Title

Characterization of the greenhouse gas emissions associated with conversion of forest to residential Development the Puget Sound, Washington.

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Publication Date
2010

WEST COAST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

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CHARACTERIZATION OF THE GREENHOUSE GAS EMISSIONS ASSOCIATED WITH CONVERSION OF FOREST TO RESIDENTIAL DEVELOPMENT IN THE PUGET SOUND REGION OF WASHINGTON

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Winrock International

DOE Contract No.: DE-FC26-05NT42593

Contract Period: October 1, 2005 - May 11, 2011

Table of Contents

List of Figures

List of Tables

Abstract

The conversion of forest lands to non-forest uses, especially conversion to residential development, is of significant concern to the Washington State Legislature and Washington Department of Natural Resources. As a result of a rapidly growing population, the risk of conversion is especially high in Puget Sound's watersheds. The objective of this study was to develop a regional characterization study for Washington State that defines residential development as it is implemented in the Puget Sound region to estimate the emissions associated with conversion of forested land for residential development. Net emissions in King County ranged from 70 t CO_2-e to 177 t CO_2-e per development. In Pierce County net emissions ranged from 412 t CO_2-e to 1,418 t CO_2-e per development. In Snohomish County development resulted in net emissions for some subdivisions while other subdivisions showed net sequestration (negative net emissions); Net emissions ranged from 12 t CO_2-e to 670 t CO_2-e, and net sequestration ranged from 8 t CO_2-e to 335 t CO_2-e. While original forest cover pre-development varied across the developments, a relationship existed between total area of development and percentage of original forest cover remaining after development. Forest cover cleared during development varied from 57-100% in areas of less than 16 acres but averaged just 35% for development areas that exceed 16 acres. This relationship could form the basis of a future performance standard for development projects such that if a developer exceeded the defined area of forest retained by 10% or more then the carbon stocks of the retained forest would be creditable. For example, the resulting available offsets range from approximately 136 tons for a 10 acre development to almost 3,000 tons for a 60 acre development in an area with forest carbon stocks of 100 t C/ac.

Executive Summary

Introduction

The conversion of forest lands to non-forest uses, especially conversion to residential development, is of significant concern to the Washington State Legislature and Washington Department of Natural Resources.

As a result of a rapidly growing population, the risk of conversion is especially high in Puget Sound's watersheds, where 80% or more of the remaining private forestlands not enrolled in the Designated Forestland Program are at high risk.[1] Although the aim of planning under the Growth Management Act in Washington State is to control population growth in rural areas, growth in unincorporated areas of King, Pierce, and Snohomish Counties has exceeded targets.

In WESTCARB Phase I the baseline for emissions from development in Washington State was estimated (Pearson et al 2007[2]). Over a ten year period from 1987-1997 an estimated 246 thousand acres were deforested for urban development across the state. Forty-two percent of this area was in the King, Pierce and Snohomish counties even though these counties represent just 8% of the State. Pearson et al. (2007) estimated net emissions across the three counties of over 7 million tons of carbon dioxide equivalent per year or 45% of the total from development across the whole state.

The estimates of Pearson et al. (2007) represent a first order approximation based on available data at the time on forest carbon stocks, forest cover change, and approximations of changes in carbon stocks. Furthermore, these results indicate that urban growth around the city of Seattle in King, Pierce and Snohomish counties is an important source of emissions from land use change in Washington State. To improve understanding of this process, Winrock International carried out a study of emissions from conversion of forest to urban area in the Puget Sound region - King, Pierce and Snohomish counties.

Purpose

The objective of this project is to develop a regional characterization study for Washington State that defines residential development as it is implemented in the Puget Sound region to estimate the emissions associated with conversion of forested land for residential development. Although studies of urban forests and ecosystems in the United States and their associated carbon stocks exist,[3] there is little information on carbon stock changes and GHG emissions

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[1] Rogers, L, Cooke, W. 2010. The 2007 Washington State Forestland Database: Final Report. University of Washington – College of Forest Resources.

[2] Pearson, T., S. Brown, N. Martin, S. Martinuzzi, S. Petrova, I. Monroe, S. Grimland, and A. Dushku. 2007. Baseline Greenhouse Gas Emissions and Removals for Forest and Agricultural Lands in Washington State. California Energy Commission, PIER Energy-Related Environmental Research Program. CEC-500-2007-026.

[3] Alberti et al. 2010. Urban terrestrial carbon stocks. *In review*.: Jo and McPherson. 1995. Carbon Storage and Flux in Urban Residential Greenspace. *Journal of Environmental Management*. 45: 109-133.; Nowack et al. 1996. Measuring and analyzing urban tree cover. *Landscape and Urban Planning*. 36: 49-57. Peper et al.

associated with the conversion process itself. In addition, existing studies of urban forests have focused on average crown cover across urban land, and have not produced a consistent set of definitions of land classes within urban and suburban areas that could be used to estimate carbon storage per unit of land class within settled areas.

The characterization will define residential development in the Puget Sound region in terms of the most common lot size and change in vegetation cover and associated carbon stocks. This regional characterization could be used both for full accounting of greenhouse gas emissions associated with development and also potentially to develop a class of offset projects permitting market pressures and incentives to decrease total net greenhouse gas emissions and retain forests in the Puget Sound region.

Project Results

Hearing Examiner decisions on applications for subdivision of land in rural and urban residential zones from 2000 to 2010 were reviewed to determine the zones where development is most intense in terms of total single-family residential lots created in each county. As most of the lots in the subdivision applications reviewed in Pierce and King Counties were located in zones with minimum lot size 0.25 acres or smaller, we infer that the most common lot size for development of residential subdivisions in unincorporated areas of Pierce and King County is 0.25 acres or smaller. Development in unincorporated areas of these two counties is relatively dense compared to development in unincorporated Snohomish County, where the most common lot size in reviewed subdivision applications was 1 acre.

Parcel boundaries for the subdivision plat were overlaid with a series of orthorectified aerial images from multiple time points to characterize the change in area of forest cover associated with development of the subdivision. The GIS analysis includes roads internal to subdivisions only, although the creation of residential subdivisions may influence the construction of access roads external to the subdivision. There is therefore the necessity for ongoing work to determine the total impact of development incorporating the dedicated roads and emission associated with clearing forest for road construction.

Development in King and Pierce Counties, where the most common lot size was 0.25 acres or less, resulted in clearing of 62% to 98% of forest cover. Development of these small lot sizes resulted in clearing of relatively more forest cover compared to 1 acre lots in zone R-5 in Snohomish County, which resulted in less than 50% clearing of forest cover for all but one of the subdivisions assessed. Proportion of existing forest cover cleared was also related to the total size of the development. Mean total development area in King and Pierce Counties and in zone R-9,600 in Snohomish Counties ranged between 3.3 ac to 9.5 ac with deforestation between 75% and 95%, while in zone R-5 in Snohomish County where the mean total development area was 30 acres only 33% of original forest cover was cleared.

To determine the direct change in carbon stock resulting from development, forest carbon stocks within the boundaries of each subdivision plat were determined by overlaying the parcel

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2001. Equations for predicting diameter, height, crown width, and leaf area of San Joaquin Valley street trees. *Journal of Arboriculture*. 27: 6.

boundaries with the USFS Forest Inventory and Analysis (FIA) biomass stock map.[4] The loss in forest cover through development led to average changes in stock in live trees of 289 t CO_2-e/ac, 1,237 t CO_2-e/ac, and 1,044 t CO_2-e/ac for King, Pierce, and Snohomish Counties respectively.

The average total emissions from forest conversion per subdivision, accounting for the quantity of cleared timber that is converted to harvested wood products resulting in long-term storage of carbon, and assuming that the remainder of cleared vegetation is diverted to energy recovery, was 235 t CO_2-e and 959 t CO_2-e for King and Pierce Counties respectively, and in Snohomish County 1,202 t CO_2-e for development in zone R-5 and 495 t CO_2-e for development in zone R-9,600.

A sample of subdivisions developed in the last ten years in the zones with the highest level of development was selected for field measurements to estimate carbon stock recovery post-development. Total stocks vary from 1.27 tons of carbon in a 0.1 acre lot to more than 39 t C in a 2 acre lot.

Full accounting of development emissions must capture both the emissions from clearing the forest and the sequestration that occurs after development. Net emissions in King County ranged from 70 t CO_2-e to 177 t CO_2-e per development. In Pierce County net emissions ranged from 412 t CO_2-e to 1,418 t CO_2-e per development. In Snohomish County, development resulted in net emissions for some subdivisions while other subdivisions showed net sequestration (negative net emissions). Net emissions ranged from 12 t CO_2-e to 670 t CO_2-e. Net sequestration ranged from 8 t CO_2-e to 335 t CO_2-e.

Net emissions from development was impacted by initial forest cover and by area of forest cleared for development. While the initial forest cover pre-development varied, a relationship existed between total area of development and percentage of original forest cover remaining after development. Forest cover cleared during development varied from 57-100% in areas of less than 16 acres but averaged 35% for development areas that exceed 16 acres.

This relationship could form the basis of a future performance standard for development projects such that if a developer exceeded the defined area of forest retained by 10% or more then the carbon stocks of the retained forest would be creditable. For example, the resulting available offsets range from approximately 136 tons for a 10 acre development to almost 3,000 tons for a 60 acre development in an area with forest carbon stocks of 100 t C/ac.

This study represents an initial analysis of development and associated emissions in three counties of the Puget Sound. The analysis shows the potential value of further examination of this category in the region. Emissions are large and are likely largely unaccounted for in inventories of greenhouse gas emissions. These emissions also present an opportunity for the creation of an offset project category. Where emissions can be reduced without leakage then these emission reductions should be creditable to developers and local authorities.

The limited time and resources for this study meant that only a limited number of development sites could be examined from limited zoning categories. A future study should look more

[4] http://fsgeodata.fs.fed.us/rastergateway/biomass/

exhaustively at development that has occurred over the last 10 years over a larger sample of counties and zoning areas within the state and should use a similar methodology to calculate forest loss, the emissions resulting from forest loss and post development carbon stock recovery.

1.0 Introduction

1.1. Background and overview

The conversion of forest lands to non-forest uses, especially conversion to residential development, is of significant concern to the Washington State Legislature and Washington Department of Natural Resources.

As a result of a rapidly growing population, the risk of conversion is especially high in Puget Sound's watersheds, where 80% or more of the remaining private forestlands not enrolled in the Designated Forestland Program are at high risk.[5] This study focuses on King, Pierce and Snohomish counties, which are closely associated with the urban growth of the city of Seattle. The forests in these counties are valuable for both timber production and the ecosystem services that they provide including their role as a sink for greenhouse gases. Temperate climate, abundant rainfall, and deep soils make these forests some of the most productive in the nation.[6] Thus the Puget Sound watersheds represent an important area with overlapping competing demands from urban development, timber production and greenhouse gas sequestration.

In WESTCARB Phase I the baseline for emissions from development in Washington State was estimated (Pearson et al 2007[7]). Over a ten year period from 1987-1997 an estimated 246 thousand acres were deforested for urban development across the state. Forty-two percent of this area was in the King, Pierce and Snohomish counties even though these counties represent just 8% of the State. Pearson et al (2007) estimated net emissions across the three counties of over 7 million tons of carbon dioxide equivalent per year or 45% of the total from development across the whole state. The estimates of Pearson et al. (2007) represent a first order approximation based on available data at the time on forest carbon stocks, forest cover change, and estimations of changes in carbon stocks. Furthermore, these results indicate that urban growth around the city of Seattle in King, Pierce and Snohomish counties is an important source of emissions from land use change in Washington State.

The present study was conducted to characterize common practice for conversion of forest land to residential development in three counties of the Puget Sound region to estimate immediate emissions and baseline carbon stocks in converted lands. Estimation of baseline carbon stocks could be used to create a performance standard above which developers would receive credit for retaining forest cover on land converted for residential use. The characterization will cover minimum lot sizes and site clearing that are implemented according to local zoning standards

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[5] Rogers, L, Cooke, W. 2010. The 2007 Washington State Forestland Database: Final Report. University of Washington – College of Forest Resources.

[6] WA DNR. 2009. Future of Washington Forests: Washington's Forests, Timber Supply, and Forest-Related Industries.

[7] Pearson, T., S. Brown, N. Martin, S. Martinuzzi, S. Petrova, I. Monroe, S. Grimland, and A. Dushku. 2007. Baseline Greenhouse Gas Emissions and Removals for Forest and Agricultural Lands in Washington State. California Energy Commission, PIER Energy-Related Environmental Research Program. CEC-500-2007-026.

and common practice as well as landscaping and disposal of removed vegetation. The characterization will also include an analysis of the carbon stocks in existing vegetation on forested land pre- and post-conversion.

1.2. Administration of development in the Puget Sound region

Various development regulations and official controls are applied in Washington State at different levels to ensure that development occurs in a coordinated manner that meets the needs of an expanding population while conserving the natural resource base of the State. Different mechanisms are in place in the three counties to concentrate development in urban areas and ensure appropriate development in rural areas.

1.2.1. The Growth Management Act

The Washington State Growth Management Act (GMA) requires the fastest growing counties and cities in the State to plan goals for sprawl reduction, concentrated urban growth, preservation of open space and areas for recreation, environmental protection, and promoting natural resource industries. Each of the three counties in the study has prepared a "unified development code" that includes regulations controlling how land is subdivided, used, and developed.

1.2.2 The development process

The development of large residential subdivisions for single-family detached housing begins when a parcel of land that is zoned for residential development is subdivided into smaller lots. This process is regulated by two categories of development controls: zoning and subdivision development provisions.

Zoning

Zoning defines the permitted uses of property, density coverage, setbacks, and landscaping levels for a given area. Zoning effectively controls what kind of development is allowed to occur in any given area. For example, zoning prevents commercial development in residential districts. Likewise, zoning can be used to prevent dense residential development in traditionally rural areas.

