United States Department of Agriculture

Watershed Climate Change Vulnerability Assessment
Lolo National Forest

EXECUTIVE SUMMARY

Forest Service

Northern Region (R1) & Lolo National Forest

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Watershed Climate Change Vulnerability Assessment
Lolo National Forest

Executive Summary

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This report builds on the excellent previous vulnerability work conducted by: R1 (Gallatin and Helena); R2 (Grand Mesa, Uncompahgre, Gunnison, and White); R3 (Coconino); R4 (Sawtooth); R5 (Shasta-Trinity); R6 (Umatilla); R8 (Ouachita); R9 (Chequamegon-Nicolet), and R10 (Chugach) National Forests. These pilots were compiled with additional insights by Furniss and others (2013). We also thank D. Isaak, RMRS; S. Wenger, University of Georgia; and D. Nagel, RMRS for their generous help with data interpretation and development.

A NOTE ABOUT TABLES AND FIGURES

All tables and figures with alphanumeric designations (e.g., Table F.1) can be found within the body of this report. The letter represents the first letter of the report section name (e.g., F=Findings). All tables and figures designated with a only a number (e.g., Table 1, Figure 1) are not included in the body of this report, but are listed in Appendix 1 and 2, respectively. The tables and figures themselves can be found in the supplementary materials on the accompanying CD or on-line at http://www.fs.usda.gov/main/lolo/workingtogether.

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ES. Executive Summary

Introduction

Climate change is complicating the ability of the nation's forests to "sustain the health and productivity" of forestlands (USFS mission) and secure "favorable conditions of water flows" (Organic Act of 1897) in the nation's headwaters. A recent report by the U.S. Government Accountability Office (GAO) noted that federal lands are at risk from a wide range of potential climatic impacts, and that the agency will face multiple challenges in responding (USGAO 2007). Challenges include the need for the US Forest Service (USFS) to shift from focusing on historic conditions to anticipating and managing for an uncertain future and the need for more specific guidance on climate adaptation actions.

With over 2 million acres of varied landscape providing diverse vegetation, wildlife habitat, water resources, and recreational opportunities, LNF seeks to proactively understand potential impacts from climate change to better manage its outstanding natural resources and maintain maximum ecosystem resiliency.

The LNF is part of the Columbia River Basin, where minimum air temperatures have increased by 1°C (~2°F) and maximum temperatures have increased by 1.3°C (~2.3°F) during the period 1970-2006 (Littell et al. 2010). During the same period, precipitation has shown indications of decline (Littell et al. 2010). Although the future is uncertain, reasonable scenarios of climate change suggest average annual air temperatures will increase by 1.8°C (3.2°F) by the decade of the 2040s and 3.0°C (5.3°F) by the 2080s (relative to a baseline of 1970-1999 average temperatures) (CIG 2008). These projections suggest average annual temperature will exceed the range of the 20th century variability. Average annual precipitation is not likely to exceed the range of variability of the previous century, though seasonal patterns in precipitation may shift (CIG 2008).

One of the clearest signals from climate and streamflow models is that seasonal shifts in precipitation and increased temperature will likely result in lower summer flows and, in lower elevation streams, earlier and potentially higher and more frequent peak flows (Mantua et al. 2010; Wu et al. 2012). Earlier streamflow timing has already been recorded across western North America (Stewart et al. 2005; Regonda et al. 2005). By the 2040s, spring snow water equivalent is projected to decline by 22-35% in the Columbia Basin (Littell et al. 2010).

These changes present both challenges and opportunities for forest managers. Managing for climate change will be inherently uncertain and will require a shift in thinking because managers cannot assume persistence of existing conditions, but must plan for inevitable ecological change (Stein et al. 2013). Essentially, managing for climatic change is managing for resilient ecosystems and infrastructure. To help managers prioritize actions for improving or maintaining resiliency, the goal of this assessment is to determine the relative vulnerability of three forest resources that are likely to be strongly affected by climate change: aquatics (bull trout), water supply, and infrastructure (recreation areas, trails, and roads). We also include discussion of preliminary vulnerability considerations for the western pearlshell mussel (*Margaritifera falcate*). This assessment seeks to understand the magnitude of potential climate change effects to these resource values and to proactively inform *where* resources are relatively more vulnerable and to investigate *why* they are likely to be vulnerable, thereby providing additional insight toward initial prioritization of watersheds for special management consideration.

APPROACH

The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as "the degree to which a system is susceptible to or unable to cope with, adverse effects of climate change" (IPCC 2007). Thus, *vulnerability* is a function of *exposure* (the magnitude or probability of physical changes in climate conditions), *sensitivity* (the likelihood of adverse effects to an organism or system given climate changes and potential interacting non-climate stressors), and *adaptive capacity* (the intrinsic ability for an organism or system to reduce its sensitivity by successful response to changing climate [e.g., plastic or evolutionary responses, range shifts]) (IPCC 2007) (Figure ES.1). Ultimately, the goal of a vulnerability assessment is to identify potential future impacts from climatic change and to identify vulnerable areas to provide a solid foundation for climatic change adaptation management and planning (Glick et al. 2011). *Adaptation* refers to conservation or management actions that reduce vulnerability. Here, we focus on actions that can be effected by local managers to reduce exposure (e.g., riparian shading to buffer stream warming) or sensitivity (e.g., removing culvert barriers so bull trout have access to colder waters, improving and protecting critical aquatic habitat, or monitoring water diversions to ensure sufficient water supply). We do not discuss *mitigation* as a form of adaptation, which in climate circles refers to efforts to reduce carbon emissions.

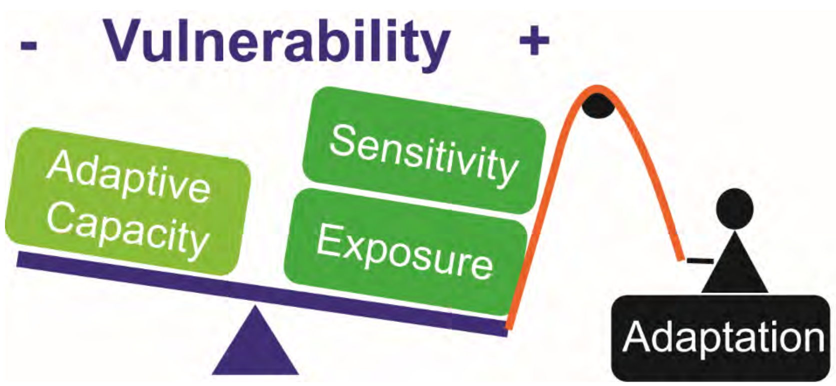

Figure ES.1. *Vulnerability is a function of climate exposure and sensitivity. Adaptive capacity (a system's intrinsic ability to reduce its sensitivity) can reduce vulnerability, although we do not address it here. The goal of the vulnerability assessment is to plan for adaptation management actions to reduce vulnerability, primarily through reducing sensitivity to climate change.*

To address vulnerability, we calculated and combined measures of climate exposure and resource sensitivity believed to be reasonable proxies for assessing the magnitude of potential climatic changes and the sensitivity of these resources to those changes. We calculated climate exposure as the degree to which stream temperature and flow are projected to change from baseline conditions (modeled average conditions for 1993-2011) under a "middle-of-the-road" scenario of carbon emissions for the period of the 2040s (2030-2059) and for the 2080s (2070-2099) for comparison. The indices we used to quantify sensitivity are proxies for intrinsic and extrinsic stressors to the resources that may increase their sensitivity to climate change. For the final vulnerability assessment, we combined all sensitivity indices into an inclusive sensitivity value and compared this against a combined exposure value for the 2040s. We did not assess 2080 vulnerability because of the significant uncertainty associated with that distant future. However, one can consider the 2080s maps as a "high" exposure scenario as compared to the 2040s, which can be considered a "moderate" mid-century exposure scenario.

The goal of this approach was to optimize trade-offs between practicality, transparency, comprehensiveness, and ecological relevance (for the aquatic species). We offer these scenarios as a general and reasonable framework to help facilitate informed management decisions. Addressing specific indicators at local scales will likely require further investigation and perhaps more time to understand and witness true ecosystem response.

METHODS OVERVIEW

For assessment of water resources and infrastructure, our study area incorporated all lands in the LNF and intervening non-Forest Service lands, for a total study area of 5,135 mi^2 (13,300 km^2) (Figure ES.2). Because there are adjoining areas of critical importance to bull trout (bull trout populations do not stop at inter-forest boundaries), we used a larger study area boundary (6,429 mi^2; 16,650 km^2) for that analysis. Study areas were defined following the boundaries of 6^{th} level hydrological unit codes (HUC 12).

For each resource value (aquatic species, water supply and infrastructure), we created a conceptual model linking exposure and sensitivity to the quantification of vulnerability (see general schematic in Figure ES.3). For each *resource area* and *resource value*, we listed the resource *needs* that describe conditions necessary for maintaining the resource value. Resource needs in blue boxes are affected by climate (*exposure*) and those in green boxes represent other stressors that increase a resources' *sensitivity* to climate change. The *analytical unit* for exposure and sensitivity was also shown in the conceptual model. We measured exposure using various types of habitat configurations (contiguous suitable habitat, or "patch") for aquatic species and HUC-12s for water supply and infrastructure.

For climate exposure stressors, we calculated metrics using modeled future scenarios of climate change impacts on stream temperature and flow. Sensitivity metrics were assumed to be temporally static; a necessary assumption given the inability to project changes in those stressors. We then calculated combined exposure and sensitivity *indices* by taking the geometric mean of all exposure and sensitivity metrics, respectively.

