United States Department of Agriculture
Forest Service

Climate Change Report

Colville National Forest Plan Revision
Draft Environmental Impact Statement

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Colville National Forest – Forest Plan Revision

Summary of Climate Change

July 9, 2015

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INTRODUCTION

The information contained in this document is a synthesis of currently available scientific information. The Forest Service and other agencies will continue to conduct scientific research on the effects of climate change and monitor actual changes. The adaptive management approach of the forest planning process would allow the Forest Service to update and adjust the forest plan additional information becomes available. This climate change discussion compiles and synthesizes scientific information on past and projected trends in regional climate and climate-related impacts to National Forest System lands. It also identifies possible management options to reduce ecosystem vulnerability to climate change and to increase ecosystem resilience to both climate and non-climate stressors.

BACKGROUND ON CLIMATE CHANGE

Warming of the climate system is evident from observation of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (IPCC, 2014). Climate change is expected to profoundly alter vegetation structure and composition, terrestrial ecosystem processes, and the delivery of important ecosystem services over the next century. Since 1750, atmospheric carbon dioxide (CO_2) concentrations have increased from 280 to over 390 parts per million (ppm) and are expected to continue rising, reaching 450 to 875 ppm by 2100 (Peterson et al. 2014). The scientific community generally agrees that substantial warming of Earth's surface (2.0°- 4.5° C) will accompany the increasing concentration of greenhouse gases in the atmosphere. Carbon dioxide (CO_2) is a prominent greenhouse gas (IPCC, 2014).

Definition of Climate Change
Climate change in usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. (IPCC, 2014)

Terrestrial ecosystems strongly influence the global carbon cycle and combined with oceans, are estimated to absorb about half of the carbon dioxide (CO_2) currently being released by human activities (Dilling et al., 2003). Simulated global patterns of carbon flux suggest that western U.S. forests are a carbon sink (Potter and Klooster, 1999). Temperate forest ecosystems contain a significant amount of soil carbon (Rasmussen, 2006) and tree-based carbon (Hurteau et al., 2008). These carbon stocks are significant resources that prevent additional significant carbon inputs into the global carbon cycle and provide a mechanism for carbon storage from natural and anthropogenic sources.

BIOGEOGRAPHICAL SETTING AND NATURAL RESOURCES

The 1.1-million-acre Colville National Forest (CNF) in northeast Washington is bordered to the north by British Columbia, to the west by the Okanogan National Forest, to the east by the Idaho Panhandle National Forests, and to the south by a portion of the Colville Confederated Tribes Indian Reservation. The CNF has three ranger districts: Republic, Newport, Sullivan Lake, and Three Rivers. The Forest Supervisor's office is located in Colville, Washington (Gaines et al. 2012)

Northeast Washington is geologically complex and includes the Columbia Basin and the Okanogan Highlands, which function as a transition zone between the Cascade and the Rocky Mountain Ranges. Between one-third and one-half of the CNF was burned during the 1920s and 1930s thus the current forest is relatively young. Federally listed species include the endangered woodland caribou (*Rangifer tarandus*), threatened grizzly bear (*Ursus arctos*), and Canada lynx (*Lynx canadensis*). There are currently no federally listed plants on the Colville; however, the moonwort (*Botrychium lineare* W.H. Wagner) was determined to be warranted but precluded. (Gaines et al. 2012)

CARBON STEWARDSHIP

The management of forest and ecosystem carbon is an important responsibility of land management agencies. This is not to imply that maximizing carbon storage should be the most important or overriding purpose of land management. Land managers and their stakeholders should determine the state of the carbon resource, where carbon stewardship fits in the goals of resilient ecosystems, and how carbon management might be blended with other ecosystem services. Carbon management is complex, maximization of carbon storage is not necessary the best management strategy. Carbon stewardship needs to consider ecosystem function and risk of disturbance to carbon (i.e. wildfire) (Hurteau et al. 2009).

Forest carbon stewardship is best described through an expression of directives. Management to maximize carbon storage or alter carbon storage in an ecosystem needs to take place in context with other natural processes as well as land management goals and objectives. The below carbon stewardship directives are intended to provide considerations for integrating carbon management with planning and implementation processes. The processes are attempting to adapt forests to the impacts of a changing climate, increased disturbance cycles, 100 years of fire suppression in fire

adapted ecosystems, and increasing environmental pollution load. These preliminary forest carbon stewardship directives are intended to be refined, updated, and integrated based on field experience and best available science as it continues to emerge.

