Table 299. Summary of cumulative effects to energy and minerals from other resource management plans

Resource plan	Description and Summary of effects
Adjacent National Forest Plans	The forest plans for NFS lands adjacent to the HLC NF include the Custer-Gallatin, Lolo, Flathead, and Beaverhead-Deerlodge NFs. All plans address Energy and Minerals. Generally speaking, management of Energy and Minerals is consistent across all NFs due to law, regulation, and policy. The management of Energy and Minerals would be complementary and consistent. This includes specific adjacent landscapes that cross Forest boundaries, such as the Upper Blackfoot, Divide, Elkhorns, Crazies, and the Rocky Mountain Range.
National Park Service – Glacier National Park General Management Plan 1999	The general management plan for Glacier National Park calls for preserving natural vegetation, landscapes, and disturbance processes. Mineral and energy projects in the Rocky Mountain Range GA and would be consistent with these conditions.
BLM Resource Management Plans (RMP)	BLM lands near the HLC NF are managed by the Butte, Missoula, and Lewistown field offices. The Butte plan was recently revised (2009) while the existing plans for the Missoula and Lewistown areas are under revision. These plans contain components related to Energy and Minerals, and would be complementary to the draft plan.

Conclusions

Access to locatable, leasable and salable minerals, as well as, opportunities for mineral entry, mineral leasing and mineral disposal would vary by alternative. The variations across alternatives are due to differences in RWAs, motorized, and mechanized access, as well as plan components related to restricting surface occupancy on future mineral and energy projects. Alternative E offers the most opportunities for mineral-related activities, followed by alternatives A, C, B and D, in order of decreasing opportunities.

3.31 Carbon Sequestration

3.31.1 Introduction

Carbon sequestration and associated climate regulation have been identified as key ecosystem services provided by the Forest. The potential effects of alternatives are analyzed relative to carbon storage (sequestration) potential. Concerns with carbon, climate change, and associated ecosystem responses have been raised during the forest plan revision process. The relationship between climate change and other resources are addressed in the appropriate resource section. This section addresses carbon sequestration.

Concerns with carbon, climate change, and associated ecosystem responses have been raised during the forest plan revision process. Carbon sequestration is one way to mitigate greenhouse gas emissions by offsetting losses through capture and storage of carbon. The FS recognizes the vital role that our nation’s forests and grasslands play in carbon sequestration (USDA 2015).

The key indicators used are:

- The sequestration and storage of carbon pools (stocks) in terms of total ecosystem carbon (Tg, teragrams) and carbon in harvested wood products (MgC, megagrams of carbon)
- Natural/human- caused changes to landscape that influence carbon storage and sequestration (i.e., vegetation succession, vegetation treatments, fire, insect outbreaks, disease) – influence to carbon pools

Analysis area

The Forest has identified carbon sequestration (storage) and associated climate regulation as a key ecosystem service, and describes potential effects of the proposed action and alternatives at the scale of the Forest. The temporal scale for analyzing carbon stocks and emissions is the life of the plan (15 to 20 years), with some analysis occurring across the longer term (50 years), consistent with the analysis period for other key ecosystem characteristics associated with the terrestrial vegetation.

3.31.2 Regulatory framework

There are no applicable legal or regulatory requirements or established thresholds concerning management of forest carbon or greenhouse gas emissions. The 2012 Planning Rule and associated directives require an assessment of baseline carbon stocks and a consideration of this information in management of the forests (USDA, 2015). The FS continues to develop principles and direction for consideration of biological carbon in land management and planning decisions. Forests play an active role in controlling concentration of carbon dioxide in the atmosphere. Forests store large amounts of carbon in their live and dead wood and soil, and are an important carbon sink, removing more carbon from the atmosphere than they are emitting (Pan, 2011).

3.31.3 Assumptions

For the action alternatives, the strategies described in appendix C of the revised forest plan would generally be followed during implementation of the plan.

Numerous assumptions are included in the literature citations used for climate modeling and carbon estimates; each publication enumerates these assumptions.

3.31.4 Best available scientific information used

An ever-increasing body of knowledge exists regarding climate change and carbon sequestration. The best available science is used to summarize conditions relative to the HLC NF. This analysis relies on several recently published works by carbon and greenhouse gas emissions experts. This section also references vegetation modeling done for terrestrial vegetation and timber.

Estimates of future carbon stocks and their trajectory over time are uncertain due to the uncertainty associated with multiple interacting factors that influence them. This includes climate change and its effects on vegetation, which is difficult to predict, especially in the complex terrain and variable site conditions found on the HLC NF. While advances have been made in accounting for the relationship between greenhouse gases and climate change, difficulties remain in reliably attributing observed temperature changes to natural or human causes at smaller than continental scales (Intergovernment Panel on Climate Change (IPCC), 2007).

3.31.5 Affected environment

Forest ecosystems (including nonforested vegetation types) cycle carbon; they are in a continual flux, emitting carbon into the atmosphere and removing it, i.e. storing it as biomass. Carbon sequestration is the process by which atmospheric carbon dioxide is taken up by vegetation through photosynthesis and stored as carbon in biomass (tree trunks, branches, foliage and roots) and soils.

