Arnold Schwarzenegger
Governor

EMISSIONS AND POTENTIAL EMISSION REDUCTIONS FROM HAZARDOUS FUEL TREATMENTS IN THE WESTCARB REGION

PIER PROJECT REPORT

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Prepared By:

WINROCK INTERNATIONAL

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission) conducts public interest research, development, and demonstration (RD&D) projects to benefit the electricity and natural gas ratepayers in California. The Energy Commission awards up to $62 million annually in electricity-related RD&D, and up to $12 million annually for natural gas RD&D.

The PIER program strives to conduct the most promising public interest energy research by partnering with RD&D organizations, including individuals, businesses, utilities, and public or private research institutions.

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- Buildings End-Use Energy Efficiency
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- Environmentally Preferred Advanced Generation
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This *Final Report on WESTCARB Fuels Management Pilot Activities in Shasta County, California* is a report for the West Coast Regional Carbon Sequestration Partnership – Phase II (contract number MR-06-03L, work authorization number MR-045), conducted by Winrock International. The information from this project contributes to PIER's Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Energy Commission's Web site at www.energy.ca.gov/pier or contact the Energy Commission at (916) 654-5164.

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Abstract

This report summarizes efforts by Winrock International and the WESTCARB Fire Panel to develop a methodology for estimating greenhouse gas (GHG) benefits of project activities to reduce emissions from wildland fires in low to mid elevation mixed conifer forests. These efforts focused on low to mid elevation mixed conifer forests and included a conceptual framework developed to aid in determining the full impacts of hazardous fuels treatments, four workshops with carbon and fire experts, numerous consultant activities, and field measurements of hazardous fuels treatments in Shasta County, California and Lake County, Oregon. The task of developing a rigorous methodology to quantify baseline emissions from wildland fires and emission reductions attributable to fuel reduction is complex due to the methodological challenges of modeling fire behavior and emissions, the relatively low annual risk of fire for any given potential project location, and the emissions resulting from fuels treatments. Given (current hazardous fuel removal technologies and) the low probability of fire on any given acre in any given year, hazardous fuel reduction treatments in the forest types addressed in this report cannot directly generate offsets. However, careful design of fuel treatments building from the methodology employed in this analysis can minimize risks to lives and property while also minimizing emissions. Integration of fire and an avoided emissions framework with other ecosystem services will go even further toward a sustainable approach to ecosystem management.

Keywords: *Carbon, sequestration, emission, forest, hazardous fuel reduction, California, wildland, fire, wildfire, greenhouse gas*

Executive Summary

Introduction

The West Coast Regional Carbon Sequestration Partnership (WESTCARB), led by the California Energy Commission, is one of seven US Department of Energy regional partnerships working to evaluate, validate and demonstrate ways to sequester carbon dioxide and reduce emissions of greenhouse gases linked to global climate change. Emissions from fire were identified in WESTCARB Phase I as the single largest source of GHG emissions from land use. Thus the focus of this research was to determine if GHG emissions from wildfire could be reduced and provide a potential opportunity for landowners to generate a new type of carbon mitigation or "offset" activity. For such activities to yield GHG offsets, rigorous measurement, monitoring and verification (MMV) methodologies and reporting protocols must be developed to meet the standards of voluntary and regulated markets for high-quality GHG reductions. Fire suppression and hazardous fuel accumulation are concerns primarily in low to mid elevation mixed conifer forests that prehistorically experienced frequent and low severity fires; we therefore focused our analysis and findings on these ecosystems.

Purpose

The aim of this research was to determine whether a methodology could be developed for use by developers of potential carbon projects to quantify their baseline emissions, project emissions with activities to reduce hazardous fuels, and estimate the associated project carbon benefit.

Project Objectives

The overall goal of WESTCARB Phase II is to validate and demonstrate the region's key carbon sequestration opportunities through pilot projects, methodology development, reporting, and market validation. WESTCARB research will facilitate informed decisions by policymakers, communities, and businesses on how to invest in carbon capture and storage technology development and deployment to achieve climate change mitigation objectives. The opportunity presented here is decreasing wildland fire emissions through hazardous fuel treatment, combined where feasible with fuel removal to a biomass energy facility.

Project Methodology

A conceptual framework was developed to determine the net impact hazardous fuel treatment activities have on the total quantity of greenhouse gases in the atmosphere? This framework incorporated the critical elements of fuel treatments and wildfire as they relate to net CO_2 emissions:

1. **Annual Fire Risk**
2. **Emissions as a Result of Treatment**
3. **Emissions as a Result of Fire**
4. **Removals from forest Growth / Regrowth**
5. **Retreatment**
6. **Shadow Effect**

The following framework was used to estimate losses and gains in stored carbon with and without treatments (with and without “project”) and fire:

Gain from *decreased* intensity or spread of fire due to fuel treatment within the treatment and shadow area * annual fire probability

+ **Loss** from biomass removed during treatment

+ **Gain** /**Loss** from substitution of fuels for energy generation

+ **Gain** from long term storage as wood products from removed biomass during fuels treatment

+ **Loss** from decomposition of additional dead wood stocks created through fuels treatment

+ **Gain** /**Loss** from growth differences between with and without treatment and with and without fire

+ **Loss** from fires occurring in with project case (with treatment) * annual fire probability

+ **Loss** from retreating stands through time

A positive net result indicates increased carbon storage as a result of the with-treatment project, while a negative net result indicates a net loss in carbon storage and increased emissions as a result of the with-treatment project.

The individual elements of this framework were quantified to determine their overall impact on net emissions/removal, and on-the-ground projects were implemented to test the overall validity of the framework.

Project Outcomes

Fire represents a significantly more complex opportunity than traditional land use greenhouse gas reduction activities such as afforestation, changes in forest management, and forest protection. This is because a fuel reduction project compares emissions that would have occurred from fires without any treatment on the landscape, which necessarily requires a complex fire baseline modeling effort, against emissions that did occur through fuel treatment. For this purpose it was necessary to examine the risk of a fire burning through a particular location or fireshed in a given year and the emissions that would occur if such a fire did occur.

The reality is that fire risk in any given location on the landscape considered in this report is relatively low (< 0.76% per year), and consequently amortized baseline emissions are low. This reality must be balanced with the emissions that occur when a catastrophic fire does occur. While emissions from fire in the baseline scenario are relatively low, emissions from fuel treatment in the project scenario are not insignificant in that they occur across a relatively broad area in order to intersect with an unknown future fire location.

Substantial emissions occur in the event of a wildfire but significant greenhouse gas emissions still occur on treated sites. In addition regrowth of a healthy forest means that sites have to be retreated with accompanying emissions on a regular schedule (likely <20 years). The impact of growth is complex but in the absence of wildfire growth modeling for these projects show that the treated stands as a whole will store less carbon than the untreated stands – the opposite is true in the event of a wildfire but such a fire is a low probability event.

Consolidating across the conceptual framework we can reached the following conclusions:

- Fire risk is very low (<0.76%/yr)
-Treatment emissions are relatively high and are incurred across the entire treated area
-Treatment never reduces fire emissions by more than 40% and on average across five sites only reduced emissions by 6%
-In the absence of fire, treatment reduces sequestration
-Retreatment will have to occur with accompanied emissions
-A positive impact of treatment beyond the treated area is not guaranteed and is unlikely to ever be large enough to impact net greenhouse gas emissions

So low fire probability is combined with high emissions and low sequestration in the absence of a fire and relatively few emissions reductions in the event of fire.

Conclusions

Reducing emissions from fire could be an important contribution to reducing CO_2 emissions overall, yet the inherent reduction of carbon stocks in hazardous fuels treatments, combined with the low annual probability of fire on a given acre of land prevent the development of a workable carbon offset methodology for such treatments. It may be possible that specific treatments, removing a minimum amount of small diameter ladder fuels in certain forest ecosystems can yield an overall emission reduction. Furthermore, low-emissions technologies to be developed in the future may yield increased emission reductions. In the case of the standard fuels treatments for mixed conifer forests in Northern California and Southern Oregon, which served as the field test for this research, treatments led to increased net emissions over the 60-year modeling period. However, reducing the risk of fire is a critical activity for many other reasons, including enhancing forest health, maintaining wildlife habitat, and reducing risk to life and property, and so hazardous fuel treatments must go ahead and should be planned to minimize net emissions.

In today's world where actions to curb atmospheric greenhouse gas concentrations are growing more urgent, an accurate accounting is important of all emission sources (and sinks) at national, regional and local scales. The work completed here allows a better understanding of the relative emissions that arise from hazardous fuel treatments and wildfires in low to mid elevation mixed conifer forests. While our results show that, in the absence of wildfire, fuels treatments did not lead to net emission reductions at these demonstration sites, it is important for planners to understand relative greenhouse gas emissions in order to be able to design treatments in a way that minimizes emissions while maximizing non-greenhouse gas benefits.

1.0 Introduction

1.1 Background and overview

The West Coast Regional Carbon Sequestration Partnership (WESTCARB), led by the California Energy Commission, is one of seven US Department of Energy regional partnerships working to evaluate, validate and demonstrate ways to sequester carbon dioxide and reduce emissions of greenhouse gases linked to global warming. Terrestrial (forestry and land use) sequestration options being investigated include afforestation, improved management of hazardous fuels to reduce emissions from wildfires, biomass energy, and forest management. Shasta County, California and Lake County, Oregon were chosen for WESTCARB Phase II terrestrial sequestration pilot projects because of the diversity of land cover types present, opportunities to implement the most attractive terrestrial carbon activities identified in Phase I, and replication potential elsewhere in the WESTCARB region.