- Emphasize ecosystem function and resilience first. Carbon sequestration capacity depends on sustaining and enhancing ecosystem function to maintain resilient forests adapted to changing climate and other conditions.
- Recognize carbon sequestration as one of many ecosystem services. Carbon sequestration is one of the many benefits provided by forests, grasslands, and forest products, now and in the future. Carbon sequestration should be considered in context with other ecosystem services.
- Consider system dynamics and scale in decision making. Evaluate carbon sequestration and cycling at landscape scales over long time frames. Explicitly consider uncertainties and assumptions in evaluating carbon sequestration consequences of ecosystem stewardship options.
- Use the best information and methods to make decisions concerning carbon stewardship. Base carbon stewardship and policy decisions on the best available science based knowledge and information about system response and carbon cycling in ecosystems and wood products. Use this information wisely by dealing directly with uncertainties, risks, opportunities, and tradeoffs through sound and transparent risk management practices.
- Work for program integration and balance. Carbon stewardship and management is part of a balanced and comprehensive program of sustainable ecosystem management and response to ecosystems outside the historic range of variability. As such carbon stewardship has ecological, economic, and social implications and interactions with other Forest Service programs and strategies.

FOREST LEVEL PREDICTIONS OF CLIMATE CHANGE

Though the science of predicting potential climate change has been improving, currently there is no site specific information available that would indicate the potential rate or direction of climate change at a level detailed enough to use for vegetation modeling or specific land management at the Forest or project level. Scientific research and historical data has allowed for the development of models at regional scale that develop general predictions of potential future scenarios over the long term. Analysis for specific years or specific areas on the Colville National Forest is not possible with current models or analysis.

REGIONAL CLIMATE CHANGE OVERVIEW

Atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases have increased rapidly over the past century or more. Atmospheric CO2 concentrations are expected to continue to rise for the foreseeable future, although future rates of increase may vary with changes in the global economy and the success or failure of international efforts to reduce or limit the growth of greenhouse gas emissions. Although atmospheric CO_2 concentrations are of concern primarily

because of their potential to influence global temperatures (i.e., the "greenhouse effect"), higher CO_2 concentrations may also influence vegetation growth and water-use efficiency and are therefore linked more directly to forest ecosystem functioning and natural resource management. Other greenhouse gases affected by land management is methane (CH_4) and to a much lesser extent nitrous oxide (N_2O) emissions from motorized vehicles including heavy equipment (IPCC, 2014).

Temperatures have been increasing in Washington State over the past century. In the last 100 years, temperatures have increased by about 1.5 °Fahrenheit (Mote 2003a). The warming trends have been strongest in the winter months and weakest in the autumn months. Precipitation has also been increasing during the past century with the largest relative increases occurring during the spring in the eastern portion of the state (Mote 2003b).

The Climate Impacts Group at the University of Washington has projected future changes in climate of the Pacific Northwest based on climate projections produced for the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report. They predict that temperatures will raise an average of 0.5°Fahrenheit per decade over the next century (Elsner et al. 2009), a potentially larger increase than experienced in the past 100 years. Predictions are for warming trends to be greater in the eastern part of the state. Precipitation projections for the region are more variable than temperature projections. In general, precipitation is predicted to increase in the winter and decrease in the summer (Mote et al. 2005a).