The importance of carbon storage capacity of the world’s forests is tied to their role in removing atmospheric carbon that is contributing to global warming. Forests and other ecosystems are carbon sinks because growing plants remove carbon dioxide from the atmosphere and store it. Sequestering, or storing, carbon in these ecosystems can help offset sources of carbon dioxide. In addition, transferring ecosystem carbon to harvested wood products results in carbon being stored and not contributing to net greenhouse gas emissions; substitution of wood for more fossil fuel-intensive materials has a carbon emissions benefit (USDA 2015).

Carbon stocks and trends

The 2.9 million-acre HLC NF is about 1.5 percent of the nearly 190 million acres of NFS lands in the United States. The NFS constitutes one-fifth (22%) of the Nation's total forest land area and contains one-fourth (24%) of the total carbon stored in all United States forests, excluding interior Alaska (USDA 2015). The NFS forest carbon resource has been growing since 1990, according to FIA data. NFS lands are not subject to conversion to other land uses, such as agriculture or development. Thus carbon storage alterations from land use conversions is not a major factor for the forestlands within NFs, including the HLC NF.

Total ecosystem carbon

The total ecosystem carbon stocks on the Helena side (western portion) of the HLC NF have slightly decreased since 1990, while the Lewis and Clark (eastern portion) remained fairly steady.

Carbon flux is the change in carbon stocks over time, calculated by taking the difference between the inventories and dividing by the number of years between the inventories (Woodall, Smith, & Nichols, 2013). A negative change means carbon is being removed from the atmosphere and sequestered by the forests (carbon sink), while a positive change means carbon is added to the atmosphere by forest-related emissions (carbon source) (USDA 2015). While the carbon flux for most timesteps on most NFs in the Northern Region are between 0 and -2, indicating that these forests balance as a carbon sink, the flux on the Helena NF is between 0 and +1, indicating that it is functioning as a carbon source. The flux on the Lewis and Clark NF is also slightly positive but very close to zero (ibid).

The recent disturbances from bark beetles and fires may have weakened pre-disturbance sequestration rates on the HLC NF. However, the affected forests remain forests, not converted to other land uses, and long-term forest services and benefits will be maintained. As forested stands develop, the strength of the carbon sink increases until peaking at an intermediate age and then gradually declining but remains positive (Pregitzer & Euskirchen, 2004). Carbon stocks continue to accumulate as stands mature, although at a declining rate, until impacted by future disturbances.

Harvested wood products

Carbon has been removed from the Forest through harvest of trees over the past 100 or more years. Some of this carbon is stored in wood products or in landfills and contributes to the total forest carbon storage on the Forest. The cumulative carbon stored in harvested wood products from 1910 to 2010 is in decline.

Influence of disturbance on carbon stocks

Forests are highly dynamic systems that are continuously repeating the natural progression of establishment, growth, death, decay and recovery, while cycling carbon throughout the ecosystem and the atmosphere. Natural and human-related disturbances, such as wildfires, insect and disease activity, timber harvesting and weather events, can cause both immediate and gradual changes in forest structure, which in turn affect forest carbon dynamics by transferring carbon between the different ecosystem and atmospheric carbon pools.

The types and pattern of major disturbances affecting carbon stores over a 20 year period on the Helena and Lewis and Clark NFs respectively are displayed in Figure 23 and Figure 24. Across the HLC NF, there were substantial fire impacts from 2000 to 2007 as well as substantial insect impacts from 2006 to 2011, more-so than the Regional trends due to a recent mountain pine beetle outbreak. Beetle outbreaks redistribute carbon from live (sinks) to dead pools (sources), although slow decomposition of snags and recovered tree growth can result in resilience of aboveground carbon stocks (Hansen et al 2015). Harvest affected a relatively smaller proportion and has declined slightly throughout the monitoring period.

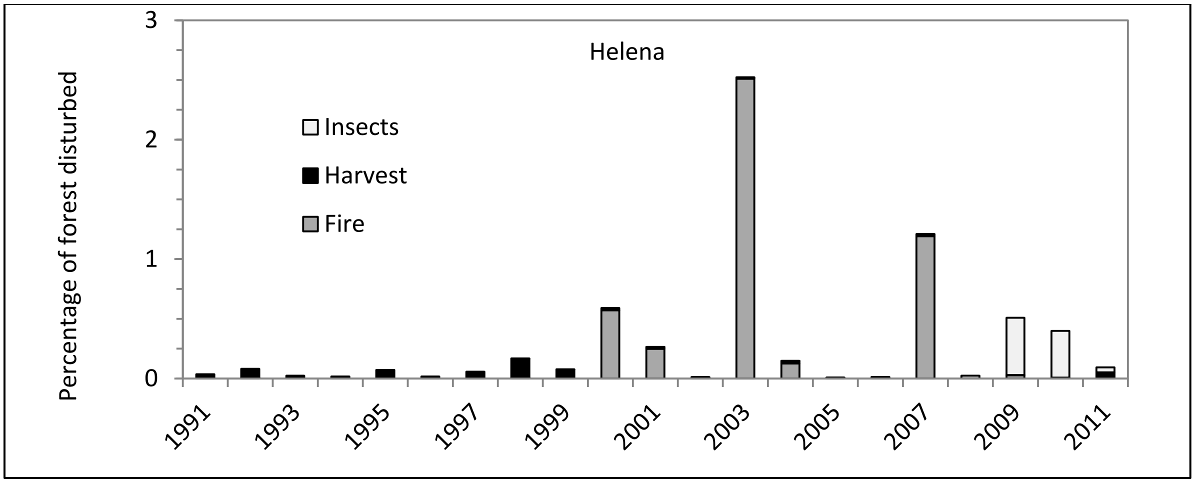

Figure 23. The percentage of forested areas disturbed from 1991 to 2011 by disturbance type on the Helena National Forest (USDA, 2017e)