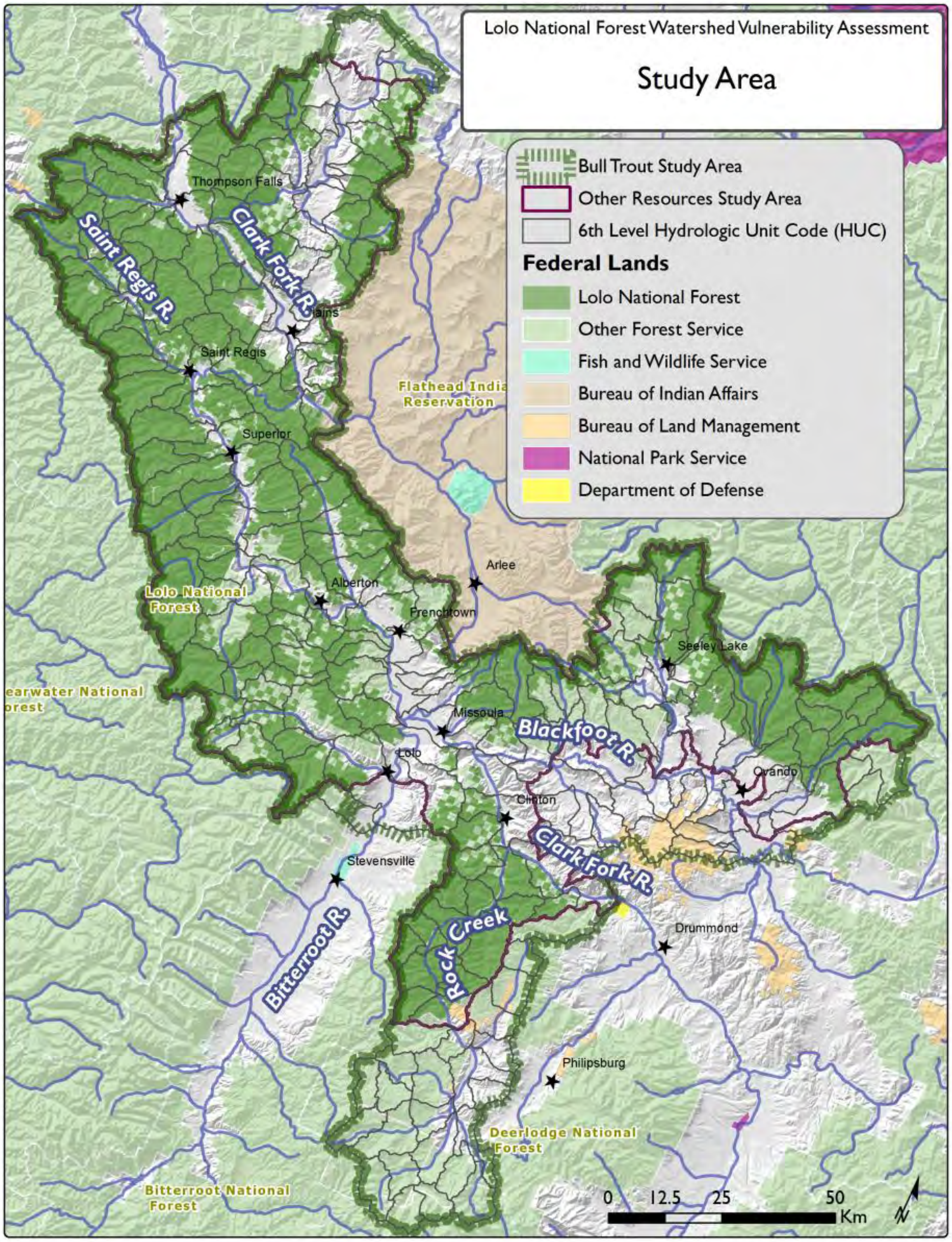

Figure ES.2. *Study area for the Lolo National Forest (LNF) Watershed Vulnerability Assessment. For the bull trout analysis, the study area incorporated all of the LNF lands and neighboring watersheds of particular interest for bull trout. For other resource areas and values, we only considered watersheds covering LNF and intervening private lands.*

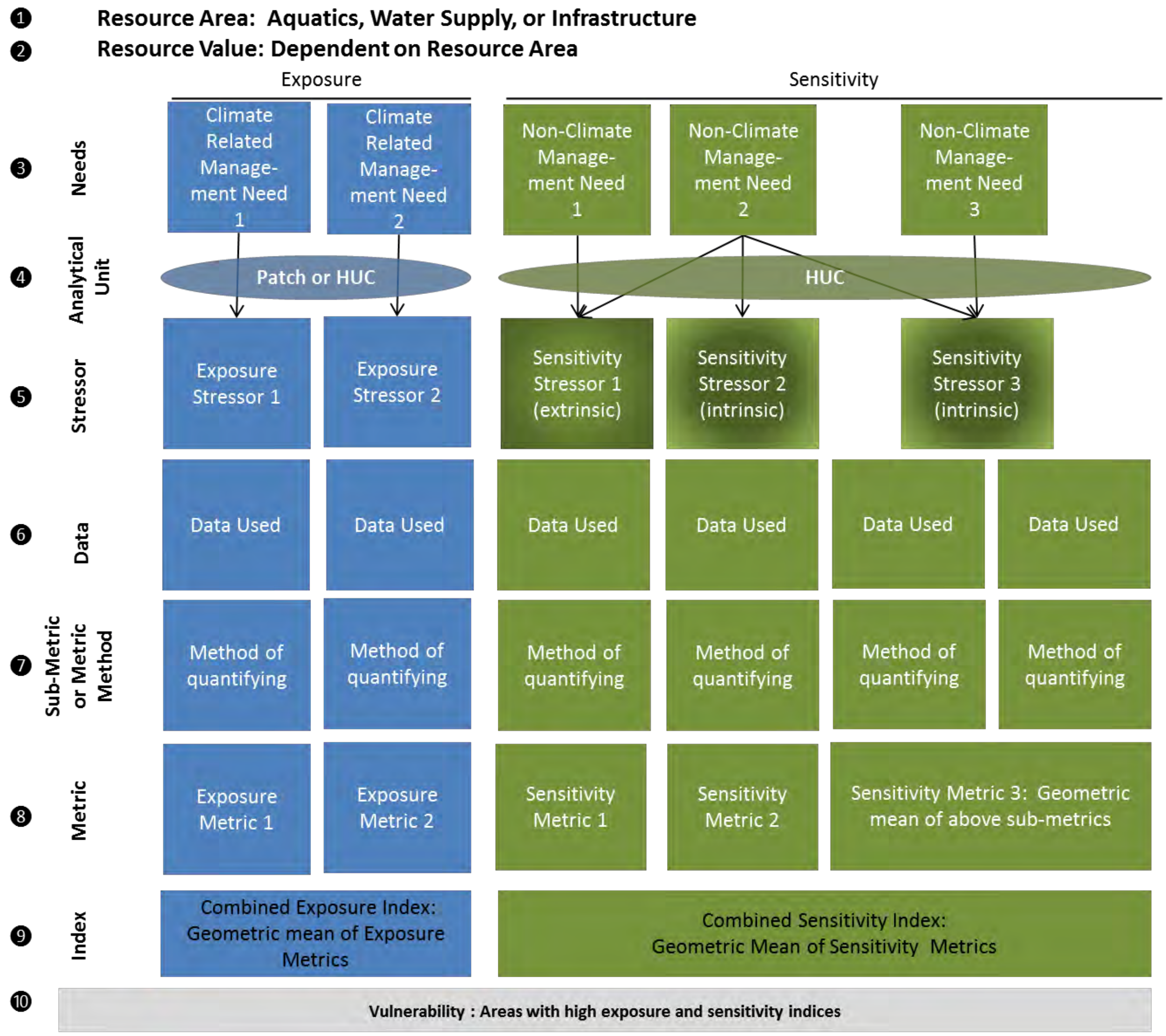

Figure ES.3. *Schematic of conceptual models used to link resource needs to each metric calculated in this analysis for each resource value analyzed.*

Finally, we mapped relative vulnerability for each resource by comparing exposure and sensitivity indices, which we placed into "clusters" (1-5) by minimizing within-group and maximizing between-group variations (based on the algorithm by Jenks 1977). We assumed exposure index values in clusters 1 or 2 had low, cluster 3 had moderate, and clusters 4 and 5 had high exposure stress. For sensitivity, we assumed sensitivity index values in clusters 1 or 2 had low and in clusters 3, 4, or 5 had high sensitivity to exposure. Thus, we mapped vulnerability as follows:

<table>
<tr><td></td><td></td><td colspan="5">Sensitivity</td></tr>
<tr><td>cluster</td><td></td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td rowspan="5">Exposure</td><td>1</td><td colspan="5" rowspan="2">Low Exposure</td></tr>
<tr><td>2</td></tr>
<tr><td>3</td><td colspan="2">Moderate Exposure, Low Sensitivity</td><td colspan="3">Moderate Exposure, High Sensitivity</td></tr>
<tr><td>4
5</td><td colspan="2">High Exposure, Low Sensitivity</td><td colspan="3">High Exposure, High Sensitivity</td></tr>
</table>

Exposure and sensitivity metrics for bull trout, water supply, and infrastructure used in this analysis (see main report for detail):

Bull Trout

- Exposure
  - Reduction in thermally suitable habitat patch
  - Winter flood scour
  - Reduced summer mean flow
- Sensitivity
  - Low population size/viability
  - Low stream connectivity
  - Increased sediment
    - Road crossings
    - Parallel roads near streams
  - Low channel complexity
    - Riparian cover
    - Roads near streams (2 metrics)
    - Grazing allotments near streams
  - Water diversions
  - Low stream-floodplain connection (valley confinement)
  - Presence of brook trout

Water Supply

- Exposure
  - Reduced summer mean flow
  - Change in timing of center of flow mass
- Sensitivity
  - Water diversions

Infrastructure (Recreation sites, trails, roads)

- Exposure
  - Winter flooding
- Sensitivity
  - Location in floodplain
  - Location in area of high geologic hazard or alluvial fan
  - Culverts per mile (road infrastructure only)

All exposure analyses relied on two climate datasets, the NorWeST temperature dataset (Isaak et al. 2015a) and the Western US Stream Flow Metric dataset (Wenger et al. 2010; Wenger & Luce 2011). The NorWeST dataset provides modeled August mean stream temperature (AMT) (Figure ES.4).

We used the Western US Stream Flow Metric dataset (Wenger et al. 2010; Wenger & Luce 2011) to calculate all stream flow exposure indices. To represent high flow effects, we used the winter 95 (W95) flow metric, which represents the number of days in winter in which flows are amongst the highest 5% for the year (Figure ES.5).

To represent low flows, we used the mean summer (MS) flow metric, in units of cubic feet per second (cfs) (Figure ES.6).

To represent shifts in timing of flow regimes, we used the center of flow mass (CFM) metric, with units of day of the water year (Figure ES.7). CFM represents the day of the water year at which 50% of the year's flow has passed; also known as the center of the flow mass or the center of timing.

FINDINGS

Results of the vulnerability assessment should be interpreted as hypotheses about relative impacts from potential climatic exposure and the potential sensitivity to that exposure. As with all initial hypotheses, they should be reassessed as additional information becomes available. The vulnerability assessment results are relative within the study area, and results are dependent on the assumptions made herein. Vulnerability maps are best viewed alongside the exposure and sensitivity maps on which they are based, and all metrics and indexes should be verified with on-the-ground knowledge for management purposes. Results presented here are for the 2040s. Detailed results are presented in tables and figures listed in Appendix 1 and 2 (including results for the 2080s), respectively, and can be found in the supplementary materials on the accompanying CD or on-line at http:/www.fs.usda.gov/main/lolo/workingtogether.

A NOTE ABOUT UNCERTAINTY

There is inherent uncertainty in the findings of this analysis because:

- climate projections from global circulation models (GCMs) are inherently uncertain;
- translating GCM outputs into measures of in-stream temperature and flow requires additional models with additional assumptions leading to associated increases in uncertainty;
- this assessment relies on proxy measures that we assume relate exposure and sensitivity to actual potential impacts from climatic change;
- all spatial data are imprecise, and there are errors inherent to all data.

We have detailed the uncertainty of specific metrics in the Methods sections and in figure captions of the main report.

