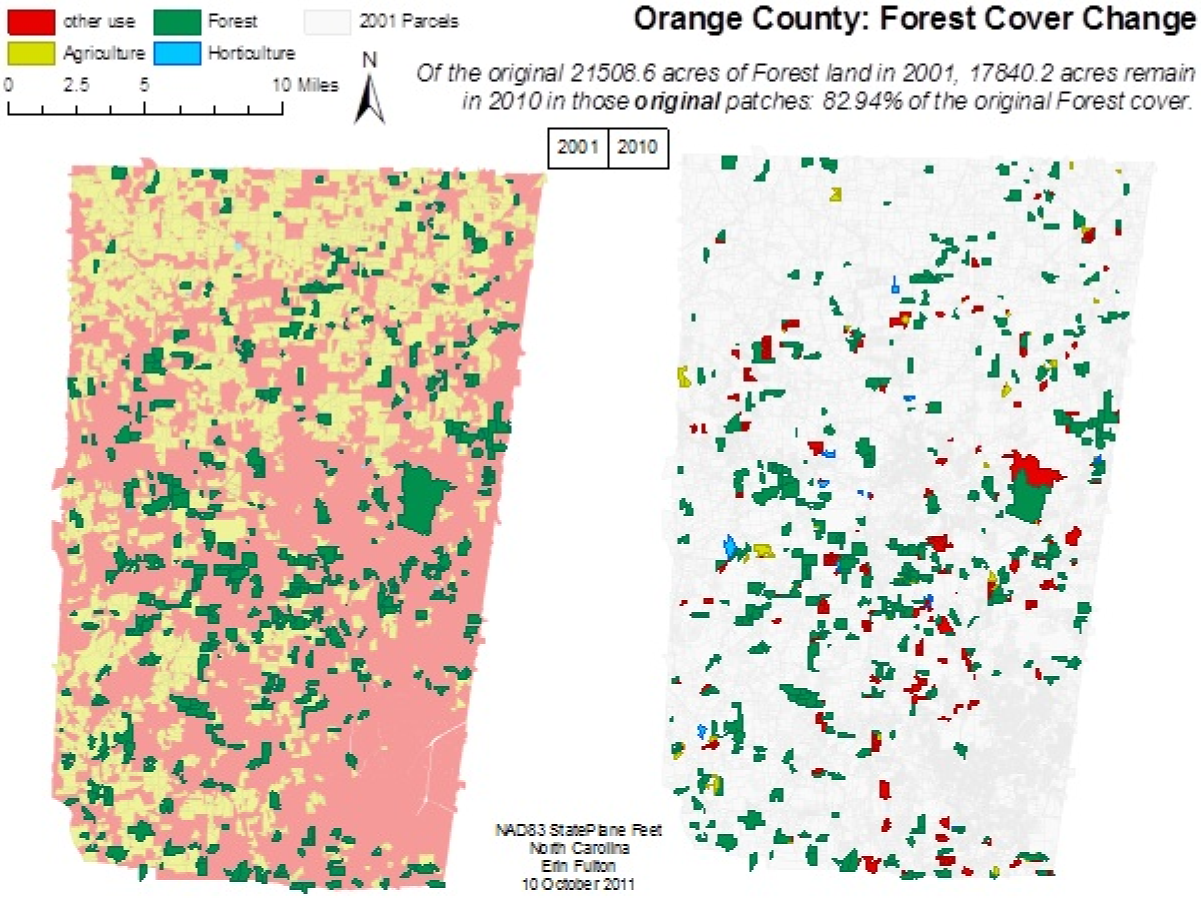
Map 4: Areas of the Duke Forest with a potential for future conversion, and proxy sites as required by American Carbon Registry

5. Durham Co. Forest Cover Change



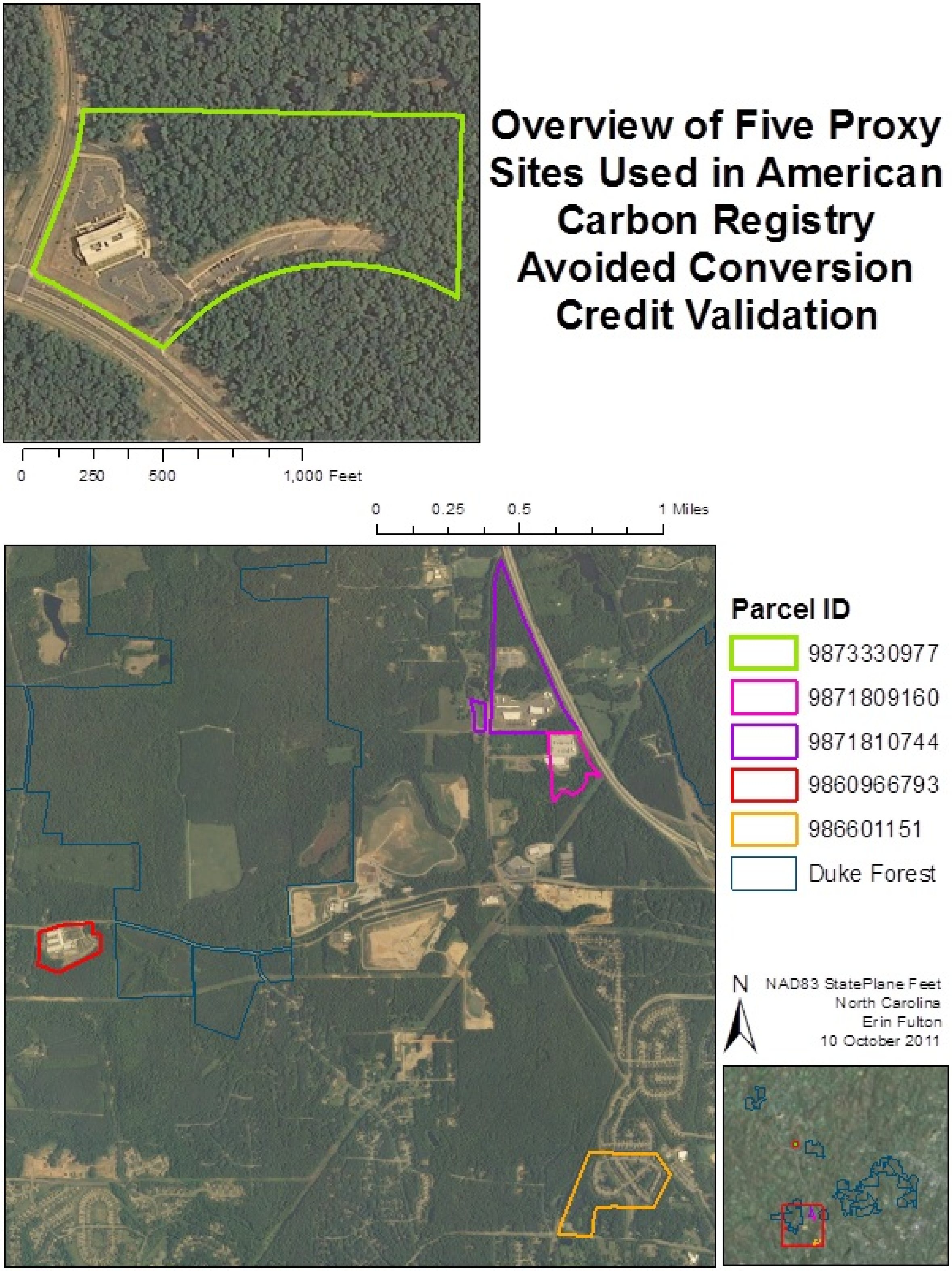
Map 5: Forest cover change between 2001 and 2011 in Durham County (based on taxed land use)

6. Orange Co. Forest Cover Change



Map 6: Forest cover change between 2001 and 2010 in Orange County (based on taxed land use)

7. Selection of Proxy Sites for Duke Forest Avoided Conversion


Overview of Five Proxy Sites Used in American Carbon Registry Avoided Conversion Credit Validation