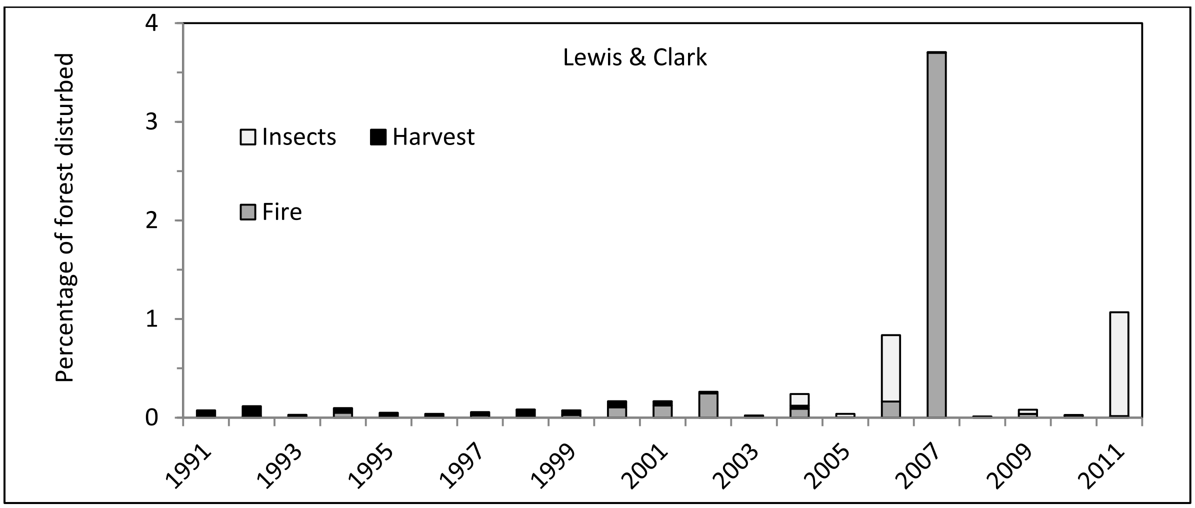

Figure 24. The percentage of forested areas disturbed from 1991 to 2011 by disturbance type on the Lewis and Clark National Forest (USDA, 2017e)

Figure 25 displays the estimated effect of the various disturbances on carbon storage for the Helena and Lewis and Clark NFs. Root disease is not a substantial disturbance on the HLC NF.

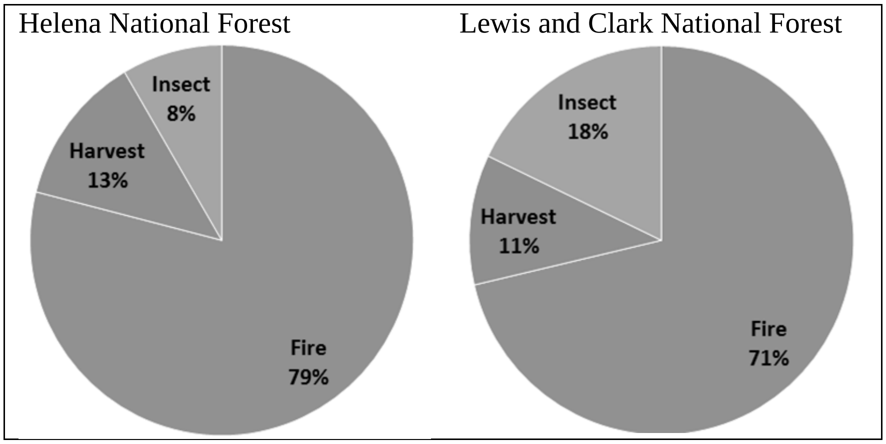

Figure 25. The proportional effect of fire, insect, disease[1] and harvest on carbon storage on the HLC NF 1990-2011, (ForCaMF model; USDA, 2017)

1. Disease was included in this modeling, but was not recorded on the HLC NF.

Fire, which disturbed the greatest amount of forest area also had the greatest impact on carbon storage on the HLC NF, according to results from the ForCaMF model. Lost carbon storage through harvest and insects accounts for a substantially smaller amount.

The impact of a disturbance is felt beyond the year it happens. The increased impact on carbon stocks from the effect of increased wildfire activity in the years since 2000 is clearly reflected. The effects of these fires will continue through future decades because carbon added through growth and recovery may not equal carbon that would have been added through continued growth, and because decaying material will mitigate carbon added through recovery.

Forests in the Helena portion of the HLC NF were a carbon sink from 1950-1993 then switched to a carbon source (USDA 2017e). This shift corresponds to the increased effects of disturbances, aging, and climate effects. Forests in the Lewis and Clark portion of the HLC NF switched from mostly a carbon sink to a source in the 1970s and carbon stocks have continued to decline (ibid). Increased disturbance and aging effects were responsible, though unfavorable climate conditions also played a role.