Fire was identified as the single largest source of emissions from forestland in California (Brown et al 2004). In California an estimated 1.83 $MMTCO_2e$ are emitted per year due to fires on forests and rangelands (Pearson et al. 2009). For Oregon the value is 1.03 $MMTCO_2e$/yr, for Washington 0.18 $MMTCO_2e$/yr and for Arizona 0.47 $MMTCO_2e$/yr (Pearson et al. 2007 a,b,c). Policy mechanisms and/or incentives to decrease these emissions could therefore have profound effects on GHG emissions at the state and regional levels.

All carbon project activities work through interventions that lead to a decrease in emissions or an increase in removals (sequestration) relative to a reference or baseline case. In this situation, a carbon project developer would need to estimate the emissions from fire that are likely to occur within defined project boundaries without the implementation of project activities, and how the implementation of project activities would decrease these emissions. Therefore, the substantial challenge is to define the risk of fire and the emissions associated with that risk and to quantify how fuels treatments can diminish these emissions. A good deal of anecdotal evidence exists suggesting that fuels treatments in particular locations have appeared to reduce the intensity, spread, or emissions from fires, and/or slow the progress of fires enough to make suppression feasible. The challenge in this effort is to move from anecdotal evidence to a rigorous scientific methodology, quantifying in a transparent and replicable way the GHG benefits attributable to fuel treatments.

1.2 Project Objectives

The overall goal of WESTCARB Phase II is to validate and demonstrate the region's key carbon sequestration opportunities through pilot projects, methodology development, reporting, and market validation. WESTCARB will produce methodologies, plans, data, technical papers, and reports that facilitate informed decisions by policymakers, communities, and businesses on how to invest in carbon capture and storage technology development and deployment to achieve climate change mitigation objectives. This report focuses on one of those opportunities, creation of a methodology to track wildfire emissions reductions attributable to fuel treatments.

1.3 Report Organization

The report is organized in six key sections. In Section 2 the literature background is given together with the process undertaken: a straw-man method and the fire panel and work with fire experts. In Section 3 the analyses and results from work by fire experts are discussed. In Section 4 details and results are given from the parallel pilot studies that were undertaken under WESTCARB in Shasta County, California and Lake County, Oregon. In Section 5 the results from the consultancies and the field projects are integrated and conclusions made on the possibility of developing a methodology. In Section 6 literature that contrasts with our findings is reviewed in order to identify the sources for the different conclusions. Finally in Section 7 conclusions and recommendations are made addressing the implications of these findings and future opportunities.

2.0 Literature Background, a Straw-man and the Fire Panel

2.1 Current Status of Knowledge on Fire, Fuels Treatments and Greenhouse Gases

Calculating potential offsets from removal of hazardous fuel requires properly addressing all of the expected changes in carbon stocks and emissions that result from treatments. Past studies have addressed change in carbon stocks as a result of fire suppression policies, emissions from wildfire, and the effectiveness of treatments. More recently, a few researchers have addressed the impacts of hazardous fuels treatments on carbon stocks. However, these studies did not produce consistent results and did not always fully address all possible carbon stocks and sources of emissions. Much of this past research has considered emissions from fire as a given or has assumed that 100% of biomass removed in treatments will be utilized and none is emitted due to inefficiencies or decomposition. We explored existing research to identify which factors were considered when calculating the carbon balance of hazardous fuels treatments and to determine the most comprehensive methodology for such calculations.

2.1.1 Effects of fire suppression on carbon storage

Forest ecosystems in the U.S. provide a carbon sink that is estimated to be between 0.17 Pg C/yr and 0.37 Pg C/yr (Pacala et al. 2001). While some research has found that present day forests have lower live-tree carbon stocks than under historic active-fire conditions (North *et al*. 2009, Fellows and Golden 2008), numerous studies have found that 100 years of fire suppression has led to an increase in carbon stored in forests. Findings indicating an increase in sequestered carbon range in scope from the entire U.S. carbon sink (Houghton *et al*. 2000, Hurtt *et al*. 2002) to specific ecosystems such as oak savannah (Tilman *et al*. 2002) and Sierra mixed conifer forests (Bouldin 2009). With an increase in overall biomass, there is the potential for wildfires to release an increased amount of carbon to the atmosphere, especially as they become crown fires rather than simply surface fires, and it is important to have an understanding of the relationship between increased sequestration and increased wildfire emissions.

2.1.2 Pyrogenic CO_2 emissions

While wildfires where they occur may produce a high level of emissions, and may turn a forest from a carbon sink into a carbon source in the short-term, their impact over the long term is likely to be far less than anthropogenic emissions. A study of wildfires in the Metolius watershed in Oregon over two years found that emissions were equal to 2.5% of the statewide emissions of CO_2 from fossil fuel use and industrial processes during the same period (Meigs *et al.* 2009). Dore *et al.* (2008) found that after a stand-replacing fire, carbon losses may continue due to the slow recovery of gross primary production. However, Meigs *et al.* point out that most fires are not stand-replacing, and so it is important to account for the emissions from low to moderate severity fires. Campbell *et al.* (2007) found that over 60% of the emissions in a large wildfire in Oregon came from surface fuels, which would decompose over a period of 10 to 20 years in the absence of a fire, and would for the most part be emitted into the atmosphere anyhow.

Wiedinmyer and Neff (2007) address the variability of CO_2 emissions from fires across the U.S. that they say produce, on average, 4-6% of anthropogenic emissions. They state that wildfires have a near neutral effect on atmospheric CO_2 over the course of multiple decades when regrowth is allowed and factored into the equation. They also point out that fire presents one of the greatest risks to stored terrestrial carbon in the short term, and this risk introduces a high level of uncertainty in projecting forest carbon storage, particularly with changes in fire frequency. However, the effects of such changes are ecosystem-dependent. In looking at the case study of the Yellowstone fires, Kashian *et al.* (2006) found that with the long fire return intervals and relatively rapid regeneration that occurs in that ecosystem, landscape-level carbon storage is not significantly changed as a result of changes in fire frequency because these forests regenerate at such a rapid rate.

2.1.3 Effectiveness of fuels treatments

The basis for hazardous fuels treatments is that they reduce the intensity and extent of subsequent wildfires. It is reasonable to imagine that different fuels treatments yield different results in terms of reducing the severity and extent of wildfires. Agee and Skinner (2005) discuss a three-part objective for fuels treatments: reducing surface fuels, reducing ladder fuels, and reducing crown, and note that these goals can be accomplished using prescribed fire and thinning. However, they caution that not every forest is a high priority candidate for treatment. Lippke *et al*. (2007) found that treating the stand for a target basal area led to decreased wildfire hazard for 45 years, while removing all of the trees under 9 inches diameter at breast height (dbh) or over 12 inches dbh had little or no effect on wildfire intensity and extent. North *et al.* (2009) also found that removing overstory trees did not significantly improve fire resistance. Hurteau and North (2009) looked at eight types of treatments in Sierra Nevada mixed conifer forests and found that those that created a stand with lower tree density of primarily large, fire resistant pines were most successful at protecting the stand. Similarly, Lenart *et al*. (2009) note that after the Rodeo-Chediski fire in Arizona, those stands that had been thinned of smaller diameter trees sustained less damage than unthinned stands.

The success of treatments also depends on the forest ecosystem. Pollet and Omi (2002) show that while fuels treatments are often successful in forests with short fire-return intervals, they are less cost-effective in stands with longer fire-return intervals, and placement of treatments should be balanced with the risk of loss from a fire in urban interface areas. Schoennagel *et al*. (2004) show that while fuel load has the greatest impact on fire behavior in some areas, climatic factors are more significant in other areas where thinning may not significantly impact wildfire behavior.

It is also important to note that different types of treatments will lead to different levels of biomass reduced and carbon emitted. Lippke *et al*. (2007) note that all treatments reduce carbon storage, while not all reduce wildfire severity. The treatments that Stephens and Maghaddas (2005) and Zald *et al.* (2008) found to be most successful at reducing the severity of fires incorporate understory thinning and prescribed burning to reduce surface fuels. In a prescribed burn, the majority of the treated material is an immediate emission, although Narayan *et al*. (2007) found that prescribed fire can have reduced emissions when compared to wildfire, depending on the fire return interval. In the case of understory thinning, in many areas there are no mechanisms to use small diameter wood, and most or all of the biomass removed in such treatments will be emitted to the atmosphere as CO_2 in a relatively short time frame. North *et al*. (2007) suggest that historic forest conditions may be best adapted to resisting stand replacing fires, but they found that thinning alone did not return stands to these conditions; understory thinning combined with prescribed fire was the treatment that most closely resulted in forests that approximated 1865 conditions.

2.2 Conceptual Framework

The aim of this research was to produce a methodology that could be used by potential carbon projects to quantify their baseline emissions, project emissions with activities to reduce hazardous fuels, and estimate the associated project carbon. To that end we developed a general conceptual framework under which a detailed conceptual model could be tested to determine the full impacts of hazardous fuels treatments on wildfire and greenhouse gas emissions. The basic question is-

What net impact do hazardous fuel treatment activities have on the total quantity of greenhouse gases emitted to the atmosphere?

The general conceptual framework includes the approach for estimating the emissions in the baseline case (without fuel treatment) and the approach for the project case (with fuel treatment) as follows:

The baseline case is estimated as:

> The area that would have burned in the absence of project activities multiplied by the emissions that would be expected per unit area burned.

The project case is equal to:

> The estimated emissions from removal of hazardous fuels less any carbon stored in long-term wood products or reduced emissions from bioenergy substitutions, plus

emissions per unit area burned from any fires that occur on the project land through time after fuel treatment.

The detailed conceptual model includes the following factors:

1. **Annual Fire Risk**: The occurrence, spread, and intensity of forest wildfires are unpredictable and, for any specific area of forest, relatively rare. Given this nature of forest wildfires, the application to fuel treatments projects would need to examine the likelihood of fire occurring on any given acre across the project area in any given year. In this model, a performance standard function for fire is needed that is referred to here as an annual fire risk (or probability) distribution. This fire risk distribution would be applied in both with and without project scenarios.