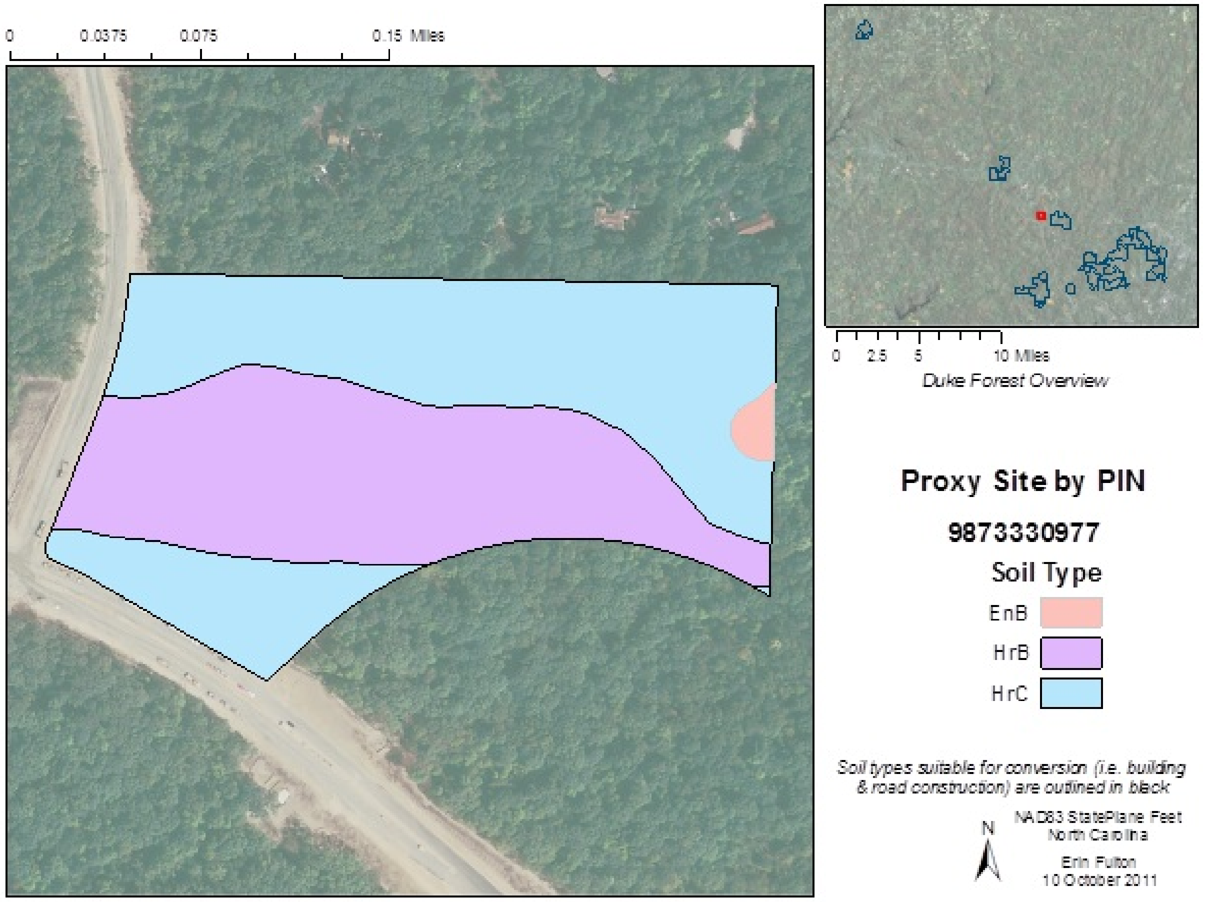
Map 7a: Overview of five proxy sites selected for use in Duke Forest Avoided Conversion projects by American Carbon Registry protocol. Sites were chosen based on close proximity to the Duke Forest, and their similarities in soil composition, elevation, and percent slope.

Soil Composition & Conversion Suitability

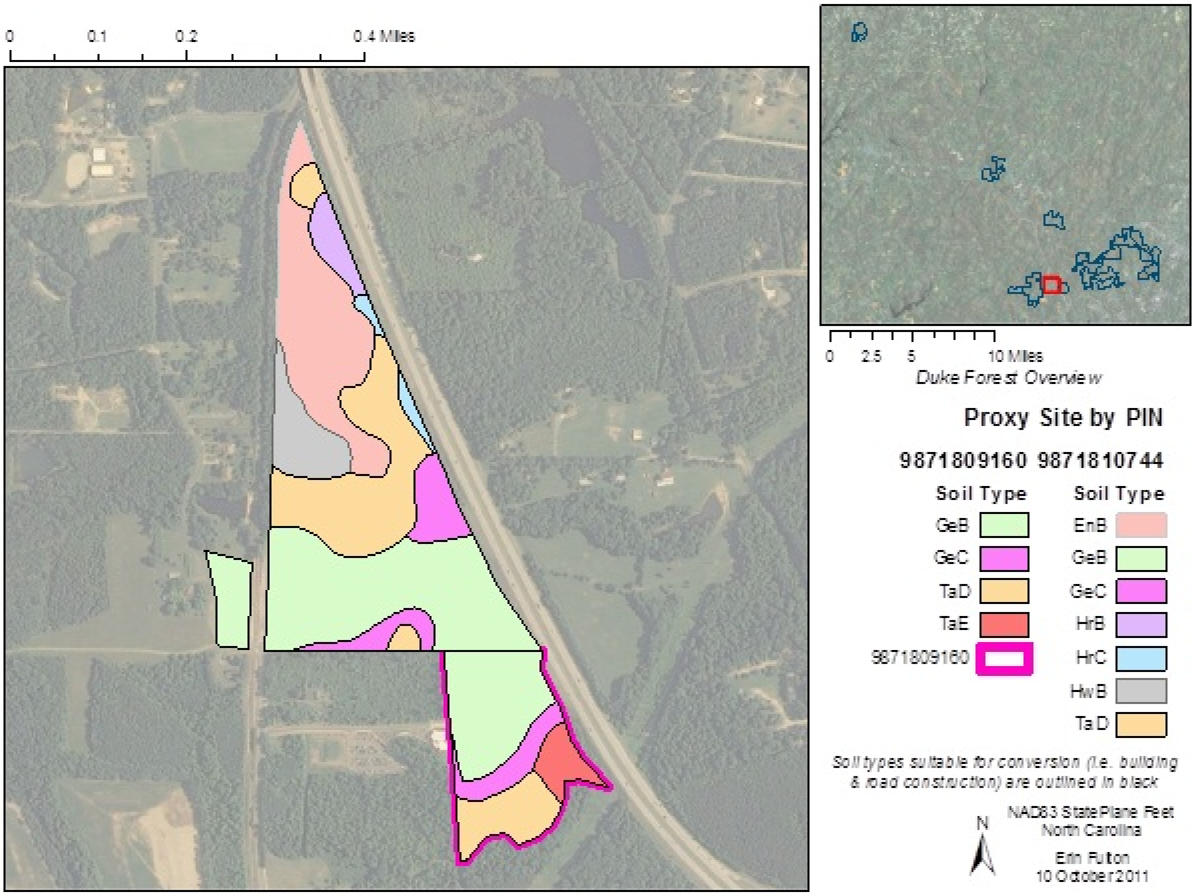
	Percent area of soil suitable* for development	Relevant Soil Types
Duke Forest	52.29%	AbB, AbC, AbC2, AdB, AdD, ApB, ApC, CbB2, CbC, CcC2, CfB, DcB, EcC3, GeB, GeC, GeD, GrB, GrC, HbB, HbC2, HrB, HrC, HsC, HwB, LbB2, LgB, MbB2, Me, MfB, MfC, PfC, TaD, VaB, VaB2, VaC2, VbC3, WbC2, WbD, WcD, WmD
AC Hypothetical	67.06%	GeB, GeC, HrB, HrC, HwB, Lg, TaD, WxD
PIN: 9873330977	98.88%	HrB, HrC
PIN: 9860966793	26.80%	HrB, HrC
PIN: 986601151	25.90%	ApC, HrB, GeC, HwB
PIN: 9871810744	77.95%	GeB, GeC, HrB, HrC, TaD
PIN: 9871809160	87.82%	GeB, GeC, TaD, TaE

** Includes 'Not limited' and 'Somewhat limited' ratings from USDA Natural Resources Conservation Service Soil Survey*

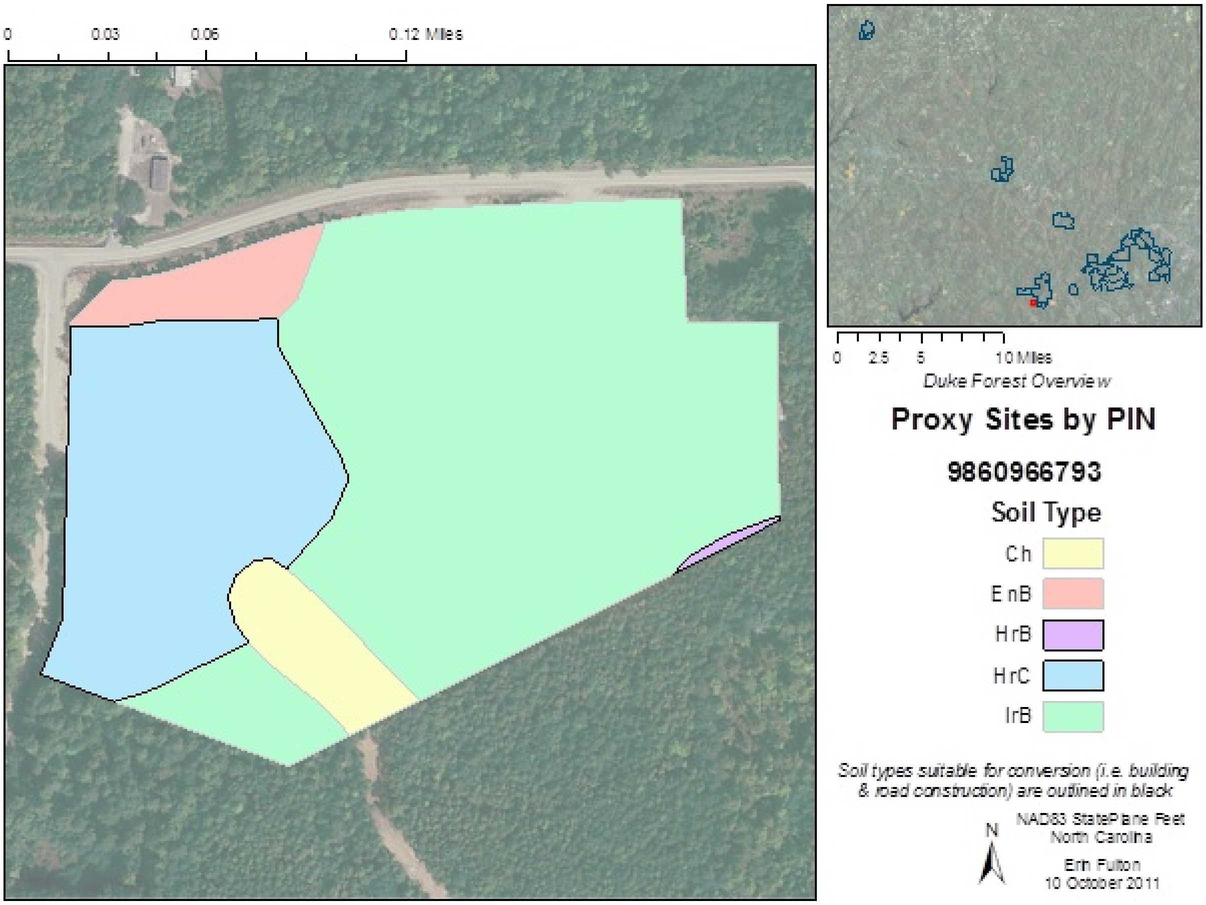
Table 7: Table comparing the percent area of soils suitable for conversion and development for Avoided Conversion projects