Subdivision

Subdivision is the re-division of land into five or more lots, tracts, parcels, sites, or divisions for sale, lease, or transfer of ownership[8]. The subdivision development process begins when a preliminary map or "plat" delineating small divisions within a larger parcel is submitted to county authorities. The preliminary plat is subject to a public hearing before a planning commission or hearing examiner. Once a preliminary plat is conditionally approved, the applicant has 5 years to file the final plat.

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[8] Washington State Subdivision Act of 1969

Development

Depending on the initial development site conditions, clearing of existing vegetation and some excavation may be required to prepare parcels for construction. At a minimum, trees and stumps must be removed from the building site and wherever excavation may be required for such things as basements, septic systems, wells, or utilities. However, the impacts of conventional development can be significant, including complete clearing of existing vegetation, leveling and grading topography, and compacting of soils. Various county ordinances regulate the removal of trees and soil disturbance for site preparation in the Puget Sound region. Figure 1 shows pre- and post-construction lots in the same subdivision in Snohomish County.

Figure 1 Examples of 1 acre residential lots in Snohomish County immediately following site clearing and post-construction

1.2.3 Density incentive provisions

Cluster development in rural areas allows for the preservation of open space while continuing to provide at least the same number of lots for residential development. This is accomplished through density incentives that are applied to reduce the minimum allowable lot size. For example, developers may receive on-site density incentives for maintaining a minimum proportion of a development site in open space.

1.3. Project objectives

The objective of this project is to develop a regional characterization study for three counties of Washington State that defines residential development as it is implemented in the Puget Sound region to estimate the emissions associated with conversion of forested land for residential development. Although studies of urban forests and ecosystems in the United States and their associated carbon stocks exist,[9] there is little information on carbon stock changes and GHG

[9] Alberti et al. 2010. Urban terrestrial carbon stocks. *In review*.: Jo and McPherson. 1995. Carbon Storage and Flux in Urban Residential Greenspace. *Journal of Environmental Management*. 45: 109-133.; Nowack et al. 1996. Measuring and analyzing urban tree cover. *Landscape and Urban Planning*. 36: 49-57. Peper et al.

emissions associated with the conversion process itself. In addition, existing studies of urban forests have focused on average crown cover across urban land, and have not produced a consistent set of definitions of land classes within urban and suburban areas that could be used to estimate carbon storage per unit of land class within settled areas.

The characterization will define residential development in the Puget Sound region in terms of the most common lot size and change in vegetation cover and associated carbon stocks. This regional characterization could be used both for full accounting of greenhouse gas emissions associated with development and also potentially to develop a class of offset projects permitting market pressures and incentives to decrease total net greenhouse gas emissions and retain forests in the Puget Sound region.

1.4. Report organization

The introduction to this report is followed by a description of the methods used to achieve the project objectives. Methods used to define common practice, including spatial analysis and field measurements, are explained in this section. Following the methods section, the results of the study are presented in terms of the most common lot size for residential development in the three counties, zones with most extensive and/or intense development, associated land cover change determined from spatial analysis, and estimation of carbon stock recovery in the baseline determined with field measurements of biomass stocks in residential areas. The discussion of the results is followed by conclusions and suggestions for the development of a performance standard. Detailed information on county development standards and field measurement methods are included in the appendices.

2001. Equations for predicting diameter, height, crown width, and leaf area of San Joaquin Valley street trees. *Journal of Arboriculture*. 27: 6.

2.0 Analysis of Zoning and Deforestation

2.1. Background on zoning in forest areas

The rural and urban residential zones in Pierce, King and Snohomish were examined and characterized by minimum lot size.

The King County Code Development Standards[10] divide residential zones into three categories: rural, urban reserve, and urban residential.

The Pierce County Code Development Regulations[11] defines residential zones under urban and rural classifications.

The Snohomish County Unified Development Code[12] defines urban residential and rural zones. The purpose of urban residential zoning in Snohomish County is to provide for predominantly single family residential development with minimum density of 4 dwelling units per acre.

Rural residential zoning in the three counties is generally applied to lands that are not designated as agricultural or forest lands of long-term commercial significance. Minimum lot size in these urban and rural residential zones in the three counties ranges from 0.02[13] acre to 40 acres.

2.2. Analysis methods

Hearing Examiner decisions on applications for subdivision of land in rural and urban residential zones from 2000 to 2010 were reviewed to determine the zones where development is most intense in terms of total single-family residential lots created in each county. Samples of approved applications for subdivision to create lots for single family residential units in each county were randomly selected for review. The following criteria were assessed for each subdivision application:

- number of lots created,
- zoning designation,
- subdivision design (cluster or non-cluster), and
- forest cover.

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[10] K.C.C. Chapter 21A.12

[11] P.C.C. Title 18A

[12] S.C.C. Title 30

[13] In King County, base density for urban residential zone R-48 is defined as 48 dwelling units per acre while minimum lot size in rural residential zone R-40 in Pierce County is 40 acres.

Forest cover was assessed by inputing the location information from the hearing examiner decisions into Google Earth.

2.3. Residential zones with highest levels of development

2.3.1. King County

Six zoning codes were evaluated in King County based on eligibility for single family dwellings. The six codes ranged in density requirements from a maximum density of 0.2 to 8 dwellings per acre (Table 1).

Table 1 Zoning categories and maximum development density for King County

Zoning Category	Zoning Code	Definition	Maximum Density
Rural Area	RA5	Rural area – 5 acre	0.2 dwellings/acre
Urban Residential	R1	Residential – 1 dwelling/acre	1 dwelling/acre
	R4	Residential – 4 dwellings/acre	4 dwellings/acre
	R6	Residential – 6 dwellings/acre	6 dwellings/acre
	R8	Residential – 8 dwellings/acre	8 dwellings/acre

In King County the majority of lots created through the subdivision applications assessed were made for parcels in zone R-4, R-6, and R-8 (Figure 2). Cluster development is not permitted in these three zones in King County.

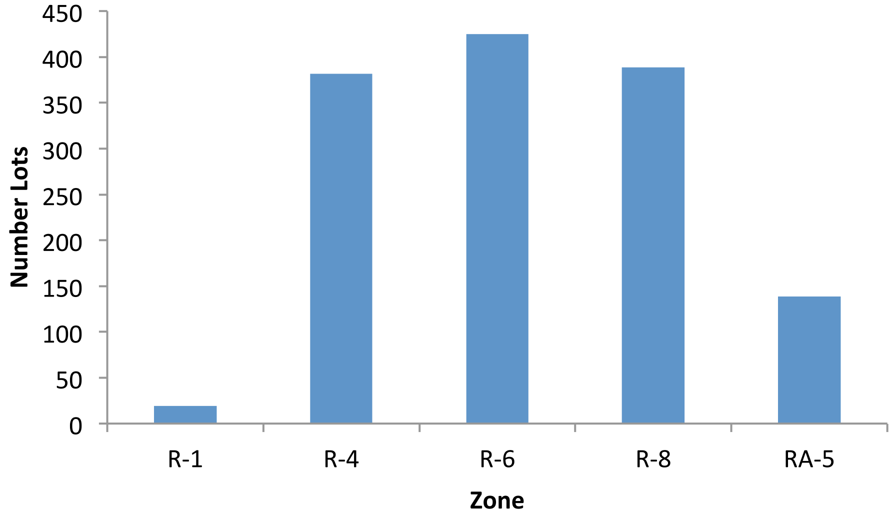

Figure 2 Number of lots for single family residential units created per zone from sample of 50 applications for subdivision in King County from 2000 to 2010.

Only 22 subdivision applications were assessed for land cover prior to development. The majority of the subdivisions (81%) in King County were developed on land with at least partial forest cover (Figure 3).

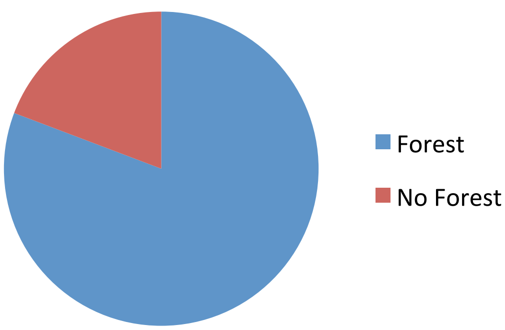

Figure 3 Subdivisions developed on land with forest cover in King County

2.3.2. Pierce County

Five zoning codes were evaluated in Pierce County based on eligibility for single family dwellings. The five codes ranged in density requirements from a maximum density of 1 to 25 dwellings per acre (Table 2).

Table 2 Zoning categories and maximum development density for Pierce County

Zoning Category	Zoning Code	Definition	Maximum Density
Urban Centers	CC	Community Center	25 dwellings/acre
Urban Residential	MHR	Moderate High Density - Residential	25 dwellings/acre
	MSF	Moderate Density Single-Family	6 dwellings/acre
	SF	Single Family	4 dwellings/acre
Rural Residential	Rsv5	Rural Residential, Resource Lands and Other Zones Reserve 5	1 dwelling/acre

In Pierce County, the largest proportion (40%) of the subdivisions applications assessed were made for parcels in the Moderate Density Single-Family zone (MSF), accounting for the majority of lots created for single family residential units (Figure 4). None of the applications reviewed indicated that cluster design was used.

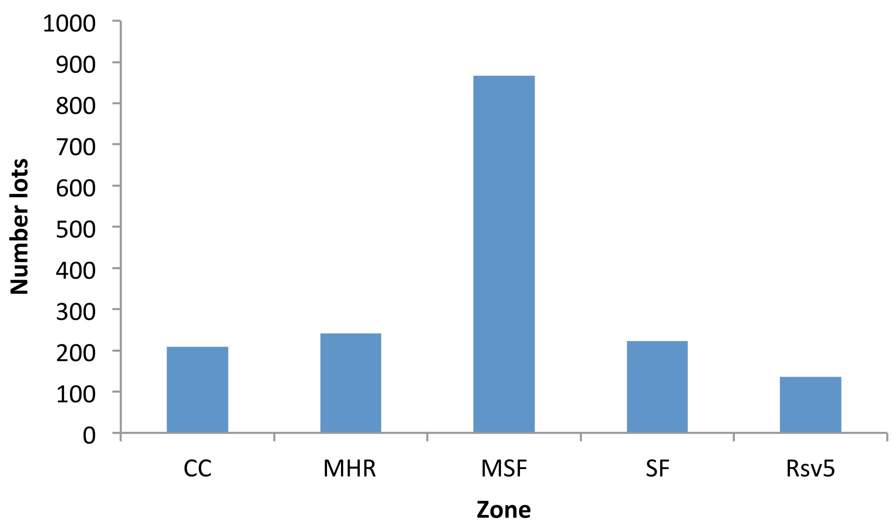

Figure 4 Number of lots for single family residential units created per zone from sample of 49 applications for subdivision in Pierce County from 2000 to 2010.

Slightly more of these subdivision projects in Pierce County included in the sample (55%) occurred on parcels with at least partial forest cover than on parcels with no forest cover (Figure 5).

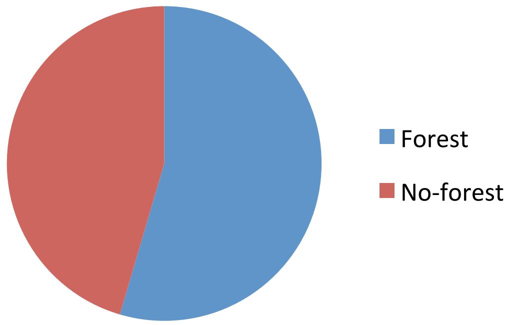

Figure 5 Development projects occurring on parcels with forest cover and with no forest cover per zone from sample of approved applications for subdivision in Pierce County from 2000 to 2010.

2.3.3. Snohomish County

Four zoning codes were evaluated in Snohomish County based on eligibility for single family dwellings. The five codes ranged in density requirements from a maximum density of 0.1 to 6 dwellings per acre (Table 3).

Table 3 Zoning categories and maximum development density for Snohomish County

Zoning Category	Zoning Code	Definition	Maximum Density
Urban Residential	R-7,200	Residential – 7,200 square feet	6 dwellings/acre
	R-9,600	Residential – 9,600 square feet	4.5 dwellings/acre
Rural	R-5	Rural – 5 acre	0.2 dwellings/acre
	RRT-10	Rural Resource Transition – 10 acre	0.1 dwelling/acre

In Snohomish County the majority of the subdivisions applications assessed were made for parcels in zone R-5, accounting for the majority of lots created for single family residential units (Figure 6). All of the applications for subdivision in zone R-5 were cluster subdivision with 1 acre lots. Cluster design is not allowed in zone R-9,600 or zone R-7,200.

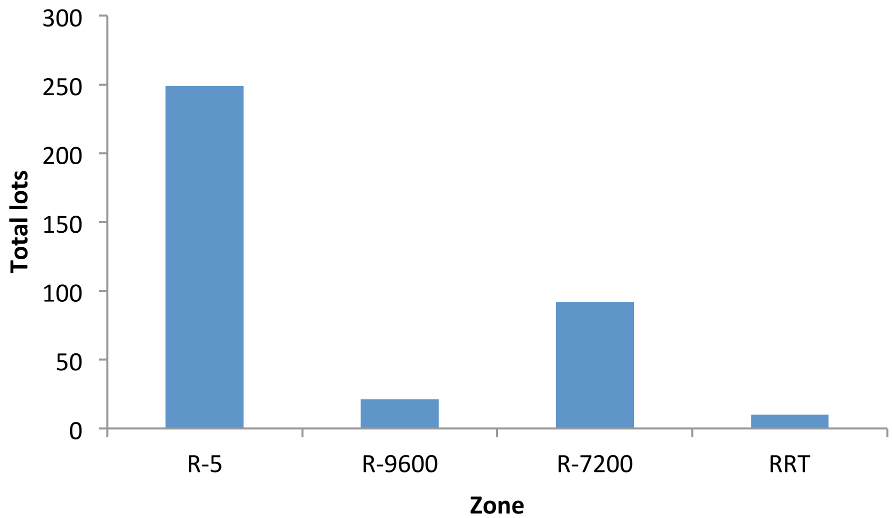

Figure 6 Number of lots for single family residential units created per zone from sample of 25 applications for subdivision in Snohomish County from 2000 to 2010.