Winter temperatures play a large role in determining whether precipitation falls as snow or rain. Despite increases in precipitation in eastern Washington State, warming temperatures have led to decreases in snowpack. Mote (2003a) reported reductions of 30 to 60 percent in April 1 snowpack from 1920 through 2000 over much of Washington State. The largest decreases in snowpack have been at lower elevations (less than 5,900 feet). Projected temperature increases for the coming century are expected to increase the proportion of winter precipitation falling as rain, increase the frequency of winter flooding, reduce snowpack, increase winter streamflow, result in earlier peak flows, and decrease late spring and summer flows (Hamlet et al. 2007; Hamlet and Lettenmaier 1999). The snowpack in the Cascades is projected to decrease by 44 percent by 2020 and by 58 percent by 2040 relative to the recent past. Peak runoff is expected to occur 4 to 6 weeks earlier (Climate Change Impacts Group 2004), while reduced summer streamflows will be more common and widespread (Miles et al. 2000; Snover et al. 2003; Stewart et al. 2004). April 1 snow water equivalent is projected to decrease by an average of 27 to 29 percent across the state by the 2020s, 37 to 44 percent by the 2040s, and 53 to 65 percent by the 2080s (Elsner et al. 2009). SWE on April 1 is an important metric for evaluating snowpack changes because in the PNW, the water stored in the snowpack on April 1 is strongly correlated with summer water supply. The reduction of snowpack in the regions of highest elevation is projected to be less significant. There is no discussion of uncertainty or confidence intervals in the modeling methodology presented in the above references.

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BASELINE CLIMATE DATA

Temperatures increased across the region from 1895 to 2011, with a regionally averaged warming of about 1.3°Fahrenheit (Kunkel et al. 2013). While precipitation has generally increased, trends are small as compared to natural variability. Both increasing and decreasing trends are observed among various locations, seasons, and time periods of analysis. Studies of observed changes in extreme precipitation use different time periods and definitions of "extreme," but none find statistically significant changes in the Northwest (Groisman et al. 2004). These and other climate trends include contributions from both human influences (chiefly heat-trapping gas emissions) and natural climate variability, and consequently are not projected to be uniform or smooth across the landscape or through time.

As a result of changes in long-term average trends, some conditions/events we now consider to be extreme will occur more frequently or with greater magnitude, while others will occur less frequently (e.g., more unusually warm periods and fewer cold spells). In many cases, changes in the frequency and magnitude of extreme events (droughts, severe fires, etc.) will have the most significant and long-lasting consequences for land and resource management.

PROJECTED CLIMATE TRENDS

The climate observations and projections reported here are long-term trends in average conditions. Climate has varied and will continue to vary, from year-to-year and decade-to-decade around the long-term trend. The effects of longer term climate trends may be either amplified or moderated by climate variability resulting from the shorter-term El Nino Southern Oscillation and the Pacific Decadal Oscillation.

Northwest is projected to be within a range of an 11% decrease to a 12% increase for 2030 to 2059 and a 10% decrease to an 18% increase for 2070 to 2099 (Mote and Salthe, 2010). For every season, some models project decreases and some project increases (Kunkel et al. 2013), yet one aspect of seasonal changes in precipitation is largely consistent across climate models: for scenarios of continued growth in global heat-trapping gas emissions, summer precipitation is projected to decrease by as much as 30% by the end of the century (Kunkel et al. 2013; Mote and Salthe, 2010). Northwest summers are presently dry and although a 10% reduction (the average projected change for summer) is a small amount of precipitation, unusually dry summers have many noticeable consequences, including low streamflow and greater extent of wildfires due to lower fuel moisture levels throughout the region (Littell et al. 2010). Projected temperature increases are large relative to natural variability; the relatively small projected changes in precipitation are likely to be masked by natural variability for much of the century (Deser et al. 2012).

DESCRIPTION OF OBSERVED AND PROJECTED CHANGES

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Climate models are unanimous in projecting increasing average annual temperatures over the coming decades in the Pacific Northwest. The average of multiple climate model projects predicts annual temperatures will increase 2.2° F by the 2020's and 3.5° F by the mid-21st century, compared to the average for 1970 to 1999. Temperature increases are projected to occur during all seasons, with the greatest increases projected in summer. Beyond mid-century, model projections diverge substantially in response to differences among scenarios in assumed emissions, with increases in average annual temperature ranging from 5.9° F to 9.7° F in the Pacific Northwest by the end of the 21st century.

Projected changes in Pacific Northwest precipitation are more variable among models, but generally suggest no substantial change in the average annual amount of precipitation from the variability experienced during the 20th century. Given the variability in results among models, projections of precipitation are considered less certain than temperature projections. Most of the models project decreases in summer precipitation, increases in winter, and little change in the annual mean.