2. **Emissions as a Result of Treatment**: Fuels treatments lead to reductions in carbon stocks in the treated stands as fuels are cut to the ground and/or removed. These fuels enter the atmosphere via one of 5 pathways –
   a. Decomposition over time of the treatment-produced dead material on the forest floor
   b. Prescribed under burn with associated CO_2 and non-CO_2 greenhouse gas emissions
   c. Piling and burning with associated CO_2 and non-CO_2 greenhouse gas emissions
   d. Extraction for wood products with subsequent emissions due to milling inefficiency and product retirement (and burning/decomposition)
   e. Extraction for the production of energy with associated emissions from combustion balanced to a given extent by offsetting the displaced fossil fuel emissions from energy production

3. **Emissions as a Result of Fire**: If a fire occurred in a forest stand, emissions will clearly differ depending on whether or not treatment has occurred and on climatic conditions. Given the complexity of fire behavior, invariably fire emissions must be modeled based on input data on stocks and stand composition.

4. **Forest Growth / Regrowth**: Forest growth must also be considered in both the project and baseline case. Fuels treatments may lead to either an increase or decrease in growth rates relative to the baseline:
   a. Removing hazardous fuels will provide more growing space for the remaining trees, allowing them to grow at a faster rate, possibly removing additional carbon from the atmosphere.
   b. Alternatively, removing hazardous fuels removes trees that in the baseline would have been sequestering carbon from the atmosphere thus leading to a net decrease in growth in the project case relative to the baseline.

5. **Retreatment:** As a result of forest growth, there will likely be a need to retreat forests periodically to maintain the benefits of reduced emissions from wildfire.

6. **Shadow Effect**: The baseline and project must also account for the "shadow effect" of fuel treatments—that is an area that is not treated, but, because of treatments there is a reduced risk of fires and/or reduced fire emissions as a result of treatment. This may be because the fire is more easily extinguished or because the fire will have decreased to the forest floor and will not immediately climb back into the canopy.

The impact of the project on gains and losses of carbon is summarized as follows:

> **Gain** from *decreased* intensity or spread of fire due to fuel treatment within the treatment and shadow areas * annual fire probability
>
> + **Loss** from biomass removed during treatment
>
> + **Gain** /**Loss** from substitution of fuels for energy generation
>
> + **Gain** from long term storage as wood products
>
> + **Loss** from decomposition of additional dead wood stocks created through fuels treatment
>
> + **Gain** /**Loss** from growth differences between with and without project treatment and with and without fire
>
> + **Loss** from fires occurring in with project case * annual fire probability
>
> + **Loss** from retreating stands through time

A positive net result indicates increased carbon storage or decreased emissions as a result of the project, while a negative net result indicates decreased carbon storage or increased emissions as a result of the project.

2.3 Creation of a "straw man" methodology

Considering the complexity of the task and absence of any comparable effort to use as a starting point for the effort, the decision was made to create an initial simplified methodology that could be presented to a panel of fire experts and serve as the basis for discussions, critiques and progress forward:

Brown et al. 2006, *Protocol for monitoring and estimating greenhouse gas benefits from hazardous fuels management in Western U.S. forests. Report for the West Coast Regional Carbon Sequestration Partnership Phase II.*

Winrock took the approach of a 10-year moving window of fire probability based on data for northern California defining the risk of the project area burning in the baseline. The straw man methodology is included in **Appendix A**.

2.4 WESTCARB Fire Panel

Fire experts from the WESTCARB region were identified and invited to join a WESTCARB Fire Panel for GHG methodology development[1]. Four meetings were held with various members of the Fire Panel participating.

The full Fire Panel was convened in October 2006, to begin the task of methodology development with Winrock's "straw man" methodology as a starting point. The workshop brought together fire scientists, carbon scientists and fuels management experts for discussion of approaches to quantifying baseline emissions from wildfires, estimating emission reduction/sequestration benefits of fuel reduction, and developing measuring, monitoring and verification protocols to qualify these projects for carbon reporting and/or markets. The desired outcome of the workshop was to identify areas of agreement and issues requiring further research, as well as to clarify roles and potential contributions of Fire Panel members in ongoing protocol development. Fire Panel members were reminded that the desired outcome of the WESTCARB fire methodology task was a methodology that is cost-effective, practical and transparent for landowners/land managers to use, conservative in its GHG estimates, and has sufficient scientific credibility ultimately to qualify these activities for carbon market recognition.

Workshop participants included:

- California Department of Forestry and Fire Protection: Elsa Hucks, Doug Wickizer
- California Air Resources Board: Neva Sotolongo
- Lake County Resources Initiative: Bill Duke
- Oregon Department of Forestry: Jim Cathcart
- Oregon State University: Olga Krankina
- Sylvan Acres LLC: Brent Sohngen
- University of California at Berkeley - Center for Fire Research and Outreach: Max Moritz
- USDA Forest Service - Pacific Northwest Research Station - Pacific Wildland Fire Sciences Laboratory: Sam Sandberg
- USDA Forest Service - Pacific Southwest Research Station - Redding Silviculture Laboratory: Bob Powers
- USDA Forest Service - Pacific Southwest Research Station – Sierra Nevada Research Center: Mark Nechodom
- USDI National Park Service - Whiskeytown NRA: Tim Bradley
- W.M. Beaty and Associates: Bob Rynearson
- Western Shasta Resource Conservation District: Leslie Bryan, Jack Bramhall
- Winrock International: Sandra Brown, Tim Pearson, Nancy Harris, Silvia Petrova, Nick Martin, John Kadyszewski

[1] While the members of the fire panel were instrumental in discussing issues related to hazardous fuels treatments, fire risk, and methodology development, the panel did not reach a final consensus, and the ultimate findings of this report are the conclusions of the authors, rather than the full fire panel.

An expert subgroup met in May 2007 to discuss, in a smaller group setting, key methodological issues that had been identified in the full Fire Panel meeting as needing further discussion or alternative approaches. In preparation for this meeting, Winrock asked Panel members Sam Sandberg of the PNW Research Station, and Scott Stephens and Max Moritz of the University of California at Berkeley, to work on developing alternative baseline methodologies for estimating emissions and area burned, respectively. Progress and results to date on alternative approaches were presented, followed by open discussion and consideration of next steps.

Meeting participants included:

- University of California at Berkeley - Center for Fire Research and Outreach: Max Moritz, Eric Waller, Scott Stephens
- USDA Forest Service - Pacific Northwest Research Station - Pacific Wildland Fire Sciences Laboratory: Sam Sandberg (Emeritus Physical Scientist)
- USDA Forest Service - Pacific Southwest Research Station – Sierra Nevada Research Center: Mark Nechodom
- TSS Consultants: David Ganz
- Spatial Informatics Group: David Saah
- Winrock International: Sandra Brown, Tim Pearson, Nancy Harris, Silvia Petrova, Nick Martin

The subgroup met again in March 2008 to review the current status of the various separate efforts, determine if and how these efforts could be unified, and identify gaps that needed to be addressed. Participants at this meeting included:

- University of California at Berkeley - Center for Fire Research and Outreach: Max Moritz
- USDA Forest Service - Pacific Northwest Research Station - Pacific Wildland Fire Sciences Laboratory: Sam Sandberg (Emeritus Physical Scientist)
- USDA Forest Service - Pacific Southwest Research Station – Sierra Nevada Research Center: Mark Nechodom
- TSS Consultants: David Ganz
- Spatial Informatics Group: David Saah
- Oregon Department of Forestry: Jim Cathcart
- Oregon State University: Olga Krankina
- Winrock International: Sandra Brown, Tim Pearson, Nancy Harris, Nick Martin, Katie Goslee

A final meeting took place in April 2010, when the researchers still actively involved met to determine final commonalities in their respective findings and discuss the overall potential for reducing greenhouse gas emissions through hazardous fuels reductions. Participants at this meeting included:

- University of California at Berkeley - Center for Fire Research and Outreach: Max Moritz
- Spatial Informatics Group: David Saah
- Oregon Department of Forestry: Jim Cathcart
- Winrock International: Sandra Brown, Tim Pearson, Katie Goslee

3.0 Consultancies with fire experts and additional fire analyses

After the full WESTCARB Fire Panel workshop in October 2006, it was determined that expert fire modelers would be required to create a credible fire emissions reduction methodology. Two teams were contracted: Dr. Sam Sandberg, Emeritus Physical Scientist representing the USDA Forest Service - Pacific Northwest Research Station - Pacific Wildland Fire Sciences Laboratory, and Drs. Max Moritz, Scott Stephens and Eric Waller of the University of California at Berkeley - Center for Fire Research and Outreach. Two existing WESTCARB partners also conducted complimentary fire analyses – Oregon State University and the Oregon Department of Forestry.

3.1 Fire risk and firesheds

The UC Berkeley team focused on developing baseline fire risk (probability of an area being burned in a given year) for Shasta County, California, where fuel treatments were implemented in the WESTCARB terrestrial pilot locations.

Following the spring 2008 fire panel meeting, the work of the Center for Fire Research and Outreach was extended, and a consultancy with Dr. David Saah of the Spatial Informatics Group was added to incorporate the concept of firesheds and their relevance to fuels treatments.

The UC Berkeley team focused on developing alternate approaches to quantify baseline fire risk (i.e. probability of an area being burned in a given year) across the regions of northern California where WESTCARB fuel reduction pilot activities are being monitored. . The group reached final conclusions that reinforced the findings of the initial Winrock work (in the straw man methodology) that modeled fire return intervals were between 120 and 300 years for mixed conifer forest types in Shasta County giving annual fire probabilities of less than 0.8% (0.008) (Figure 1).