The majority (84%) of the subdivision projects assessed occurred on parcels with at least partial forest cover (Figure 7).

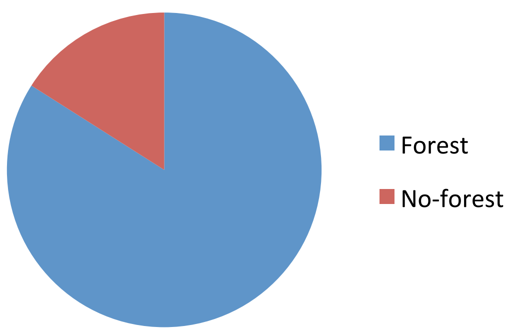

Figure 7 Development projects occurring on parcels with forest cover and on parcels with no forest cover per zone from sample of approved applications for subdivision in Snohomish County from 2000 to 2010.

2.4. Zoning summary

As most of the lots in the subdivision applications reviewed in Pierce and King counties were located in zones with minimum lot size 0.25 acres or smaller, we infer that the most common lot size for development of residential subdivisions in unincorporated areas of Pierce and King County was 0.25 acres or smaller. Development in unincorporated areas of these two counties is relatively dense compared to development in unincorporated Snohomish County, where the most common lot size in reviewed subdivision applications was 1 acre. Although the most common lot size in King and Pierce County might result in less area of forest conversion per lot developed compared to development in Snohomish County, the impact of residential development on forest in King and Pierce counties could be significant because the majority of subdivisions evaluated in these counties occurred on land with forest cover.

The majority of lots in unincorporated Snohomish County were located in cluster developments in zone R-5. Because the minimum allowed lot size without density incentives in Snohomish County in zone R-5 was 5 acres, the majority of residential subdivisions in Snohomish County occurred in rural areas in zones where large lot subdivisions would likely not be common practice without cluster development.

This study focuses from this point onwards on those zones where single family residential development is a primary use and large residential subdivision developments are a common practice. In each county, residential development standards are defined for rural and urban residential zones. In urban residential zones, dimensional standards ranged from very dense development with very small lot sizes (as high as 48 units per acre in King County) to moderate density development with an average of 4 units per acre with a minimum lot size of approximately 0.25 acre. In rural residential areas, development is typically less dense. It is reasonable to assume that the proportion of the area cleared of vegetation for each lot developed in rural zones with very large minimal lot size is small compared to zones with smaller lot sizes. Furthermore, large residential subdivisions are not a common practice in these zones. On the other hand, zones with very dense development likely result in 100% clearing of vegetation and more impervious surface areas as a proportion of total lot area. Therefore, the greatest opportunity for changing common practice to mitigate emissions may be expected in the zones listed in Table 4, taking into account the zones with the highest levels of development in the three counties.

Table 4 Medium density residential zones in King, Pierce, and Snohomish Counties

County	Zone	Category	Minimum Lot Size (ac)
King	R-4	Urban Residential	0.25
Pierce	MSF	Urban Residential	0.17
Snohomish	R-5	Rural Residential	0.40* / 5
	R-9,600	Urban Residential	0.22

**Minimum area achieved through application of density incentives*

3.0 Analysis of Deforestation with Development

3.1. Methods for spatial analysis of deforestation

The steps used to define common practice for forest clearance and associated emissions in the three counties are described in Figure 8.

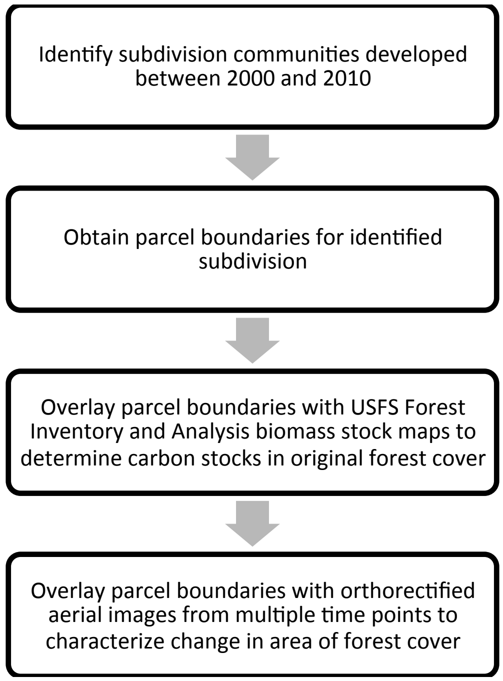

Figure 8 Flow chart of steps used for defining common practice for site preparation

To identify new home communities developed in the last ten years (2000-2010), archived Hearing Examiner decisions for each county were reviewed to identify approved applications for preliminary subdivision plats in the zones with the highest level of development and the greatest opportunity for changing common practice listed in Table 5. Google Earth was used to locate these subdivisions to verify that they had actually been developed and to visually assess land cover before and after development to select subdivisions developed on land with at least partial forest cover. The visual assessment was based on a time series of aerial images in Google Earth.

Parcel boundaries for the subdivision plat were overlaid with a series of orthorectified aerial images from multiple time points to characterize the change in area of forest cover associated with development of the subdivision. An example of aerial images overlaid with parcel boundaries is shown in Figure 9.

Figure 9 Aerial images overlaid with parcel boundaries used to estimate change in forest cover and carbon stocks associated with development for a Snohomish County R-9600 subdivision Copper Creek

Images were processed to identify forest and non-forest land cover classes to quantify the area of deforestation associated with the land use change.

The GIS analysis includes roads internal to subdivisions only, although the creation of residential subdivisions may influence the construction of access roads external to the subdivion. For some subdivisions, external access roads may already exist, while in other cases the creation of subdivisions may influence the construction of these roads. There is therefore the necessity for ongoing work to determine the total impact of development incorporating the dedicated roads and emission associated with clearing forest for road construction.

3.2. Results for spatial analysis of deforestation

The spatial analysis identified the area of cleared forest per development and per parcel for King, Pierce and Snohomish Counties.

3.2.1. King County

In King County five developments were examined as part of the spatial analysis with a total area of 16.6 acres and an average area of 3.3 acres per development. Prior to development the areas were on average 76% forested with a range between 59% and 95%. All five developments were in zone R-4.

Five subdivisions in zone R-4 were included in the spatial analysis for King County. Percent change in forest cover associated with development of these subdivisions ranged from 62% to 88% (Table 5).

Table 5 Results from spatial analysis of forest area (acres) pre- and post-development in zone R-4 in King County

Subdivision name	Total subdivision area	Forest area before development		Forest area after development		Deforestation	
		Area	% total area	Area	% total area	Area	%
Canterberry Crossing	3.2	2.6	81%	0.3	9%	2.3	88%
Edenwood	3.1	2.9	95%	0.4	13%	2.5	86%
Evetts Park	4.1	2.4	59%	0.7	17%	1.7	71%
Hidden Tree	3.2	2.2	69%	0.4	12%	1.8	82%
Norway Knoll	3.0	2.4	79%	0.9	30%	1.5	62%

Figure 11 shows an example of forest clearing for development in zone R-4 of King County. Of existing forest cover pre-development, 86% was cleared.

a. 

b. 

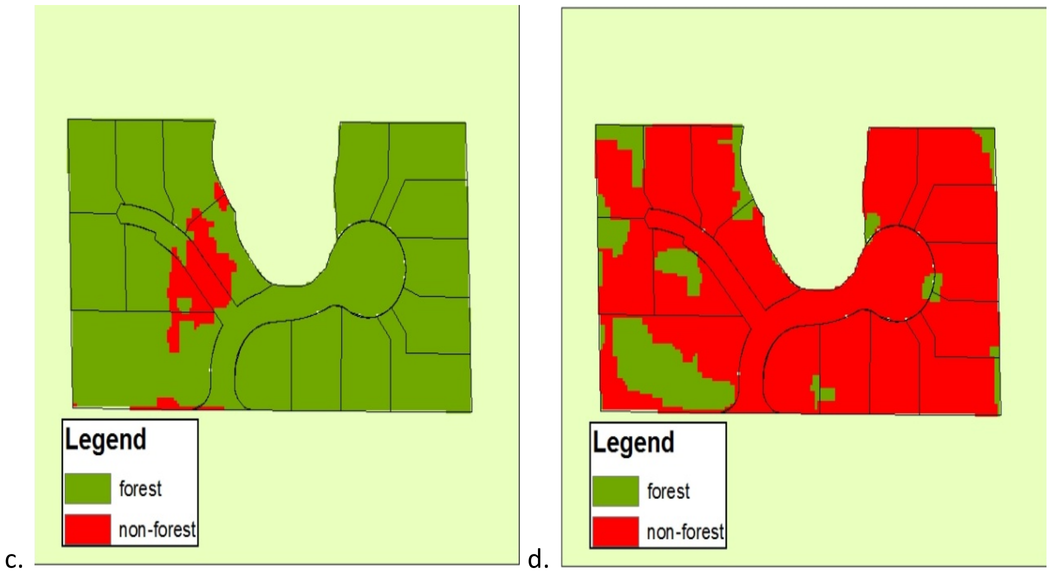

Figure 10 Edenwood development in King County: (a) imagery before development (image circa 1990), and (b) after development 2009, and (c) classification of forest and non forest before development and (d) classification after development.

3.2.2. Pierce County

In Pierce County four developments were examined as part of the spatial analysis with a total area of 28.3 acres and an average area of 7.1 acres per development. Prior to development the areas were on average 88% forested with a range between 81% and 95%. All four developments were in zone MSF.

Table 6 shows results of the analysis of deforestation in four subdivision developments in zone MSF in Pierce County. Most of the existing forest cover was cleared for development in all four subdivisions (92 – 98%).

Table 6 Results from spatial analysis of forest area (acres) pre- and post-development in zone MSF in Pierce County

Subdivision name	Total development area	Forest area before development		Forest area after development		Deforestation	
		Area	% total area	Area	% total area	Area	%
Pierce-MSF-1	8.5	6.9	81%	0.3	4%	6.6	96%
Pierce-MSF-2	8.2	7.6	92%	0.6	8%	7.0	92%
Pierce-MSF-4	7.1	5.9	83%	0.2	3%	5.7	97%
Pierce-MSF-5	4.5	4.3	95%	0.1	2%	4.2	98%

Almost complete clearing of forest area for development of MSF subdivisions are shown in Figures 12 and 13. Figure 12 shows clearing of 97% of forest cover in subdivision MSF-4.

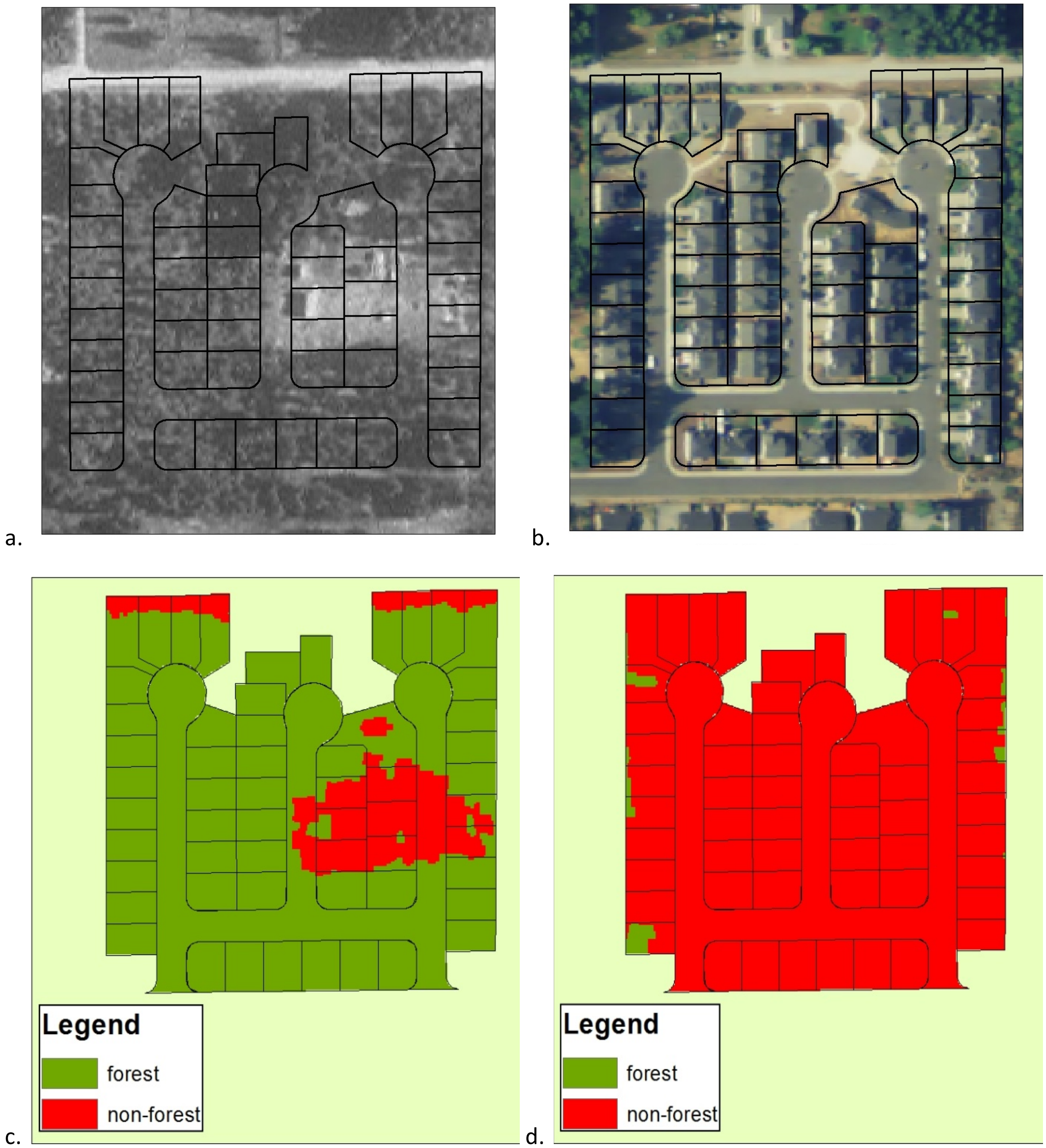

Figure 11 MSF-4 development in Pierce County: (a) imagery before development (image circa 1990), and (b) after development 2009, and (c) classification of forest and non-forest before development and (d) classification after development

Figure 13 shows 96% clearing in subdivision MSF-1.