Observed regional warming has been linked to changes in the timing and amount of water availability in basins with significant snowmelt contributions to streamflow. Since around 1950, area-averaged snowpack on April 1 in the Cascade Mountains decreased about 20% (Mote, 2006; Pierce et al, 2008), spring snowmelt occurred 0 to 30 days earlier depending on location, late winter/early spring streamflow increases ranged from 0% to greater than 20% as a fraction of annual flow (Hidalgo et al. 2009; Reclamation, 2011) and summer flow decreased 0% to 15% as a fraction of annual flow (Stewart et al., 2005), with exceptions in smaller areas and shorter time periods (Mote et al. 2008). It is unknown if snowmelt predictions for the Cascade Mountains reflect potential conditions for the mountains of the Colville National Forest.

Hydrologic response to climate change will depend upon the dominant form of precipitation in a particular watershed, as well as other local characteristics including elevation, aspect, geology, vegetation, and land use (Mote, P.W., 2003a; Safeeq et al. 2013). The largest responses are expected to occur in basins with significant snow accumulation, where warming increases winter flows and advances the timing of spring melt (Hidalgo et al, 2009; Hamlet and Lettenmaier, 2005). By 2050, snowmelt is projected to shift three to four weeks earlier than the 20th century average, and summer flows are projected to be substantially lower, even for predicted greenhouse gas emissions scenarios that assumes substantial emissions reductions (Elsner et al. 2009). Basins with a significant groundwater component may be less responsive to climate change than indicated by other research literature (Tague et al. 2008).

Changes in river-related flood risk depends on many factors, but warming is projected to increase flood risk the most in mixed basins (those with both winter rainfall and late spring snowmelt-related runoff peaks) and remain largely unchanged in snow-dominant basins; 27 regional climate models project increases of 0% to 20% in extreme daily precipitation, depending on location and definition of "extreme" (for example, annual wettest day). Averaged over the region, the number of days with

more than one inch of precipitation is projected to increase 13% in 2041 to 2070 compared with 1971 to 2000 under a scenario that assumes a continuation of current rising emissions trends, though these projections are not consistent across models (Wehner, M.F., 2013). This increase in heavy downpours could increase flood risk in mixed rain-snow and rain-dominant basins.

CLIMATE CHANGE IN NORTHEASTERN WASHINGTON

Increasing temperatures and a greater annual variation in precipitation in Northeastern Washington State are predicted from expected increases in anthropogenic CO_2. The Pacific Northwest has warmed 1.3°F between 1895 and 2011, with statistically-significant warming occurring in all seasons except for spring. All but five of the years from 1980 to 2011 were warmer than the 1901-1960 average. The trend is for continued future warming. The frost-free season (and the associated growing season) has lengthened by 35 days from 1895 to 2011 in the Pacific Northwest. (Snover et al. 2013, Parks 2010) Temperature records show significant seasonal and annual decreases in the number of frost days and changes in spring minimum temperatures. Warmer spring temperatures coupled with increases in mean and variance of spring precipitation correspond strongly to earlier snow melt out, an increased number of snow-free days, and observed changes in stream flow timing and discharge. (Pederson et al. 2011)

The variation in precipitation will have effects on water release timing, length of the growing season, and soil moisture conditions. Predicted increases in early season snowmelt/late season precipitation (Miller et al., 2003) (which will increase fuel loading due to greater understory growth) and hotter, drier summers have the high potential to increase wildfire activity and carbon emissions from forested areas (Miller and Urban, 1999; Kim, 2005). Research shows increases in understory biomass with amplified pollution and climate change, suggesting future increases in fire severity and fire size (Hurteau and North, 2009). Climate change modelers agree that climate will become more extreme as oscillations between wet and drought conditions become more common. It is suggested that land managers not recreate a fixed pre-settlement condition but strive for forest conditions that are more resilient and resistant to disturbance impacts (North et al., 2009 and Millar et al., 2008).

There has been a general decline in snowpack; Cascade spring snowpack has declined 23% during 1930-2007. There is predicted a relatively steady loss rate of snowpack at 2.0% per decade, yielding a loss of 16% from 1930 to 2007. (Stoelinga et al. 2010) Over the past four decades, records show a tendency toward decreased snowpack with peak snow water equivalent arriving and melting out earlier. The declining snowpack will result in: earlier stream flow timing, small increase in annual stream flow, increasing winter stream flow, and declining summer stream flow (Snover et al. 2013).