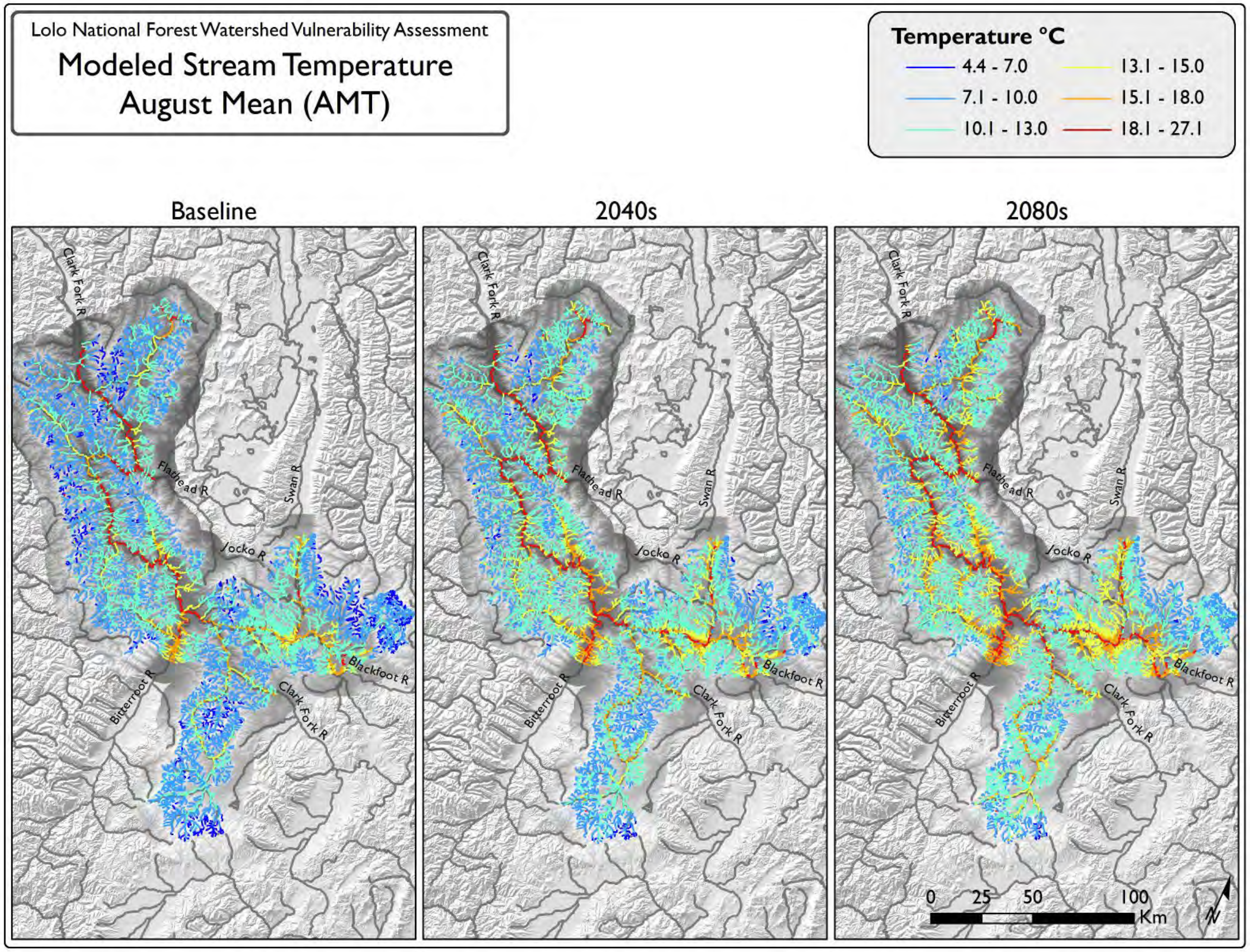

Figure ES.4. *NorWeST modeled August mean stream temperature (AMT) data for baseline (1993-2011) and for the 2040s (2030-2059) and 2080s (2070-2099).*

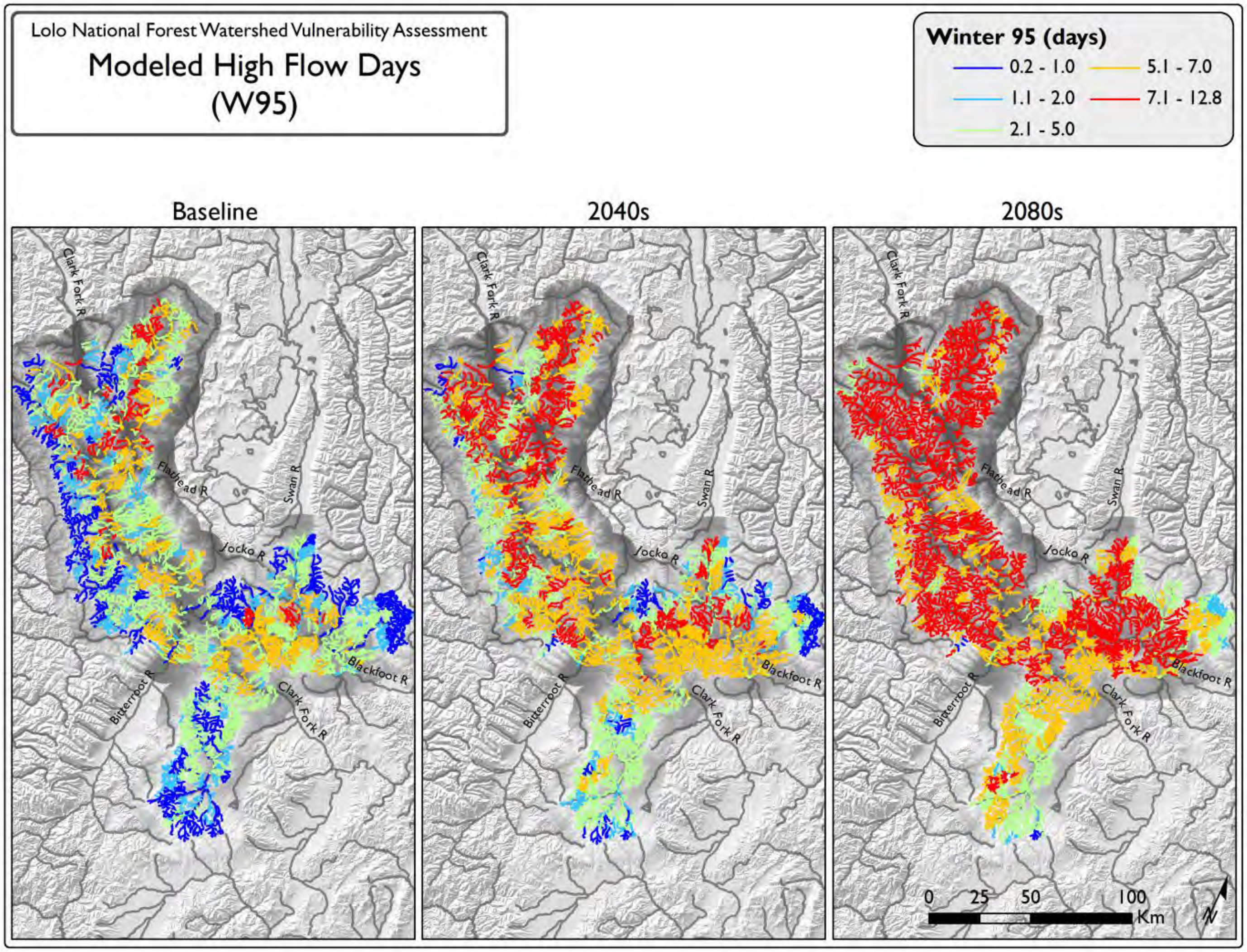

Figure ES.5. *Modeled high flow days (W95) for baseline and for the 2040s and 2080s.*

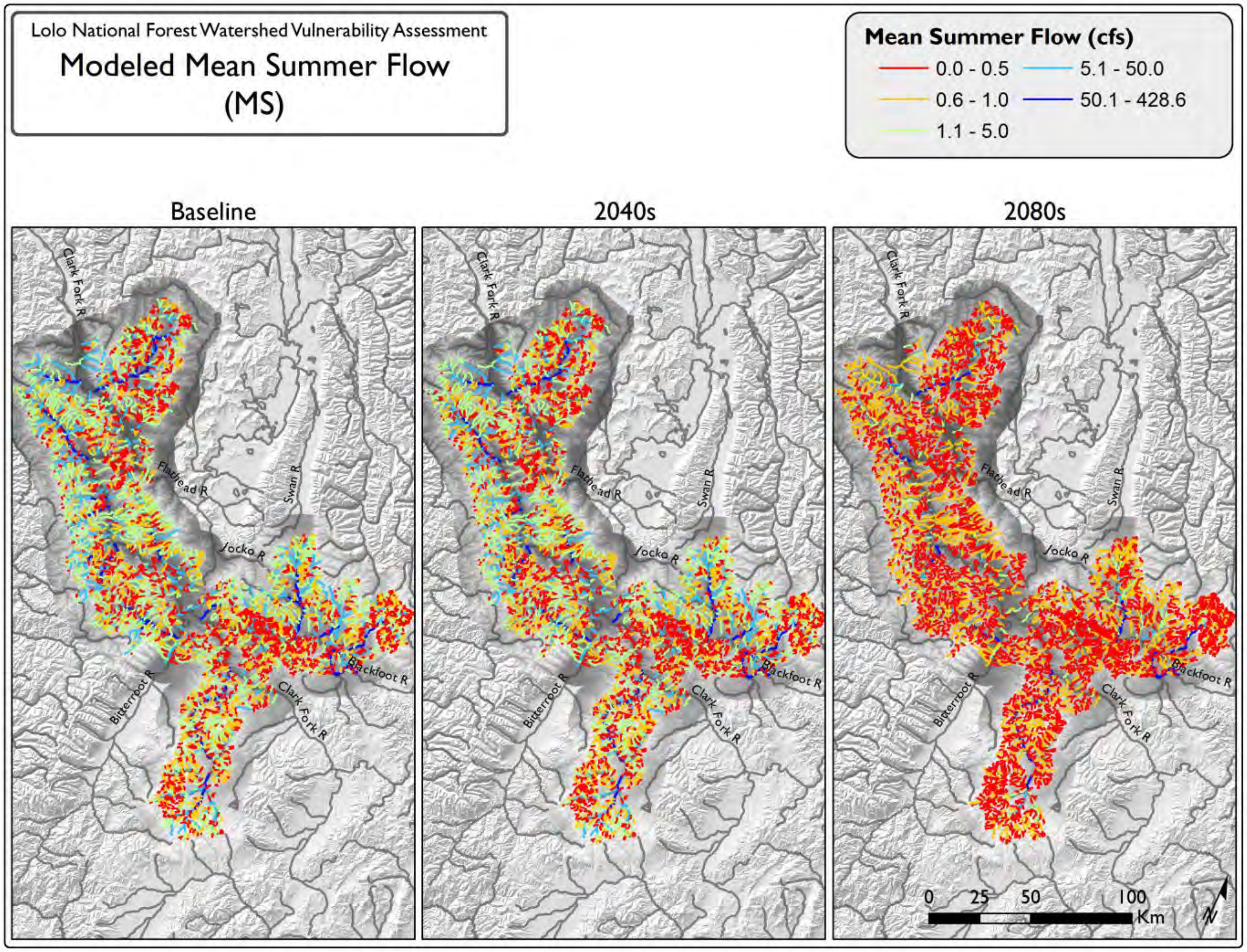

Figure ES.6. *Modeled mean summer flow (MS) for baseline and for the 2040s and 2080s.*