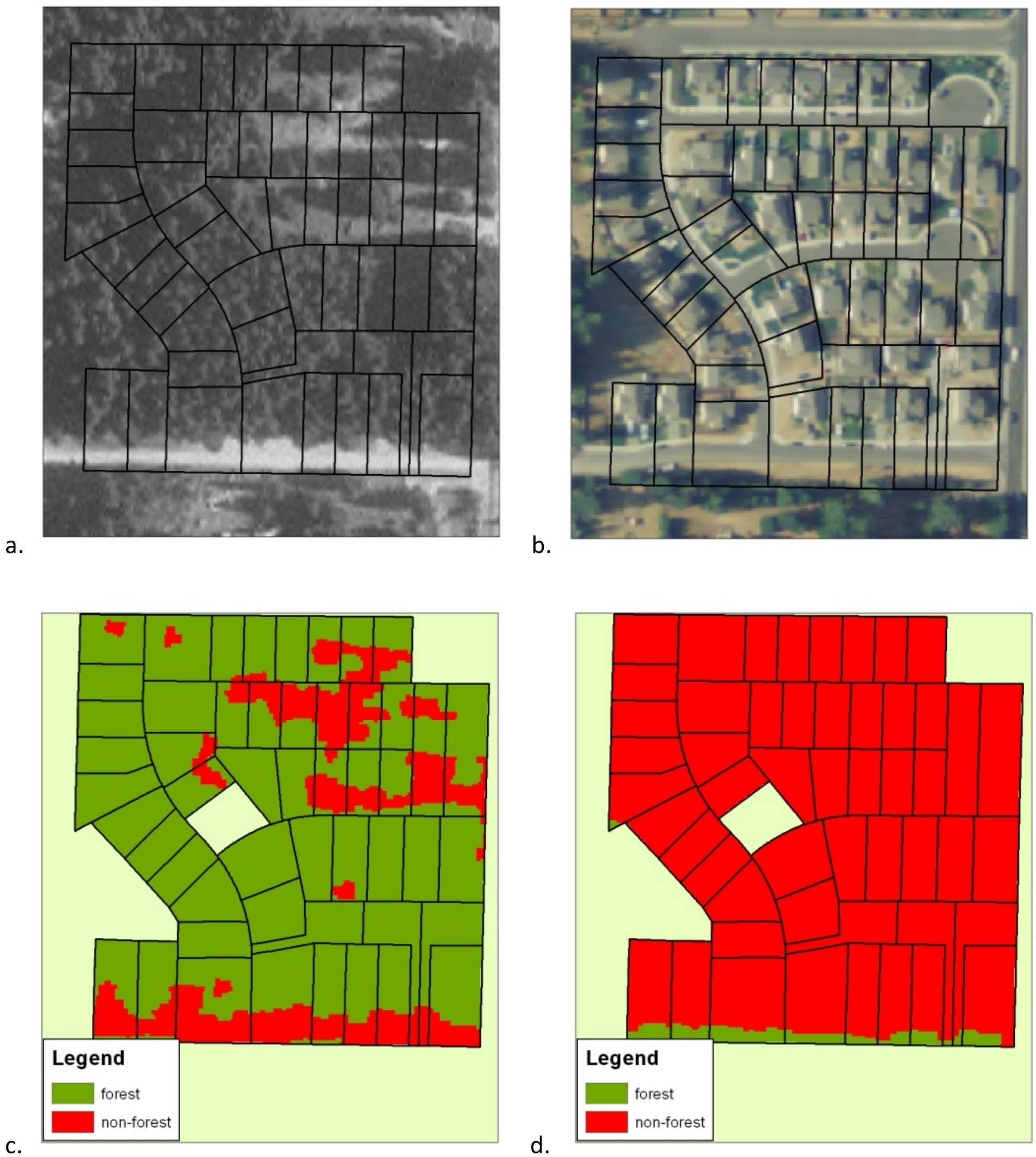

Figure 12 MSF-1 development in Pierce County: (a) imagery before development (image circa 1990) and (b) after development 2009, and (c) classification of forest and non forest before development and (d) classification after development

3.2.3. Snohomish County

In Snohomish County sixteen developments were spatially analyzedwith a total area of 316.1 acres and an average area of 19.8 acres per development. Prior to development the areas were on average 73% forested with a range between 21% and 99%. Eight of the developments were in zone R-5 and eight were in zone R-9,600.

Zone R-5 developments had an average of 91% forest cover before development, and 61% after development, showing an average decrease in forest cover of 33%. In zone R-9,600 (minimum lot size 0.22 acres) there was an average of 56% forest cover before development and 16% after, showing an average decrease in forest cover of 75%. While developed areas in R-5 (minimum lot size 5 acres) had more forest cover prior to development than R-9,600 (average - 83%), on average only 33% of forest area was cleared in R-5 subdivisions while on average 75% of forest area was cleared for development in R-9,600 subdivisions (Table 7).

Table 7 Results of spatial analysis of forest area (acres) pre- and post-development in zones R5 and R-9,600 in Snohomish County

Subdivision name	Total development area	Forest area before development		Forest area after development		Deforestation	
		Area	% total area	Area	% total area	Area	%
Zone R-5							
Blacktail Forest	67.3	42.3	63%	23.3	35%	19.0	45%
Cascade Peaks	30.5	29.2	96%	17.7	58%	11.5	39%
Echo Ridge	21.9	21.8	99%	17.5	80%	4.3	20%
Kenrose Heights	19.1	19.0	99%	13.8	72%	5.2	27%
Quail Ridge	19.9	17.7	89%	15.7	79%	2.0	11%
Ridgewood Estates	57.5	47.4	82%	29.4	51%	18.0	38%
Snowbird	16.1	15.9	99%	12.8	80%	3.1	19%
Wardrum Woods	7.6	7.4	97%	2.6	34%	4.8	65%
Zone R-9,600							
Cedarwood Estates	3.5	1.5	43%	0.4	11%	1.1	74%
Copper Creek	14.2	10.9	77%	3.8	27%	7.1	65%
Creekwood	7.7	2.2	29%	0.4	5%	1.8	82%
Holly Hill Estates	3.7	3.5	95%	1.5	41%	2.0	57%
Lake View Park	2.6	0.6	21%	0.1	4%	0.5	82%
Margate	16.9	10.3	61%	2.2	13%	8.1	79%
Summerset	12.2	6.1	50%	0.0	0%	6.1	100%
The Park at Creekside	15.5	11.1	72%	4.5	29%	6.6	59%

Figure 13 shows a R-5 cluster subdivision in Snohomish County before and after development. The significant majority of the forest area remains following development (80%).

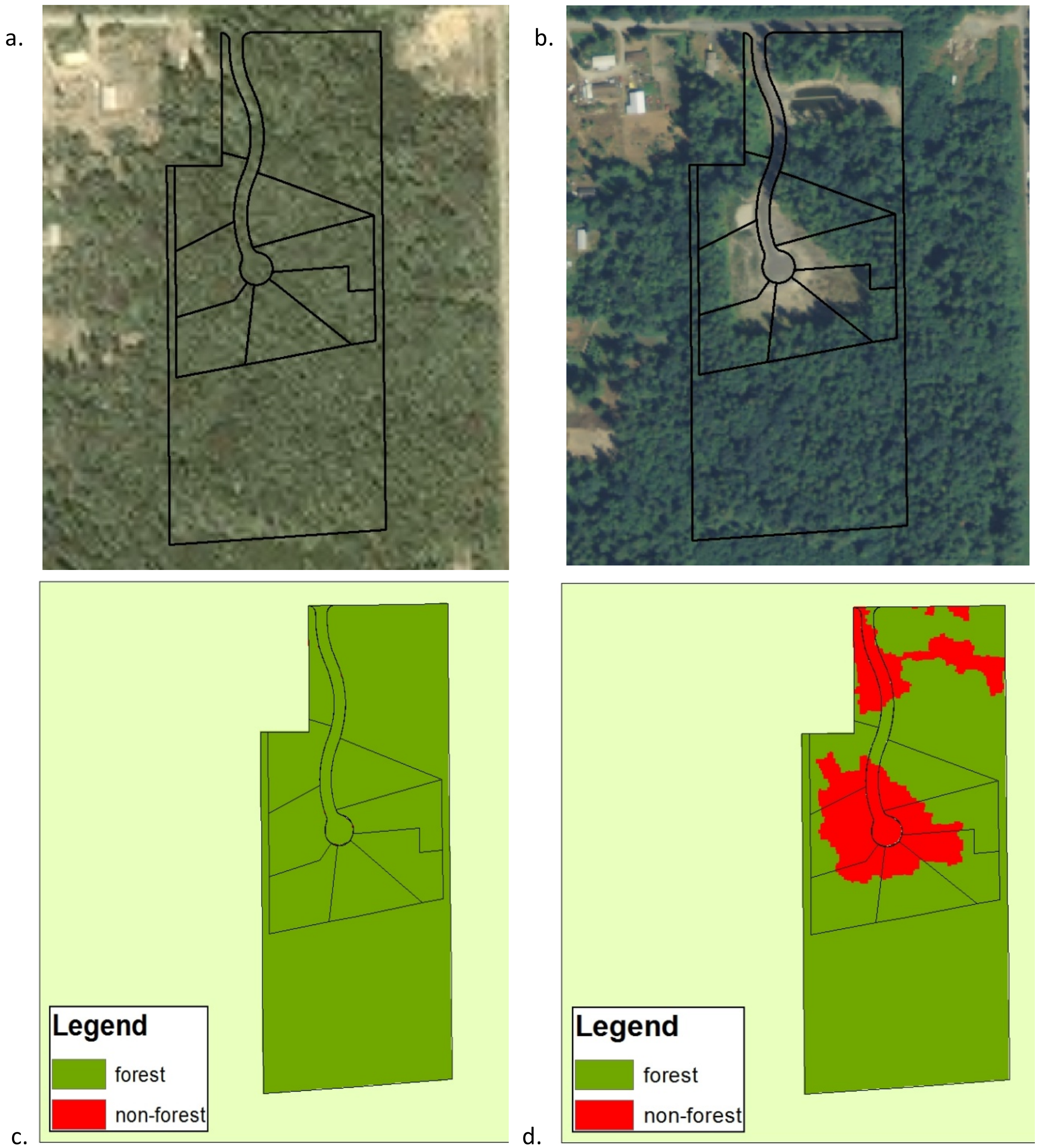

Figure 13 The R-5 Echo Ridge Development parcel boundaries overlaid with aerial imagery (a) from 2004 (before the development) and (b) 2009 (after the development) and (c) classification of forest before development and (d) classification of forest and non forest after development.

In contrast, R-9,600 subdivisions had less forest cover before development and a greater proportion of existing forest was cleared during development. For example in Figure 14, 51% the development was already cleared for farmland before development and during development almost all the remaining trees were cleared.

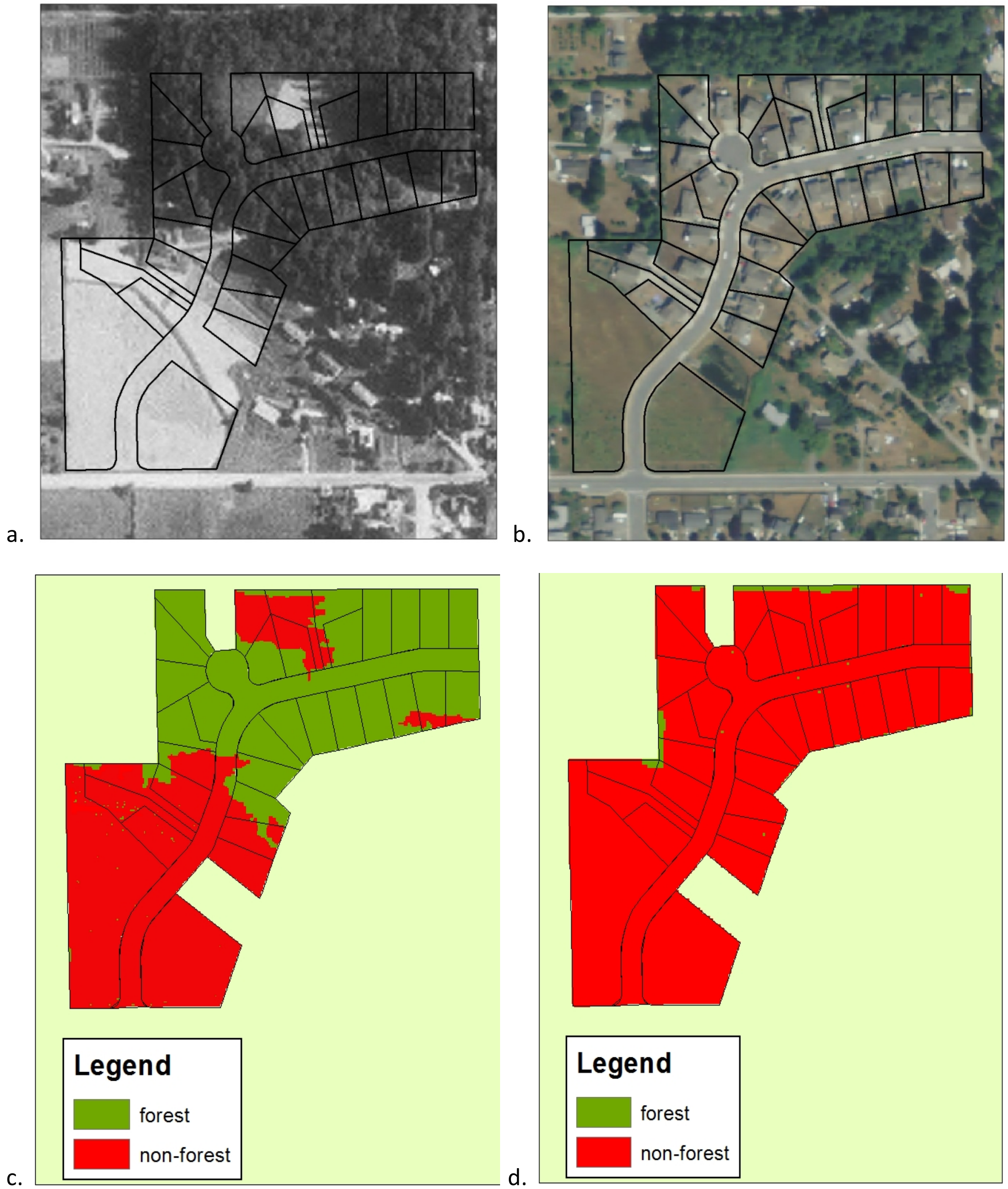

Figure 14 The R-9,600 Summerset Development: parcel boundaries overlaid with (a) aerial imagery from circa 1990 (before the development) and (b) 2009 (after the development) and (c) classification of forest and non forest before the development and (d) classification after the development.