OBSERVED TRENDS IN FOREST CARBON

Analyses of trends in North American terrestrial ecosystem productivity during the late 20th century based on satellite imagery generally confirm a net carbon sink for the North American continent,

although there is considerable year-to-year and geographical variation (Potter et al. 2007; Running et al. 2004; Nemani et al. 2003; Potter et al. 2003; Slayback et al. 2003; Hicke et al. 2002; Myneni et al. 2001). The inter-annual and spatial variability of productivity are commonly attributed to anomalies in seasonal temperature and precipitation, and ecosystem disturbances such as drought, fire, and insect outbreaks (Potter et al. 2008a; Piao et al. 2007; Potter et al. 2007; Boisvenue and Running 2006; Angert et al. 2005; Goetz et al. 2005; Running et al. 2004; Nemani et al. 2003; Nemani et al. 2002).

Recent estimates find that the terrestrial ecosystems of the United States remove approximately 505 million metric tons (Mt) of carbon per year (± 50 percent) from the atmosphere and store it as plant material and soil organic matter (King et al. 2007; Pacala et al. 2007). Estimates of the net sink from forests, forest soils and wood products range from 203 to 293 Mt C per year, or roughly half of the total sink. Wood products account for approximately 6 to 12 percent (30 to 57 Mt per year) of the total U.S. carbon sink. (US EPA 2008; Birdsey et al. 2007) Forests and wood products offset approximately 10 to 20 percent of U.S. fossil fuel emissions (US EPA 2008; Pacala et al. 2007).

The reservoir of stored carbon in U.S. forests is approximately 42,700 to 66,600 Mt (US EPA 2008; Birdsey et al. 2007). Public forestlands contain approximately 37 percent of this carbon reservoir. National Forests store an estimated 8,900 Mt of carbon, or from 13 to 21 percent of all forest carbon of the United States. (Smith and Heath 2004) Carbon stocks on the Colville National Forest contribute approximately 0.14% to 0.21% of the total U.S. forest carbon reservoir on public lands (USDA Forest Service, 2015). Trends in carbon stocks and flux on the Colville National Forest can be inferred from 20th century trends in forest age and structure classes. Recent scientific literature documents the general pattern of changes in carbon stocks and net ecosystem productivity. On the Colville National Forest, the distribution of forest age and structure classes has changed substantially since the early 20th century. Intermediate age classes (40-100 years of age) have increased in area, while the amount of young stands has decreased. In most forest types, the abundance of older, late successional stands has declined. The cause of these changes varies by forest type and geographic location, but the most wide-spread agents of change are root disease, white pine blister rust, timber harvest, and the substantial decline in acres burned since 1940. A significant portion of the increase in intermediate age classes is the result of forest re-growth following large stand replacing fires in the early 20th centuries.

Total carbon stocks decline as a result of disturbance and then increase, rapidly during intermediate years and then at a declining rate, over time until another significant disturbance (regeneration timber harvest or tree mortality resulting from drought, fire, insects, disease or other causes) kills large numbers of trees. Carbon flux and net ecosystem productivity are lowest, and usually negative (a carbon source to the atmosphere) in young stands (0-30 years) following disturbance because carbon emissions from decay of dead biomass exceed the amount of carbon removed from the atmosphere by photosynthesis within the stand. As the stand develops, Net ecosystem productivity increases and the stand becomes a carbon sink. Net ecosystem productivity and carbon sink strength

generally peak at the intermediate stage of stand development, then decline with age but often remain positive. (Canadell et al. 2007; Pregitzer and Euskirchen 2004)

Forests generally mirror those identified for much of the Inland Northwest (Hessburg and Agee 2003). Hessburg et al. (2000) constructed historical and current vegetation maps from 1932 to 1966 and 1981 to 1993 aerial photographs, respectively for sample sub-basins within the interior Columbia River basin. Comparing historic and current vegetation maps, they found that forests of northeastern Washington, northern Idaho, and northwestern Montana experienced a significant increase in area of intermediate structural classes. Stand initiation structures (new forests) declined significantly due to fire exclusion, despite timber harvest activity. However, they noted that timber harvest activities reduced the abundance of medium- and large-sized trees distributed in other forest structures as remnants of stand-replacing fires.