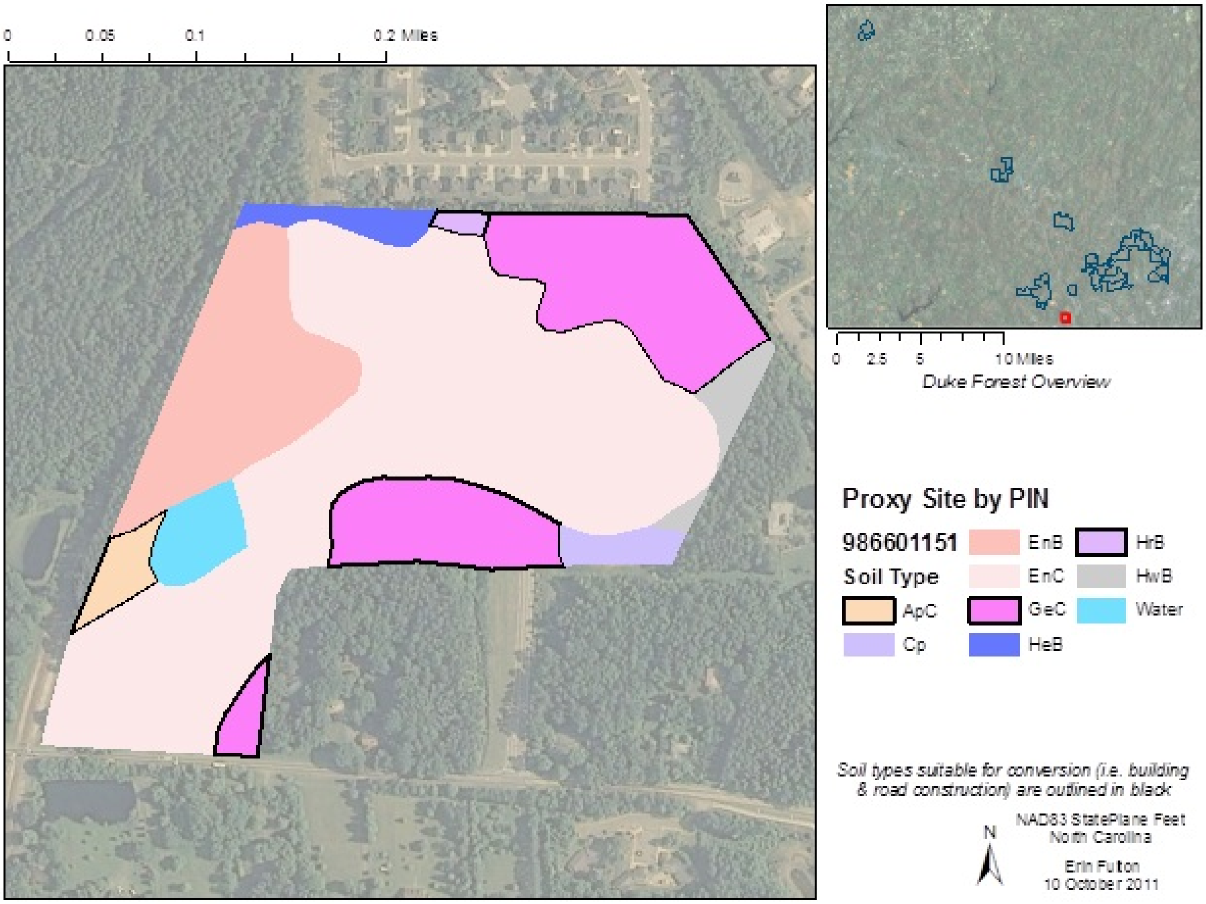
Map 7b: Soil composition of a proxy site, with types suitable for conversion and development outlined in black.



Map 7c: Soil composition of a proxy site, with types suitable for conversion and development outlined in black.

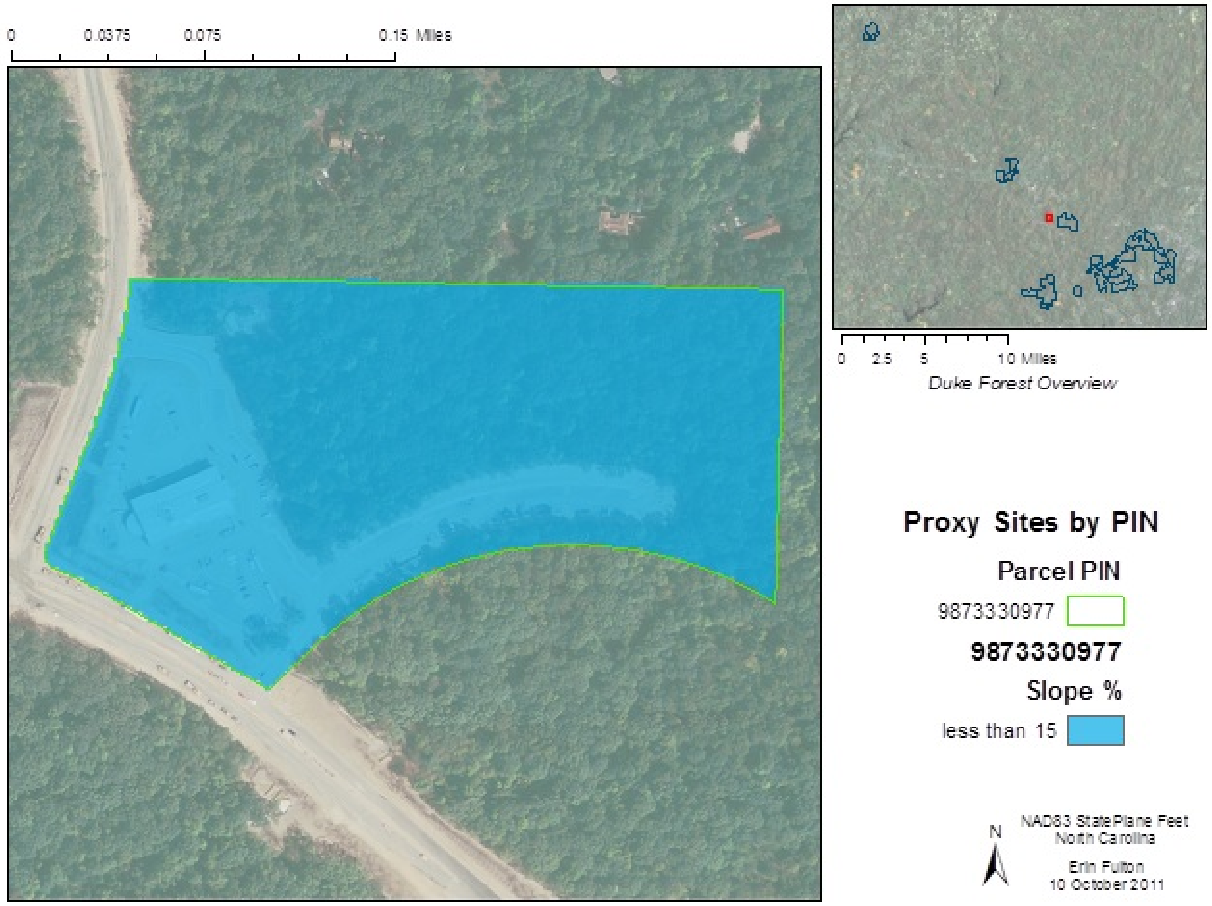


Map 7d: Soil composition of a proxy site, with types suitable for conversion and development outlined in black.