3.3. Deforestation with development summary

The most common lot size in King and Pierce Counties was 0.25 acres or less and resulted in clearing of 62% to 98% of forest cover. Development of these small lot sizes resulted in clearing of relatively more forest cover compared to 1 acre lots in Snohomish County, which resulted in less than 50% clearing of forest cover for all but one of the subdivisions assessed (Table 8). Proportion of existing forest cover cleared seems to be in part a function of lot size, because subdivision developments with smaller lot sizes in zone R-9,600 in Snohomish County had similar levels of clearing compared to development of lots in King and Pierce Counties. Impervious surfaces in smaller lots (primarily the house and driveway) are a greater proportion of the total area of the lot compared to larger lots, as measured in the field (see Section 4.3.2), leaving less area available for vegetation cover. As well, it is likely that more extensive clearing facilitates construction activities in a relatively smaller area. In the 1 acre lots in Snohomish County remaining forest cover on residential lots was generally found on the back of the lot, where most likely it does not present an impediment to construction activities. However, part of the difference in forest cover between the large 1 acre lots in Snohomish County and relatively smaller lots in all three counties can be explained by the use of cluster development in the 1 acre lot subdivisions, where the developer is obligated to leave part of the development project area as green space. Cluster development was not used in the R-9,600 zone in Snohomish County or in any of the subdivision developments in King or Pierce Counties.

Proportion of existing forest cover cleared was also related to the total size of the development. Mean total development area in King and Pierce Counties and in zone R-9,600 in Snohomish Counties ranged between 3.3 ac to 9.5 ac with deforestation between 75% and 95%, while in zone R-5 in Snohomish County where the mean total development area was 30 acres only 33% of original forest cover was cleared (Table 8). In the relatively larger, less dense developments there is greater opportunity to retain existing forest cover.

Table 8 Summary of the results from the spatial analysis showing lot sizes, % cover before development and the % forest cover lost during development

County	Zone	Minimum Lot Size *(ac)*	Mean Total Development Area *(ac)*	Initial Forest Cover *(%)*	Deforestation *(%)*
King	R-4	0.25	3.3	76%	78%
Pierce	MSF	0.17	7.1	88%	95%
Snohomish	R-9600	0.22	9.5	56%	75%
Snohomish	R-5	1.00*	30.0	83%	33%

**with clustering*

4.0 Greenhouse Gas Emissions Associated with Development

To assess the greenhouse gas emissions associated with conversion the specific subdivisions spatially analyzed in Section 3 were further studied to estimate the greenhouse gas emissions that resulted from the development of each residential lot.

4.1. Change in stocks associated with measured area of deforestation

To determine the direct change in carbon stock resulting from development, forest carbon stocks within the boundaries of each subdivision plat were determined by overlaying the parcel boundaries with the USFS Forest Inventory and Analysis (FIA) biomass stock map.[14] Biomass was converted to carbon by applying the commonly used conversion factor of 0.5 t C/t biomass, and then converted to CO_2-e by applying the conversion factor of 3.67 t CO_2-e/t C. The most common forest type in the three counties was Douglas fir, with a minority of sites dominated by Red Alder forest.

4.1.1. King County

In King County the five development sites had carbon stocks of between 38 and 43 t C/ac. The loss in forest cover through development led to changes in stocks in live trees equivalent to between 230 and 351 t CO_2-e with an average of 289 t CO_2-e or 89 t CO_2-e per acre of the total area of development (Table 9).

Table 9 Predevelopment carbon stocks and decrease in stocks as a result of forest conversion (acres) from development in zone R-4 in King County

Subdivision name	Forest carbon stocks *(t C/ac)*	Total development *(Area)*	Deforestation *(Area)*	Deforestation *%*	Decrease in forest carbon stocks *(t C)*	Equivalent carbon dioxide emission *(t CO_2-e)*
Canterberry Crossing	42	3.2	2.3	88%	95	350
Edenwood	38	3.1	2.5	86%	96	351
Evetts Park	39	4.2	1.7	71%	67	245
Hidden Tree	41	3.2	1.8	82%	74	271
Norway Knoll	43	3.0	1.5	62%	63	230

4.1.2. Pierce County

In Pierce County the four development sites had carbon stocks of between 42 and 87 t C/ac. The loss in forest cover through development led to changes in stock in live trees equal to between

[14] http://fsgeodata.fs.fed.us/rastergateway/biomass/

631 and 2,216 t CO_2-e with an average of 1,237 t CO_2-e or 170 t CO_2-e per acre of the total area of the development (Table 10).

Table 10 Predevelopment carbon stocks and decrease in stocks as a result of forest conversion (acres) from development in zone MSF of Pierce County

Subdivision names	Forest carbon stocks (t C/ac)	Total development (Area)	Deforestation (Area)	%	Decrease in forest carbon stocks (t C)	Equivalent carbon dioxide emission (t CO_2-e)
Pierce-MSF-1	46	8.5	6.6	96%	304	1,113
Pierce-MSF-2	87	8.2	7.0	92%	604	2,216
Pierce-MSF-4	48	7.1	5.7	97%	269	988
Pierce-MSF-5	42	4.5	4.2	98%	172	631

4.1.3. Snohomish County

In Snohomish County the sixteen development sites had carbon stocks of between 32 and 68 t C/ac. The average carbon stock for the R-5 development sites was 44 t C/ac and the average for the R-9,600 sites was 37 t C/ac. The loss in forest cover through development led to changes in stock in live trees equal to between 59 and 4,737 t CO_2-e with an average of 1,044 t CO_2-e or 51 t CO_2-e per acre of the total area of the development. Looking at the development zones separately the mean emission from the R-5 development sites was 1,489 t CO_2-e and for the R-9,600 sites 598 t CO_2-e (Table 11).

Table 11 Predevelopment carbon stocks and decrease in stocks as a result of forest conversion (acres) from development in zone R-5 and R-9,600 in Snohomish County

Subdivision names	Forest carbon stocks (t C/ac)	Total development (Area)	Deforestation (Area)	%	Decrease in forest carbon tocks (t C)	Equivalent carbon dioxide emission (t CO_2-e)
Zone R-5						
Blacktail Forest	68	67.3	19.0	45%	1,292	4,737
Cascade Peaks	41	30.5	11.5	39%	472	1,729
Echo Ridge	48	21.9	4.3	20%	205	750
Kensrose Heights	35	19.1	5.2	27%	182	667
Quail Ridge	41	19.9	2.0	11%	82	300
Ridgewood Estates	39	57.5	18.0	38%	693	2,541
Snowbird	38	16.1	3.1	19%	118	432
Wardrum Woods	43	20.7	4.8	65%	206	757
Zone - 9,600						
Cedarwood Estates	36	3.5	1.1	74%	40	147
Copper Creek	39	14.2	7.1	65%	276	1,014

Creekwood	32	7.7	1.8	82%	58	213
Holly Hill Estates	33	3.7	2.0	57%	66	242
Lake View Park	35	2.6	0.5	82%	16	59
Margate	46	16.9	8.1	79%	372	1,366
Summerset	35	12.2	6.1	100%	213	780
The Park at Creekside	40	15.5	6.6	59%	263	965

4.2. Estimation of timber transferred to harvested wood product pool and immediate emissions from forest conversion

To estimate emissions from forest clearing, knowledge about the fate of the cleared biomass is needed. Interviews with county planners and property developers revealed that merchantable timber is sold when land with forest cover is cleared for development. This information was used to determine carbon stocks transferred to harvested wood products and long-term emissions from this pool. We assumed that the proportion of cleared forest vegetation that is merchantable timber is transferred to harvested wood products.

The simplifying assumption is made that any products projected to still be in use or stored in landfills 100 years after harvest are a permanent sequestration with the remaining proportion considered immediately emitted.

The relative amount of the initial stock that would have been extracted for wood product production and the proportions in use or in landfills after 100-years is derived from US Forest Service data and analyses (Table 12)[15]. Forest type was determined from the USFS FIA carbon stock maps and the Pacific Northwest-West region was used to determine the fractions of softwood and hardwood growing stocks, and sawtimber volumes.

Table 12 Average disposition patterns of carbon as fractions in industrial roundwood in the Pacific Northwest, West 100 years following harvest[16]

Year after production	Hardwood				Softwood			
	In use	Landfill	Energy	Emitted w/o energy	In use	Landfill	Energy	Emitted w/o energy
100	0.030	0.177	0.448	0.345	0.130	0.279	0.242	0.349

[15] Smith, J.E., Heath, L.S., Skog, K.E. and Birdsey, R.A. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-243. Newtown Sq, PA. USDA.

[16] Smith, J.E., Heath, L.S., Skog, K.E. and Birdsey, R.A. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-243. Newtown Sq, PA. USDA.

A permanent ban on land-clearing burning in Snohomish, King, and Pierce Counties was adopted by the Puget Sound Clean Air Agency (PSCAA), and went into effect July 1, 2008.[17] Other means that may be used to dispose of vegetation from land clearing include chipping, energy recovery or incineration at appropriate facilities, or landfill.[18] For example, a strong business infrastructure has developed in Pierce County diverting landclearing debris to recycling, landscape mulch, or for energy as hog fuel.[19]The simplifying assumption is made that this material is diverted to incineration facility with direct conversion of biomass to CO_2 with minimal emission of non-CO_2 gases. Any avoided emission from substitution of hog fuel for fossil fuels is not included here at this time.

4.2.1. King County

In King County the total emissions from forest conversion incorporating the impact of harvested wood products and energy recovery ranged from 186 t CO_2-e to 279 t CO_2-e with an average of 235 t CO_2-e (Table 13).

Table 13 Emissions from conversion of forest to urban area in zone R-4 in King County

Subdivision name	Forest carbon stock change (t CO_2-e)	HWP emissions (t CO_2-e)	Energy recovery emissions (t CO_2-e)	Total emissions (t CO_2-e)
Canterberry Crossing	350	105	173	278
Edenwood	351	103	176	279
Evetts Park	245	72	122	194
Hidden Tree	271	67	171	238
Norway Knoll	230	71	115	186

4.2.2. Pierce County

In Pierce County the total emissions from forest conversion incorporating the impact of harvested wood products and energy recovery ranged from 508 t CO_2-e to 1,664 t CO_2-e with an average of 959 t CO_2-e (Table 14).

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[17] http://www1.co.snohomish.wa.us/Departments/PDS/Divisions/Fire_Marshal/Burninfo.htm

[18] WAC 173-425-040

[19] Pierce County Department of Public Works and Utilities. 2008. Stepping up to the Challenge. Supplement to the Tacoma-Pierce County Solid Waste Management Plan.

Table 14 Emissions from conversion of forest to urban area in zone MSF in Pierce County

Subdivision	Forest carbon stock change (t CO_2-e)	HWP Emissions (t CO_2-e)	Energy Recovery Emissions (t CO_2-e)	Total Emissions (t CO_2-e)
Pierce-MSF-1	1,113	342	538	880
Pierce-MSF-2	2,216	817	847	1,664
Pierce-MSF-4	988	307	476	783
Pierce-MSF-5	631	192	316	508

4.2.3. Snohomish County

In Snohomish County the total emissions from forest conversion incorporating the impact of harvested wood products and energy recovery ranged from 374 t CO_2-e to 3,642 t CO_2-e in zone R5 with an average of 1,202 t CO_2-e. In zone R-9,600 emissions ranged from 52 t CO_2-e to 1,080 t CO_2-e with an average of 495 t CO_2-e (Table 15).

Table 15 Emissions from conversion of forest to urban area in zones R-5 and R-9,600 in Snohomish County

Subdivision name	Forest carbon stock change (t CO_2-e)	HWP Emissions (t CO_2-e)	Energy Recovery Emissions (t CO_2-e)	Total Emissions (t CO_2-e)
Zone R-5				
Blacktail Forest	4,737	1,608	2,034	3,642
Ridgewood Estates	1,729	555	936	1,491
Wardrum Woods	750	247	396	643
Cascade Peaks	667	208	371	579
Echo Ridge	300	95	161	256
Kenrose Heights	2,541	750	1,279	2,029
Quail Ridge	432	137	237	374
Snowbird	757	229	372	601
Zone R-9,600				
Cedarwood Estates	147	45	80	125
Creekwood	1,014	301	510	811
Summerset	213	63	118	181
The Park at Creekside	242	69	126	195
Copper Creek	59	19	33	52
Holly Hill Estates	1,366	420	660	1,080
Lake View Park	780	244	435	679
Margate	965	309	526	835

4.3. Post-development carbon sequestration

To develop an estimate of carbon sequestration post-development, it is necessary to correlate lot size and:

a. Impervious area (i.e. the footprint of buildings plus patios, decks, paths and driveways) – the area unavailable for biomass accumulation

b. Biomass of grass and other non-herbaceous vegetation

c. Biomass of shrubs

d. Biomass of trees

A sample of subdivisions developed in the last 10 years in the zones with the highest level of development was selected for field measurements and property owners were contacted to obtain permission to access properties for field work. The objective of field measurements was to gather data to estimate post-deforestation carbon stocks on forested land that is converted to moderate density residential subdivision development in King, Pierce, and Snohomish Counties. The assessment considered the conversion of forest to the following land covers: landscaping vegetation, street trees, open spaces, and impervious surfaces.