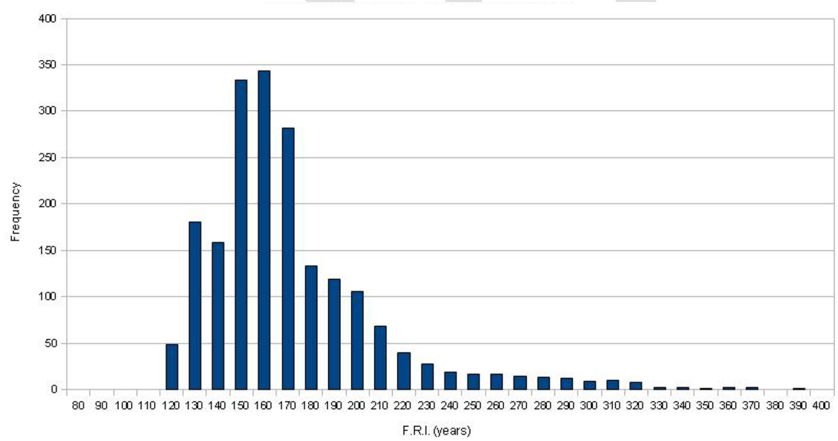

Figure 1: Histograms of fire return intervals for Sierra mixed conifer. Fire return intervals are calculated based on transformation of relative fire probabilities and historical burning rates for Shasta County over 2001-2007

The Berkeley team produced a map showing how this value varies across the northern Californa landscape and across vegetation types (Figure 2).

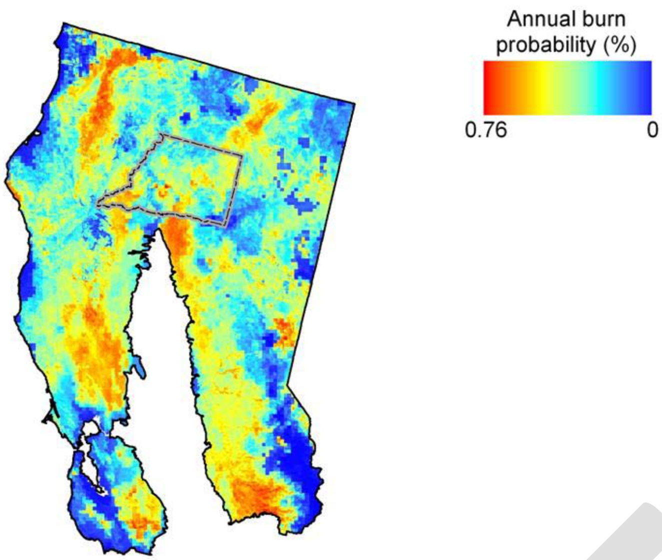

Figure 2: Annual burn probability as calculated by the UC Berkeley fire team (led by Max Moritz)

Within Shasta County ,firesheds were delineated based on five main factors: the “fire behavior triangle” (fuels, weather and topography), barriers to fire spread (both natural and anthropogenic), potential fire behavior (under a “near-worst case” weather scenario), fire occurrence probability patterns, and fire history (Figure 3). For each fireshed a full set of attributes were defined (Table 1).

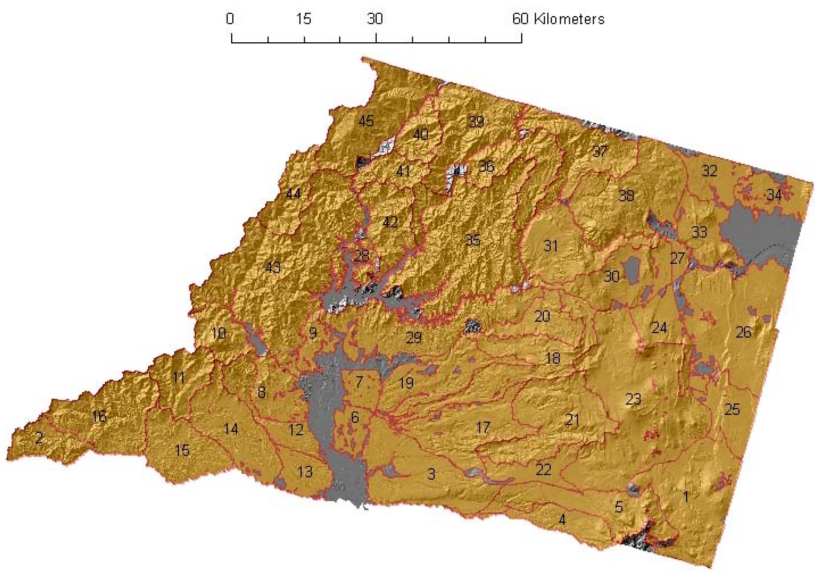

Figure 3: Firesheds delineated for Shasta County, California. Areas not enclosed by a fireshed are non-wildland/non-burnable, i.e. water, urban, agricultural, or barren (Saah *et al.* 2010).

Table 2: Summary of fireshed attributes for Shasta County, California. NLCD indicates the land cover type code from the National Land Cover Database, 2001 (42 is evergreen forest, 43 is mixed forest, 52 is shrub, 71 is grassland/herbaceous). Area indicates the total number of acres in the fireshed. Fire probability values range between 0 and 1 and listed wind speed values are those expected under near-worst case scenarios. Surface flame length is listed in meters, surface fire line intensity is kW/m. Low, medium and high crown fire activity are classified as 1, 2, and 3 respectively.

Fireshed	NLCD Cover Type	Area (Acres)	Fire Probability	*Fire Probability Standard Deviation*	Windspeed (mph)	Topographic Roughness Index	Surface Flame Length	Surface Fire Line Intensity	Crown Fire Activity Class
1	42	85,157	0.261	*0.054*	23.53	1.019	27.88	42,526	3
2	42	24,859	0.389	*0.061*	21.9	1.081	20.95	37,143	1
3	71	73,845	0.461	*0.050*	24.25	1.006	7.89	9,219	1
4	42	25,997	0.447	*0.103*	22.8	1.015	37.1	58,395	3
5	42	56,444	0.339	*0.140*	23.65	1.029	30.45	47,855	3
6	71	14,817	0.392	*0.018*	23.86	0.999	3.66	3,995	1
7	71	13,811	0.433	*0.014*	23.85	1	2.84	2,494	1
8	52	27,656	0.551	*0.045*	24.02	1.021	7.59	10,514	1
9	43	21,696	0.538	*0.058*	23.76	1.026	9.25	12,346	1
10	42	25,386	0.454	*0.065*	23.36	1.08	22.89	39,623	3
11	42	31,825	0.409	*0.061*	23.63	1.086	21.48	37,845	1
12	52	29,314	0.49	*0.046*	23.93	1.031	11.72	16,694	1
13	71	21,114	0.427	*0.024*	24.28	1.002	5.51	5,939	1
14	52	53,956	0.464	*0.041*	23.57	1.013	7.01	9,993	1
15	71	45,640	0.478	*0.030*	23.66	1.025	4.16	6,489	1
16	52	62,906	0.45	*0.056*	23.22	1.084	12.12	22,309	1
17	52	58,341	0.49	*0.040*	23.51	1.015	11.02	13,856	1
18	42	68,791	0.473	*0.071*	23.73	1.022	23.53	37,999	3
19	71	48,316	0.466	*0.055*	24.02	1.012	6.01	6,777	1
20	52	27,252	0.498	*0.077*	23.32	1.02	16.49	22,853	1
21	42	72,889	0.456	*0.073*	23.22	1.029	39.64	65,216	3
22	42	23,030	0.478	*0.032*	23.76	1.005	38.32	59,289	3
23	42	159,183	0.343	*0.051*	23.32	1.017	38.94	63,243	3
24	42	27,912	0.378	*0.031*	22.3	1.016	21.14	28,548	3
25	52	31,802	0.353	*0.038*	22.55	1.009	8.9	8,312	2
26	42	105,654	0.39	*0.029*	22.84	1.008	7	6,056	2
27	42	6,335	0.4	*0.014*	22.64	1.004	2.13	1,335	1
28	52	9,045	0.579	*0.016*	24.15	1.058	5.5	6,261	1
29	42	70,176	0.537	*0.044*	24.01	1.037	6.34	7,902	1
30	42	47,571	0.395	*0.044*	23.41	1.016	11.89	13,756	2
31	42	53,530	0.472	*0.049*	23.22	1.036	20.87	33,088	1
32	42	25,018	0.425	*0.007*	22.65	1.001	14.86	18,262	2
33	42	31,906	0.418	*0.015*	23.63	1.021	9.36	11,660	1
34	42	25,027	0.409	*0.014*	22.37	1.003	4.38	3,221	2
35	42	133,539	0.5	*0.030*	23.88	1.106	14.8	21,026	1
36	42	45,897	0.48	*0.050*	24.06	1.099	30.32	46,920	3
37	42	53,928	0.405	*0.084*	22.59	1.081	25.48	36,514	3
38	42	83,237	0.401	*0.054*	23.76	1.041	31.85	50,594	3
39	42	60,599	0.505	*0.043*	22.88	1.108	24.31	36,169	3
40	42	20,114	0.534	*0.028*	23.32	1.108	20.82	31,915	1
41	42	29,433	0.521	*0.036*	23.25	1.123	14.88	20,581	1
42	42	37,955	0.575	*0.039*	24.12	1.093	9.7	12,673	1
43	42	163,176	0.506	*0.051*	23.3	1.101	12.79	20,239	1
44	42	29,424	0.449	*0.061*	25.12	1.096	34.54	58,901	3
45	42	67,736	0.414	*0.102*	22.79	1.073	22.68	30,693	3

The final report of the UC Berkeley team is included in **Appendix B**.

3.2 Fire Fuelbeds and Baseline Emissions

Dr. Sam Sandberg was tasked with developing estimates of emissions to be paired with the baseline rate of fire.

