

Chapter 4: Climate Change, Water Resources, and Roads in the Blue Mountains

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Introduction

Water is a critical resource in dry forest and rangeland environments of western North America, largely determining the distribution of plant and animal species across a broad range of elevations and ecosystems. Water is also essential for human endeavors, directly affecting where and how human communities and local economies have developed. The Blue Mountains of northeast Oregon and southeast Washington are an important source of water for forest ecosystems and human uses. Surrounding communities rely on water from national forest lands in the Blue Mountains for drinking water, industrial uses, irrigation, livestock watering, and recreation, among other uses. Climate change affects water supply by changing the amount, timing, and distribution of precipitation and runoff. These changes have the potential to affect water supply, roads and other infrastructure, and access to national forest lands in the Blue Mountains region. Reduced or less reliable water supply affects local economic activities, planning, and resource management. Damage to roads, bridges, and culverts creates safety hazards, affects aquatic resources, and incurs high repair costs. Reduced access to public lands reduces the ability of land managers to preserve, protect, and restore resources and to provide for public use of resources. Understanding vulnerabilities and the processes through which climate change affects hydrology will help U.S. Forest Service land managers identify adaptation strategies that maintain ecosystem function, a sustainable water supply, and a sustainable road system.

In this chapter, we (1) identify key sensitivities of water supply, roads, and infrastructure to changes in climate and hydrology; (2) review current and proposed management priorities, and share management approaches that already consider climate or climate change; and (3) use the latest scientific information on climate change and effects on hydrologic regimes (see chapter 3) to identify adaptation

Climate change affects water supply by changing the amount, timing, and distribution of precipitation and runoff.

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strategies and tactics. During a workshop convened in La Grande, Oregon, in April 2014, participants reviewed the latest science on the sensitivity of water resources and related water uses and infrastructure to climate change in the Blue Mountains (boxes 4.1 and 4.2). Workshop participants worked collaboratively to identify adaptation options to reduce vulnerability to climate change and facilitate transition to new conditions. The results of this vulnerability assessment and adaptation planning process are described in the sections below.

Water Resources and Uses

In the predominantly dry climate of the Blue Mountains region, water is the most critical natural resource for human habitation and enterprises. Many streams and groundwater systems surrounding the Blue Mountains region originate from the Malheur, Umatilla, and Wallowa-Whitman National Forests, thus providing a valued ecosystem service to local communities and economies. There are about 6,800 water rights on national forest lands in the Blue Mountains; 43 percent provide water for domestic livestock, 32 percent support instream flows, 9 percent are for wildlife, 5 percent are for irrigation, and 3 percent are for domestic uses (Gecy 2014). By volume, instream flows account for 75 percent of water rights, with irrigation and domestic uses each accounting for 1 percent by volume, and water for livestock accounting for 2 percent by volume (Gecy 2014). Six municipalities (Baker City, La Grande, Long Creek, Walla Walla, Pendleton, and Canyon City) rely directly on the national forests for municipal water supply. In addition, 20 smaller communities rely on surface or groundwater from the Blue Mountains forests for drinking water. There are 320 points of diversion (under a certificated water right) within the boundaries of national forests in the Blue Mountains that provide water for domestic use (Gecy 2014; e.g., see fig. 4.1).

Water is critical for livestock on national forests and surrounding lands, and consumption for this purpose is broadly dispersed across different ecosystems. About 42 percent of national forest land in the Blue Mountains is considered suitable for sheep and cattle grazing, and grazing occurs on these lands in 455 of 552 subwatersheds within the Blue Mountains (Gecy 2014). Water for livestock is the largest permitted water use on national forest land by number of certificated water rights.

All basins in national forests of the Blue Mountains region are fully allocated in terms of water available for appropriation under state law in the dry summer season. In national forests, water is generally available for campgrounds and administrative sites and for other appropriated uses (e.g., livestock and wildlife),

Box 4.1—Summary of climate change effects on water resource use in the Blue Mountains

Broad-scale climate change effect

Decreasing snowpack and declining summer flows alter timing and availability of water supply.

Resource entity affected

Drinking water supply for municipal and public uses both downstream from and on the national forests, other forest uses including livestock, wildlife, recreation, firefighting, road maintenance, and instream fishery flows. Change in availability of water supply to meet human uses increases the risk of scarcity and of not satisfying consumptive and instream needs.