Net ecosystem productivity, or NEP, is defined as gross primary productivity (GPP) minus ecosystem respiration (ER) (Chapin et al. 2006). It reflects the balance between (1) absorbing CO2 from the atmosphere through photosynthesis (GPP) and (2) the release of carbon into the atmosphere through respiration by live plants, decomposition of dead organic matter, and burning of biomass (ER). When NEP is positive, carbon accumulates in biomass. Ecosystems with positive NEP are referred to as a carbon sink. When NEP is negative, ecosystems emit more carbon than they absorb. Ecosystem with negative NEP is referred to as a carbon source.

The following information is based on the publication Baseline Estimates of Carbon Stocks in Forests and Harvested Wood Products for National Forest System Units – USDA Forest Service, Pacific Northwest Region (2015). It is stated in the methodology that at scales of the individual national forest level, uncertainty can exceed 25% and at the individual carbon pool level (seven separate pools were modeled) that uncertainty can exceed 100%. The estimates of carbon pools and fluxes come from a draft pre-decisional document.

As of 2012, the Colville National Forest stores approximately 93.5 teragrams (Tg) of carbon. A teragram is one trillion grams, a unit of mass equal to 10^{12} grams. A gram is equal to the weight of a paperclip; 454 grams makes a pound. A Tg is approximately 380,000 Chevrolet Suburbans; a four wheel drive Chevrolet Suburban weighs 5,824 pounds. From 1990 to 2012, the modeled number varies from 90 to 94 Tg.

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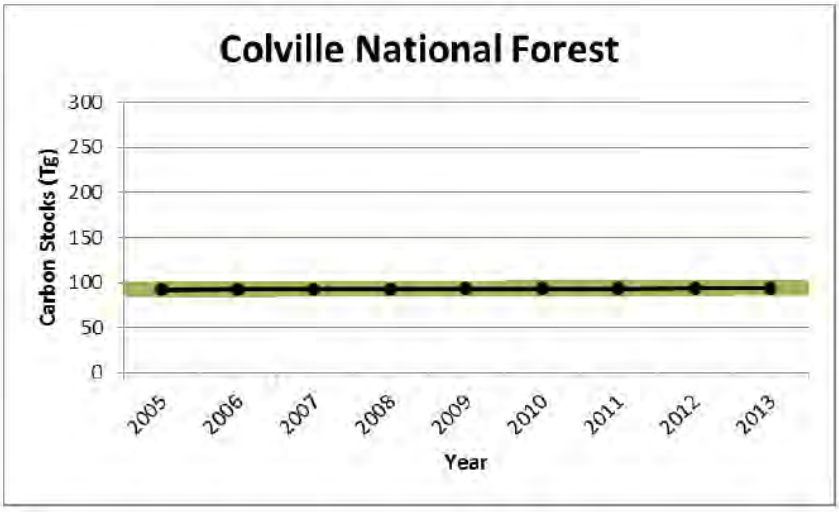

Figure 1 – Total Forest Ecosystem Carbon Stocks and Uncertainty Estimates (95% confidence level)

The average density of forest carbon is approximately 200 megagrams of carbon per hectare (Mg C/ha) (approximately 200 US tons) on the Colville National Forest (USDA Forest Service 2015).

Projected trends in forest carbon stocks and flux estimates indicate that currently Colville National Forest is a net carbon sink, absorbing approximately 0.2 Tg of carbon a year. In the early 1990's it is modeled that the Colville was a net carbon source releasing approximately 0.7 Tg of carbon a year. (USDA Forest Service 2015). All these modeled numbers are within the uncertainty intervals suggesting that in a given year the Colville can be a net source or sink for carbon.