4.3.1. Field measurements of existing biomass in developed residential areas

The field sites were defined using parcel data to determine the boundaries of residential subdivisions and individual lots. Initially the study area included 8 moderate density residential subdivisions from the three counties comprising 174 residential lots. Due to low response rate (<10%) to requests to access properties for measurements, additional subdivisions were added to the study area. Where required, permission to access lots was requested in the field from property owners so that additional lots could be included in the sample. Biomass measurements were collected from a total of 97 properties in subdivisions ranging in age from recently developed to those developed several decades previously. Landscaping vegetation within the boundaries of residential lots was measured, including isolated trees, shrubs, grass, and other herbaceous vegetation.

For each property measured, a complete inventory of vegetation and impervious surfaces was conducted. More detail on field methods may be found in the field measurement plan included in Annex 2.

4.3.2. Calculation of carbon stocks

The carbon stocks in trees, shrubs, and herbaceous vegetation cover was estimated for each property included in measurements. For trees and shrubs, allometric equations were applied to estimate biomass using appropriate correction factors as needed. For shrubs, an allometric equation developed for shrubs in Shasta County, California was used[20]. For trees, we used allometric equations developed from a compilation of equations from the literature predicting the biomass of trees from diameter measures for species in the United States. Carbon stocks in grass and other herbaceous vegetation were estimated using conversion factors from Jo and McPherson 1995.[21]

Relatively high variation was recorded for all categories arising from the variability in land management associated with the individual preferences and interests of the home owners. In particular, trees and shrubs can be planted at any point in time so that some present after 30 years for example will have been planted immediately after development but others would have been planted at any point in the intervening years.

Impervious area

In the 174 lots measured in the Puget Sound area the impervious area was recorded. The relationship between lot size and impervious area is displayed in Figure 15. Impervious area approaches 100% in very small lots but drops to below 20% in lots of more than 1.5 acres.

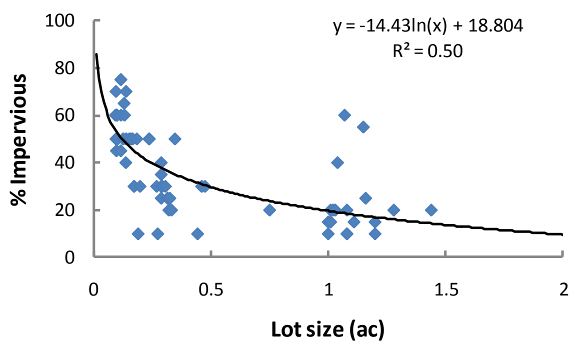

Figure 15 Relationship between lot size and impervious area

Biomass of grass and other herbaceous vegetation

Grass cover varies from almost zero in very small lots to approximately 50% in 1.5 acre lots (Figure 16). Non-grass herbaceous vegetation has very low coverage in all instances (2-3%). There was no strong relationship between non-herbaceous grass cover and lot size.

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[20] Goslee, K., T. Pearson, S. Brown, B. Rynearson, L. Bryan, S. Petrova, and S. Grimland. 2010. WESTCARB Afforestation Pilot Projects in Shasta County, California. California Energy Commission, PIER. CEC-500-2010-XXX.

[21] Jo, H, McPherson, G. 1995. Carbon storage and flux in urban residential greenspace. *Journal of Environmental Management* 45 (109-133).

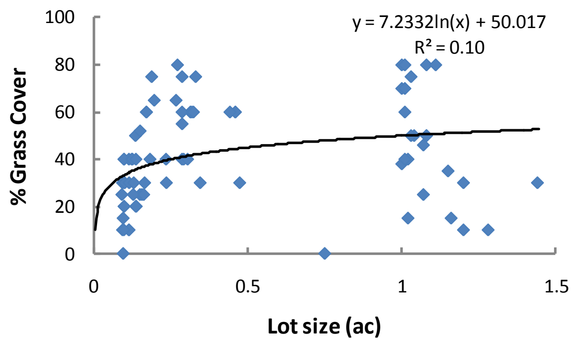

Figure 16 Relationship between lot size and area of grass

Biomass of shrubs

The relationship between lot size and number of shrubs and between mean shrub biomass and years since development are shown in Figure 17. The number of shrubs increases slightly with lot size, varying between approximately 10 shrubs in very small lots to 30 shrubs in 1.5 acre lots. Mean biomass of planted shrubs increases with time, reaching approximately 0.3 t C / shrub at 25 years post-development. Here we make the assumption that the long term average stock can be approximated by the predicted biomass of individual shrubs after 20 years of growth multiplied by the number of shrubs per lot.

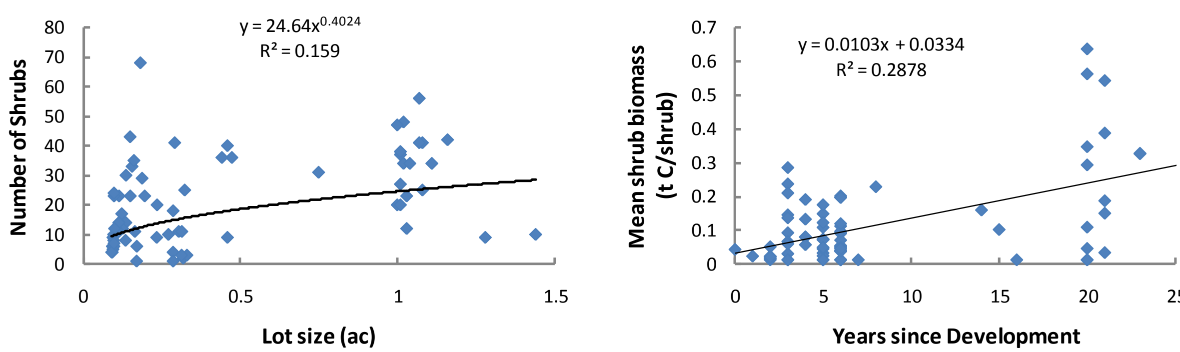

Figure 17 Relationship between lot size and number of shrubs and relationship between years since development and mean shrub biomass

Biomass of trees

For trees the area available for planting was defined by the area not covered by an impervious surface. A relationship between the non-impervious area and the total number of trees per lot was developed (Figure 18). Due to the fact that trees can be planted at any point in time the maximum diameter at breast height (DBH) of trees measured in the developed lots was used in the analysis with the assumption that these trees would have been planted shortly after initial development. It was assumed that trees with DBH greater than this maximum had not been felled during development and were excluded. The relationship between the number of years since development and maximum DBH of trees is shown in Figure 19(b). The species that can be planted and therefore the ultimate biomass of planted trees varies with plot size. Based on the collected data and expert opinion the average DBH once the developed yards have reached maturity are estimated to be:

For yards ≤ 0.15 acres	15 cm
For yards 0.16 – 0.49 acres	30 cm
For yards ≥ 0.5 acres	50 cm

Using allometric equations[22] the mean stock per tree was calculated for the assumed mature post-development tree (15 cm DBH – 0.07 t; 30 cm DBH – 0.39 t; 50 cm DBH – 1.33 t). This mean stock was then applied to the projected relationship between number of trees per lot and non-impervious area.

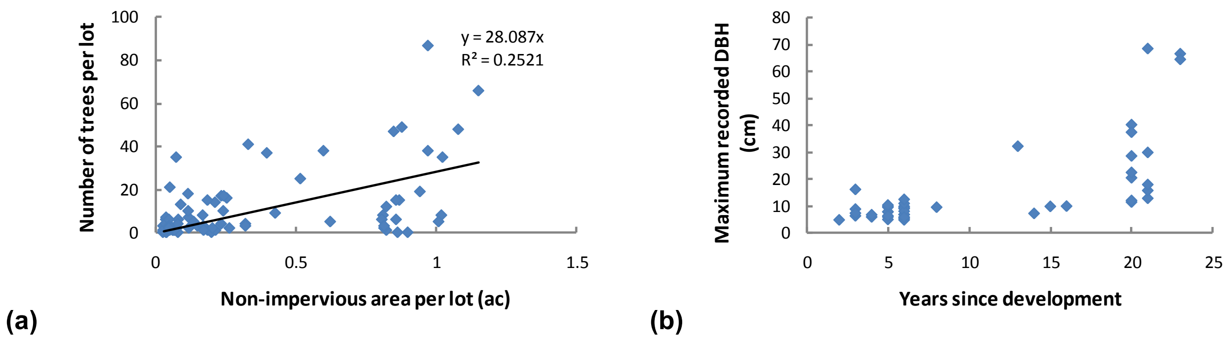

Figure 18 Relationship between number trees in a developed lot and the total non-impervious area in each lot and relationship between the number of years since development and the maximum recorded breast height diameter (DBH)

Total Stocks

The post-development carbon stock for areas deforested during development will be equal to the sum of stocks in trees, shrubs and herbaceous vegetation. In Figure 19 and Table 16 the estimated stocks are shown by lot size. Total stocks vary from 1.27 tons of carbon in a 0.1 acre lot to more than 39 t C in a 2 acre lot.

[22] Jenkins, J.C.; Chojnacky, D.C.; Heath, L.S.; Birdsey, R.A. 2003. National scale biomass estimators for United States tree species. Forest Science. 49: 12-35.

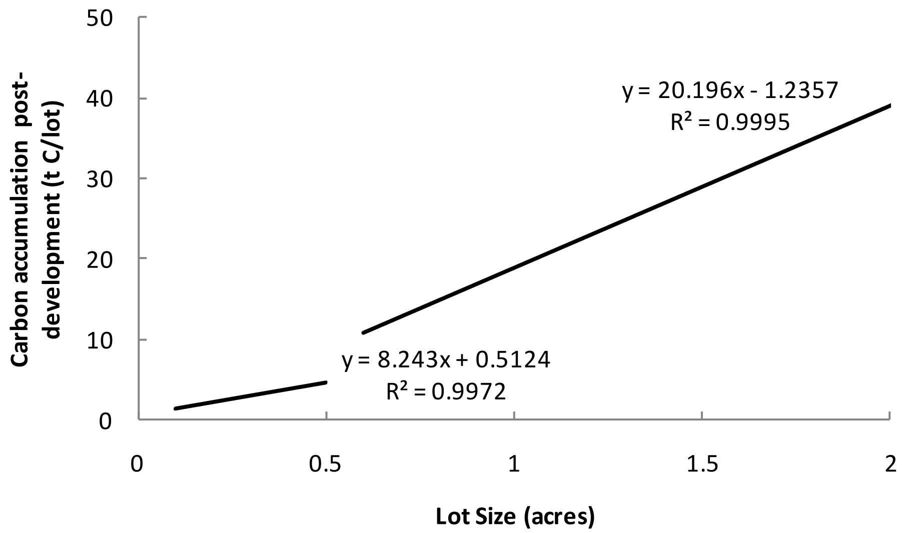

Figure 19 Relationship between lot size and carbon accumulation in all vegetation types post-development

Table 16 Estimated carbon stocks in herbaceous vegetation, shrubs and trees by lot size. Also displayed are the estimated % of the lot that is impervious, % covered by grass plus the estimated ultimate number of shrubs and trees.

Lot Size ac	Impervious %	Grass %	Number of trees	Total tree biomass t C	Total grass biomass t C	Total non-grass herbaceous biomass t C	Number of shrubs	Total shrub biomass t C	Total biomass t C
0.1	52	33	1	0.0	0.03	0.00	10	1.20	1.27
0.2	42	38	3	0.6	0.07	0.01	13	1.56	2.21
0.3	36	41	5	1.0	0.12	0.01	16	1.92	3.01
0.4	32	43	8	1.6	0.16	0.01	18	2.15	3.88
0.5	29	45	10	1.9	0.21	0.01	20	2.39	4.56
0.6	26	46	12	8.0	0.26	0.01	21	2.51	10.76
0.7	24	47	15	10.0	0.31	0.02	23	2.75	13.04
0.8	22	48	18	12.0	0.36	0.02	24	2.87	15.21
0.9	20	49	20	13.3	0.41	0.02	25	2.99	16.71
1	19	50	23	15.3	0.47	0.02	27	3.23	19.00
1.1	17	51	26	17.3	0.52	0.02	28	3.35	21.17
1.2	16	51	28	18.6	0.57	0.03	29	3.47	22.67
1.3	15	52	31	20.6	0.63	0.03	30	3.59	24.84
1.4	14	52	34	22.6	0.68	0.03	31	3.71	27.01
1.5	13	53	37	24.6	0.74	0.03	32	3.83	29.18
1.6	12	53	40	26.6	0.80	0.03	33	3.95	31.35
1.7	11	54	42	27.9	0.85	0.03	34	4.07	32.86
1.8	10	54	45	29.9	0.91	0.03	35	4.19	35.03
1.9	10	55	48	31.9	0.97	0.04	36	4.31	37.20
2	9	55	51	33.9	1.02	0.04	36	4.31	39.25

4.4. Full Accounting of Development Emissions

Full accounting of development emissions must capture both the emissions from clearing t forest and the sequestration that occurs after development. Here the total net emissions are estimated for the 25 analyzed development sites across King, Pierce and Snohomish Count

This study did not include soil emissions, though site preparation could cause significant emissions from soil disturbance. Following site preparation, landscaping restores soil carb while impervious surfaces completely stop emissions. Small lots result in a relatively large proportion of impervious surface to total lot area, possibly resulting in zero net change in s carbon stocks. Further investigation is needed to characterize soil carbon emissions resulti from conversions of forest to suburban area.