Current condition, existing stressors

All basins are fully allocated in terms of water available for appropriation under state law. On national forests, water is generally available for campgrounds and administrative sites and for other appropriated uses (e.g., livestock and wildlife), although in dry years, availability may be limited at some sites, especially in late summer. In drought years, downstream “junior” users may not receive water for various purposes, primarily irrigation. Six municipalities rely directly on the national forests for drinking water supply (Baker City, La Grande, Walla Walla, Pendleton, Long Creek, and Canyon City). Ecological effects include the following: onforest dams for storage facilities and stream diversions affect stream channel function; and development of springs and ponds for livestock affect many groundwater-dependent ecosystems. Changes in water supply are expected to influence water use by vegetation, exacerbate low soil moisture, and influence fire frequency with various secondary effects on water supply and quality.

Sensitivity to climatic variability and change

Regional water supplies are highly dependent on snowpack extent and duration; April 1 snow water equivalent is the traditional indicator of late-season water availability. Declining summer low flows will affect water availability during this period of peak demand (e.g., for irrigation and power supply).

Expected effects of climate change

Decreased snowpack extent and duration are expected to affect the timing and availability of water supply, particularly in late summer when demand is high for both consumptive and instream uses. Decreased summer low flows will limit water availability during critical times and for multiple uses.

Box 4.1 continued**Adaptive capacity**

Within-forest impacts will likely be less than downstream, although some facilities may see reduced water supply in late summer. Annual operating plans could be adjusted to limit potential for effects on streams and springs by permitted livestock and wildlife during dry years. Off-forest effects may be greater; although some municipalities have backup wells, and water supply for drinking water and other uses is likely to be affected. There is a need for coordination at the county and state level for conservation planning. There may be an increase in proposals for groundwater and surface storage development.

Risk assessment

Potential magnitude of climate change effects

- For those watersheds determined to be sensitive
 - Moderate magnitude by 2040
 - High magnitude by 2080

Likelihood of climate change effects

- For those watersheds determined to be sensitive
 - Moderate likelihood by 2040
 - High likelihood by 2080

Box 4.2—Summary of climate change effects on roads and infrastructure in the Blue Mountains

Broad-scale climate change effect

Increase in magnitude of winter/spring peak streamflows.

Resource entity affected

Infrastructure and roads near perennial streams, which are valued for public access.

Current condition, existing stressors

Many kilometers of roads are located close to streams on the national forests, and these roads have high value for public access and resource management. A large backlog of deferred maintenance exists because of decreasing budget and maintenance capacity. Many roads are in vulnerable locations subject to high flows.

Sensitivity to climatic variability and change

Roads in near-stream environments are periodically exposed to high flows. Increased magnitude of peak flows increases susceptibility to effects ranging from minor erosion to complete loss of the road prism, resulting in effects on public safety, access for resource management, water quality, and aquatic habitat.

Expected effects of climate change

Projections for increased magnitude of peak flows indicate that more kilometers of road will be exposed to higher flow events and greater impacts.

Adaptive capacity

Knowing the extent and location of potentially vulnerable road segments will help with prioritizing scarce funding, targeting “storm damage risk reduction” treatments, and communicating potential hazard and risk to the public.

Risk assessment

Potential magnitude of climate change effects

- For those watersheds determined to be sensitive
 - Moderate magnitude by 2040
 - High magnitude by 2080

Likelihood of climate change effects

- For those watersheds determined to be sensitive
 - Moderate likelihood by 2040
 - High likelihood by 2080