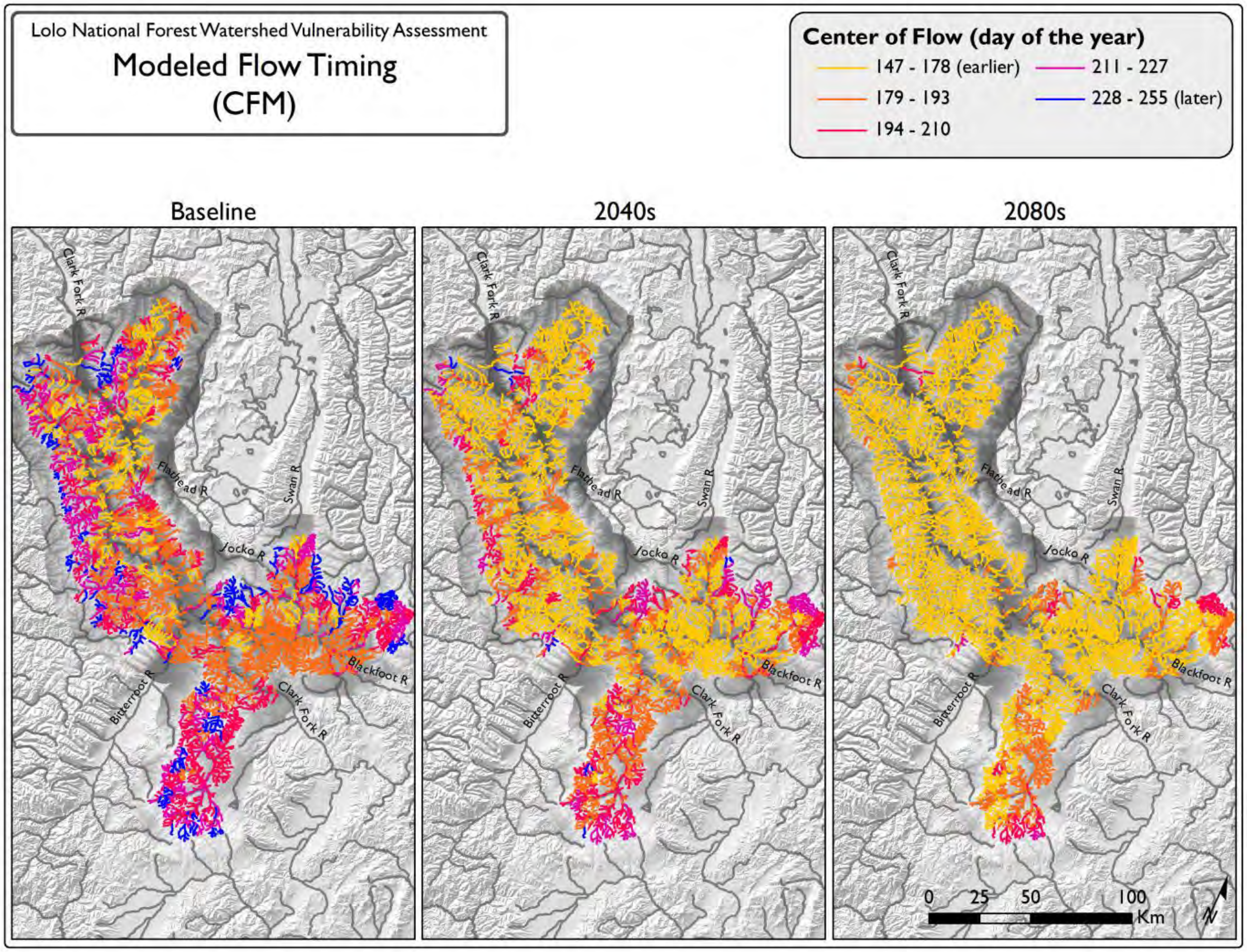

Figure ES.7. *Modeled flow timing (CFM) for baseline and for the 2040s and 2080s.*

Bull Trout Findings

For bull trout, we assessed vulnerability separately for temperature and flow because of the very different nature of temperature and flow exposure effects and because of the much higher uncertainty in flow indices as compared to temperature.

In general, Lolo Creek and the Thompson River areas stand out as areas that ranked most vulnerable to both flow and temperature stressors (having high exposure and sensitivity). In contrast, local bull trout populations in Rock Creek and the upper Blackfoot watersheds appeared to be least vulnerable. The least vulnerable watersheds were some of the highest elevation areas within the LNF.

Overall, bull trout local populations are projected to be more exposed to changes in flow than to increased temperatures. Because these rankings are relative across watersheds within the LNF, this does not necessarily indicate that bull trout are expected to be more impacted by flow than by temperature, only that *relative to other areas in the LNF*, temperature increases were not expected to be as great in bull trout local populations as in watersheds not inside a bull trout local population area (an area identified as having few to no bull trout). Bull trout generally occupy higher elevation streams which represent some of the best remaining thermally-suitable areas, and higher elevation streams are projected to warm less quickly than lower elevation streams. However, bull trout local populations are also situated in areas that are projected to have some of the greatest increases in winter flows, particularly in the western half of the study area. Further, the higher elevation headwater streams favored by bull trout currently have lower flow. These streams may be particularly susceptible to projected reductions in summer flows.

Table ES.1 (below) summarizes overall findings for exposure, sensitivity, and vulnerability for bull trout. Results for temperature-based vulnerability are illustrated in Figure ES.8 and flow-based vulnerability is shown in Figure ES.9.

Table ES.1. Summary of Bull Trout Findings

Analysis	General Result	Most Affected Areas	Least Affected Areas
Exposure			
Temperature	Greatest exposure is at lower elevations, generally not in areas with bull trout local populations	30% or more reduction in thermally suitable patch (<13˚C) in Lolo-Grave Creek, East Fork Clearwater, Upper and Middle Little Thompson Creeks, McGinnis Creek, Grant Creek, West Fork Petty and Eds Creeks, and Upper and Lower South Fork Fish Creeks.	0-16% reduction in patch <13 ˚C in local populations in Rock Creek, upper Blackfoot (North Fork, Monture, Cottonwood and Morrell), and lower Clark Fork areas (Trout, Cedar, St. Regis, Prospect and Graves)
Flow (Combined high winter flows and low summer flows)	For both high winter flows and low summer flows, the greatest exposure is in the western study area and extending south along the slopes of the Montana-Idaho border	Highest combined exposure to both high winter flows and reduced low flows in the 2040s was in the Prospect Creek local population, and in Albert Creek and parts of the St. Regis, Lolo, Graves, and Fish Creek local populations.	Lowest exposure was in the North Fork Blackfoot, Welcome and Hogback Creek bull trout populations.
Sensitivity			
Low population size/viability	Because both the calculation of the population viability metric and the delineation of bull trout local populations were on the basis of occupancy – few local populations had extremely low metric values. Higher elevation headwaters generally had the best population viability, lowland and river mainstems had the worst.	Graves Creek, Petty Creek, Hogback Creek, and Butte Cabin Creek had some of the highest metric values.	Four of the five local populations with the lowest population viability, on average, were in the Rock Creek drainage.
Low stream connectivity	Low stream connectivity, as measured here, comes substantially from culverts, as opposed to dams or natural impediments.	Connectivity was lowest in the Lolo Creek local population	Populations with no anthropogenic barriers included North Fork Blackfoot River, and Grant, Stony, Hogback, and Ranch Creeks.

Table ES.1, continued

Analysis	General Result	Most Affected Areas	Least Affected Areas
Sensitivity, continued			
Sediment (road proximity and crossings)	Areas in or immediately below wilderness have less stress from roads.	The Thompson, St. Regis River and Trout Creek local populations, on average, were expected to have the most sediment stress, followed by Lolo, Placid, and Grant Creek populations	Local populations in the Blackfoot and Rock Creek drainages, Prospect Creek, Graves Creek, Rattlesnake Creek and Fish Creek had lowest sediment stress.
Low physical complexity (riparian cover, roads near streams, grazing on shallow slopes)	Areas in or immediately below wilderness have less stress from riparian impacts.	Combining all these sub-metrics, only the lower St. Regis local population included a HUC-12 that had the highest level of stress from low physical complexity of channels and riparian areas.	On average, North Fork Blackfoot River, and Gold, Prospect, Hogback, and Welcome Creek local populations were least stressed.
Water diversions	Areas of high stress from water diversion were more heavily concentrated in the eastern half of the LNF. Diversion proportions ranged up to 40% of maximum mean summer flow.	Local populations with highest stress from water diversions included Rock Creek in the N. Fork Blackfoot population area, Placid Creek, McGinnis Creek in the Thompson River area, and Grant Creek.	The local populations with lowest stress, on average, were Welcome and Butte Cabin Creeks.
Low stream-floodplain connection	Bull trout populations in the LNF are mostly found in tributary reaches where terrain is steep and streams are relatively confined; thus most of the local populations were rated as high stress for this metric (confined mile per stream mile).	The northwestern portion of the study area was generally more confined. The local populations with nearly no unconfined streams included Graves, Hogback, and Welcome Creek.	No streams within HUC-12s ranked as low sensitivity to this metric.
Brook trout presence	No spatial trends identified in the study area.	Local populations that are expected to have highest stress from brook trout include Fish Creek, Lolo Creek, Grant Creek, Rattlesnake Creek, North Fork Clearwater, and Cottonwood Creek	Local populations that were *not* expected to have high stress from brook trout included North Fork of Blackfoot River, East Fork Clearwater, Morrell Creek, western portions of the Thompson River local population, Cedar Creek, West Fork Rock Creek, Stoney Creek, Hogback Creek, and Welcome Creek.

Table ES.1, continued

Analysis	General Result	Most Affected Areas	Least Affected Areas
Vulnerability			
Temperature exposure combined with sensitivity	Highest vulnerability areas were mostly outside of local population boundaries, generally at lower elevations. Of the areas considered to be Bull Trout Important Habitat (i.e., critical habitat or high abundance), most fell in the category of low exposure to increased temperature.	Bull trout patches most vulnerable to temperature, with both high exposure and high sensitivity were Lolo Creek, Thompson River, Grant Creek, Petty Creek and Fish Creek.	Bull trout patches least vulnerable to temperature included Prospect Creek, St. Regis River, Cedar Creek, Trout Creek, Gold Creek, Morrell Creek, Cottonwood Creek, Monture Creek, N. Fork Blackfoot River and all of the Rock Creek local populations
Flow exposure combined with sensitivity	Spatial variability of vulnerability to flow is high – there are no obvious patterns.	The bull trout patches most vulnerable to changes in flow, with both high exposure and high sensitivity included Lolo Creek, Thompson River, Prospect Creek, Graves Creek, Albert Creek, Lower Petty Creek, and portions of the St. Regis River	Local populations that were least vulnerable to changes in flow included Cedar Creek, Trout Creek, Grant Creek, Rattlesnake Creek, Gold Creek, Morrell Creek, Cottonwood Creek, Monture Creek, N. Fork Blackfoot River, and all of the local populations in Rock Creek.