Sam Sandberg used the USFS fire model - Fuel Characteristic Classification System (FCCS). He proposed a process that could be used on a specific land ownership to estimate future carbon emissions for managed and unmanaged (i.e. baseline) scenarios: 1) predict into the future what harvest and fuel treatment strategies would be applied to a management unit; 2) customize fuelbeds to represent each of the future time periods and management options; 3) calculate the probability of wildfire on each fuelbed before and after treatment based on adjustments to the baseline algorithm using fire potentials; 4) calculate the carbon release from prescribed fire treatments and expected wildfire area. The adjusted annual fuel risk by different fuelbeds in the Shasta County region is shown in Figure 4, and the average emission from a fire in each fuelbed type by different moisture conditions in Figure 5. The final report of Sam Sandberg can be found in **Appendix C**.

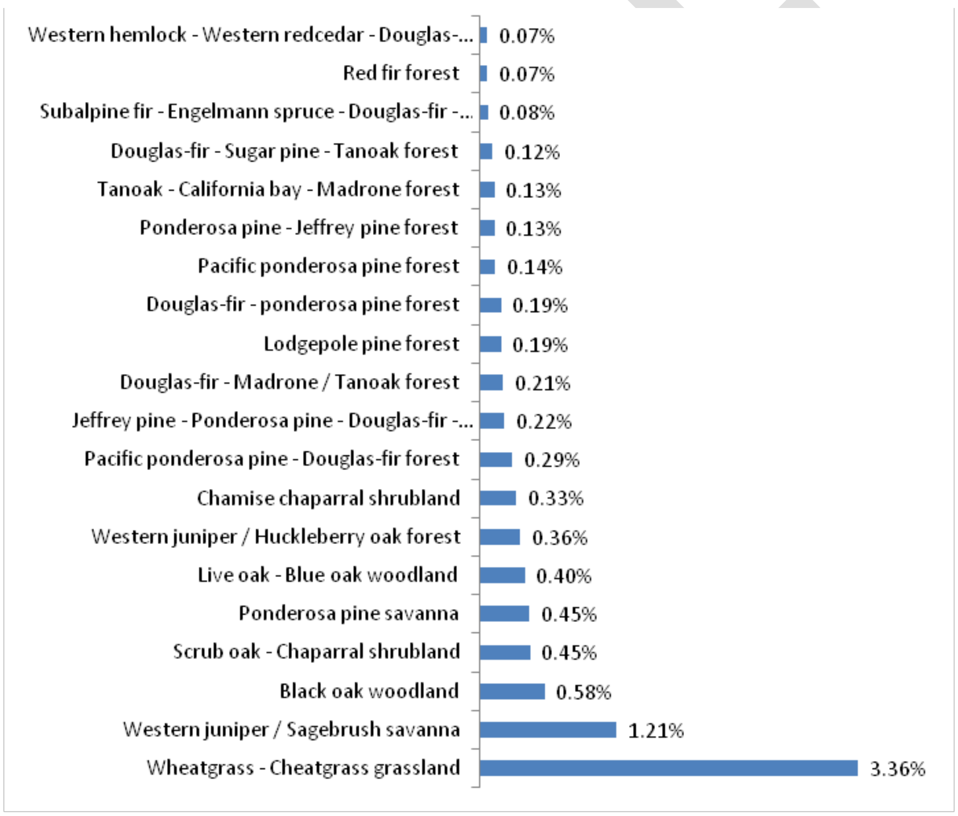

Figure 4 Historic annual fire risk for FCCS fuelbeds in ecosystem province M261 (Sierran Steppe – Mixed Forest – Coniferous Forest – Alpine Meadow). The individual fire risk are assumed to be the same for any Project Area (including Shasta County) in the Province

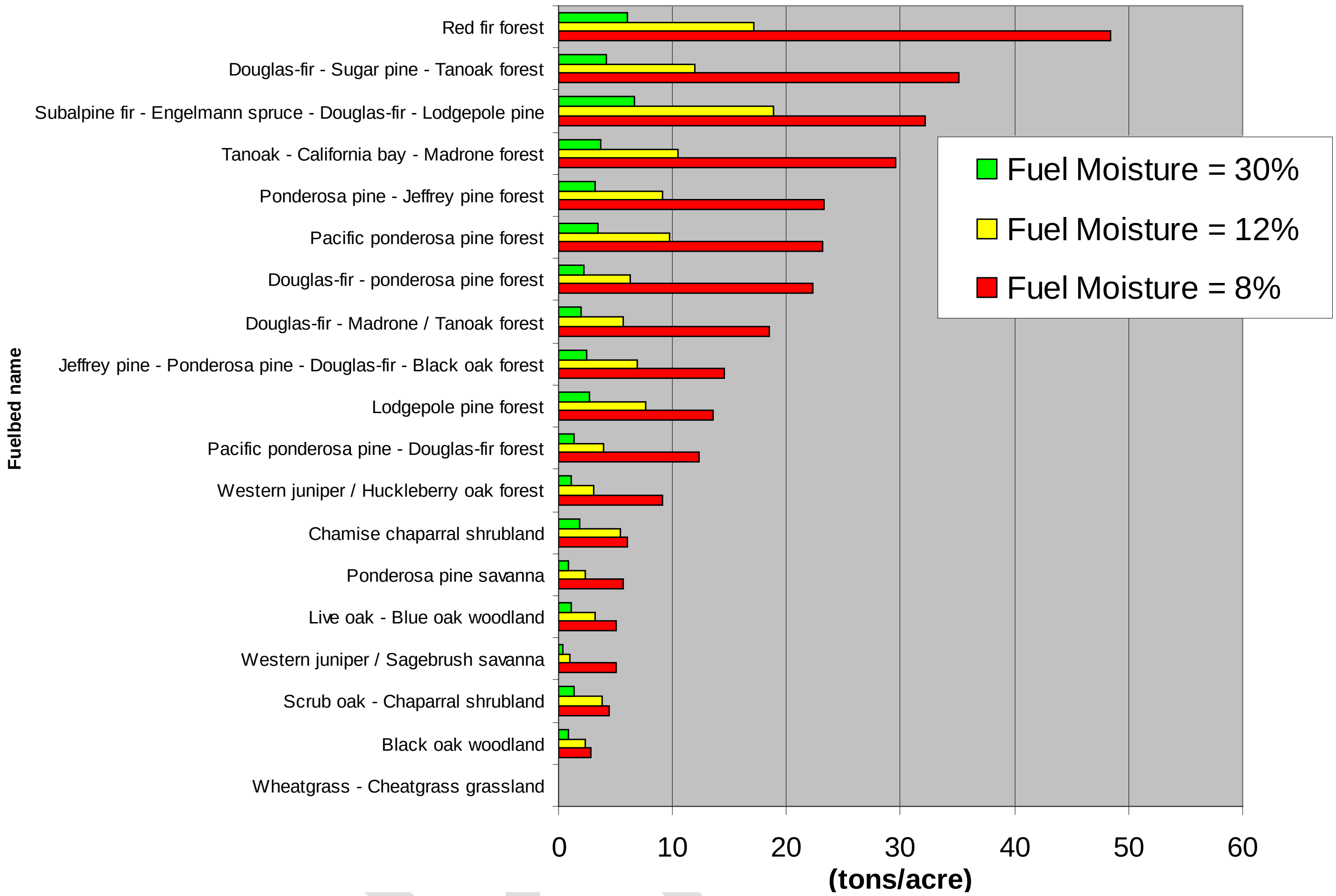

Figure 12. Carbon emissions (tons/acre) for FCCS fuelbeds in Oregon/California at three 1000-hr moisture content profiles. The "8%" moisture profile represents an average wildfire; 12% and 30% represents a range in emissions expected from prescribed fire in each fuelbed.

3.3 Impact of Fuel Treatments on Stand Growth

Oregon State University completed literature and analyses of data on rates of decomposition of woody debris. OSU also examined the impact of fuel treatments on stand growth and carbon sequestration using the STANDCARB model. The reference data for model calibration was obtained from the US Forest Service – Forest Inventory and Analysis database, and model settings were adjusted to represent realistically the regional patterns (in Southern Oregon) of live tree biomass accumulation with age of forest stands for one forest type (Ponderosa pine). The team developed a set of thinning and fire scenarios to be simulated. Preliminary model outputs suggest that after 200 years of application of aggressive thinning (e.g., 35% removal every 15 years or 50% removal every 25 years) carbon stores in live biomass and total biomass declined by about 20 and 30 t C/ha respectively, with smaller losses for moderate thinning regimes. This loss represents 15-20% of the baseline scenario, though use of harvested wood could reduce this loss. On average, over 200 years of applying these thinning schedules the losses of live biomass ranged from 4 to 14 t C/ha compared to a no-thin scenario. The effect of thinning on the average C store in forest fuels was small; moderate thinning had virtually no effect; more aggressive thinning reduced forest fuel load on average by 0.5-1.9 t C/ha or 1-4% of the forest fuel load in baseline scenario. For thinning to be effective as a measure to reduce carbon emissions from fires, the emission reduction has to be greater than the estimated losses of biomass caused by thinning. OSU's reports are included in **Appendix D**.