4.4.1. King County

In King County development resulted in net emissions for all subdivisions included in the analysis, as shown in Table 17. Net emissions ranged from 70 t CO_2-e to 177 t CO_2-e.

Table 17 The net greenhouse gas emission/sequestration from urban developm (acres) at five sites in Zone R-4 in King County

Subdivision names	Total development area	Number of built lots	Average size of built lots	Built lots as a proportion of total area	Development emission t CO_2-e	Carbon stock recovery t CO_2-e	N en t
Canterberry Crossing	3.2	20	0.12	75%	278	110	
Edenwood	3.1	15	0.16	80%	279	102	
Evetts Park	4.1	10	0.35	85%	194	124	
Hidden Tree	3.2	19	0.12	71%	238	105	
Norway Knoll	3.0	20	0.12	78%	186	109	

4.4.2. Pierce County

In Pierce County development resulted in net emissions for all subdivisions included in the analysis, as shown in Table 18. Net emissions ranged from 412 t CO_2-e to 1,418 t CO_2-e.

Table 18 The net greenhouse gas emission/sequestration from urban development (acres) at four sites in Zone MSF in Pierce County

Subdivision names	Total development area	Number of built lots	Average size of built lots	Built lots as a proportion of total area	Development emission t CO_2-e	Carbon stock recovery t CO_2-e	Net emission t CO_2-e
Pierce-MSF-1	8.5	51	0.17	100%	880	353	527
Pierce-MSF-2	8.2	25	0.26	80%	1664	246	1,418
Pierce-MSF-4	7.1	59	0.11	92%	783	308	475
Pierce-MSF-5	4.5	15	0.15	50%	508	96	412

4.4.3. Snohomish County

In Snohomish County development resulted in net emissions for some subdivisions while other subdivisions showed net sequestration (negative net emissions) as shown in Table 19. Net emissions ranged from 12 t CO_2-e to 670 t CO_2-e. Net sequestration ranged from 8 t CO_2-e to 335 t CO_2-e. Net sequestration can result when the emissions from forest clearance are low and the pre-development carbon stocks on developed land are low. Low emissions from forest clearance can be a result of low initial forest cover or high forest cover retention. Low carbon stocks on land prior to development can result from low initial forest cover on developed land or direction of development away from forested areas.

Table 19 The net greenhouse gas emission/sequestration from urban development (acres) at 15 sites in zone R-5 and R-9,600 in Snohomish County

Subdivision name	Total development area	No. of built lots	Average size of built lots	Built lots as a proportion of total area	Development emission t CO_2-e	Carbon stock recovery t CO_2-e	Net emission t CO_2-e
Zone R-5							
Blacktail Forest	67.3	51	1.07	81%	3642	3815	-173
Cascade Peaks	30.5	14	1.09	50%	1491	1070	421
Echo Ridge	21.9	7	1.03	33%	643	501	142
Kenrose Heights	19.1	9	1.01	47%	579	630	-51
Quail Ridge	19.9	9	0.46	21%	256	142	114
Ridgewood Estates	57.5	25	1.10	48%	2029	1925	104
Snowbird	16.1	5	1.04	32%	374	361	13

Wardrum Woods	7.6	12	1.11	176%	601	936	-335
Zone R-9,600							
Cedarwood Estates	3.5	25	0.11	81%	125	133	-8
Copper Creek	14.2	53	0.11	42%	811	281	530
Creekwood	7.7	30	0.12	48%	181	169	12
	3.7	15	0.17	69%	195	105	90
Lake View Park	2.6	13	0.17	85%	52	92	-40
Margate	16.8	61	0.16	58%	1080	410	670
Summerset	12.2	32	0.23	61%	679	284	395
The Park at Creekside	15.5	68	0.10	43%	835	327	508

5.0 Forest Conversion and Carbon Projects

The opportunity to provide economic incentives for preventing the conversion of forest land to other uses through a carbon credit trading system has been explored by the Washington State Government. The following issues were identified in Washington State's Department of Natural Resources Future of Washington Forests Report as challenges to creating a carbon credit system that would bring financial benefits to forest land owners:

1. Establishing carbon ownership rights;
2. Determining the source of carbon credit generation and compensation;
3. Estimating baseline carbon stocks above which carbon credits can be traded;
4. Accounting for long term storage of carbon in wood products;
5. Addressing leakage caused by the displacement of conversion to alternative locations;
6. Ensuring permanence of credits generated by preventing conversion of forest land to other uses.

These same issues apply to the development of a financial mechanism to provide an economic incentive for reducing emissions from conversion of forest land to residential development. In regards to Point 3 above, the Forest Sector Workgroup of the 2008 Washington State Climate Action Team identified the baseline for avoided forestland conversion as "the carbon storage in trees left, if any, following development clearing according to current legal provisions." However, no estimation of this baseline exists.

Deforestation events for development are poorly accounted for under current greenhouse gas emission monitoring systems. If such knowledge was available it becomes possible to consider the costs and benefits of different forms of development and to make policy decisions to influence the magnitude of emissions associated with development. One mechanism that could be used is the crediting of development projects that improve upon the business-as-usual scenario in terms of emissions associated with deforestation for development.

Carbon projects are formulated based on the difference in carbon emissions or sequestration between a baseline, or business-as-usual scenario, and project case. For avoided emissions projects, carbon credits are calculated as the difference in carbon emissions between a baseline case, such as complete or partial deforestation of a tract of land for development, and the project case.

5.1. Issues for avoided conversion projects

Population growth and the expansion of urban area drive competition between incompatible land uses.

This raises several issues:

- With any avoided conversion project, there is always the risk of "leakage." Leakage refers to emissions that occur outside of the project boundary as a result of project activities. In the case of avoided forest conversion for development, there is the risk that development will be displaced from the project area to another forested location due to market demand, resulting in emissions associated with forest clearing at the other location. To prevent leakage, the Forest Sector Workgroup recommended that market demand for development be met with a smaller development footprint either through clustering or transfer into urban areas, avoiding displacement of development to other forested locations.
- Emission reduction credits awarded for avoided conversion should be "permanent," therefore forested tracts not developed as a result of clustering or other mechanisms should be permanently protected with a forest conservation easement or other legal instrument with similar third party enforceability and durability.
- Some of the timber removed during site preparation for development may be transferred to the Harvested Wood Products (HWP) pool or land-filled. This should be accounted for as a part of the estimation of emissions associated with forest conversion for development.
- Transaction costs to project developers are likely too high to provide an incentive for the crediting of emission reductions on a project-by-project basis. A performance standard approach, as detailed in the following section, would encourage broad participation while generating real and credible emission reductions.

5.2. Performance Standards

The purpose of carbon projects is to produce credits that are considered real and equal to emissions occurring from industry, transport, residences, agriculture and other emission sectors. For credits to be real they must lead to carbon benefits beyond the business-as-usual scenario or baseline. There are two approaches to assessing business-as-usual:

- Project-specific baselines

- Performance standard

Performance standards (also known as benchmarks) are one approach for defining the baseline and proving additionality for carbon offset projects. Well designed performance standards ensure, across a portfolio of projects, that the average project is providing additional carbon credits above the baseline due to a balancing of projects that will be overcredited with those that will be undercredited. Where a balance is not achieved and a standard leads to more overcrediting than undercrediting then so-called "hot air" is created. Credits are issued for emission reductions that are not really reductions and these are then traded allowing others to increase their own emissions leading to a net increase in the concentration of atmospheric greenhouse gases.

Performance standards are best applied when emissions or sequestration can be defined relative to a unit of production and where little variability in emissions or sequestration occurs from one location to another.

Performance standards function accurately only across a portfolio of similar project types. A proportion will be overcredited relative to the actual project-specific baseline and at least a balancing proportion should be undercredited.

5.3. Challenges to developing a mechanism to generate offsets from residential development

Various mechanisms could be considered for generating offsets from residential development. Mechanisms that create incentives for developers to mitigate emissions from site preparation by leaving trees standing on forest converted to residential subdivisions likely presents the greatest opportunity for developing such a mechanism. However, challenges exist.

5.3.1. Leakage

In terms of residential subdivision development, preventing residential development in areas with forest cover could lead to leakage because high demand for real estate produces likely would shift to another area. In another example, a subdivision project may reduce emissions from deforestation by creating less residential lots and designating part of the project area as greenspace, but result in conversion of forest elsewhere by another development project to fill the deficit in available housing units.

A clustered approach to development could present an option for mitigating leakage if the number of lots created by a given development is maintained by reducing the minimum allowable lot size. However, reducing the minimum allowable lot size through clustering could create an incentive for the development of large residential subdivisions in areas where they are not usually a common practice. For example, in Snohomish County, it is not likely that large lot residential subdivisions development would be a common practice in zone R-5 if it were not possible to reduce the minimum lot size to 1 acre through cluster development. As a result of density incentives, zone R-5 had the highest level of development of all residential zones assessed in applications to the Snohomish County Hearing Examiner for subdivision.

5.3.2. Additionality

In order for an offset project to generate a real positive impact on the atmosphere in terms of reduced GHG emissions, the project must be additional. This is to say that the project must prove that the offsets are generated as a direct result of the economic incentive of carbon financing. For project developers, the burden of proving the additionality of individual projects could be a barrier to participation in carbon markets

5.3.3. Carbon credit ownership

Various actors participate in the development process. While the developer might be responsible for site plans and site preparation for construction, the homeowner's association could be responsible for landscaping the developed properties. In order for a project to be able to sell the carbon credits, it must be able to prove that it has the rights to them. In the case of avoided emissions from forest conversion for residential development, the entity responsible for making decisions regarding the removal or retention of vegetation as a part of preparing sites for construction would be the owner of offsets.

5.4. A potential approach for creating a development offset category in the Puget Sound region

As described above an offset project that merely halts development in a forested area would be subject to great leakage risk. It is possible that as many or more emissions would result at the alternative site or sites to which the development was displaced. Instead, net emission reductions can result where the course of development is altered without changing the number or category of developed properties. Ultimately the area of forest retained within the full boundary of the development must be increased relative to the proportion that would remain under business-as-usual.

The relationship between the total area of a development parcel and percentage of original forest cover remaining after conversion to urban area, as determined by the spatial analysis conducted here (see Section 4), is shown in Figure 20. Forest cover cleared during conversion varied from 50-100% in areas of less than 16 acres but averaged 35% for development areas that exceed 16 acres (Figure 21).

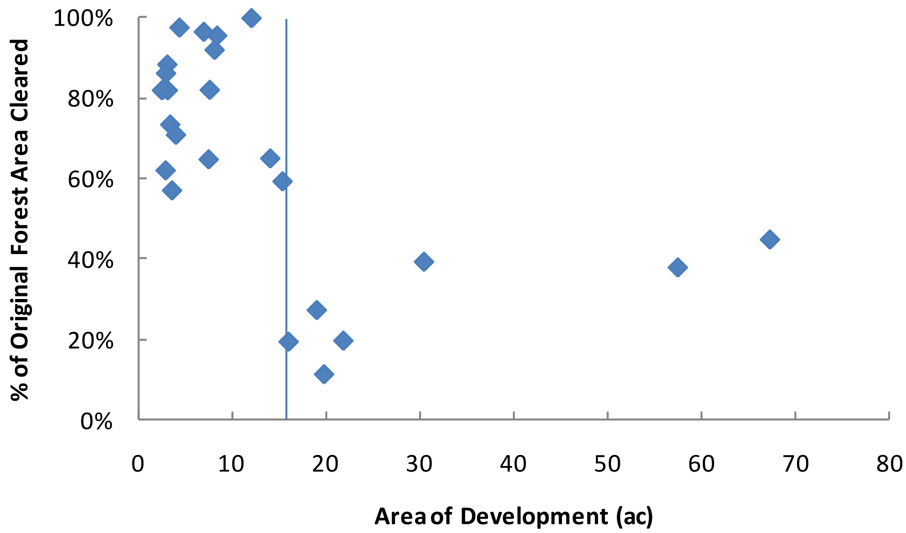

Figure 20. Relationship between total area of a development parcel and area of original forest cover remaining after conversion to urban area

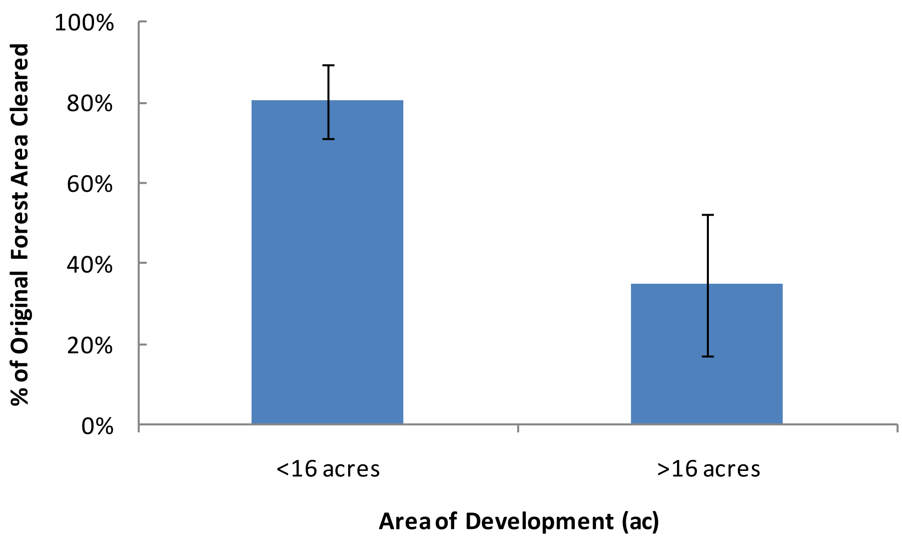

Figure 21 The percentage of original forest cover that is cleared in relation to total development size. Error bars represent 95% CI.