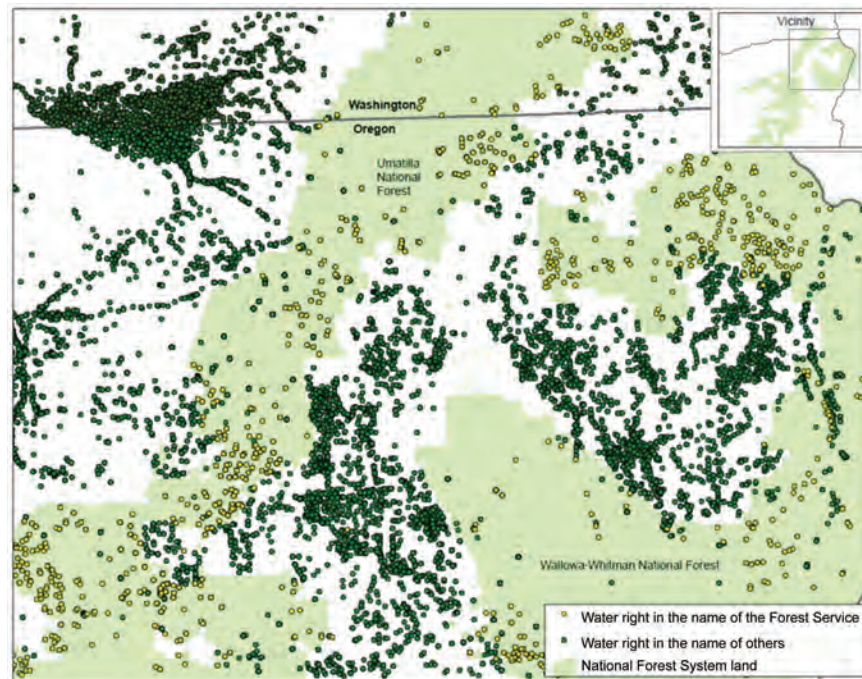


Figure 4.1—Water right points of diversions (PODs) in the name of the Forest Service and in the name of others on and near the Wallowa-Whitman and northern Umatilla National Forest. The PODs in the name of the Forest Service represent a minor percentage of consumptive water rights. Consumptive water rights in the name of others are concentrated off forest in the Umatilla, Walla Walla, Grande Ronde, and Wallowa Valleys.

In drought years, downstream “junior” users in the water allocation system may not receive water for various purposes, primarily irrigation.

although in dry years, availability may be limited at some sites, especially in late summer. Dams for storage facilities, stream diversions, and development of springs and ponds for livestock on the national forests affect hydrologic and ecologic function of groundwater-dependent ecosystems (see chapter 7). In drought years, downstream “junior” users in the water allocation system may not receive water for various purposes, primarily irrigation. It is uncertain if long-term climate change or short-term drought will alter permitted water use in the future, although significant changes in water use during the next decade or so are unlikely.

Climate Change Effects on Water Uses

Warming temperatures will lead to decreased snowpack and earlier snowmelt, resulting in shifts in timing and magnitude of streamflow and decreased summer soil moisture (see chapter 3). Across the Blue Mountains, the majority of precipitation occurs during the winter months, when consumptive demand is lowest. In summer, when demand is highest, rain is infrequent and streams are dependent on groundwater to maintain low or base flows. Because water supply in the Blue

Mountains is limited, climate change may reduce water available to meet current demands in the summer months, especially during extreme drought years and after multiple consecutive drought years. Although current conflict over water use in the Blue Mountains is not a prominent issue, future water shortages may create social and political tensions as different sectors (e.g., agriculture and municipal) compete for scarce water.

Regional water supplies depend on snowpack extent and duration, and late-season water availability (often characterized by April 1 snow water equivalent). Declining summer low flows caused by earlier snowmelt runoff could affect water availability during peak demand. Historical snowpack sensitivity (fig. 4.2) and projections of summer streamflow (fig. 4.3) across the Blue Mountains identify areas that may be particularly sensitive with respect to water supply. Lower elevation locations with mixed snow and rain will be the most vulnerable to reduced spring snowpack, but even the most persistent snowpacks at higher elevation are expected to decline by the 2080s (see chapter 3). Variable Infiltration Capacity (VIC) hydrological model runs (for natural flows, not accounting for withdrawals, use, and storage) suggest that the Burnt, Powder, Upper Grande Ronde, Silver, Silvies, Upper John Day, Wallowa, and Willow subbasins are at highest risk for summer water shortage associated with low streamflow by 2080 (fig. 4.3). Decreases in summer low flows in these areas have the greatest potential to affect agricultural irrigation and municipal uses.

Water diversions and dams can also affect the resilience of watersheds to climate change. Although dams increase water storage during low flow, diversions also increase water extraction. Aging and inefficient diversion infrastructure can increase water loss. Engaging users within basins where water shortages can occur is critical for addressing water distribution and climate change effects. Clarifying water demand, negotiating water allocations, ensuring environmental flows in the water rights process, adjudicating over-allocated basins, and monitoring compliance can help reduce susceptibility to climate stresses.

Water quantity is an important attribute of the Watershed Condition Framework (WCF) classification system used by national forests to rate overall watershed condition (Potyondy and Geier 2011). Most subwatersheds across the Blue Mountains were rated as “functioning” or “functioning at risk” for this attribute, based on the magnitude of existing flow alterations from dams, diversions, and withdrawals relative to natural streamflows and groundwater storage. The Burnt, Powder, Upper Grande Ronde, and Wallowa subbasins have the highest number of subwatersheds rated as having “impaired function” for water quantity on national forest lands (fig. 4.4). Basins with the highest off-forest consumptive uses include Walla Walla,