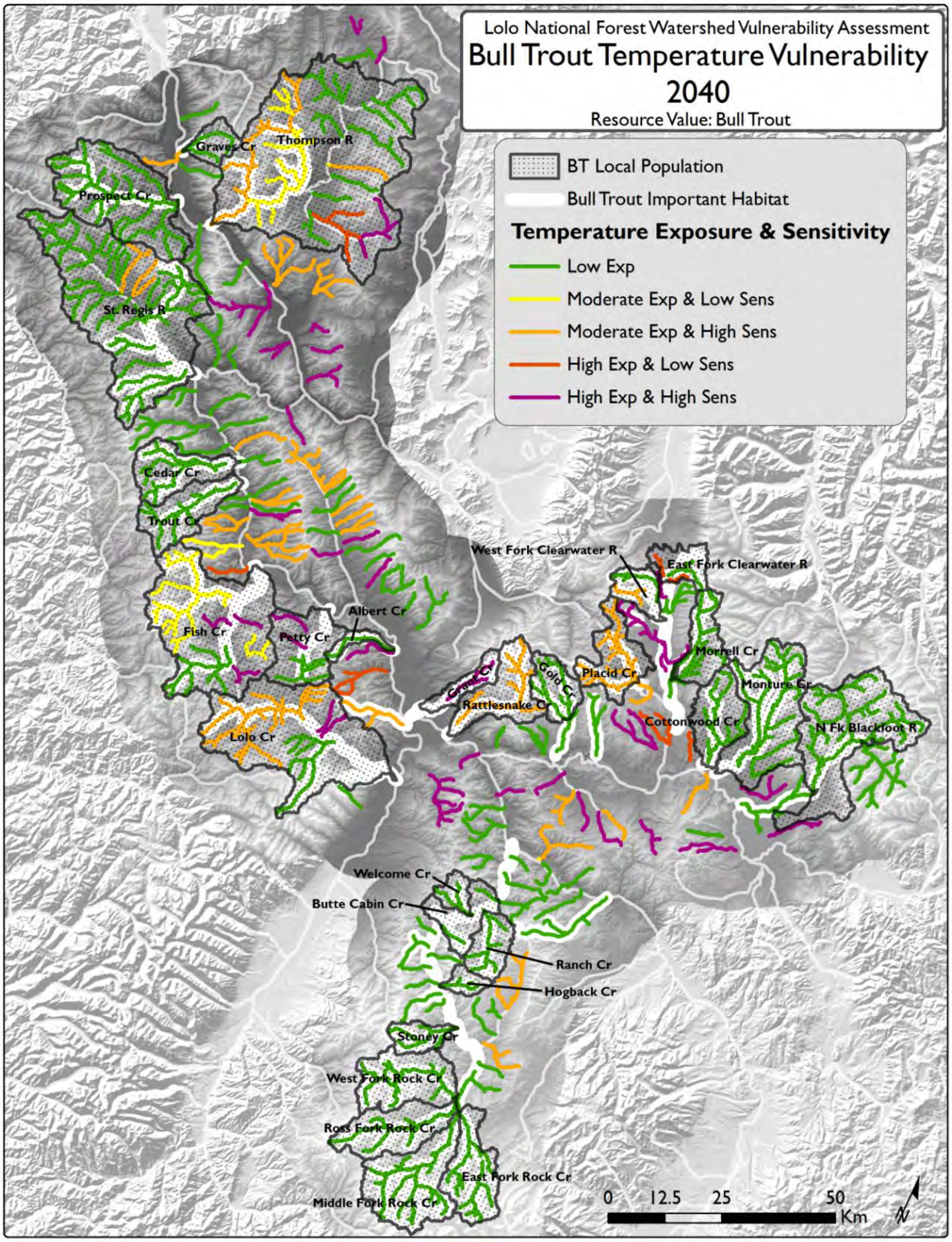

Figure ES.8. *Estimated vulnerability of bull trout to projected temperature changes, by patch, by the 2040s. Streams listed as having common or abundant bull trout by MFISH or as being critical habitat by FWS are shown in white ("Important Habitat") for reference.*

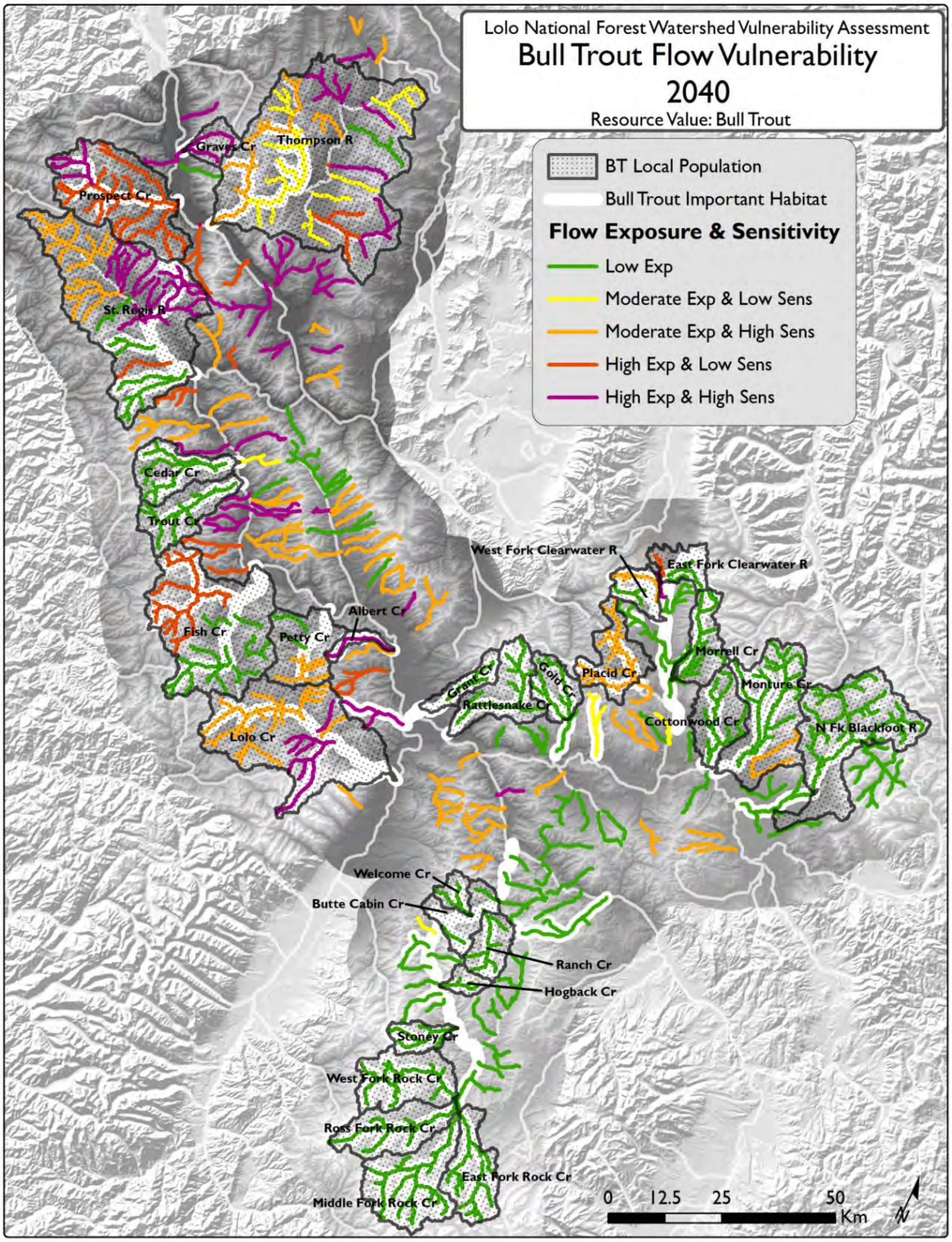

Figure ES.9. *Estimated vulnerability of bull trout to projected flow changes, by patch, by the 2040s.*

Water Supply Findings

The exposure index we used combined the low summer flow metric with the shift in timing of the center-of-flow-mass metric, and these two generally reinforced each other. The combined exposure distribution is not readily explained by elevation alone, although headwater streams generally have higher exposure, with the exception of Rock Creek. The only sensitivity metric we considered was water diversions. We note that there are watersheds where local knowledge suggests our methods have underestimated sensitivity (i.e., Lolo Creek is often dewatered). This issue arises because our data were incomplete – we lacked diversion flow quantities in some areas. Managers are reminded that results should be used to complement their knowledge of the area.

It was apparent that vulnerability closely tracked the exposure metrics. However, areas of high water diversion should be carefully considered when assessing vulnerability because actual diversions are unlikely to decrease over time. Table ES.2 summarizes overall findings for exposure, sensitivity, and vulnerability for water supply and Figure ES.10 illustrates estimated vulnerability of water supply on the LNF.

Table ES.2. Summary of Water Supply Findings

Analysis	General Result	Most Affected Areas	Least Affected Areas
Exposure			
Flow (combined low summer flow and shift in timing to earlier peak flow)	The patterns of lower summer flow and shift in flow timing reinforced each other. Combined exposure was greatest in the northwestern portions of the LNF and along the Montana-Idaho border, as well as in headwater streams of the Blackfoot River. Less exposure occurred generally in lower elevation valley streams and in Rock Creek.	High exposure occurred in Deep-Mosquito, Prospect, Lower Thompson-Fishtrap, Lolo, St. Regis, and Fish Creek drainages.	Lowest flow exposure occurred in E. Fk. Cooney, Lake-Rock, and Lost Prairie-Elk in the Blackfoot watershed, and in Deer-Cramer and Harvey-Bear along the Clark Fork drainage.
Sensitivity			
Water Diversion	Areas of high stress from water diversion were more heavily concentrated in the eastern half of the LNF. Diversion proportions ranged up to 40% of maximum mean summer flow.	Highest water diversion stress averaged by HUC-10 was expected in Deer, Cramer Creeks, Placid Creek, Rattlesnake, Grant Creeks, and Little Thompson Creek.	Most of the LNF was expected to have low to moderate stress from water diversion, although it is important to note that existing records available for this analysis may not be accurate.