This relationship could form the basis of a future performance standard for development projects such that if a developer exceeded the defined area of forest retained by 10% or more then the carbon stocks of the retained forest would be creditable.

This is illustrated below in Table 20 in which areas of forest are planned for development. Here the baseline forest retention is calculated from the proportions in Figure 21 and the performance standard is this area inflated by 10%. The calculated offsets are equal to the emissions under the performance standard minus the emissions in the project case. The resulting available offsets range from 136 tons for a 10 acre development to almost 3,000 tons for a 60 acre development.

This emission reduction can also be calculated per unit developed (Table 21). In this case the baseline (which could be further developed into a performance standard) would be an emission of 55 t CO_2-e/unit for a 10 acre development with 0.20 acre lots up to 440 t CO_2-e/unit for a 60 acre development with 5 acre lots. In the project case the hypothetical emissions per unit are lower (due to the increased forest retention) leading to net emission reductions, which could be sold by the developer as offsets.

Table 20 Hypothetical example showing the emissions and emission reductions from increasing the area of forest retained across developments of different sizes. The forest carbon stocks in this example are 100 t C/ac

Area of Development *(Acres)*	Baseline Case Forest Retention *(Acres)*	# lots	Lot size *(Acres)*	Performance Standard Forest Retention *(Acres)*	Project Case Forest Retention *(Acres)*	# lots	Lot size *(Acres)*	Equivalent stocks *(t C)*	Incorporating Wood Products *(t C)*	Incorporating post-development sequestration *(t C)*	Offsets *(t CO2-e)*
10	2.0	35	0.20	2.2	2.4	35	0.18	71	61	37	136
20	13.0	42	0.35	14.3	15.6	42	0.25	473	402	287	1,053
30	19.5	40	0.50	21.5	23.4	40	0.35	709	603	444	1,627
40	26.1	25	1.00	28.7	31.2	25	0.50	946	804	659	2,417
50	32.6	17	2.00	35.8	39.0	17	1.00	1,182	1,005	586	2,150
60	39.1	8	5.00	43.0	46.9	12	2.00	1,419	1,206	816	2,991

Table 21 Estimated emission reductions for hypothetical developments in the Puget Sound region with calculations on a per unit developed basis

BASELINE CASE:

Area of Development (Acres)	Forest Retention (Acres)	# lots	Lot size (Acres)	Baseline Emission (t C)	Incorporating Wood Products (t C)	Incorporating post-development sequestration (t C)	Per unit ($t\ CO_2$-e)
10	2.0	40	0.20	804	683	597	54.70
20	13.0	42	0.35	697	593	450	39.29
30	19.5	40	0.50	1046	889	704	64.51
40	26.1	20	1.00	1395	1,185	757	138.75
50	32.6	17	2.00	1743	1,482	774	166.97
60	39.1	8	5.00	2092	1,778	960	440.21

PROJECT CASE:

Area of Development (Acres)	Forest Retention (Acres)	# lots	Lot size (Acres)	Project Emission (t C)	Incorporating Wood Products (t C)	Incorporating post-development sequestration (t C)	Per unit ($t\ CO_2$-e)	Emission Reduction ($t\ CO_2$-e /unit)
10	2.4	40	0.18	765	650	570	52.26	2.44
20	15.6	42	0.25	438	372	264	23.07	16.21
30	23.4	40	0.35	657	559	423	38.74	25.76
40	31.2	20	0.50	876	745	652	119.55	19.20
50	39.0	17	1.00	1095	931	567	122.21	44.76
60	46.9	12	2.00	1314	1,117	618	188.71	251.50

6.0 Conclusions

Site preparation for medium density residential development in the Puget Sound region results in a significant change in forest carbon stocks relative to initial forest cover and is likely an important source of emissions from the land use sector in Washington State. If options to create the same number of lots on a given parcel of land while maintaining forest cover by reducing the minimum allowable lot size through "cluster development" were more widely and strictly applied, it could be possible to mitigate emissions from forest conversion while avoiding leakage. Cluster development represents an available option to reduce emissions for development while preventing leakage – however, it is important to ensure that cluster development, by reducing the minimum lot size, does not result in an increased conversion of forest in rural areas where medium to high-density urban development would normally not occur.

Crediting developers for avoiding immediate emissions from site preparation through a performance standard likely offers a good opportunity for mitigating emissions from forest conversion to residential development. However, common practice for vegetation removal and disposal would need to be further explored in order to establish a performance standard to credit developers for exceeding common practice for site preparation. Likewise, a region-wide performance standard would need to be designed in a way to account for lot size and original vegetation cover as the most common lot size differed between counties and subdivision, and are developed on land with varying proportion of initial forest cover.

Finally, retaining forest cover and trees on residential properties does not guarantee that this vegetation will be retained over time by property owners in the absence of regulations such as tree ordinances. The carbon stocks on urban and suburban lands will always be less than carbon stocks on forest lands. County governments could also take actions to mitigate emissions from development by directed development to open lands as opposed to land with forest cover.

This study represents an initial analysis of the impact of development and associated forest conversion and emissions in the Puget Sound. The analysis shows the potential value of further examination of this category in the region. Emissions occurring are large and are likely largely unaccounted in inventories of greenhouse gas emissions. These emissions also present an opportunity for development of an offset project category. Where emissions can be reduced without leakage, as in cluster development, then these emission reductions should be creditable to developers and local authorities.

This study was limited to a sample of development sites from limited zoning categories. A future study should look more exhaustively at development that has occurred over the last 10 years and should use a similar methodology to calculate forest loss, the emissions resulting from forest loss and post development carbon stock recovery.

Emissions associated with urban development are not limited to those associated with the loss of forest. Greenhouse gas emission consequences are also associated with the materials used in construction (e.g. wood versus concrete and steel) and in the siting of development units with regard to the future commuting distance of future residents. An entire life cycle study would be immensely valuable for understanding the total greenhouse gas consequences of development decisions.

Annex 1: Complete Urban Residential and Rural Zone Listings included in Study for Pierce, Snohomish, and King Counties

Zone	Purpose and Intent	Code
	Pierce County	
Community Center	Commercial focus with some moderate to high density residential developments	CC
Moderate-High Density Residential	Areas that are composed of moderate and high density single-, two-, and multi-family housing and compatible civic uses	MHR
Moderate-Density Single Family	Moderate density single- and two-family residential activities and and compatible civic uses in areas with a mixed residential pattern	MSF
Single Family	Low and moderate density single- and two-family residential activities and compatible civic uses in areas with a predominantly detached single-family development pattern	SF
Reserve-5	Intended to provide for rural uses at a rural density and includes lands between the Rural 10 classification and the Rural 40 or Forest Lands classifications	Rsv-5
	Snohomish County	
Residential-7,200	Provide for predominantly single family residential development that achieves a minimum net density of four dwelling units per acre.	R-7,200
Residential-9,600	Provide for predominantly single family residential development that achieves a minimum net density of four dwelling units per acre.	R-9,600
Rural Resource Transition - 10 Acre	Implement the rural residential-10 (resource transition) designation and policies in the comprehensive plan, which identify and designate rural lands with forestry resource values as a transition between designated forest lands and rural lands	RRT-10
Rural-5 Acre	Maintain rural character in areas that lack urban services	R-5
	King County	
Residential-1	Predominantly single detached dwelling units and other development types with a variety of densities and sizes in locations appropriate for urban densities	R-1
Residential-4		R-4
Residential-6		R-6
Residential-8		R-8
Rural Area-2.5	Rural areas where the predominant lot pattern is below five acres in size for lots established prior to the adoption of the 1994 Comprehenisve Plan	RA-2.5
Rural Area-5	Rural areas where the predominant lot pattern is five acres or greater but less than ten acres in size and the area is generally environmentally unconstrained	RA-5

Annex 2: Field methods

WESTCARB Regional Characterization – Field Measurement Plan

The objective of field measurements described in this plan is to gather data to estimate post-deforestation carbon stocks on forested land that is converted to moderate density residential subdivision development in Snohomish, King, and Pierce Counties. The assessment will consider the conversion of forest cover to the following landcover: landscaping vegetation, street trees, open spaces, and impervious surfaces.

Definition of study area boundaries

The study area boundaries will be defined using parcel data to determine the boundaries of residential subdivisions and individual lots. The study area will include 8 medium density residential subdivisions from the three counties comprising 174 residential lots. For this study, moderate density residential development includes subdivisions with minimum lot size between 0.25 and 1 acre. The developed subdivision selected for field measurements are listed in Table 1.

Table 22. Medium density residential subdivisions selected for field measurements

County	Town	Subdivision	No. Lots
Pierce	Spanaway	Pierce-1	51
	Bonney Lake	Pierce-2	25
	South Hill	Pierce-3	23
	South Hill	Pierce-4	59
	Tacoma	Pierce-5	15
	Puyallup	Pierce-6	40
Snohomish	Snohomish	Wardrum Woods	12
	Monroe	Ridgewood Estates	25
	Arlington	Quail Ridge	9
	Stanwood	Blacktail Forest	49
	Stanwood	Cascade Peaks	13
	Arlington	Kenrose Heights	9
	Arlington	Echo Ridge	7
King	Renton	Cavanaugh	37
	Fall City	Evetts Park	9
	Bothell	Norway Knoll	15
	Federal Way	Creekside Lane	53
	Auburn	Adlers Cove	94
	Auburn	Hidden Tree	19

The vegetation in the study area will be divided into three preliminary strata.

Preliminary Strata

Baseline strata and existing land cover:

No.	Name	Description
1	Low vegetation	Landscaping vegetation within residential lot boundaries including isolated trees,

		shrubs, grass, other herbaceous vegetation and impervious surfaces (driveways and buildings)
2	Rights of way	Isolated trees or "street trees" located along rights of way within the boundaries of the residential development and impervious surfaces
3	Open space	Vegetation within the boundaries of land dedicated to public use in the residential subdivision. Open space may include public forests, parks, etc. with trees, shrubs, grass, and other herbaceous vegetation

Delineate Strata in GIS

Strata will be delineated based on existing aerial imagery and property boundary shapefiles.

Field Verify Strata

The accuracy of the GIS data layers used to define project boundaries and project strata must be assessed. GIS data used to define the boundaries of the project lands may not accurately portray what is found on the ground. For example, the GIS layer may be shifted slightly, or the accuracy may be lower than what would be appropriate for the project. Therefore, field verification of such features will take place.

A selection of carbon pools in each stratum will be included in measurements to estimate existing carbon stocks and GHG removals in the baseline.

The carbon pools measured for each stratum are listed in a separate table. In the low vegetation stratum, pools for which destructive sampling is required for direct measurement will be estimated using default values instead. This is because destructive sampling in residential lots will not be feasible.

The following staff will be included on the field measurement team that will be responsible for collecting the field measurements: Erin Swails, Sean Grimland, Felipe Casarim, Alex Grais, and Zack Smith. The field measurements will be collected between 19 - 23 July 2010. A brief field measurement training will be conducted on 19 July prior to commencing field measurements.

The approach to measurement of each stratum is as follows: low vegetation and impervious surfaces will be measured in the developed residential lots. For each residential lot included in measurements, a complete inventory of vegetation and impervious surfaces will be conducted. Street trees will also be inventoried. For open space with forest cover, sample plots will be used. For open spaces without forest cover, an inventory method will be used as for residential lots.

Sample size

For low vegetation, the sample size will depend on the response rate to the requests for permission to access private property. If necessary, permission to access lots will be requested in the field by knocking on property owners' doors so that additional lots can be included in the sample. For rights of way, the entire street tree population will be inventoried in each neighborhood where measurements are collected. In open space and undeveloped parcels with forest cover, 10% of the area of the parcel will be measured with sample plots.

Plot design

For the low vegetation strata and open spaces without forest cover, an inventory of above ground tree and non-tree woody biomass, herbaceous vegetation cover and impervious surfaces will be conducted in each residential lot selected for sampling. The plot will include the entire residential lot. For open space with forest cover, the plot design described in "Winrock – Terrestrial Carbon Measurement – SOP Manual" will be used.

Distribution of plots in project area

Plot locations will depend on the response rate to the requests for permission to access private property. Each property for which permission is granted will be measured. If additional lots must be selected in the field, every lot where permission to access the lot is granted will be measured.

Measurement Procedures

The same measurement procedures will be used for aboveground tree biomass in low vegetation, rights of way, and open space.

Above-ground tree biomass

DBH and height of each tree will be measured and recorded following the guidance in SOP: "SOP Measurement of Trees" and "SOP Measurement of Tree Height" in "Winrock – Terrestrial Carbon Measurement – SOP Manual." The species of each tree will also be recorded.

Shrubs

For isolated shrubs, the height and two diameters for each shrub will be measured and recorded following guidance in SOP: "SOP Measurement of Shrubs." For hedgerows, the length, width, and height of the hedgerow will be measured. The species of each shrub or hedgerow will be recorded.

Herbaceous vegetation and impervious surfaces

The percentage of each ground cover type in residential subdivisions and any open space without forest cover will be estimated to the nearest 5%:

- Herbaceous ground cover, other than grass
- Grass
- Impervious surfaces: buildings, driveways, etc.

Annex 3: Subdivisions included in field measurements

County	Zone	Subdivision	Town
King	R-4	Norway Knoll	Bothell
King	R-4	Cavanaugh	Renton
King	R-4	Creekside	Federal Way
Pierce	MSF	MSF-1	Spanaway
Pierce	MSF	MSF-3	South Hill
Pierce	MSF	MSF-4	South Hill
Pierce	MSF	MSF-5	Puyallup
Pierce	MSF	MSF-7	Bonney Lake
Snohomish	R-5	Blacktail Forest	Stanwood
Snohomish	R-5	Wardrum Wood	Snohomish
Snohomish	R-5	Kensrose Heights	Arlington
Snohomish	R-5	Ridgewood Estates	Monroe
Snohomish	R-5	Quail Ridge	Arlington