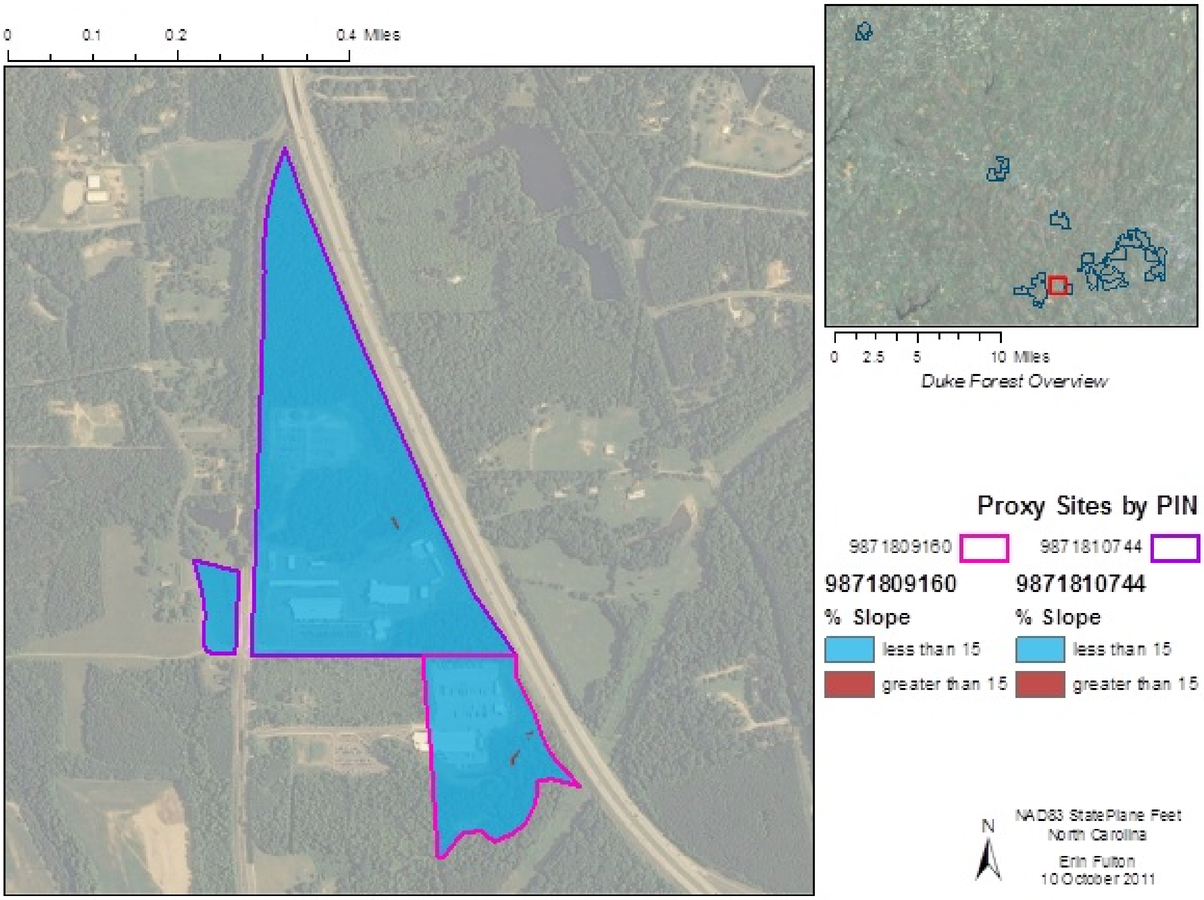


Map 7e: Soil composition of a proxy site, with types suitable for conversion and development outlined in black.

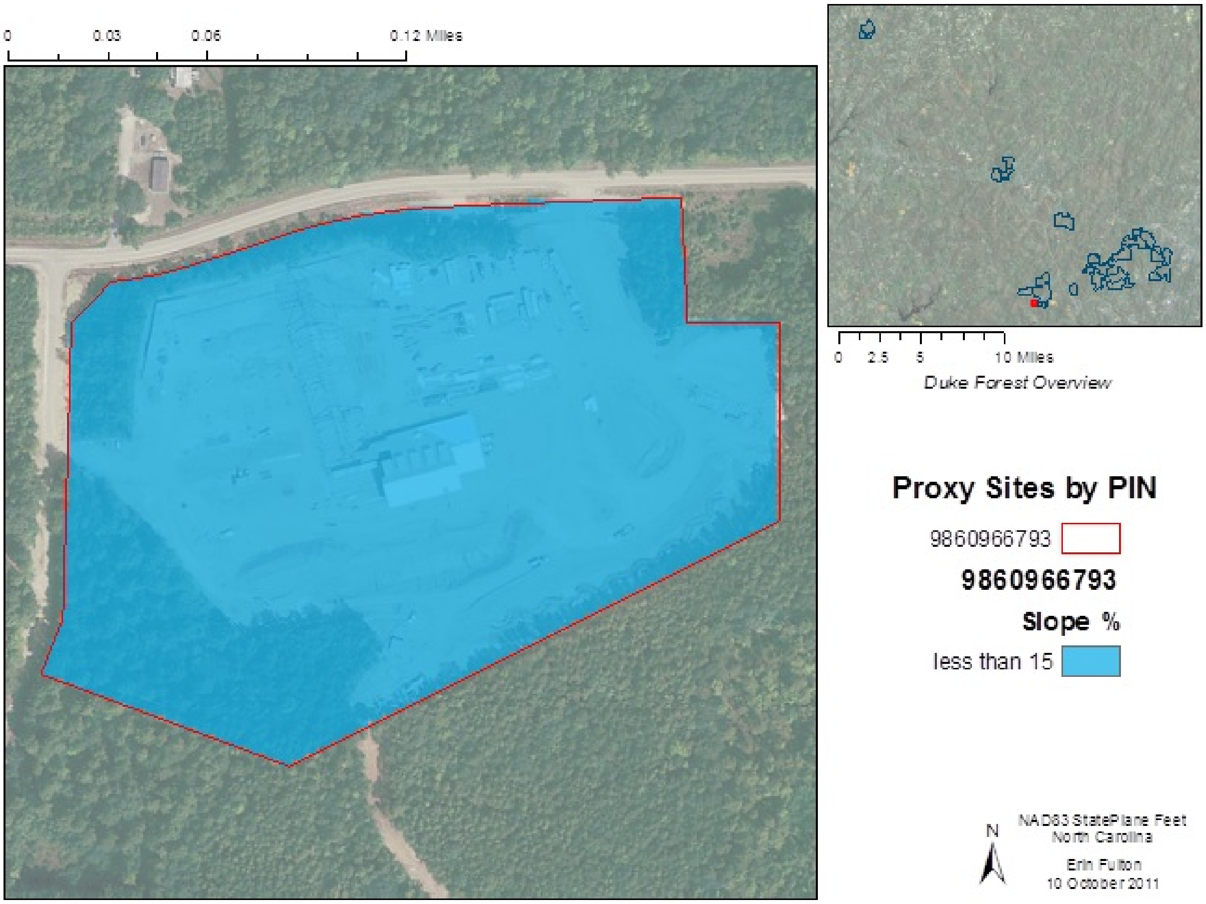
Percent Slope



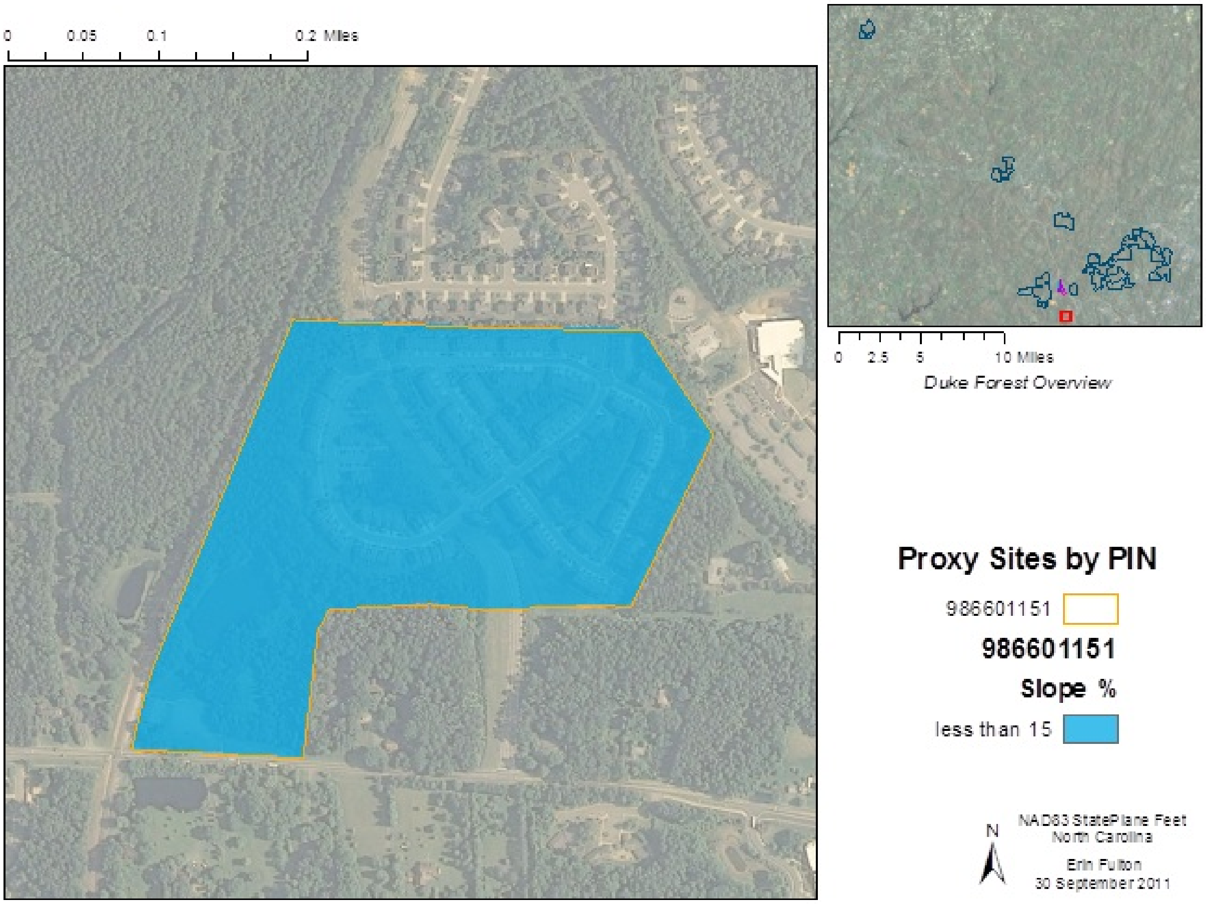
Map 7f: Degree of slope across the proxy site. To be accepted as a proxy, the majority of the site must be less than 15% slope.