3.4 Case Study Simulation of Fuel Treatments and Wildfire Emissions – Lake County, OR

The Oregon Department of Forestry conducted separate research that addressed the question—does fuels treatments result in an overall carbon benefit from reduced wildfire emissions – through a case study simulation analysis of fuel treatments and wildfire emissions (Cathcart *et al*, In Press). The case study addressed the 169,200 acre Drews Creek watershed in Lake County, Oregon that is comprised of agricultural lands, juniper woodland, dry ponderosa pine forests, and mixed conifer forests. Within the watershed, 9,500 acres have burned over the last 50 years. The researchers modeled the effects of the anticipated large "problem fire," to be avoided through the Fremont-Winema national Forest's fuel treatment planning effort. The problem fire is a blow-up event under sever fuel moisture and weather conditions that burns 11,000 acres over an 8-hour afternoon burn period. Fuels treatments were modeled by thinning from below and under-burning a total of 12,825 acres, 9.1% of the watershed's forestland. Using ArcFuels software, wildfires under extreme fuel moisture and weather conditions were simulated over the 8 hour burn period with 10,000 random ignitions for both the treated (with project) and untreated (baseline) watershed. Conditional probabilities, both for wildfire reaching a given stand and for its intensity once it reached the stand, were calculated for the treated and untreated landscapes. The effect of the fuel treatments on wildfire risk were based on the treatments lowering both the conditional probability of wildfire reaching a stand, and the probability of higher severity fires once fire reached treated stands. The conditional burn probabilities averaged 2.2% (0.0022) for the untreated watershed and 1.7% (0.0017) for the treated watershed; the effect of the fuel treatments only reducing the average conditional burn probability by 0.05% (0.0004). As seen in the other studies, the predominate simulation for a given stand was that no wildfire occurred – averaging 97.9% of the time for the treated watershed.

The study design explicitly simulated the shadow effect of the treatments by calculating the avoided wildfire emissions in untreated stands as a result of the treatments. The area of the shadow effect was assumed to be the watershed boundary. The results showed that the likelihood of fire reaching untreated stands decreases with treatment. Carbon stocks lost in thinning and under-burning were estimated to be -271,333 tons of carbon (-21.2 tons per treated acre). In comparison, only an expected 3,700 tons (0.21 tons per acre) of avoided carbon loss from wildfire accrued to the project as a result of the treatment's effect of reducing both the likelihood and intensity of wildfire. The avoided emissions from the treatment shadow effect was an additional 3,087 tons of expected avoided carbon loss (0.025 tons per untreated acre) as a result of the treatment's effect of reducing the likelihood of wildfire in untreated areas. The total avoided emissions benefit from treatment was 6,787 tons of expected carbon loss avoided (0.048 tons per forested acre). This low expected avoided emissions is again due to the infrequent probabilistic nature of wildfire. The net offset from avoiding the chance of a problem fire from a given ignition within the watershed under severe fuel moisture and weather was -264,546 tons (-1.9 tons per forested acre). Given these emissions, and the one-time investment of fuels treatments to avoid a “problem fire,” if there were five ignitions per year under severe weather conditions (dry conditions with relatively high wind speeds), the break even shelf life (the time the treatment’s carbon losses are recouped from avoided wildfire emissions spanning several years following treatment) is nine years.

4.0 Field Data and Modeled Fuels Treatment Projects

4.1 The Purpose of Measurement and Modeling Activities

To gather real-world data for an assessment of fuel treatment project methodologies, pre- and post-fuel treatment carbon stock measurements were conducted by Winrock International and its WESTCARB partners on several treated areas. The purpose of the measurements was to provide ground data from real treatments as input into a model of a hypothetical greenhouse gas emission reduction projects. Measurements identified the carbon stocks before and after treatment, the direct impacts of fuel treatments on carbon stocks in different carbon pools (e.g. increases in dead wood, decreases in dense growth), and the fuel removed from the forest for biomass energy or wood products during treatment. Two hazardous fuel treatment projects were identified in Lake County, Oregon and three in Shasta County, California.

These measurements were used to determine the carbon stocks before and after treatment and before and after a potential wildfire, for each project area. Growth modeling was conducted with the Forest Vegetation Simulator for both with and without treatment stands. Emissions from a potential fire were modeled in both with- and without-fuels treatment scenarios using both the Fuel Characteristic Classification System (FCCS) and the Forest Vegetation Simulator fire and Fuels Extension (FVS-FFE). FVS was also used to project growth on burned stands, incorporating the impacts of fire on the future stand.

More information on the fuels treatment and results can be found in the full pilot study reports:

Goslee, K., T. Pearson, S. Grimland, S. Petrova, and S. Brown. 2010. *Final Report on WESTCARB Fuels Management Pilot Activities in Shasta County, California.* California Energy Commission, PIER. CEC-500-XXXX-XXX.

And

Goslee, K., T. Pearson, S. Grimland, S. Petrova, and S. Brown. 2010. *Final Report on WESTCARB Fuels Management Pilot Activities in Lake County, Oregon.* California Energy Commission, PIER. CEC-500-XXXX-XXX.

4.2 Summary of Results

The initial stocks of forests in the five sites were between 51 and 82 t C/ac dropping to between 34 and 72 t C/ac after treatment with an average decrease of 12 t C/ac (Table 2). Decreases in stocks due to wildfire were estimated at between 8 and 12 t C/ac in the absence of treatment and between 7 and 13 t C/ac if a treatment had occurred.

Table 2: Carbon stocks (in t C/ac) for each of the five treatment locations before and after treatment and modeled with and without an immediate wildfire.

		Pre-Treatment		Post-Treatment	
		No fire	Wildfire	No fire	Wildfire
Oregon	Bull	82	70	72	59
	Collins	55	47	34	25
California	Davis	51	41	48	39
	HH	64	53	55	45
	Berry	70	58	51	44

On a percentage basis (Table 3) treatment led to an average of 19% reduction of stock (range 6-38%). Wildfires led to a reduction in stocks of 17% on average where no treatment had occurred or 19% with fuel treatment.

Table 3: The percentage change in stocks at each of the five treatment locations as a result of treatment and in response to a wildfire with and without a treatment

		Reduction due to treatment	Reduction due to fire	
			No Treatment	With Treatment
Oregon	Bull	12%	15%	18%
	Collins	38%	15%	26%
California	Davis	6%	20%	19%
	HH	14%	18%	18%
	Berry	27%	17%	14%

In all cases treatment led to a decrease in carbon removals (sequestration) in the absence of wildfire (Table 4). In every case the situation was reversed where a wildfire occurred.

Fuel treatment reduced wildfire emissions by an average of 6%. However, the ratio varied from a decrease of 38% to an increase of 16% (Table 4). This variation is likely related largely to the intensity of treatment and the size composition of the stand prior to treatment.

Table 4: The impact of fuel treatment and wildfire on carbon removals through forest growth (over 60 years), emission resulting from wildfire and net emissions considering all input factors, handling of fuels and risk of fire for each of the five locations. A negative indicates a net emission, a positive indicates a net removal

		Growth				Fire Emissions		NET EMISSIONS	
	Treatment	No	Yes	No	Yes	No	Yes		
	Wildfire	No	No	Yes	Yes	Yes	Yes	Short Term	Long Term
					t CO_2/ac				
Oregon	Bull	14	29	106	72	-43	-47	-47	-37
	Collins	92	62	-36	-26	-29	-33	-108	-113
California	Davis	212	184	55	69	-37	-34	-39	-60
	HH	205	180	57	94	-40	-35	-84	-91
	Berry	172	129	6	99	-43	-26	-83	-116

Short term = 10 years; Long term = 60 years

The net emissions incorporated regrowth following fire and following treatment plus the risk of fire occurring. Risk of fire was derived from the work of UC Berkeley and was equal to 0.64% for the sites in Shasta County and 0.60% for the sites in Lake County. Using the full accounting methodology, a proportion of biomass extracted as timber is accounted as a permanent removal. However, for biomass energy the extracted biomass serves to displace fossil fuels burned for power generation. In California, new power is generated by burning natural gas and natural gas produces fewer greenhouse gas emissions per megawatt hour of power production than burning biomass. Thus, all biomass extracted during treatment for energy production results in a net emission (albeit lower than if the stocks had been burned on site).

Many interpret the fact that biomass is replaceable (in the way that fossil fuels are not) to mean that all biomass burned has no net impact on the atmosphere. But burning biomass does increase greenhouse gases resident in the atmosphere. Burning biomass might prevent emissions from fossil fuels, but this is by no means permanent. In this debate about use of biomass for power production, it is critical to focus on the atmosphere, i.e. does the project cause an increase or decrease in the concentration of carbon dioxide in the atmosphere? In the case of burning biomass rather than natural gas, the net result is an increase in CO_2 in the atmosphere because natural gas burns more cleanly than biomass. If coal were displaced instead of natural gas the savings would be greater while if the displacement is of electricity generated by nuclear power, solar, wind or hydro power then the result is an emission with no net saving.

If the stand is not treated the fuels are available in the forest to be emitted to the atmosphere through wildfires, and as shown above in the CA and OR region this risk is very low. However, this should not be considered under the biomass energy calculations. If it is then we would be counting the baseline fire emissions twice. The baseline fire risk multiplied by the stock gives the baseline emission from wildfires, which is the emission from fuels in the absence of fuel treatment.

Considering the disposition of biomass and the risk of fire, the analyses at the five pilot sites showed net emissions of between 47 and 108 t CO_2e/ac within ten years and between 37 and 116 t CO_2e/ac after 60 years have passed (Table 4).

This analysis integrates a risk of fire based on the measured fire return interval. Thus if a fire actually occurs then the result would be a net removal but in reality the balance of probabilities indicates that a fire will not occur and in this case the net emission would be yet higher.

This analysis integrates a risk of fire based on the measured fire return interval. Thus if a fire actually occurs then the treatments reduce emissions sufficiently to result in a net removal. However, it is far more likely that a fire will not occur on the landscape, in which case, the net emission would be yet higher due to the removal of carbon stocks in the treatment.

More details are found in the two pilot study reports.

5.0 Integration and Offset Methodology Conclusions

The results of the analyses and measurements are strongly conclusive:

- The annual fire risk does not exceed 0.76% in any of the forest types examined in parts of CA and OR.
- Fuels treatment leads to reductions in stocks of 10 to 40% with corresponding emissions
- Fuels treatments must be conducted across a wide area due to the unpredictability of fire occurrence
- Fuels treatments must be repeated to maintain efficacy
- Fuels treatments undoubtedly make a fire more easy to control and thus save lives, however, the measured treatments only led to a 6% reductions in emissions from a wildfire occurring immediately after treatment in the five sites examined

The net result is an increase in emissions, as a result of treatments, of between 30 and 120 t CO_2-e/ac. In addition, this value cannot be decreased through using fuels for biomass energy for these project areas (at least given current extraction technologies and equipment fuel efficiencies).