3.31.6 Environmental consequences

Forests are biological systems that continually gain and lose carbon. Disturbances and forest management can affect net carbon stores by changing the amount of carbon stored in various pools and by altering the rate at which carbon accumulates in the ecosystem (net ecosystem productivity) (Fahey et al., 2009). Whether forests show a net gain (sink) or net loss (source) depends on the balance of these processes, and must be interpreted in light of the long development trajectories of forests in the Northern Rockies. There is general understanding of forest conditions and carbon storage dynamics and capacity, as well as estimates as to how disturbances may impact carbon stores. However, carbon sequestration and emission dynamics from forested ecosystems can be very complex and uncertain. This analysis focuses on expected trends of carbon stocks and the forest carbon flux, and the potential influence of various strategies and approaches to management of the HLC NF.

Effects common to all alternatives

Regardless of alternative, natural ecosystem processes would result in a continual flux in carbon storage and emission into the future over the short and long term, in response to the interactions between climate, disturbances, successional processes, and resulting changes in forest conditions and patterns.

The HLC NF, to the best of our knowledge, is functioning as a carbon source, releasing more carbon than it stores. Under all alternatives, lands on the HLC NF would continue to support native vegetation (forests and nonforested vegetation), and would not be converted to other uses. Therefore, long-term potential for carbon sequestration would be maintained. As forests re-grow from recent fire and insect disturbances, over time the HLC NF may function as a carbon sink. However, fire and other natural disturbances are expected to continue to occur over the next few decades. In addition, to some degree, timber harvest would affect the quantity of carbon stored in both the ecosystem and forest products over time. Forest-level carbon stocks would vary in response to the complex interactions between such factors.

All alternatives include some level of forest management. Forests can be managed to sustain and perhaps increase their ability to remove carbon from the atmosphere. Carbon sequestration may be enhanced through management strategies that maintain resilient forests that are adapted to a changing climate and other stressors, and reforest lands disturbed by wildfires and other natural events. Management strategies applicable to the HLC NF center on creating conditions that are resistant and resilient to disturbances that may be amplified by climate change.

Under all alternatives, from the standpoint of effects to carbon, the expected levels of disturbances that may most substantially influence carbon storage (wildfire, harvest, bark beetles, and prescribed fire) would be generally similar. Figure 26 displays projected percent of the HLC NF affected by these disturbances in the future in terms of the mean annual percent area averaged across the alternatives.

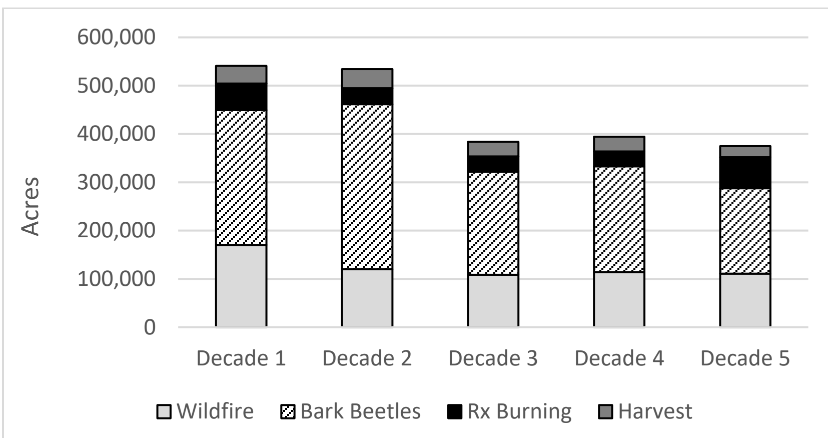

Figure 26. Projected mean area affected per decade by wildfire, bark beetles, prescribed fire, and harvest on the HLC NF over a 5 decade period

1. Source: Spectrum model for harvest; SIMPPLLE model for wildfire and insect/disease activity.

Figure 26 demonstrates that carbon storage across the HLC NF over the next approximately 15 years would be influenced primarily by natural disturbances more so than timber harvest. The majority of the Forest occurs in largely unroaded areas not suitable for timber production. Timber harvest would occur across a limited area; where it does occur, if carbon stored in harvested wood products is factored in, this would offset some of the proportion of carbon lost to tree removal. The estimated range of percent area affected by wildfire and bark beetles in the future is wide, and consistent with those the forest has experienced in the recent past.

Though FIA data indicate that the HLC NF is a net carbon source, there is uncertainty to that status, as well as uncertainty with the status of the Forest over the next 20 to 50 years.

Effects from forest plan components associated with:

Terrestrial vegetation:

Under all action alternatives, plan components for terrestrial vegetation would ensure that forested and nonforested plant communities are managed to be within their NRV, therefore ensuring that the carbon sequestration capacity is maintained over the long term on the HLC NF. Alternative A does not prescribe desired conditions based on the NRV, but would also result in the lands of the HLC NF being managed for native vegetation communities and therefore would provide a similar potential for carbon sequestration.

Fire and fuels management

Of all the potential disturbances on the landscape, fire (both natural and human ignitions) would have the greatest potential to cause short term reductions in carbon sequestration by removing vegetation as well as causing carbon emissions via the generation of smoke. However, fire is also a primary mechanism for restoring and maintaining native vegetation with conditions consistent with the NRV, thereby contributing to carbon sequestration potential over the long term. Plan components for fire and fuels management would help ensure the long term sustainability of vegetation communities while also allowing for flexibility in allowing fire to play its natural role on the landscape. These factors would generally be the same for all alternatives.