Map 7g: Degree of slope across the proxy site. To be accepted as a proxy, the majority of the site must be less than 15% slope.



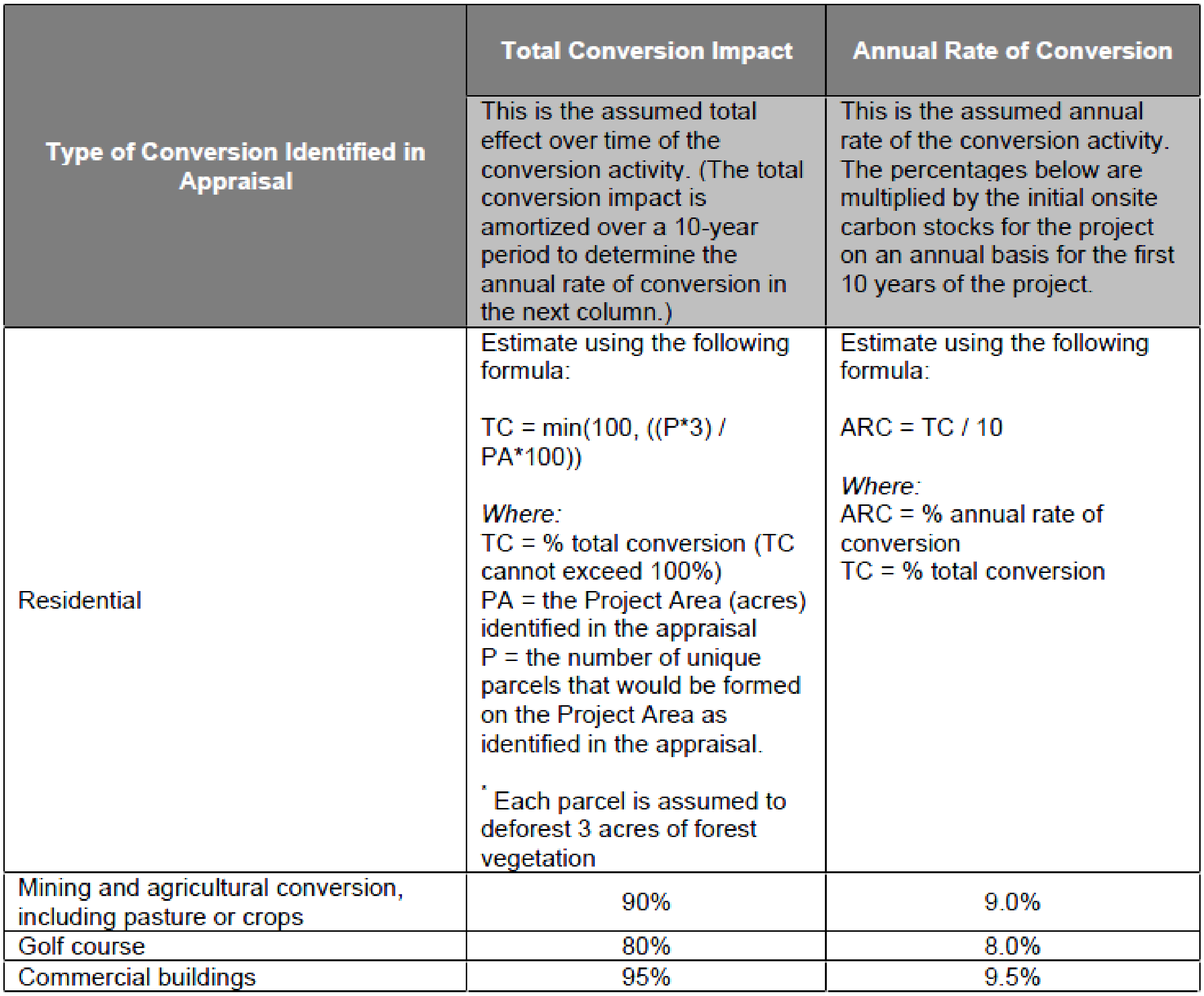
Map 7h: Degree of slope across the proxy site. To be accepted as a proxy, the majority of the site must be less than 15% slope.



Map 7i: Degree of slope across the proxy site. To be accepted as a proxy, the majority of the site must be less than 15% slope.

Figures & Tables

1. CAR Conversion rates for AC projects



Type of Conversion Identified in Appraisal	Total Conversion Impact	Annual Rate of Conversion
	This is the assumed total effect over time of the conversion activity. (The total conversion impact is amortized over a 10-year period to determine the annual rate of conversion in the next column.)	This is the assumed annual rate of the conversion activity. The percentages below are multiplied by the initial onsite carbon stocks for the project on an annual basis for the first 10 years of the project.
Residential	Estimate using the following formula: TC = min(100, ((P*3) / PA*100)) *Where:* TC = % total conversion (TC cannot exceed 100%) PA = the Project Area (acres) identified in the appraisal P = the number of unique parcels that would be formed on the Project Area as identified in the appraisal. * Each parcel is assumed to deforest 3 acres of forest vegetation	Estimate using the following formula: ARC = TC / 10 *Where:* ARC = % annual rate of conversion TC = % total conversion
Mining and agricultural conversion, including pasture or crops	90%	9.0%
Golf course	80%	8.0%
Commercial buildings	95%	9.5%

Figure 2: Default Avoided Conversion Rates for CAR projects (CAR Forest Project Protocol Version 3.2)

2. CAR 100 year decay standard for wood products

Wood Product Class	A	B	C	D	E	F	G
	Softwood Lumber	Hardwood Lumber	Softwood Plywood	Oriented Strandboard	Non-Structural Panels	Miscellaneous Products	Paper
% in each class	(X%)	(X%)	(X%)	(X%)	(X%)	(X%)	(X%)
Metric tons C in each class	Ax	Bx	Cx	Dx	Ex	Fx	Gx
100-year average storage factor, in-use (S)	0.463	0.25	0.484	0.582	0.38	0.176	0.058
Average C stored in in-use wood products (metric tons)	AxS	BxS	CxS	DxS	ExS	FxS	GxS

Figure 3a: Worksheet to estimate long-term carbon storage in in-use wood products (CAR Forest Project Protocol Version 3.2)

Wood Product Class	A	B	C	D	E	F	G
	Softwood Lumber	Hardwood Lumber	Softwood Plywood	Oriented Strandboard	Non-Structural Panels	Miscellaneous Products	Paper
% in each class	(X%)	(X%)	(X%)	(X%)	(X%)	(X%)	(X%)
Metric tons C in each class	Ax	Bx	Cx	Dx	Ex	Fx	Gx
100-year average storage factor, landfills (S)	0.298	0.414	0.287	0.233	0.344	0.454	0.178
Average C stored in landfills (metric tons)	AxS	BxS	CxS	DxS	ExS	FxS	GxS

Figure 3b: Worksheet to estimate long-term carbon storage in wood products in landfills (CAR Forest Project Protocol Version 3.2)