Ultimately, for fuels reduction to be a credible offsets project, it would be necessary to be able predict exactly where fires are going to occur and implement well designed fuels treatments in those locations. In reality this is of course impossible given current modeling capabilities.

5.1 Revisiting the Conceptual Framework

1. **Annual Fire Risk**: Multiple studies under this task identified annual fire risks of less than 1%. Based on ten-year moving average, Winrock estimated annual burn risks of 0.12% for private lands and 0.33% for public lands in Northern California. The more detailed analysis of the UC Berkeley team determined a mean annual fire probability of 0.64% for mixed conifer forests in Shasta County, California and 0.60% for mixed conifer forests in Lake Country, Oregon. In no case were probabilities higher than 0.76%/year.

Thus there is a less than 1 in 130 chance of a fire at any site in any given year and for some sites it is 1 in 300 or more.

2. **Emissions as a Result of Treatment**: Across the five measurement sites in California and Oregon hazardous fuel treatment led to reductions in stocks of between 6 and 38% (average – 19%).
Where timber was extracted, between 25.5% (in CA) and 30.9% (in OR) of the extracted biomass can be considered permanently sequestered in wood products. The remaining ~70% is emitted to the atmosphere over time.

Where biomass is extracted for power generation there is a net emission of 1.334 t CO_2/ton of biomass burned where the displaced fossil fuel is natural gas (as in California) or as low as 0.833 t CO_2/ton of biomass where the displaced fossil fuel is coal.

Any treated biomass not extracted from the forest will be emitted to the atmosphere – the only difference being if fire is used (underburn or pile) then non-CO_2 gases will also be emitted. Methane has an atmospheric impact 23 times that of carbon dioxide and nitrous oxide has an impact that is 310 times that of carbon dioxide.

3. **Emissions as a Result of Fire**: Across the five measurement sites in California and Oregon fuel treatment led to changes in emissions from subsequent wildfires of between a 16% increase[2] in emissions and a 38% reduction in emissions. On average emissions were reduced by 6%.

4. **Forest Growth/Regrowth**: Across the five measurements sites growth modeling showed a higher rate of sequestration after 60 years in stands with no treatment compared to treated stands in the absence of wildfire (on average 17% lower sequestration). Where a wildfire occurs the relationship is reversed with the total sequestration higher where treatment had occurred (on average 63% higher sequestration).

5. **Retreatment**: Hazardous fuels regrow rapidly. No analysis was conducted on this component of the conceptual framework, however, it is considered likely that retreatment will be needed every 10 to 20 years. Over a twenty year period even assuming the highest fire risk there is only a 15% chance that a fire will have occurred.

6. **Shadow Effect**: Analysis of the shadow effect by the UC Berkeley/SIG team revealed that no simple relationship or assumption can be derived. The size of the shadow effect will depend on the level of hazardous fuels in surrounding forests, the climatic conditions, the access to the site and the relative presence of fire fighters and firefighting equipment. The shadow effect may be zero where no immediate effort is possible at extinguishing the fires and where the fuel and climatic conditions are favorable for rapid reclimbing into the canopy. Dr Sam Sandberg estimated that the shadow area would not exceed five times the treated area. The Oregon Department of Forestry simulation assumed that the

[2] Increases in emissions following fuels treatments were primarily the result of an increase in 1- and 10-hour fuels.

boundary of the shadow effect coincided with the watershed boundary, and modeled emission avoidance occurring in the shadow area explicitly. In this instance, accounting for the shadow effect doubled the calculated gross emission avoidance benefits from a single random emission, but that was still much lower than the initial carbon cost of the treatments themselves.

Consolidating across the conceptual framework we can reach the following conclusions:
- Fire risk is very low
-Treatment emissions are relatively high and are incurred across the entire treated area
-Treatment never reduces fire emissions by more than 40% and on average across five sites only reduced emissions by 6%
-In the absence of fire, treatment reduces sequestration
-Retreatment will have to occur with accompanied emissions
-A positive impact of treatment beyond the treated area is not guaranteed and is unlikely to ever be large enough to impact net greenhouse gas emissions

So low fire probability is paired with high emissions and low sequestration in the absence of a fire and relatively few emissions reductions in the event of fire.

5.2 Supporting Literature

Related research on the Mendocino National Forest in Shasta County (Pearson *et al*. 2010) showed similar results. This study looked at the effects on wildfire emissions of fuels treatments done under a Forest Service Stewardship Contract. In this case, the treatments did not reduce the risk of fire, nor did they decrease emissions from fire, and the reduction of carbon stocks lead to a large net gain in overall emissions.

Our conclusions are supported by a recent study that addressed the uncertain probability of fire (Mitchell *et al.*, 2009) and the long-term carbon impacts of fire on three ecosystems in the Pacific Northwest: east Cascades ponderosa pine forests, west Cascades western hemlock-Douglas-fir forests, and Coast Range western hemlock-Sitka spruce forests. The study found that hazardous fuel reduction projects more often than not reduce more carbon than they allow the stand to store with an increased resistance to wildfire. One of the reasons for this is that much of the carbon that is stored in the forest is not immediately consumed even in high-severity fires. The authors of this study recommend that while fuel reduction projects may be the best management option in high risk forests near urban areas, other forests may be best used for their ability to sequester carbon, and not treated for fuel reduction.

6.0 Contrasting Literature

Given the conclusion of our work here that there is currently no opportunity for fuels reduction as a greenhouse gas emission offset category, it is perhaps surprising that many studies have come out demonstrating a positive greenhouse gas impact of fuels treatments. It should be noted that the majority of these studies had different purposes to our own so it is not surprising that inconsistencies exist. However, for our full atmospheric accounting purposes, the conclusions in these studies have omitted certain aspect of carbon accounting that we find to be essential. Here we take each study showing a positive impact and discuss where we feel that omissions occurred:

Finkral and Evans (2008)

The effects of a thinning treatment on carbon stocks in a northern Arizona ponderosa pine forest.

Publication Conclusion: The authors state that the thinning treatment resulted in net emissions of 3,114 kg C/ha (4.8 t CO_2-e/ac), though if the wood removed had been used in longer lasting products, the net carbon storage (relative to without thinning) would have been around 3,351 kg C/ha (1.9 t C/ac). So that thinning for treatment of fuels with storage in long term products results in a net emission reduction of 6.97 t CO_2-e/ac.

Forest type: Northern Arizona ponderosa pine

Treatments: pre-settlement restoration

Stocks: pre-treatment: 48.88 tons/ha; post-treatment: 36.42 tons/ha

Fire risk: 2.8%

Wildfire emissions: wildfire was modeled using FVS, and emissions were estimated at about 20% of carbon stocks for both treated and untreated

Emissions from prescribed fire: N/A

Emissions from treatment: 0.091 tons/ha emitted from equipment use for harvest and transport.

Utilization: firewood, because markets for longer-lived products were not available

Reassessment Conclusions: The authors assumed that a fire takes place and the emissions from fire are a given in their calculations. Accounting for the potential for fire (multiplying emissions by the 2.8% risk of fire), if wood is used as firewood, the treatment emissions are 5,457 kg C/ha (8.1 t CO_2-e/ac). In addition, in accounting for the net storage or release of carbon if the wood is used for longer lasting products, the authors did not incorporate mill inefficiencies. Incorporating both inefficiencies and risk of fire for longer lasting products, net carbon emission due to fuel treatment is 1.8 t CO_2-e/ac (1,131 kg C/ha) as opposed to the net emission reduction as a result of fuel treatment calculated in the paper of 7.0 t CO_2-e/ac (a difference of 8.8 t CO_2-e/ac) . This value does not account for the rate of turnover/retirement of the wood products – using USFS defaults for the Rocky Mountain region 63.3% of the extracted material is emitted to the atmosphere within 100 years

North, Hurteau, and Innes (2009)

Fire suppression and fuels treatment effects on mixed-conifer carbon stocks and emissions

Publication Conclusion: The authors conclude that forests with large trees, approximating 1865 active fire stand conditions, act as fire-resistant carbon sinks, storing high levels of carbon, and that such stands could be achieved with minimal reductions in existing carbon pools.

Forest types: Sierra Nevada mixed conifer

Treatments: 6 types: no thinning, understory thinning, and overstory thinning, each with and without prescribed burning

Stocks: Range of 66 Mg C/ha in most intensive treatment, overstory thin and burn, to 250 Mg C/ha in control. The percent change from pretreatment mean was as follows: burn only, -6.8%; understory thin, -28%; understory thin and burn, -34%; overstory thin, -56%, overstory thin and burn, -65%.

Fire risk: does not address risk of wildfire

Wildfire emissions: does not address emissions from wildfire

Emissions from treatment: Emissions sources included prescribed burn, equipment releases, trucking to the mill, and milling waste, with milling waste being the highest emission and prescribed burning being the second highest. (Only equipment and trucking are not accounted for in stocks above.) Carbon storage in long-lived wood products was not addressed.

Reassessment Conclusions: The study did not model fire, only discussed basic fire principles, such as fuel loads and crowning index and how these were affected by treatments. Thinning increased crowning index and prescribed fire reduced loading in most fuel classes. Without knowing the potential wildfire emissions after each treatment type, it is difficult to assess the actual carbon balance of the treatments using our framework.

USDA Forest Service (2009)

Biomass to Energy: Forest Management for Wildfire Reduction, Energy Production, and Other Benefits

Publication Conclusion: The authors conclude that the treatments provide a net benefit for total energy consumption and reduced emissions.