Timber

Plan components for timber management would allow for the short-term, localized reduction of carbon sequestration through the removal of living vegetation. The magnitude of this is greatest in alternative E and least in alternative D, but the difference between alternatives is minor. However, plan components that guide timber management, including desired vegetation conditions, would ensure that forest resiliency is promoted by these activities and therefore timber management would contribute to the long-term capacity of forests to sequester carbon.

Mining and mineral extraction

Mining undergoes site-specific NEPA analysis to determine effects and required mitigation, and effects to vegetation from mining is determined at the project level. The impacts to carbon stores from mineral extraction on the forest would be localized, and insignificant at the forestwide scale.

Livestock grazing

In all alternatives, livestock grazing would occur on the HLC NF. Plan components would ensure that grazing is managed in a manner that would maintain desirable vegetation communities, and therefore would not preclude the carbon sequestration potential of rangelands under any alternative.

Old growth

Old growth forests provide particularly concentrated sites for carbon sequestration on the landscape. These forests would fluctuate in location and abundance over time based on natural disturbances and successional processes, regardless of alternative. Plan components under the action alternatives specifically call for increasing the amount, distribution, and patch size of old growth over time, and therefore should increase the amount of carbon sequestered in these areas. The no-action alternative also includes minimum retention of certain proportions of old growth on the landscape, but would not necessarily result in the increase in overall abundance of these areas relative to the existing condition.

Aquatic habitat, RMZs, and watershed

Measures to protect aquatic habitat, RMZs, and watersheds would generally result in vegetation being maintained as needed for watershed function, and would result in a greater likelihood of vegetation cover being maintained within RMZs specifically. These measures would be greater for the action alternatives than the no-action alternative. The retention of vegetation in riparian areas would provide areas of refugia, potential old growth, and seed sources to contribute to the larger resilience (and therefore carbon sequestration potential) of vegetation on the landscape over time.

Effects common to all action alternatives

A key principle in carbon management is to emphasize ecosystem function and resilience (USDA 2015). Ecosystem resilience is also a central tenant of the 2012 Planning Rule. All action alternatives incorporate an ecologically based approach to vegetation management, including direction to manage for conditions that would occur under a natural disturbance regime, and thus be more resilient in the face of future uncertainties.

As required by planning regulations (USDA, 2015), the strategy for vegetation management on the HLC NF under the action alternatives is to provide for ecological sustainability and resilience, supporting a diversity of plant and animal communities, and to provide for social and economic contributions to local communities. In response to this direction, desired conditions for key vegetation components were developed that describe, to the best of our ability, conditions that would maintain or improve forest and ecosystem resilience and promote the adaptability of vegetation. Though the forest plan provides direction for management of the forest over a relatively short period of time (the next 15 years), desired conditions were developed with the long term view in mind as well. This is necessary because ecological, social and economic sustainability concepts require a long-term perspective. The forest plan direction in the action alternatives provide more clarity and stronger integration of ecological concepts and management for resilient forest conditions than alternative A.

All action alternatives would result in a similar and desirable trend towards improved forest resilience over the next five decade period. The forest plan direction and the management strategies and tools to achieve desired conditions, would be consistent with the adaptation actions described earlier for addressing concerns related to carbon and the role of forests as carbon sinks. All action alternatives would thus increase the likelihood of sustaining the HLC NF's ability to sequester carbon over both the short and long term.

All action alternatives include components addressing carbon storage and sequestration potential through maintenance or enhancement of biodiversity and function, and managing for resilient forests. Indirectly, all the plan direction associated with these concepts work towards achieving this desired condition. Table 300 enumerates the plan components that relate to carbon storage in the revised forest plan, and the expected effects of this direction.

Table 300. Summary of revised plan components related to carbon sequestration

Plan component	Expected effects
VEGT, VEGF, VEGNF	Desired conditions for vegetation, and the standards and guidelines that help achieve them, are designed to maintain and create vegetation able to accommodate gradual changes related to climate and tend to return toward a prior condition after disturbance (i.e., resilience). Management tools available to achieve these desired conditions would include prescribed fire, timber harvest, planting, and thinning in young forests.
FW-CARB-DC-01	The revised forest plan recognizes the importance of the role of the Forest related to carbon storage and sequestration, establishing a desired condition that directly addresses carbon sequestration. This DC focuses on sustaining this key ecosystem service through maintenance or enhancement of ecosystem biodiversity and function and managing for resilient forests adapted to natural disturbance processes and changing climates. This

Plan component	Expected effects
	approach to management of forests for purposes of contributing to climate change mitigation is supported by a number of scientific sources (Hurteau, Koch, & Hungate, 2008; North & Hurteau, 2011; E. Reinhardt & Holsinger, 2010; Ruddell, Walsh, & Kanakasabai, 2006; Ryan et al., 2010; Schaedel et al., 2017; Wiedinmyer & Hurteau, 2010).

The forest management strategies incorporated into the revised plan direction for all action alternatives are centered on the goal of maintaining or increasing forest resilience and resistance. The desired conditions are designed to sustain and create forests with the composition and structure that are able to accommodate gradual changes related to climate and with the capacity to return toward a prior condition after disturbances. Increasing forest resistance and resilience to fire, drought, insects and disease slow the release of carbon and retain larger portions in forest carbon pools, which is important considering that natural disturbances of fire and insect/disease has accounted for most of the carbon stock loss over the past 20 years. All action alternatives result in a similar and desirable trend towards improved resilience over the next five decades, and would have a potential beneficial effect on sustaining or improving the natural carbon sequestration potential of the forest lands.