3. Mortgage Cost for Acquisition of Hypothetical Sites

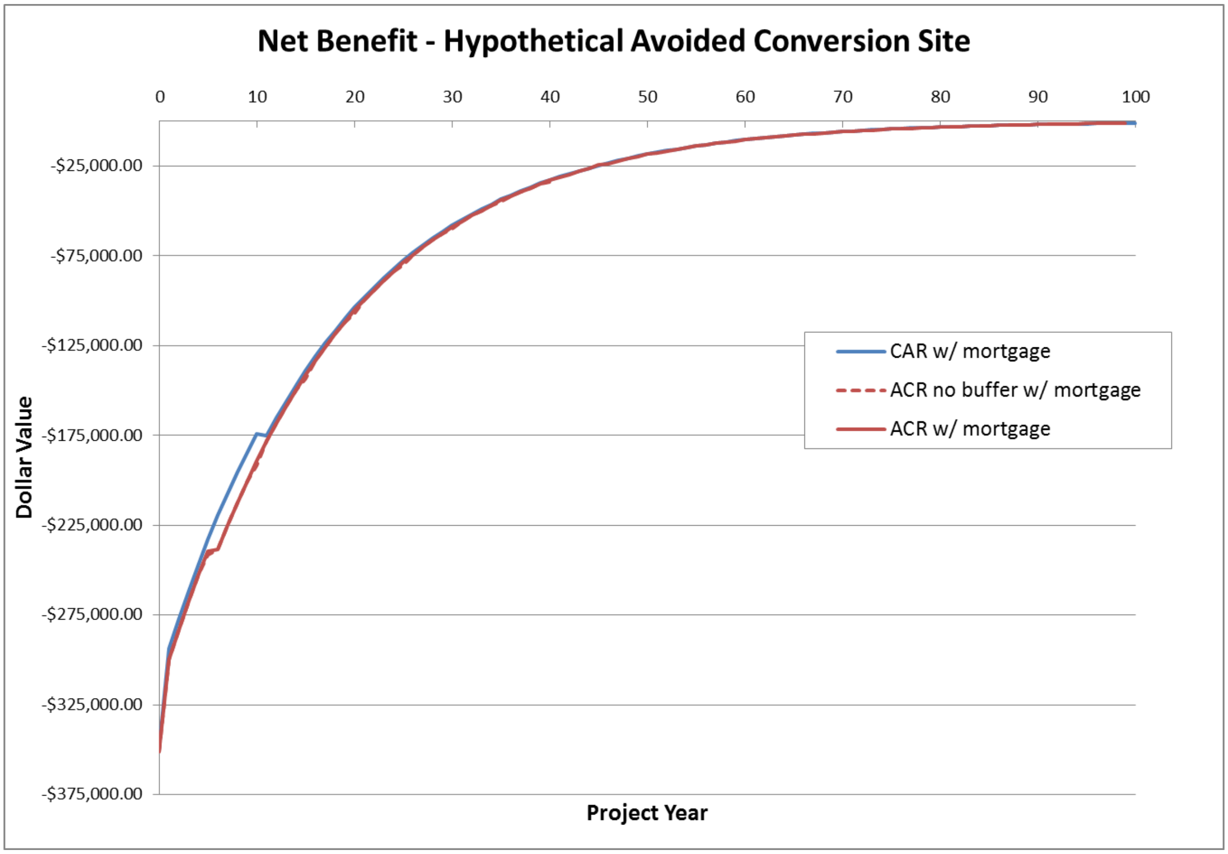


Figure 3a: Net financial benefit of carbon credits produced on the hypothetical avoided conversion project site when also taking mortgage payment into account (constant price level)

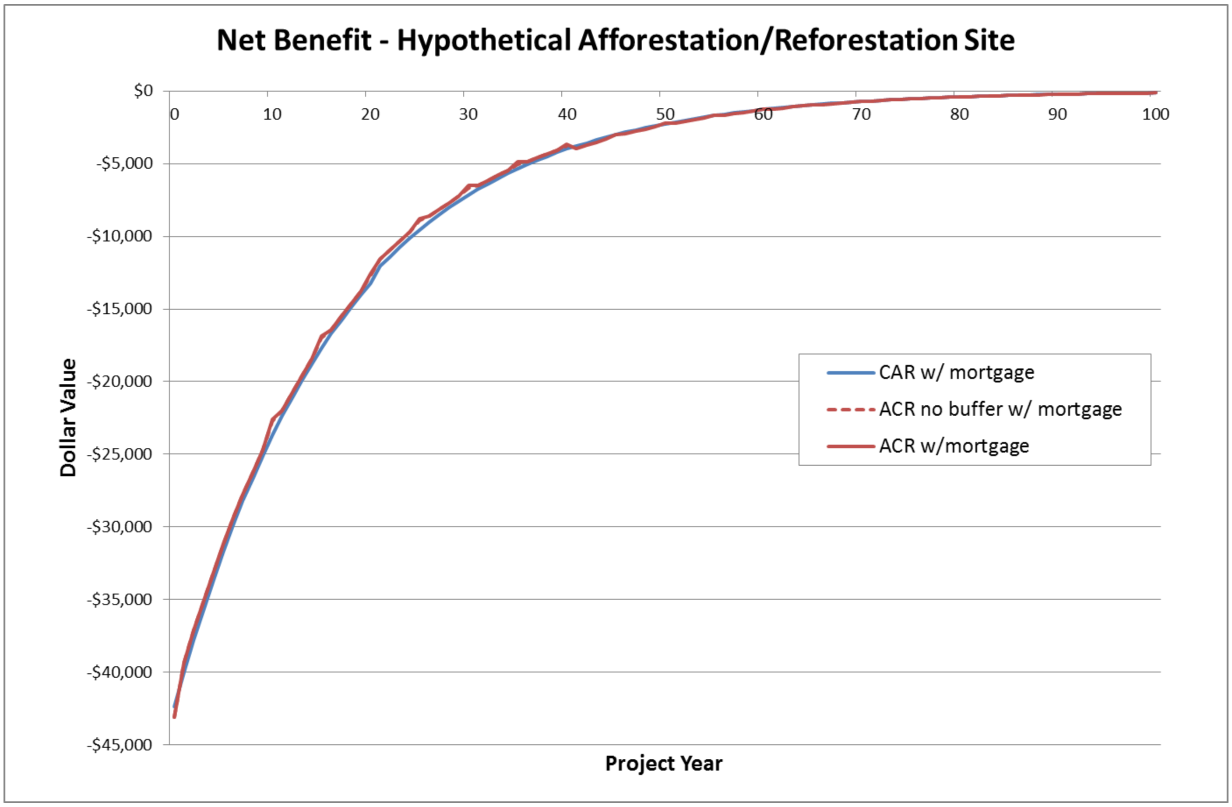


Figure 3b: Net financial benefit of carbon credits produced on the hypothetical afforestation/ reforestation project site when also taking mortgage payment into account (constant price level)

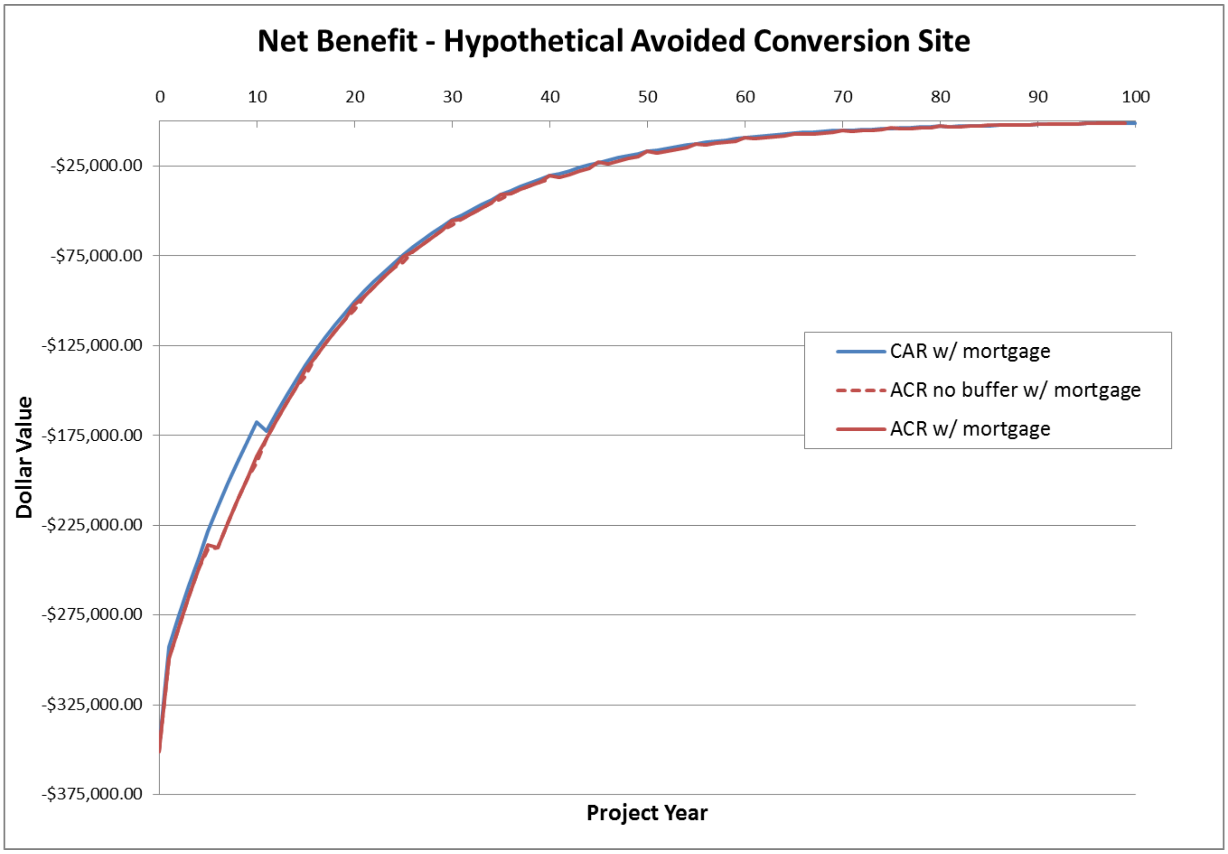


Figure 3c: Net financial benefit of carbon credits produced on the hypothetical avoided conversion project site when also taking mortgage payment into account (3% annual price increase)