Forest types: Sierra Nevada mixed conifer

Treatments: 13 prescriptions, including clear cutting, pre-commercial thinning, commercial thinning, salvage logging, select harvest, and restrictive thinning, with use of underburning

Stocks: N/A (compared treatment emissions and risk of fire, rather than calculating stocks)

Fire risk: chose discrete ignition points at locations across the landscape

Wildfire emissions: reference case: 17,000,000 tons CO_2-e;
test case: 14,000,000 tons CO_2-e;
Net *reduction* in emission due to fuel treatment:
3,000,000 tons CO_2-e.

Emissions from treatment: equipment: 1,220,000 tons CO_2-e; underburning: 1,700,000 tons CO_2-e

Utilization: biomass energy, wood products.

However, the model did not account for:

- emissions from sawlog production or
- any potential emissions or credits for offsetting natural gas

These could be calculated, respectively, as net emissions of:

- 37,603,847 tons CO_2-e for wood products (based on wood retirement rate of 64.5% over 100 years), and
- 27,613,800 tons CO_2-e for emissions from biomass energy (based on offsetting natural gas)

Reassessment Conclusions: When emissions from sawlog utilization and retirement and biomass efficiency are incorporated, the test case has more than five times higher emissions than the reference case:

Reference case: 17,000,000 tons CO_2-e;
Test case: 14,000,000 + 37,603,847 + 27,613,800
= 79,217,647 tons CO_2-e;
Net *increase* in emissions due to fuel treatment:
62,217,647 tons CO_2-e.

Hurteau, Koch, and Hungate (2008)

Carbon protection and fire risk reduction: toward a full accounting of forest carbon offsets

Publication Conclusion: The authors state that their "'back of the envelope' calculations indicate that massive CO_2 emissions from wildfire are avoidable in forests that have historically been characterized by frequent, low-severity fire."

Forest types: Ponderosa pine and mixed conifer forests in AZ, CO, OR, and CA

Treatments: Looked at four large forest fires (Rodeo-Chediski in AZ, Hayman in CO, Biscuit in OR and CA, and McNally in CA), and modeled the effects that treatments prior to fire would have had. Hypothetical treatment was a thin from below, removing the majority of small diameter trees.

Stocks: N/A (compared treatment and fire emissions, rather than calculating stocks)

Fire risk: 100%, as the study addressed fires that had occurred

Wildfire emissions: 4.2-6.1 $MMTCO_2e$ from live tree emissions, across the four fires; modeled treatment could have reduced the emissions more than 90%

Emissions from treatment: Modeled thinning removed 3.9 $MMTCO_2e$ across the four fires; study did not account for emissions from thinning and transportation

Utilization: not included, as thinned material was non-merchantable, though biomass energy may be an option

Reassessment Conclusions: The study looked at major stand replacing fires that had occurred. In reality as we have shown the risk of fire is relatively low and the risk of a large-scale crown fire is lower still. Emissions could have been reduced by more than 90%, however, the risk of fire is very unlikely to exceed 3% per year (and is likely to be less than 1% as we found in Oregon and California). When these factors are integrated in the analyses it is unlikely that a net emission reduction could result from treatment.

Wiedinmyer and Hurteau (2010)

Prescribed fire as a means of reducing forest carbon emissions in the Western United States

Publication Conclusion: The study concludes that prescribed burning could reduce fire emissions in the western U.S. by 18-25%.

Forest type: Western forests – multiple forest types

Treatments: Emissions from prescribed burning were modeled on western forests that historically had fairly frequent fire return intervals and low or mixed severity effects.

Stocks: N/A

Fire risk: 100%, as the study addressed fires that had occurred

Wildfire emissions: Annually averaged state-wide wildfire emissions ranged from 1-18 $MMTCO_2$/yr from 2001-2001 across 11 western states.

Emissions from prescribed fire: Annually averaged state-wide prescribed fire emissions ranged from 1-14 $MMTCO_2$/yr from 2001-2008 across the same states.

Emissions from treatment: same as above, as treatment consisted entirely of prescribed burning

Utilization: N/A

Reassessment Conclusions: The findings are based on the replacement of wildfire with prescribed fire, presupposing that the location of wildfires could be predicted accurately before their occurrence, allowing for management with prescribed fire only in locations that would otherwise burn in a wildfire. Modeling techniques do not yet allow us to know exactly where fires will occur, necessitating large areas of treatment in order to capture future uncertain area of wildfire. If the prescribed fire emissions are multiplied by a 20-200 factor to reflect the additional area that would have to be treated in order to be confident of capturing future wildfires (reflecting a fire risk of between 0.5 and 5% / yr) then the emissions from prescribed fires would range between 20 and 2,800 $MMTCO_2$/yr (clearly exceeding the emissions from wildfires)[3].

Robards and Wickizer (2010)

Demonstration of the Climate Action Reserve Forestry Protocols at LaTour Demonstration State Forest, WESTCARB Final Report

Publication Conclusion: This study shows a total expected emission reduction of 12,387.3 tC (47,070 t CO_2-e) over the life of the project (100 years)

Forest type: Ponderosa pine, mixed conifer, white fir, red fir

Treatments: Creation of a shaded fuel break, retaining a post-harvest basal area of 50 ft^2/ac, and reducing ground and ladder fuels.

Stocks: 98,616.9 tons of carbon across entire project area

Fire risk: 3% (assumed not calculated)

Wildfire emissions: 30% loss of carbon stocks in extreme fire conditions, 20% loss in high severity weather conditions, 10% loss in moderate severity weather conditions (assumed not calculated)

Emissions from prescribed fire: N/A

Emissions from treatment: 2,109.4 tons of carbon across fuel break (8,031 t CO_2-e).

Utilization: N/A

Reassessment Conclusions: The study relies on highly optimistic assumptions:

- First, the study uses a fire risk that is significantly higher than commonly accepted annual burn probabilities including burn probabilities calculated independently by UC Berkeley, Winrock and Dr Sam Sandberg in the course of this study. LaTour State Forest is in Shasta County so we can be confident that the actual fire risk is <0.75%/yr;
- Second, it is assumed that installation of a fuel break prevents fire from even reaching half of the project area. Essentially this states that a 300 ft wide fuel break will prevent the passage of any wildfire;
- Third, it is assumed that there is no regrowth of trees whatsoever following a wildfire.

The report states that, even with these assumptions with regard to decrease in fire incidence due to the fuel break and the lack of regrowth, there is a break even in terms of emissions in baseline and project cases with an annual fire risk of 0.44% (close to what might be expected for the region).

[3] If such large-scale prescribed burning were undertaken then through time the benefit would grow as all areas would be treated within the first years and ultimately reduced emissions would result from wildfires in the absence of additional treatment emissions (or at least just with the diminished treatment emissions that arise with retreatment).

7.0 Summary and Recommendations

Discussion/Conclusions

Reducing emissions from fire could be an important contribution to reducing CO_2 emissions overall, yet the reduction of carbon stocks in hazardous fuels treatments, combined with the low annual probability of fire on a given acre of land in the study region of northern California and southern Oregon prevent the generation of viable carbon offsets from such treatments. In the case of the standard fuels treatments for mixed conifer forests in northern California and southern Oregon which served as the field test for this research, treatments clearly led to significant increased net emissions.

Our conclusions may be subject to change in the future if new technologies are developed for fuel removal, energy generation through fuel combustion or enhanced modeling techniques are developed for predicting the location of future wildfires.

Our findings should in no way be read as an argument for halting fuel treatments. Reducing the risk of fire is a critical activity for many other reasons, including enhancing forest health, maintaining wildlife habitat, and reducing risk to life and property, and as such is an activity that must continue though unfortunately without financial support from greenhouse gas emission reduction offsets.

It may be desirable to return forests to a condition that more closely resembles pre-suppression forests. Such forests are likely to experience fewer high severity fires, and therefore release less carbon dioxide in the event of a wildfire. However, achieving these conditions will likely require the short term release of carbon dioxide currently stored as forest biomass. Therefore, it is not likely that this type of management presents a carbon offset project type, but rather a desirable overall management strategy that may lead to lower but more stable carbon stocks.

In addition, in today's world where actions to curb atmospheric greenhouse gas concentrations are growing more urgent, an accurate accounting of all emission sources at national, regional and local scales is important. The work completed here allows a better understanding of the relative emissions that arise from hazardous fuel treatments and wildfires. This may become increasingly important as fire risk is California has been projected to increase between 12 and 53 percent by the end of the century (Westerling and Bryant, 2008). Even though current technologies make it difficult for fuels treatments to lead to net emission reductions, it is important for planners to understand relative greenhouse gas emissions to be able to design treatments in a way that minimizes emissions while maximizing benefits to local populations and forest health and habitats.

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Appendix A:

Brown et al. 2006, *Protocol for monitoring and estimating greenhouse gas benefits from hazardous fuels management in Western U.S. forests*.

See separate attachment.

Appendix B:

Saah, D, T. Moody, E. Waller, E. Newman, M. Moritz. 2010. *Developing and Testing a Framework for Estimating Potential Emission Reduction Credits: a pilot study in Shasta County, California, USA.* Submitted to Winrock as WESTCARB deliverable.

See separate attachment.

Appendix C:

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See separate attachment.

Appendix D:

Oregon State University reports:

Harmon, Mark E., Carlos A. Sierra, and Olga N. Krankina. 2007. *Rates of Decomposition o fWoody Debris in WESTCARB Region.* Department of Forest Science, Oregon State University. Submitted to Winrock as WESTCARB deliverable.

Krankina, Olga N., Carlos A. Sierra, and Mark E. Harmon. 2007. *Modeling Study of Carbon Dynamics for Selected Treatments of Forest Fuels in Southern Oregon.* Department of Forest Science, Oregon State University. Submitted to Winrock as WESTCARB deliverable.

See separate attachments.