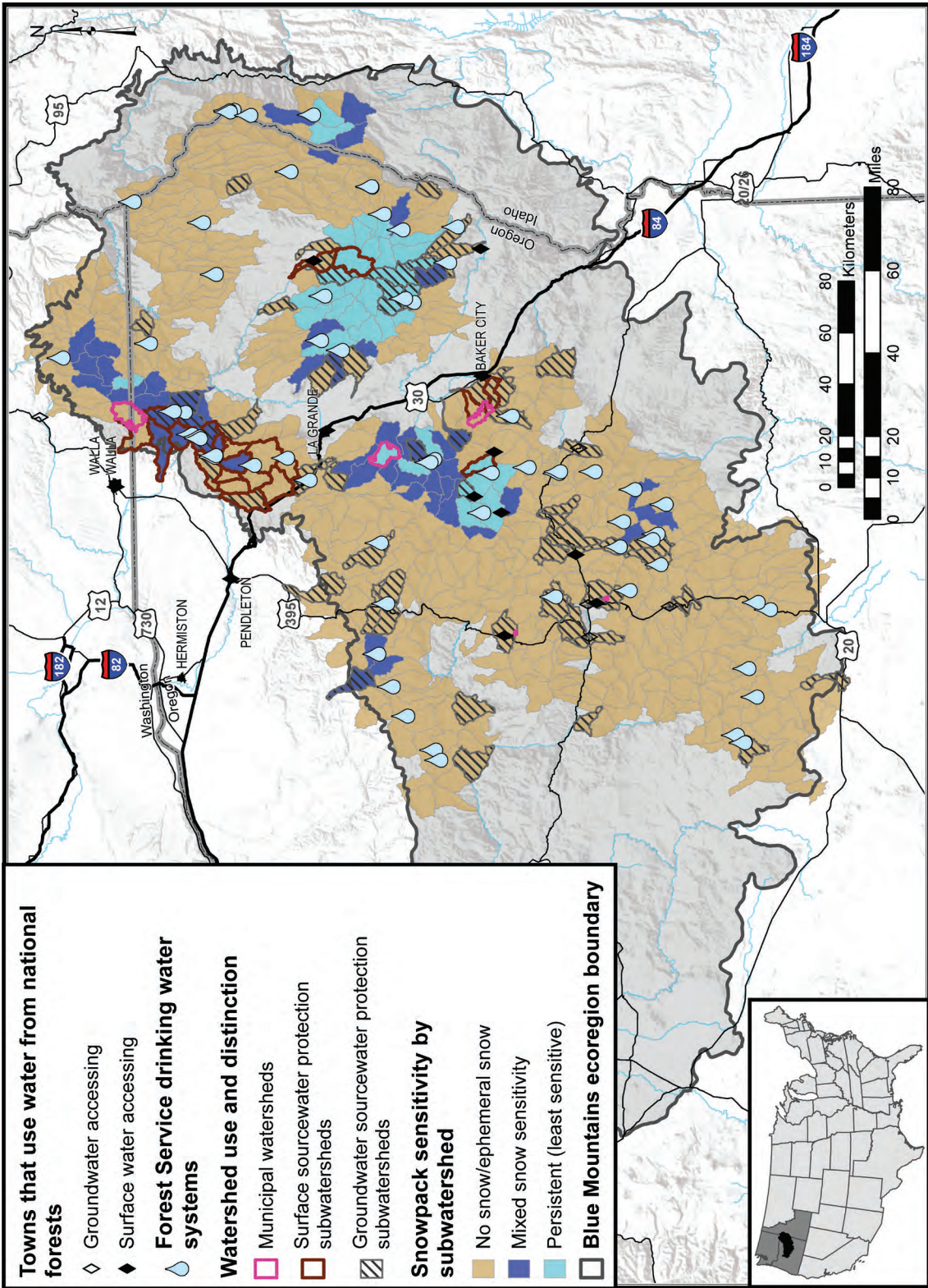


Figure 4.2—Historical snowpack sensitivity and different water uses in the Blue Mountains region. Snowpack sensitivity was classified as “no snow/ephemeral snow” if April 1 snow water equivalent was less than 3.8 cm during dry years (no snow) and greater than 3.8 cm during wet years (snow cover) in ≥ 80 percent of the subwatershed; “mixed snow sensitivity” if the timing of peak snowmelt in the warmest, driest years (e.g., 2003, El Niño year) occurred more than 30 days earlier than the coldest, wettest year (2011, La Niña year) in ≥ 50 percent of the subwatershed; and “persistent-least sensitive” if timing of peak snowmelt differed by less than 30 days between the warmest, driest years and the coldest, wettest years in ≥ 30 percent of the subwatershed. Locations in the mixed snow vulnerability category will likely see the greatest decrease in snowpack, but even the most persistent snowpacks (persistent least sensitive) will likely decline (see chapter 3). Areas of concern include municipal watersheds, locations with Forest Service drinking water systems, and national forest lands that are over-allocated downstream. Snowpack sensitivity information was adapted from Kramer (see footnote 2).