Examples of the management strategies that are incorporated into forest plan direction and would contribute to carbon sequestration potential include the following (Harmon & Marks, 2002; Kobziar, Moghaddas, & Stephens, 2006; Krankina & Harmon, 2006; Millar, Stephenson, & Stephens, 2007):

- manipulating forests to favor rapid growth;
- increasing abundance and distribution of large diameter trees of fire resistant species;
- lowering forest densities and forest fuel conditions;
- rapid reforestation after disturbances;
- maintaining healthy, vigorous trees;
- minimizing severe disturbance by fire, insects and disease;
- keeping sites fully occupied with trees;
- sequestering carbon after harvest in wood products; and
- providing wood and biomass for fuel.

Some management treatments may reduce carbon at the stand level in the short term but result in maintaining or improving carbon sequestration potential in the long term. Some examples include pre-commercial thinning in young, sapling stands, and prescribed fire and other fuel treatments. Thinning in young forests is a beneficial treatment to achieve forest conditions that improve resistance and resilience (such as desired species, tree sizes and densities) and to achieve climate change mitigation though carbon sequestration. Though thinning reduces carbon stores in the short term, there may be no discernable difference in thinned versus unthinned stands in total above-ground carbon stores several decades after thinning, due to the larger trees and differences in understory and woody material (Schaedel et al., 2017). Similarly, there are short-term loss of carbon stores with prescribed burning or other fuel treatments, but studies suggest there may be long-term benefits in the event of a future wildfire, with lower fire severity in the treated stands resulting in less consumption of live and dead tree biomass, higher tree survival, lowered decompositions emissions, and shortened recovery times (Hurteau et al., 2008; North & Hurteau, 2011; E. Reinhardt & Holsinger, 2010; Wiedinmyer & Hurteau, 2010). This fuel reduction effect is most pronounced in dry forest types that historically experienced low to moderate (mixed) severity fire.

To provide insight into the relative relationship across alternatives, the Spectrum model was used to estimate future carbon stored in above-ground pools. Impact of fire and insect/disease disturbances was factored into the model. Refer to appendix B for detailed discussion of the Spectrum modeling. Figure 27 displays the estimated amount of carbon sequestered over the next 50 years on the HLC NF. Absolute values of the carbon are less important that the relative comparison of trends over time. These model results provide insight into the relative proportion of carbon stored on the Forest, and to the rate and relative nature of carbon changes over time with anticipated disturbances. The total amount of carbon is projected to decline over time. All alternatives are similar with respect to this trend, with the highest levels in alternative D and the lowest levels in alternative E.

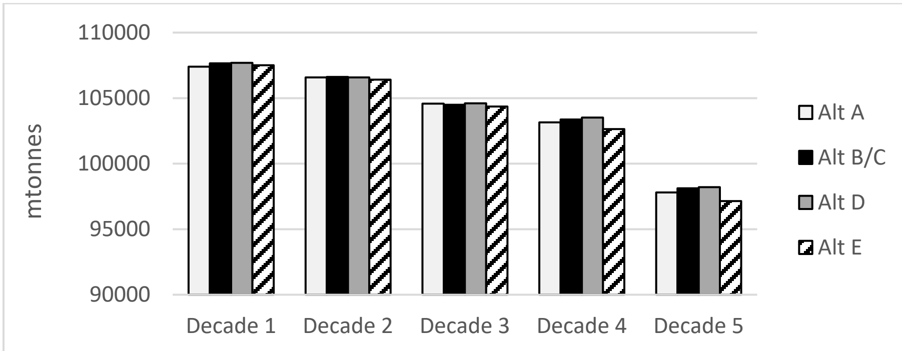

Figure 27. Estimated carbon (mtonnes) on the HLC NF projected over the next 5 decades, Spectrum model

Under the anticipated levels of fire, harvest, and growth rates of forests, the Spectrum model suggests that there would be a continuing downward trend in total carbon, consistent with the trend estimated in the recent past. This trend is likely in large part due to expected wildfire activity. The recovery of disturbed areas and the growth and increasing productivity of young forests over time would maintain some level of carbon sequestration. Carbon removed by harvest treatments at future anticipated levels would not adversely impact the live forest inventory carbon stores because of the relatively small portion of the live forest inventory expected to be harvested. Carbon storage in harvested wood products would continue to steadily contribute carbon to the total carbon pool, consistent with what has occurred in the recent past.

Alternative A, no action

The existing Forest Plans contain no plan components or direct acknowledgment related to carbon sequestration, or the use of management approaches to mitigate greenhouse gas emissions and climate change. Management would continue similarly as in the recent past, resulting in a similar pattern of carbon storage and flux as discussed in the affected environment section. Both existing plans contain direction aimed at promoting the sustainability of vegetation that could trend the forest towards greater resiliency, and thus enable the Forest to provide carbon sequestration over both the short and long term.

Cumulative effects

Within the U.S., land use conversions from forest to other uses (primarily for land development or agriculture) are identified as the primary human activities exerting negative pressure on the carbon sink that currently exists in this country's forests (Conant et al., 2007; McKinley et al., 2011; Ryan et al., 2010). The population is growing in some communities associated with the HLC NF, primarily on the west side of the plan area, and conversion of forest lands to non-forest purposes may occur to some degree on private lands near the Forest.