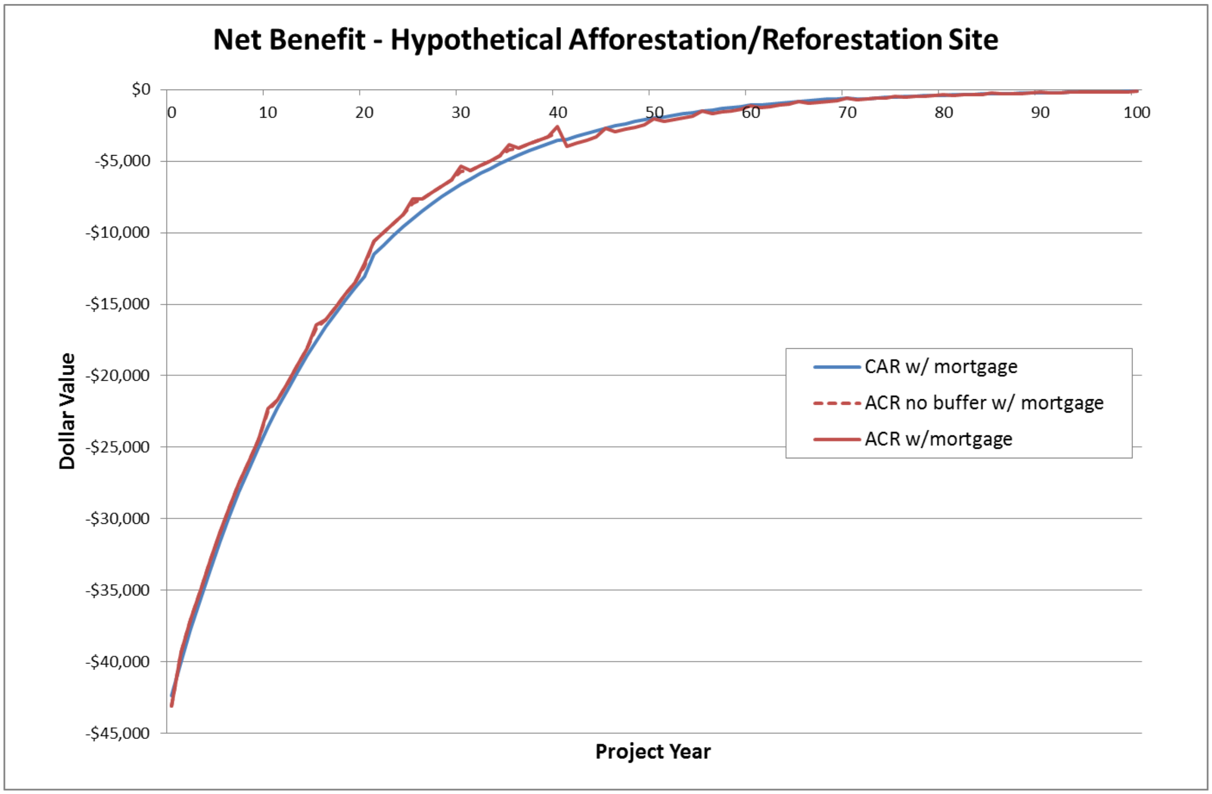


Figure 3d: Net financial benefit of carbon credits produced on the hypothetical afforestation/ reforestation project site when also taking mortgage payment into account (3% annual price increase)

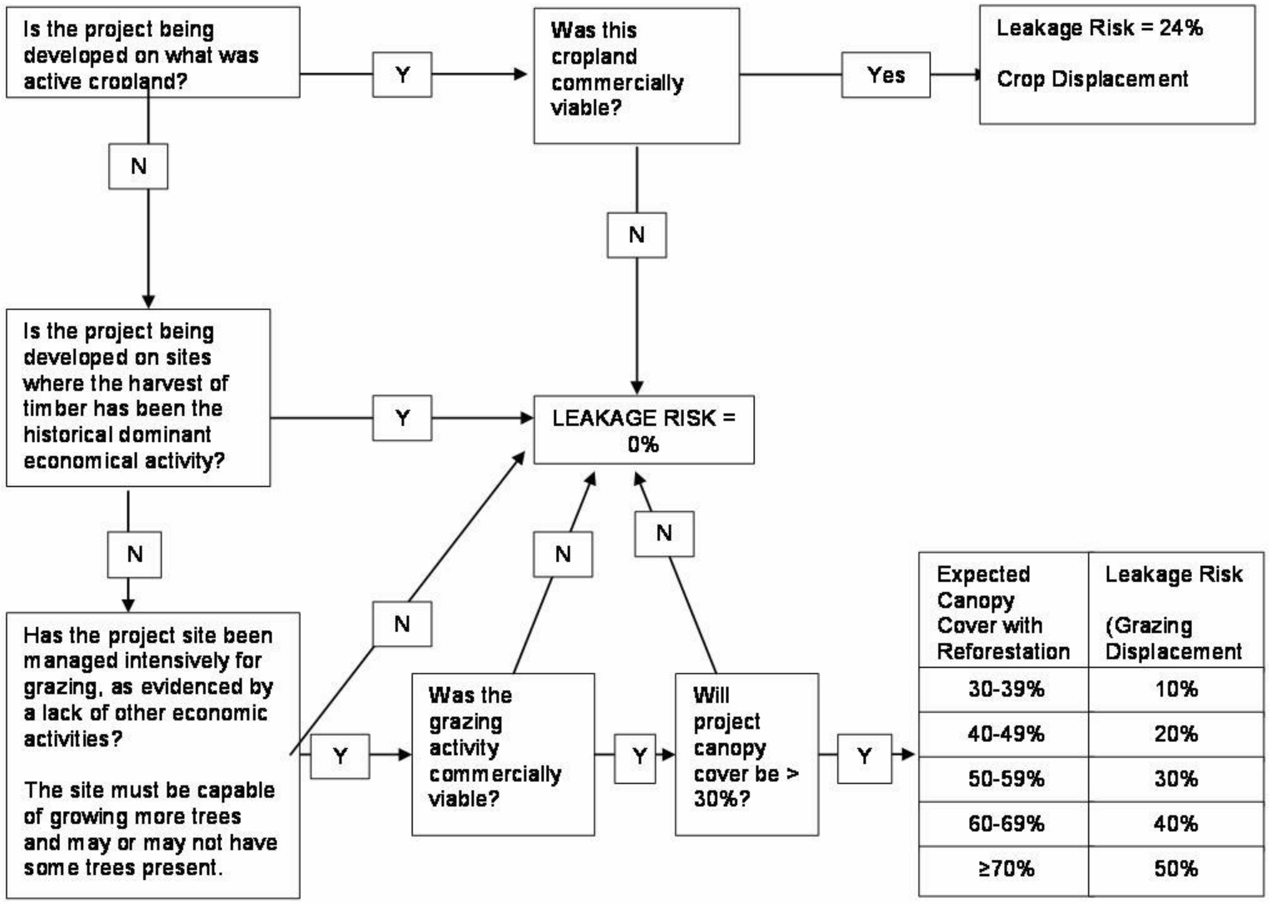
Hypothetical Site - Afforestation/Reforestation				
Acres	**Full land & Building Value***	**30 yr Mortgage Interest Rate**	**Monthly Payment****	**$$ in Interest over life of loan**
215.57	$535,926.00	4.153%	$3,418.91	$402,266
*Based on Alamance County Tax Data (2009) Land Present-Use Value				
**Includes taxes, insurace, and PMI				
30 year mortgage interests rates found online at Yahoo Real Estate				
http://realestate.yahoo.com/loans				

Figure 3e: Financial table for Afforestation/Reforestation Hypothetical Site mortgage

Hypothetical Site - Avoided Conversion				
Acres	**Full Land & Building Value***	**30 yr Mortgage Interest Rate**	**Monthly Payment****	**$$ in Interest over life of loan**
700.68	$4,484,382.00	4.153%	$28,607.87	$3,365,979
*Based on Orange County Tax Data (2010) Valuation				
**Includes taxes, insurace, and PMI				
30 year mortgage interests rates found online at Yahoo Real Estate				
http://realestate.yahoo.com/loans				

Figure 3f: Financial table for Avoided Conversion Hypothetical Site mortgage

4. CAR worksheet for reversal risk rating



Assumptions:

•Leakage risk for cropland displacement is based on a default rate developed by Murray et al (*Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture*, USEPA, 2005).