Table ES.2, continued

Analysis	General Result	Most Affected Areas	Least Affected Areas
Vulnerability			
Exposure combined with sensitivity	Water supply vulnerability in the 2040s was estimated to be greatest in the higher elevation northwestern areas of the LNF, especially along the Montana-Idaho border and in higher elevation tributaries of the Blackfoot River.	Highest vulnerability (high exposure plus high sensitivity) watersheds include Dunham Creek, Morrell Creek, Upper Placid Creek, West Fork Fish Creek, Dry Creek, East Fork Lolo Creek, Upper Lolo Creek, West Fork Butte Creek, Chippy Creek, West Fork Fishtrap Creek, West Fork Lower Thompson River, Ashley Creek, and Upper Prospect Creek.	Lowest vulnerability (low exposure and/or moderate exposure plus low sensitivity) occurred in the Rock Creek drainage, in lower elevation tributaries on the LNF in general.

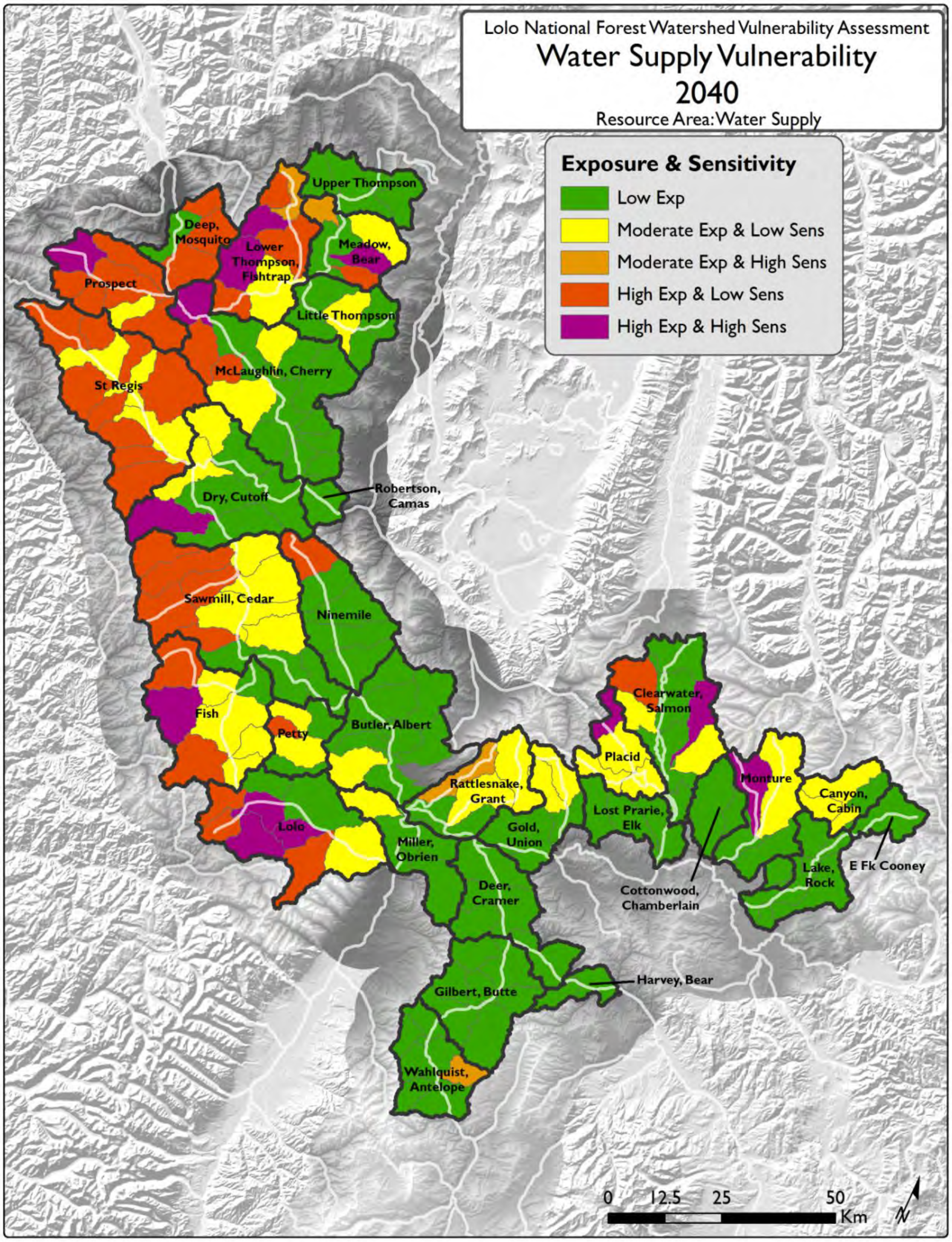

Figure ES.10. *Estimated water supply vulnerability, by HUC-12, by the 2040s.*

Infrastructure Findings

We characterized the exposure of recreation sites, trails, and jurisdictional roads to likelihood of winter flooding. Winter flooding was expected to increase across the area, with greatest exposure at lower elevations and relatively less exposure at higher elevations. High elevation areas that were currently expected to see 0 to 1 day of high winter flow would see 1 to 5 days by the 2040s.

Overall, recreation site and trail vulnerability fell generally into two vulnerability categories: high exposure plus low sensitivity (62% of HUC-12s for each) and moderate exposure plus low sensitivity (19 – 20% of HUC-12s). These watersheds have infrastructure that is more vulnerable because they are in floodplains or in areas of geologic hazard, or both. Clearly, as assessed here, exposure is a bigger issue with recreation site and trail infrastructure than is sensitivity, with a few targeted exceptions.

Forty-four percent of HUC-12s in the study area had roads in the highly vulnerable category of high combined exposure and sensitivity. The high vulnerability areas are scattered throughout the study area and are generally concentrated in lower elevation areas. Tables ES.3, ES.4, and ES.5 below summarize exposure, sensitivity and vulnerability results for recreation sites, trails, and roads, respectively, and Figures ES.11, ES.12, and ES.13 illustrate vulnerability for each infrastructure type.

Table ES.3. Summary of Recreation Site Infrastructure Findings

Analysis	General Result	Most Affected Areas	Least Affected Areas
Exposure			
Winter flooding	Winter flooding was expected to increase across the area, with greatest exposure at lower elevations and less exposure at higher elevations.	Most affected areas averaged by HUC-10 included Upper Thompson, Meadow-Bear, Little Thompson, McLaughlin-Cherry, Prospect, St. Regis, Dry-Cutoff, and Lost Prairie-Elk Creeks.	Least affected areas averaged by HUC-10 included Canyon-Cabin, East Fork Cooney and Rattlesnake-Grant Creeks.
Sensitivity			
Location in floodplain	Recreation sites were largely located out of floodplains	8 HUC-12s had 2-5 sites within the floodplain and one (in the Gilbert-Butte Creeks area) had 6-8 sites in the floodplain	Most of the LNF
Location in high geologic hazard area	There was no apparent spatial pattern for geologic hazard sensitivity across the LNF.	Averaged by HUC-10, most affected was Miller-O'Brien Creeks	Most of the LNF

Table ES.3, continued

Analysis	General Result	Most Affected Areas	Least Affected Areas
Vulnerability			
Exposure combined with sensitivity	As assessed here, exposure is a bigger issue with recreation site infrastructure than is sensitivity, with a few targeted exceptions.	HUC-12s with high exposure and high sensitivity included Rock Creek-Kitchen Gulch, Lower Clearwater River, Lower Fish Creek, Clark Fork River-Siegel Creek, Savenac Creek, Lower Lolo Creek, Bitterroot River-Hayes Creek, and Upper Fishtrap Creek.	Higher elevation areas were generally less vulnerable.

Table ES.4. Summary of Trail Infrastructure Findings

Analysis	General Result	Most Affected Areas	Least Affected Areas
Exposure			
Winter flooding	Winter flooding was expected to increase across the area, with greatest exposure at lower elevations and less exposure at higher elevations.	Most affected areas averaged by HUC-10 included Upper Thompson, Meadow-Bear, Little Thompson, McLaughlin-Cherry, Prospect, St. Regis, Dry-Cutoff, and Lost Prairie-Elk Creeks.	Least affected areas averaged by HUC-10 included Canyon-Cabin, East Fork Cooney and Rattlesnake-Grant Creeks.
Sensitivity			
Location in floodplain	Trails were largely located out of floodplains	Averaged by HUC-10, most affected were East Fork Cooney, Canyon-Cabin, Ninemile, and Miller-O'Brien Creeks.	Most of the LNF
Location in high geologic hazard area	There was no apparent spatial pattern for geologic hazard sensitivity across the LNF.	Averaged by HUC-10, most affected were East Fork Cooney, Monture and Miller-O'Brien Creeks.	Most of the LNF
Vulnerability			
Exposure combined with sensitivity	As assessed here, exposure is a bigger issue with trail infrastructure than is sensitivity, with a few targeted exceptions.	HUC-12s with high exposure and high sensitivity included Rock Creek-Kitchen Gulch, Lake Creek, Lower Clearwater River, Ninemile-Butler, Stony Creek, Clark Fork River-Siegel Creek, Bitterroot River-Hayes Creek, Big Rock Creek, and Dry Creek	Higher elevation areas were generally less vulnerable.

Table ES.5. Summary of Road Infrastructure Findings

Analysis	General Result	Most Affected Areas	Least Affected Areas
Exposure			
Winter flooding	Winter flooding was expected to increase across the area, with greatest exposure at lower elevations and less exposure at higher elevations.	Most affected areas averaged by HUC-10 included Upper Thompson, Meadow-Bear, Little Thompson, McLaughlin-Cherry, Prospect, St. Regis, Dry-Cutoff, and Lost Prairie-Elk Creeks.	Least affected areas averaged by HUC-10 included Canyon-Cabin, East Fork Cooney and Rattlesnake-Grant Creeks.
Sensitivity			
Location in floodplain	Roads were largely located out of floodplains	Averaged by HUC-10, most affected were Monture, Clearwater-Salmon, Dry-Cutoff Creeks, and St. Regis River.	Most of the LNF
Location in high geologic hazard area	There was no apparent spatial pattern for geologic hazard sensitivity across the LNF.	Averaged by HUC-10, most affected were Ninemile, St. Regis River, Lolo and Little Thompson Creeks.	Most of the LNF
Number of culverts	Culverts throughout the LNF averaged mostly less than 1 per mile and distribution was relatively uniform with no discernable pattern.	Averaged by HUC-10, most affected were Clearwater-Salmon, Placid, Gold-Union, Ninemile, Dry-Cutoff, St. Regis River, Meadow-Bear, and Deep-Mosquito Creeks.	Most of the LNF had less than one culvert per mile.
Vulnerability			
Exposure combined with sensitivity	Seventy-two percent of HUC-12s had USFS roads with high exposure and low sensitivity, and these HUCs are concentrated in low-elevation areas. Roads in areas of moderate or lower exposure and either high or low sensitivity are generally located in HUC-12s within headwater areas at higher elevation.	Forty-four percent of HUC-12s in the study area had roads in the highly vulnerable category of high combined exposure and sensitivity. The high vulnerability areas are scattered throughout the study area and are generally concentrated in lower elevation areas.	Least affected areas are generally at higher elevations.