The impact of the alternatives and proposed forest plan direction on atmospheric concentrations of greenhouse gasses or global warming is not likely to be large at the global scale, considering the global scale of the atmospheric greenhouse gas pool and the multitude of natural events and human activities contributing globally to that pool.

Federally owned forest lands are managed to ensure sustainable timber yields, and unlike other parts of the world, over-harvesting of timber is not a primary concern for decreased carbon sequestration

(Halofsky et al., in press-b). Sustainable management practices and promoting healthy, resilient forest ecosystems increase the ability of the forest to provide long-term carbon sequestering services (ibid).

An area of vulnerability to forest resilience and associated carbon sequestration and storage values is the increased risk of uncharacteristic fire, insect, and disease activity that might occur with climate change. Once a tree dies or loses a leaf or other plant part containing carbon, it will decompose and its sequestered carbon is either respired into the atmosphere or transformed into soil carbon. Large, high severity fires or large-scale insect outbreaks, can affect regional carbon stocks and flux within forest ecosystems. In the short term (decades), disturbances with high tree mortality can convert carbon sinks to a carbon source (Kurz, Dymond, et al., 2008; Kurz, Stinson, & Rampley, 2008; Kurz, Stinson, Rampley, Dymond, & Neilson, 2008). Over the long term (centuries), the effects of disturbances on the regional carbon balance are neutral, assuming similar vegetation regrows on the disturbed area and the long-term frequency and severity of disturbances does not change (Canadell et al., 2007; Kashian, Romme, Tinker, Turner, & G., 2006). It is possible that over the very long term, climate changes may alter site conditions and disturbance patterns on the HLC NF to a degree that substantially impacts forest regrowth or vegetation types. This may reduce the Forest’s capacity for carbon sequestration. This effect would be small in relation to global capacity to sequester carbon (Halofsky et al., in press-b). The net effects on forest health and carbon sequestration have a high degree of uncertainty, primarily because of uncertainty in the magnitude of future climate change, and complex interactions of forest with disturbances, climate and ecological processes.

Conclusions

The HLC NF is likely functioning as a carbon source due to recent disturbances. However, it is not possible to conclude this with certainty. The forest may shift to a carbon sink in the future, if the carbon stored by regrowth outpaces carbon losses from future disturbances. All of the action alternatives do more to explicitly promote resilience, and thus the long-term carbon storage potential than the no-action alternative. However, there is not a measurable difference between alternatives, because in all cases native vegetation (forests and nonforested plant communities) would be maintained on NFS lands; the land would not be not converted to other uses. Natural disturbances would influence carbon storage much more so than forest management activities, and although the future is highly uncertain, the degree to which disturbances impact the landscape would be similar for all alternatives.

NFs are especially important for the persistent, long-term contribution to greenhouse gas mitigation they are capable of providing. This is because land use conversion from forests to other uses is a primary human activity affecting carbon stores both globally and nationally, and forests on NFS lands are not subject to conversion to non-forest uses.

Natural ecosystem processes and disturbances would continue to be the primary influence on carbon storage, accumulation and emission patterns. Forest plan direction for vegetation management is designed to maintain and increase forest resistance and resilience to fire, drought, insects, and disease. All action alternatives are expected to result in a similar and desirable trend towards improved forest resilience. This is beneficial because it will help sustain or improve the carbon sequestration potential of the forest lands.

HLC NF lands would continue to experience fluctuation in carbon stores and accumulation into the near future (i.e., 20 to 50 years), consistent with the natural variation that would be expected in an ecosystem influenced mostly by natural disturbance regimes and ecosystem processes. Projected impacts of fire and insect/disease on forest cover and potential loss of carbon is much greater than the projected amount of harvest. Under any alternative, harvest would have little impact on a potential future scenario of carbon accumulation and loss.

Uncertainties in the amount of future disturbances exist, especially related to factors associated with climate changes. If changes in natural fire regimes occur, perhaps to a regime of more frequent, more severe, and/or more extensive areas burned over shorter time periods, then the relationship between carbon sequestered in live forest inventory and that within decaying dead trees after fire could shift.

3.32 Climate

3.32.1 Introduction

Climate is described by the long-term characteristics of precipitation, temperature, wind, snowfall, and other measures of weather that occur over a long period in a particular place (Halofsky et al., in press-b), and is a primary driver of the ecosystem.

The HLC NF lies at the boundary between the warm, wet, maritime airflows from the Pacific Ocean and the cooler, drier airflows from Canada. The climate of the plan area varies, but is dominated by cold continental, cold-dry continental, and cool temperate with maritime influence (McNab and Avers 1994). Summers are generally dry, and the precipitation in winter is primarily snow. In some areas, spring and fall precipitation is also snow. Total precipitation is generally 10-50” per year, although it can be higher in some mountainous areas. Winter temperatures can fluctuate widely, and harsh chinook winds are a highlighted climatic feature.

3.32.2 Information sources

An ever-increasing body of knowledge exists regarding climate and climate change. This summary is based in large part upon the work of the Northern Rockies Adaptation Partnership, which is a “science-management” collaboration with the goals of 1) assessing vulnerability of natural resources and ecosystem services to climate change; and 2) developing science-based adaptation strategies that can be used by NFs to understand and mitigate the negative effects of climate change. The Northern Rockies region includes the U.S. FS Northern Region 1 and the adjacent Greater Yellowstone area, spanning northern Idaho, Montana, Northwest Wyoming, North Dakota, and South Dakota. Five subregions are identified and assessed; the HLC NF is in the Eastern Rockies subregion.