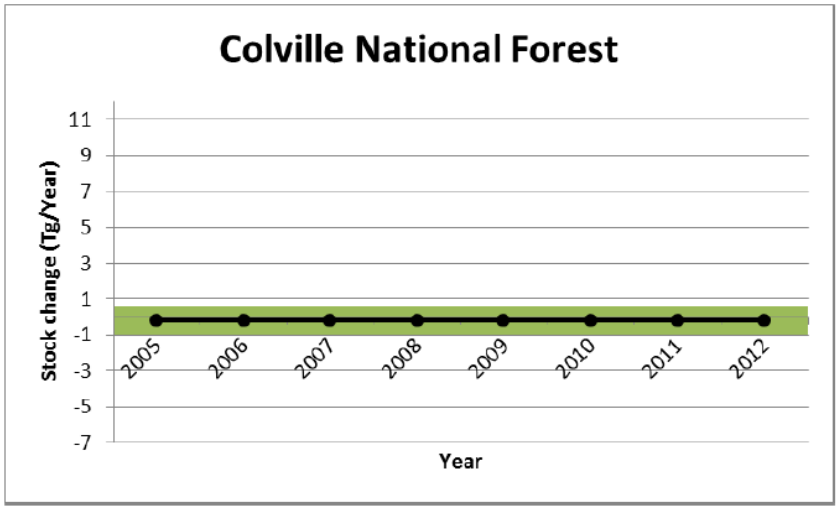

Figure 2 – Carbon Stock Flux and Uncertainty Estimates (95% confidence level)

Harvested wood products (HWP) are products made from wood including lumber, panels, paper, paperboard, and wood used for fuel (Skog, 2008). HWP fraction of the carbon pool is small compared to ecosystem carbon (Butler et al. 2014). In the context of total forest carbon, including

both ecosystem carbon and carbon from harvested wood products, it is estimated that HWP carbon stocks represent 5.25% of total forest carbon storage associated with national forest in the Pacific Northwest Region in 2012. This is 5 times less than the uncertainty in the national level modeling and up to 20 times less than the uncertainty in modeling specific carbon pools. (USDA Forest Service 2015) At the national level, based on EPA's total US HWP 2005 stock estimate of 2,354 teragrams of carbon (US EPA 2012), the Pacific Northwest Region HWP carbon stocks represents 5.8% of total HWP carbon stocks (Butler et al. 2014). Recent literature suggestions that in the Pacific Northwest Region of the Forest Service the decay of HWP harvested from 1909 to 2012 now exceeds additions to the HWP carbon pool from products harvested from National Forest System lands (Butler et al. 2014).

EFFECTS OF CLIMATE CHANGE ON SPECIFIC RESOURCE AREAS

The effects of climate change when appropriate and applicable to that resource is provided in the specialist report for that resource. An analysis of the effects of climate change of a resource is most appropriate to be done by that resource specialist.

RESOURCE VULNERABILITIES ON THE COLVILLE NATIONAL FOREST SERVICE

The following identified vulnerabilities were developed during a two day workshop of Forest Service mangers and scientists. These managers and scientists reviewed current climate change science and identified resources vulnerable to expected climate change (Gaines et al. 2012).

Based on the scientific understanding developed on the first day of the two day climate change workshop, participants were asked to identify and rank resources (as high, moderate, or low) in relation to perceived vulnerability to climate change. Vulnerability was defined as the extent to which a natural or social system is susceptible to sustained damage from weather extremes, climate variability, and change (and other interactive stressors) (Binder et al. 2009). Vulnerabilities were categorized into those related to the management of vegetation and habitats, and those related to aquatics and infrastructure. The vulnerabilities related to vegetation and habitat management included two general themes: the conservation of biodiversity, and the restoration of resilient forests and disturbance regimes. The vulnerabilities related to aquatic and infrastructure resources included water quality and quantity, the risk to roads and other facilities from changes to hydrologic regimes, and at-risk aquatic species and habitats. (Gaines et al. 2012)

Resource Vulnerability Area	Ranking	Vulnerability
Vegetation and habitat	High	• Plant migration could reduce the availability of white bark pine and shift the location of other forest types reducing the availability of alpine habitats. • Habitat specialists (caribou, lynx, and wolverine denning habitat) will have the most difficult time adjusting.