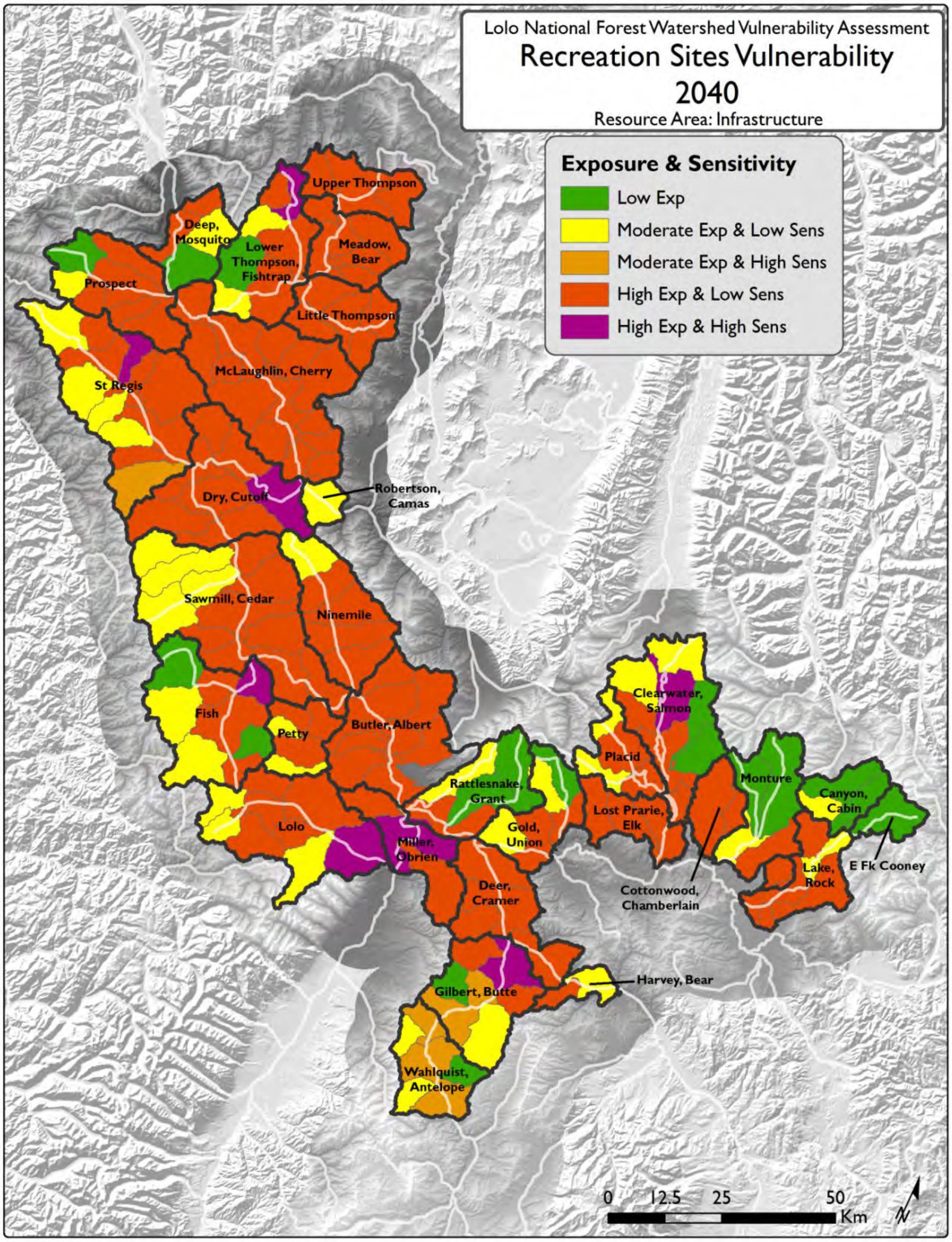

Figure ES.11. *Estimated vulnerability of recreation sites, by HUC-12, by the 2040s.*

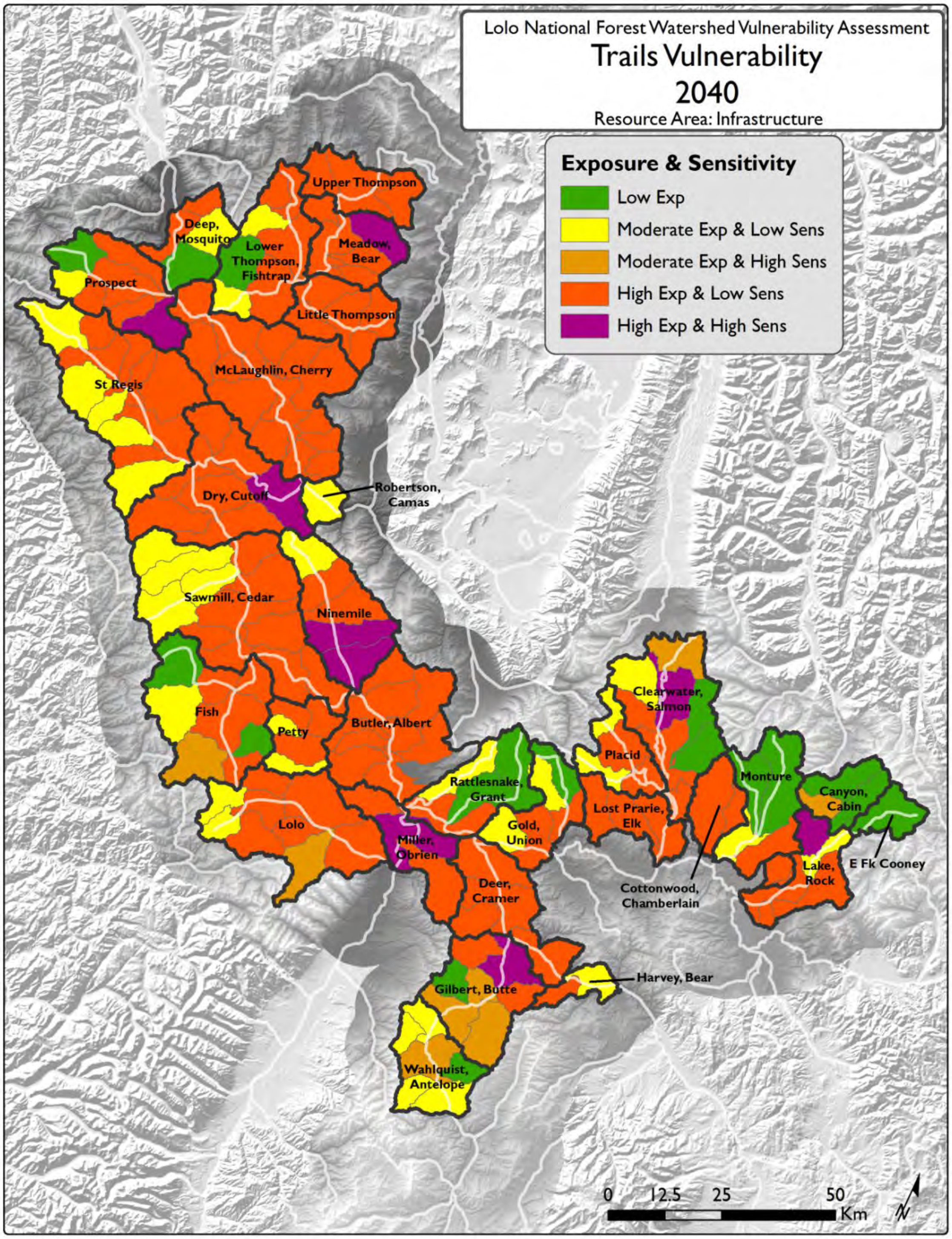

Figure ES.12. *Estimated vulnerability of trails, by HUC-12, by the 2040s.*

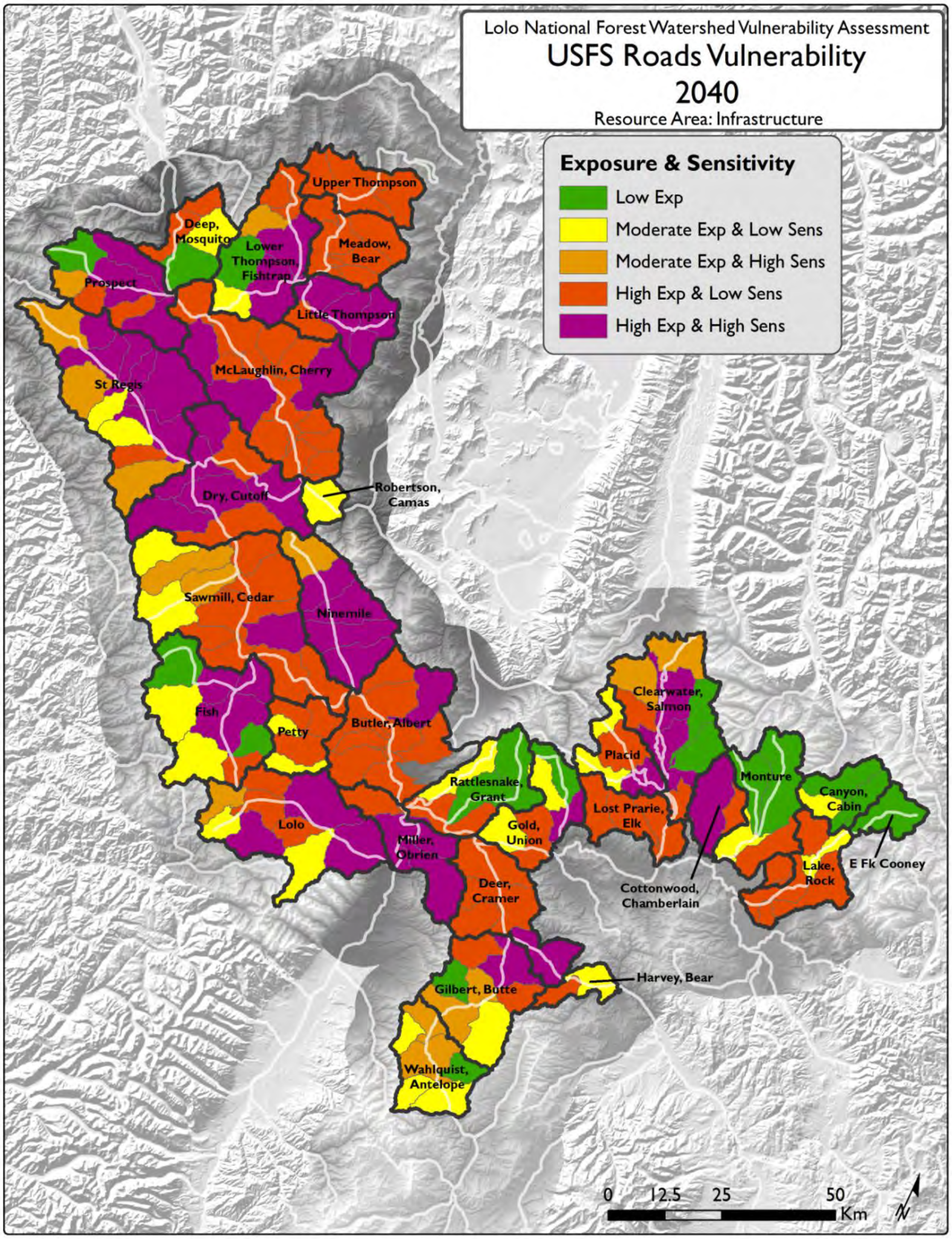

Figure ES.13. *Estimated vulnerability of LNF-jurisdiction roads, by HUC-12, by the 2040s.*

MANAGEMENT IMPLICATIONS

The goal of this vulnerability assessment is to provide management guidance in meeting LNF conservation goals to maintain resilient ecosystems given the added uncertainties and complexities of climate change. This analysis provides insight into one potential quantification of vulnerability based on one scenario of climate exposure and key potential drivers of sensitivity, suggesting adaptation actions to reduce vulnerability (Figure ES.1, above). Assessing vulnerabilities and prioritizing management actions are but one step in a broader management framework (see Table I.1 in main report). Each watershed has unique attributes that will determine specific ecological dynamics and responses to climatic changes.