Global climate models are the principal source of future climate projections, and are effective at simulating global climate characteristics; however, because the spatial patterns of regional climate are far more heterogeneous than suggested by global climate model outputs, specific downscaling techniques are utilized to provide inputs for regional and sub-regional analyses (Daniels et al., 2012). The Northern Rockies Adaptation Partnership compiled downscaled climate information to a sub-regional level, which is a scale that is meaningful for the HLC NF and its surrounding landscapes.

The Coupled Model Intercomparison Project began in 1995 to coordinate a common set of experiments for evaluating changes to past and future global climate; this approach allows for comparison of results from different global climate models around the world (Halofsky et al., in press-b). Version 3 simulations were forced with emissions scenarios from the Special Report on Emissions Scenarios, which represent futures with different combinations of global population growth and policies. Conversely, version 5 simulations are driven by “representative concentration pathways” which do not define emissions but rather concentrations of greenhouse gases and other agents that influence the climate, and do not assume any particularly climate policy actions (ibid). The Northern Rockies Adaptation Partnership considered Coupled Model Intercomparison Project version 5 climate scenarios but also utilizes the best available information from multiple literature sources, some of which are based upon version 3 modeling results.

Climate projections embody a number of uncertainties, including the uncertainty of future emissions driven by socioeconomic processes and unpredictable policy choices, variability internal to a given global climate model’s simulation of weather and climate, variability related to parameterization and other model characteristics, and uncertainty or error in observed climate data used in downscaling global climate model output (Daniels et al., 2012).

3.32.3 Current climate and recent historical trend

Historic trends in climate are correlated to changes in ecosystem components, and therefore future climate is an important component of the effects analyses for forest plan revision. Natural climate cycles have occurred historically and will continue into the future. Human activities such as fuel burning, industrial activities, land-use change, animal husbandry, and agriculture lead to increases in ambient greenhouse gases, which contribute to the “greenhouse effect” (Melillo et al 2014). Warming temperatures are the most certain consequence of increased carbon dioxide in the atmosphere (Halofsky et al., in press-b).

The climate of the Northern Region fluctuates between cool and warm periods and is affected by multiple factors. The influences of sea surface temperature and atmospheric pressure are thought to directly influence drought in the western U.S. (Kitzberger et al. 2007). Multiple indices exist to measure sea surface temperatures, including the Pacific Decadal Oscillation, which tracks variations in the northern Pacific that tend to cycle every 20 years (Zhang et al. 1997). Correlations between these variations and ecological disturbances such as wildfire have been shown. Also, in the Northern Rocky Mountains the majority of the variability in peak and total annual snowpack and streamflow is explained by season-dependent interannual-to-interdecadal changes in atmospheric circulation associated with Pacific sea temperatures (Pederson, Graumlich, Fagre, Kipfer, & Muhlfeld, 2010).

Recent climate cycles can be demonstrated by variations in the Pacific Decadal Oscillation. The early 1900’s was a relatively normalized period where warm and cool years were relatively equally represented and fluctuations fairly low. The following period until the 1940’s was dominated by warm conditions, while the period from about 1950 to 1980 was dominated by cool conditions. During this cool period, ecological disturbances such as wildfire affected a relatively small area, although this was also influenced by human actions such as fire suppression and livestock grazing. Since the 1980’s, the Northern Region and the HLC NF have experienced a warm Pacific Decadal Oscillation cycle, along with increased extent and frequency of disturbances including wildfire and insect outbreaks.

Other climate data shows trends for temperature and precipitation over the recent historical period. In the Eastern Rockies subregion, the Northern Rockies Adaptation Partnership found that from 1895 to 2012, the annual mean monthly maximum temperature increased by about 2.2 degrees Fahrenheit, while the annual mean monthly maximum temperature increased by about 1.8 degrees Fahrenheit with little to no change in annual mean monthly precipitation (Halofsky et al., in press-b). Current climate conditions in this subregion include an annual mean monthly maximum temperature between 53 and 54 degrees Fahrenheit; an annual mean monthly minimum temperature around 30 degrees Fahrenheit; and an annual mean monthly precipitation just over 2 inches.

3.32.4 Future climate and expected impacts

The influence of future climate spans across all resources. Natural variation in climate will continue, coupled with the effects of anthropogenic influences. Different climate models project differing rates of change in temperature and precipitation because they operate at different scales, have different climate sensitivities, and incorporate feedbacks differently. However, the climate models are unanimous in projecting increasing average annual temperatures over the coming decades. The authors of the Northern Rockies Adaptation Partnership found that [**emphasis added**]:

“*Global climate models project that the Earth’s current warming trend will continue throughout the 21st century in the Northern Rockies. Compared to observed historical temperature, average warming across the five NRAP subregions is projected to be about* ***4 to 5 °F by 2050****, depending on greenhouse gas emissions. Precipitation may increase slightly in the winter, although the magnitude is uncertain. Climatic extremes are difficult to project, but they will probably be more common, driving biophysical changes in terrestrial and aquatic ecosystems. Droughts of increasing frequency and magnitude are expected in the future, promoting an increase in wildfire, insect outbreaks, and non-native species. These* *periodic disturbances, will rapidly alter productivity and structure of vegetation, potentially altering the distribution and abundance of dominant plant species and animal habitat." (Halofsky et al., in press-b)*