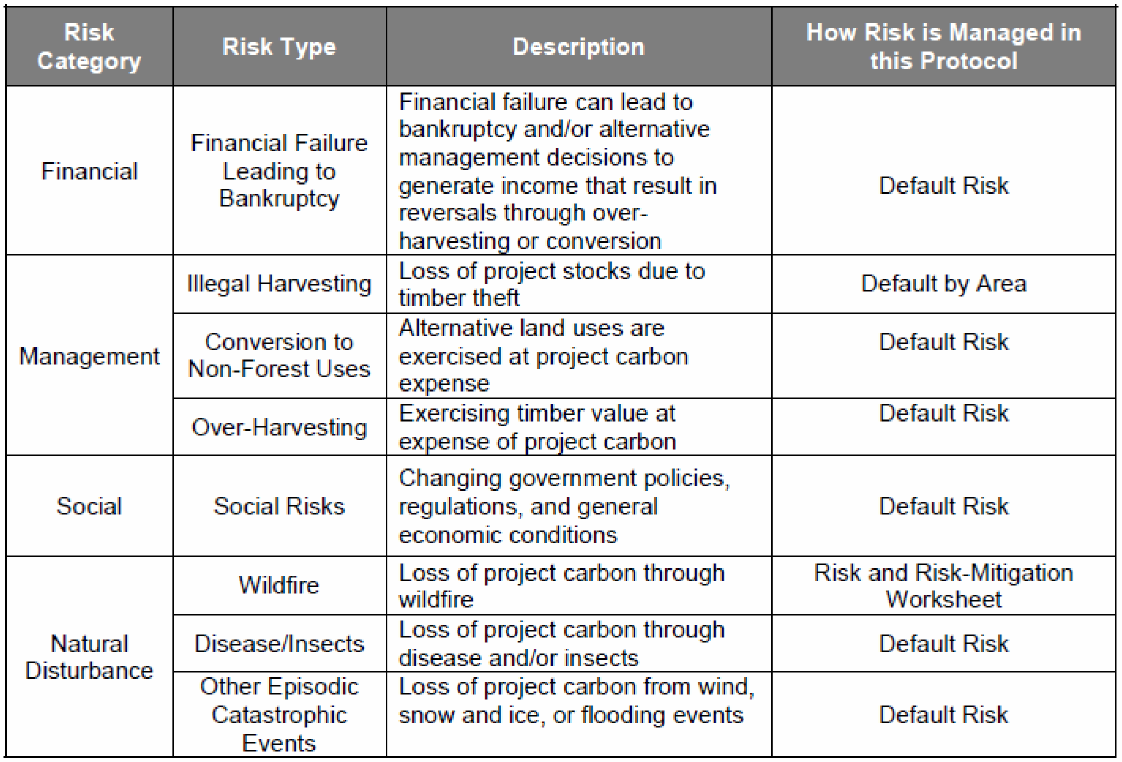
•Grazing activity will not be affected if canopy cover associated with reforestation remains below 30%.

•Grazing activity is displaced proportionally with canopy cover increases above 30%.

•Demand for crops is inelastic.

•"Commercially viable" is defined here as profitable either without subsidies or with a reliable, long-termed sustained form of subsidies. The assessment of commercially viable shall be determined by analysis of comparable practices within the assessment area on comparable conditions (slope, soils, access to markets, etc.). For grazing, if the level of grazing activity has been equal to, or less than, .5 Animal Unit Months (AUMs) per acre, the grazing activity is not commercially viable.

Figure 4a: Flowchart showing for assessing risk for activity shifting leakage (CAR Forest Project Protocol Version 3.2)



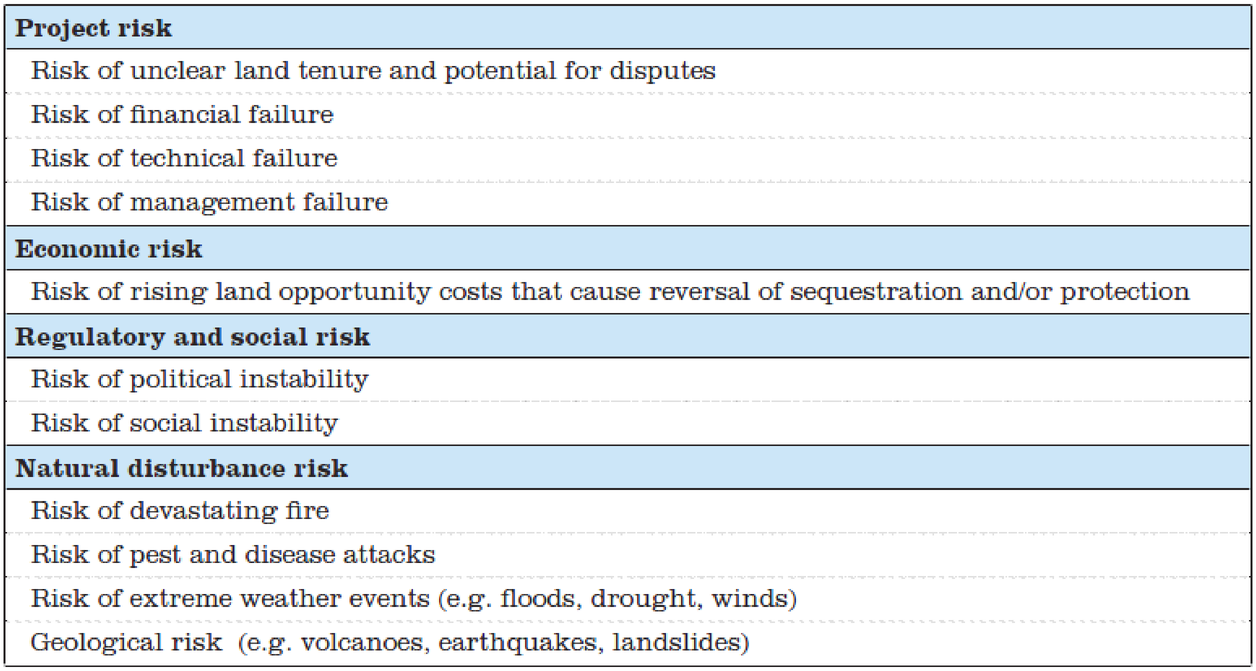
Risk Category	Risk Type	Description	How Risk is Managed in this Protocol
Financial	Financial Failure Leading to Bankruptcy	Financial failure can lead to bankruptcy and/or alternative management decisions to generate income that result in reversals through over-harvesting or conversion	Default Risk
Management	Illegal Harvesting	Loss of project stocks due to timber theft	Default by Area
	Conversion to Non-Forest Uses	Alternative land uses are exercised at project carbon expense	Default Risk
	Over-Harvesting	Exercising timber value at expense of project carbon	Default Risk
Social	Social Risks	Changing government policies, regulations, and general economic conditions	Default Risk
Natural Disturbance	Wildfire	Loss of project carbon through wildfire	Risk and Risk-Mitigation Worksheet
	Disease/Insects	Loss of project carbon through disease and/or insects	Default Risk
	Other Episodic Catastrophic Events	Loss of project carbon from wind, snow and ice, or flooding events	Default Risk

Figure 4b: Types of reversal risks associated with forest carbon projects (Table from CAR Forest Project Protocol Version 3.2, Appendix D)

Identification of Risk	Contribution to Reversal Risk Rating	
Default Financial Risk	**5%** (PIA only)	**1%** (PIA w/ Conservation Easement or Deed Restriction or on public lands)
Management Risk II (Illegal Removals of Forest Biomass)	**0%** (U.S. Default harvesting risk)	
Management Risk II (Conversion of Project Area to Alternative Land Uses)	**2%** (w/o Qualified Conservation Easement or Deed Restriction)	**0%** (w/ Qualified Conservation Easement or Deed Restriction explicitly encumbering all development rights)
Management Risk III (Over-Harvesting)	**2%** (w/o Qualified Conservation Easement or Deed Restriction)	**0%** (w/ Qualified Conservation Easement or Deed Restriction explicitly encumbering all development rights)
Social Risk	**2%** (U.S. Default Social Risk)	
Natural Disturbance Risk II (Disease or Insect Outbreak)	**3%** (Default Risk Contribution from Disease or Insect Outbreak)	
Natural Disturbance Risk III (Other Episodic Catastrophic Events)	**3%** (Default risk Contribution from Other Catastrophic Events)	

Figure 4c: Contribution to overall reversal risk rating by each risk type (Table compiled from CAR Forest Project Protocol Version 3.2, Appendix D)

5. ACR categories for reversal risk rating



Project risk
Risk of unclear land tenure and potential for disputes
Risk of financial failure
Risk of technical failure
Risk of management failure
Economic risk
Risk of rising land opportunity costs that cause reversal of sequestration and/or protection
Regulatory and social risk
Risk of political instability
Risk of social instability
Natural disturbance risk
Risk of devastating fire
Risk of pest and disease attacks
Risk of extreme weather events (e.g. floods, drought, winds)
Geological risk (e.g. volcanoes, earthquakes, landslides)

Figure 5: Types of reversal risks associated with forest carbon projects under American Carbon Registry standards (Table from Voluntary Carbon Standard: Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination, 2008)