Managers can use the results of this assessment in numerous ways, including identification of data gaps, development of monitoring programs, integration with existing prioritization programs, development of short and long-term strategies to increase resilience of the resource where it is likely to have the most benefit, development of education and outreach materials, and collaboration with other agencies and local communities (Furniss et al. 2013).

We hope this analysis will further provide an opportunity for the LNF to educate the public about the potential climatic impacts to forest resources and LNF's adaptive management strategies to address potential impacts. In addition, this report can be used to identify where collaborative efforts with state, federal, and tribal agencies, community councils, and NGOs would be most productive in developing successful adaptation measures.

BULL TROUT MANAGEMENT IMPLICATIONS

Bull trout require colder water than most other salmonids, and given documented increases in stream temperatures, a sizeable percent of their cold-water habitat may already have been lost (Isaak et al. 2010). Additionally, changes in hydrological regimes have measurably reduced summer flows (Luce & Holden 2009), and projections of increased frequency of higher flows are likely to result in increased scour during bull trout incubation (Goode et al. 2013). Although western Montana has been identified as likely providing some of the coldest waters across their range, recent projections of bull trout occurrence probability are low in many areas of the LNF under a scenario of high climatic changes (Isaak et al. 2015b).

Relative differences in vulnerability across the LNF are important, especially given the potential for bull trout to adapt to changing climatic conditions through evolutionary or plastic responses. As managers are faced with managing habitat for bull trout conservation, it is critical to understand where and which conservation and adaptation actions are likely to most contribute to increased resiliency of bull trout populations. A substantial amount of complementary research has been conducted for the species across multiple scales, and we urge managers to consider our results in conjunction with those efforts.

Improving bull trout habitat will be necessary, but not necessarily sufficient for bull trout recovery. For example, recent modeling suggests reducing impacts from nonnatives would provide relatively high improvement in bull trout population status, but restoration of natal habitat was found not likely to be highly effective (Peterson 2015). Beyond habitat, demographic and genetic trends are critical to long term species persistence (Moore et al. 2014; Nicotra et al. 2015; Kovach et al. 2015).

In summary, bull trout conservation is complex, and the findings here are aimed to provide LNF managers the context of vulnerability for optimizing forest operations with respect to both efficiency and effectiveness. Ideally, decisions should be considered within a broader context spatially and ecologically, which demands concurrent consideration and collaboration with other responsible stakeholders. The concepts of niche redundancy, resilience, and representation are critical to long-term conservation of bull trout. Management actions without expansive thought beyond the LNF boundaries will not be effective. Management that is too localized and singularly focused has plagued salmonid conservation throughout the Columbia Basin (Rieman et al. 2015). The findings provided here should be compared and complimented with other studies to adaptively manage bull trout, throughout their range and engaging with all stressors, to maximize the demographic, life-history, and genetic diversity of a comprehensive bull trout portfolio (Schindler et al. 2010).

Our analysis focused on these types of physical habitat drivers of bull trout sensitivity to climate change, where we believe managers can most successfully act to reduce vulnerability (Table ES.6).

Table ES.6. Example management actions for bull trout conservation.

Mode of Action	Example Management Actions
Assess	- Verify temperature and other climatic projections with monitoring - Continue active monitoring of bull trout presence, redd counts - Continue coordination with RMRS re: eDNA monitoring - Maintain and develop GIS layers of bull trout presence and abundance - Monitor for genetic and demographic trends
Engage	- Continue support for interpretive efforts, interacting with schools and other programs re: bull trout awareness - Continue coordination with FWP and MDT re: surveys, identification and eradication of non-natives, LWD replacement at bridges - Coordinate with FWP to increase monitoring - Engage ditch and water managers re: drought planning and reducing summer diversions
Manage	- Manage for resilience (reduce stressors in high sensitivity areas, protect refugia in low exposure areas, manage proactively in high exposure areas) ▪ Increase/maintain riparian shading and encourage species diversity in plantings ▪ Improve base flows via beaver reintroductions or beaver analogs ▪ Continue to remove unnatural barriers and improve habitat connectivity ▪ Interface with TMDL efforts to reduce sediment ▪ Restore/maintain channel complexity via rehabilitation pilots (e.g., LWD reintroduction), particularly at over-wintering habitat or areas of high summer thermal-stress ▪ Evaluate and manage road system in strategic locations such that modifications (relocation, removal, etc.) facilitate stream, floodplain and riparian processes (wood delivery, complexity, thermal buffering, etc.) ▪ Manage grazing allotments using stream and riparian-based methods (e.g., greenline-based approaches) ▪ Develop plan to manage/remove invasives ▪ Remove genetic and population bottlenecks

Water Supply Management Implications

Projected shifts in hydrological regimes may change availability of water for all uses, including instream flows for aquatic ecosystems, groundwater recharge supporting wetland ecosystems, municipal and public water supplies, agricultural irrigation diversions, and Forest Service potable water systems.

As summer water supply becomes scarcer in the future, managers will need to prioritize where enhancement of watershed storage would be beneficial as an adaptation strategy. Groundwater storage can increase watershed resiliency during drought cycles now and in the face of future climate-driven low flows. Enhancement could take the form of constructed impoundments at existing lakes, if feasible and ecologically benign, or could be achieved naturally, and with potentially greater ecological benefits, by beaver reintroduction.

This vulnerability analysis may also be useful for prioritizing where additional instream flow for aquatic life could be beneficial in the face of decreasing summer flows in the future. The Water Rights Compact between the State of Montana and the USDA Forest Service grants the USFS specific instream flow rights on a number of tributaries on the Lolo NF to protect base flows for fishery protection. Identifying especially vulnerable streams for both water supply and bull trout, combined with manager's knowledge of opportunities and limitations, may help guide prioritization decisions.

Table ES.7. provides examples of management actions to reduce the vulnerability of water supplies.

Table ES.7. Example management actions for maintaining sufficient water supply.

Mode of Action	Example Management Actions
Assess	- Verify diversion sites and quantify flow diversion - Continue existing monitoring and monitor flow withdrawals under SUPs to ensure adherence to water rights and appropriate habitat protections - Assess feasibility and potential influence of beaver or beaver analog projects; identify watersheds for pilot reintroductions - Perform stream reconnaissance during project assessments and inventory all human-related water withdrawals in accord with appropriate use
Engage	- Continue to educate community on outdoor watering restrictions and water-use guidelines - Coordinate with DNRC to provide verification of appropriate water use at key locations - Continue communications with state agency, NGO, and private partners on beaver management and enhancement - Coordinate with ditch managers and others to encourage drought planning and voluntary actions to reduce instream withdrawals, particularly in summer - Enhance partnerships for monitoring and actions that consider complete watershed dynamics headwaters to mouths - Continue Wyden authority towards necessary improvements on private lands
Manage	- Manage for resilience (reduce stressors in high sensitivity areas, protect refugia in low exposure areas, manage proactively in high exposure areas, implement water-saving efforts forestwide) ▪ Continue instream flow securement program; consider objections to new water rights where instream flow reservations are not established ▪ Implement water-saving initiatives forestwide: install water-saving facilities, meter water usage, and maintain LNF watering devices in good working order; use grey-water for irrigation as possible; xeriscape and use native, drought-resistant plants and water-smart landscaping; irrigate efficiently with timed sprinkler systems and allow for less vibrant summer lawns

Infrastructure Management Implications

Campgrounds, roads, and trails provide the foundation for recreational opportunities on public lands, and roads and trails are crucial for forest and fire management. The LNF is responsible for maintaining over 8,900 mi of roads, 1,698 mi of trails, and almost 300 recreation sites, including trailheads, loading ramps, campgrounds and picnic areas. Climate change is likely to make some of this infrastructure more exposed to flooding, especially early-season rain-on-snow events that may have greater magnitude than our present runoff regime. Along with the potential for winter flooding, infrastructure location in the floodplain or areas of high geologic hazard (landslides, avalanches, and alluvial fans) are inherent stressors considered in this analysis. For roads, another inherent stressor we considered was the number of culverts because they can increase the probability of road wash-outs.

Use of the vulnerability results in management decisions should be contingent on field verification of susceptibility to flooding and geologic hazards; this is true for both low and high vulnerability areas. Most floodplains on the LNF are not FEMA-mapped and our analysis of floodplain location is limited by modeling assumptions. Our analysis of geologic hazards is also limited by the scale at which data are available (for example, presence in an alluvial fan may not be hazardous in all instances). We strongly recommend that managers carefully analyze the figures and tables of the individual metrics that make up infrastructure vulnerability designations. Table ES.8. provides examples of management actions to reduce the vulnerability of infrastructure.

Table ES.8. Example management actions for maintaining infrastructure.

Mode of Action	Example Management Actions
Assess	- Verify infrastructure locations in flood prone or high geologic-risk locations - Continue monitoring to evaluate efficacy of AOP/Q100 stream simulation efforts and strategies for stream crossing structures - Create and maintain GIS layer of vulnerable roads, trail, and campground facilities
Engage	- Maintain and enhance partnerships for infrastructure improvements and monitoring
Manage	- Manage for resilience (reduce stressors in high sensitivity areas, protect refugia in low exposure areas, manage proactively in high exposure areas) ▪ Consider road and trail relocation and realignment to areas of lower risk ▪ Provide adequate drainage through road and trail prism and drainage reconstruction; if prisms cannot be relocated from flood prone areas, elevate surface above flood risk level and armor via rock or vegetation ▪ Relocate roads in transport dominated reaches where possible ▪ Provide adequate BMP and maintenance on road-stream crossings ▪ Replace outdated and undersized structures at road-stream crossings; ensure adequate flow given risks of rain-on-snow events and post-fire debris ▪ Ensure ditches do not connect to stream network and reduce diversion potential for stream flow down road ▪ Remove or modify vulnerable campgrounds ▪ Prevent new development in floodprone areas

Full report available on-line at: http://www.fs.usda.gov/main/lolo/workingtogether.