Resource Vulnerability Area	Ranking	Vulnerability
		• Riparian and wetland habitats may be particularly vulnerable. • Habitat connectivity will be reduced for some species and may be most detrimental for low-mobility habitat specialists. • Dry forest stands with high tree densities and fuel loads become increasingly susceptible to fire, insects, disease, and drought. • Larger and more frequent disturbances could make it difficult for forests/habitats to recover and cause them to be more susceptible to invasive species. • Past management for timber production and fire exclusion has made old forests more susceptible to fire, including severe fire. • Species with narrow ecological amplitude and endemics may be at high risk for local extinction.
	Moderate	• Elk and deer may be vulnerable to increased diseases. • Species on the edges of their ranges or with limited mobility may be at risk for local extinction. We need to assess whether or not these are "lost causes" before investing in their conservation.
	Low	• Habitat generalists (grizzly bear, wolves, red squirrel, black bear) that are more mobile may fair better. • Increased carbon dioxide might increase growth of already overstocked stands.
Aquatic and infrastructure	**High**	• Municipal/agricultural watersheds may lose the capacity to deliver water at current levels. • Reduced cold water in streams could reduce fish habitat availability and alter the timing of spawning or the ability of fish to spawn. • Roads and other facilities could be threatened by increased frequency of extreme hydrologic events such as floods and debris flows. • Some aquatic species could become more susceptible to disease and changes in stream productivity. • Water availability for ecosystem processes (e.g., soil water for plant growth) could be reduced or shifted seasonally.
	Moderate	• Ski area operation could be affected by reduced winter snowpack. • Riparian areas could become harder to manage as stream networks become smaller and less connected (loss of perennial headwater streams). • Grazing allotments may be changed owing to changes in water availability and forage productivity.
	Low	• Sustaining tribal use areas may become more difficult as resources become scarcer. • Roads may require more maintenance owing to increased use. Facilities may receive greater use (and wear) from longer recreational seasons.

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MANAGEMENT STRATEGIES FOR THE ADAPTATION TO CLIMATE CHANGE

In 2008, the US Climate Change Science Program produced a report: Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources. One chapter was developed by US Forest Resource research scientists and other outside scientists directly concerning the current science available on adaptation responses for National Forest Systems lands. (Joyce et al. 2008).

Below is a summary of specific adaptation responses that have potential to allow the Colville National Forest to create resilient landscapes and assist in the management of natural systems within the dynamics of climate change. This summary is in line with the Forest Carbon Principles presented above; developing resilience, promoting diversity and function in ecosystems, and using the best scientific knowledge to understand systems and manage them for the long term.

- Reducing, minimizing, or eliminating the potential for introduction, establishment, spread and impact of invasive species across all landscapes and ownerships.

- Be proactive in reducing hazardous fuels and enhancing the restoration and post-fire recovery of fire-adapted ecosystems.

- The combination of extended dry periods resulting from fewer, stronger rainfall events with warmer temperatures could render northeastern forests more susceptible to fire than they have been for the past 100 years of fire suppression.

- Climate change is expected to alter forest and rangeland productivity.

- Under a changing climate, landscape fragmentation may exacerbate or cause unexpected changes in species and ecosystems.

- Primary premise for adaptive approaches is that change, novelty, uncertainty, and uniqueness of individual situations are expected to define the planning backdrop of the future. No single approach would fit all situations.

- The Forest Service needs to implement a variety of management approaches to reduce the impact of existing stressors on National Forest System lands.

- Resistance practices include thinning and fuels abatement treatments at the landscape scale to reduce crown fire potential and risk of insect epidemic, maintaining existing fuel-breaks.

- Maintaining prior species may require significant extra and repeated efforts to supply needed nutrients and water, remove competing understory, fertilize young plantations, develop a cover species, thin, and prune.

While there may be specific questions that research scientists need additional data and work to answer, the Forest Science and related universities and institutions has a robust base of scientific

research and management strategies that can respond to the changing conditions of climate change: the direct, indirect, and cumulative effects of variations in temperature and water availability that would occur in the coming decades.

CONCLUSIONS

The modelled predictions of climate change in the future are for increasing temperatures, changes in how precipitation occurs across the landscape (less snow persistence), higher stream peak flows, and increases in summer moisture stress. Maximizing carbon stock retention and conservation of existing carbon stocks while restoring forest stands to durable, natural stand structures should be goals of forest management, in order to increase and retain long term carbon stocks (Beedlow et al. 2004). Current and future management of National Forest System lands can use adaptation principles and the base of scientific research to manage the land and resources of the Colville National Forest for the benefit of the people of the United States and ensure the Forest is conserved for multiple uses by future generations.

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