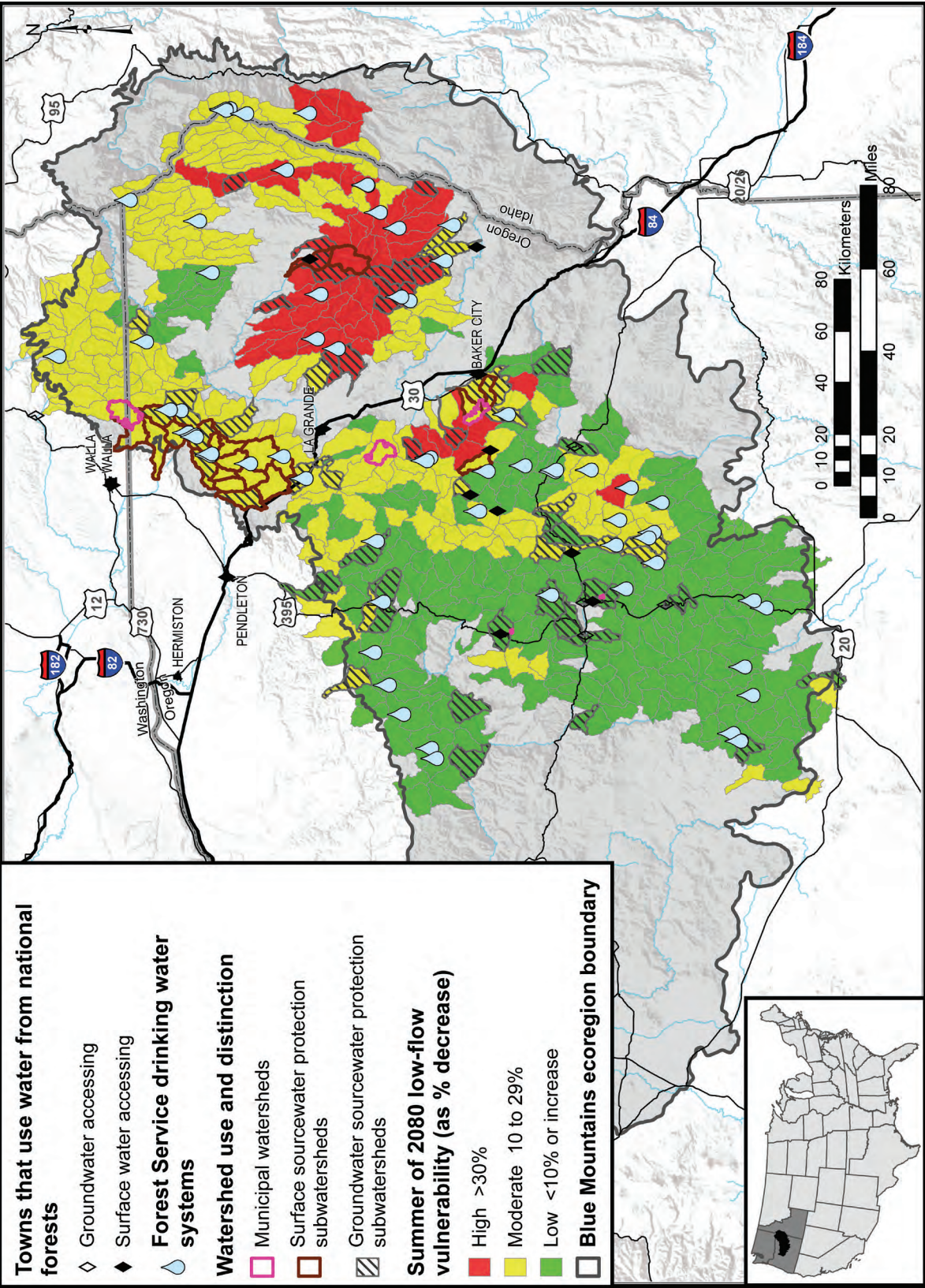


Figure 4.3—Projections of risk of summer water shortage associated with low streamflows in summer for 2080. Projections were calculated using flow data from the Variable Infiltration Capacity model based on historical data for 1915–2006, and summer flow simulated for a global climate model ensemble for the A1B emission scenario (from Wenger et al. 2010). The Burnt, Powder, Upper Grande Ronde, Silver, Silvies, Upper Grande Ronde, Silver, Wallowa, and Willow Creek watersheds are at highest risk of summer water shortage.

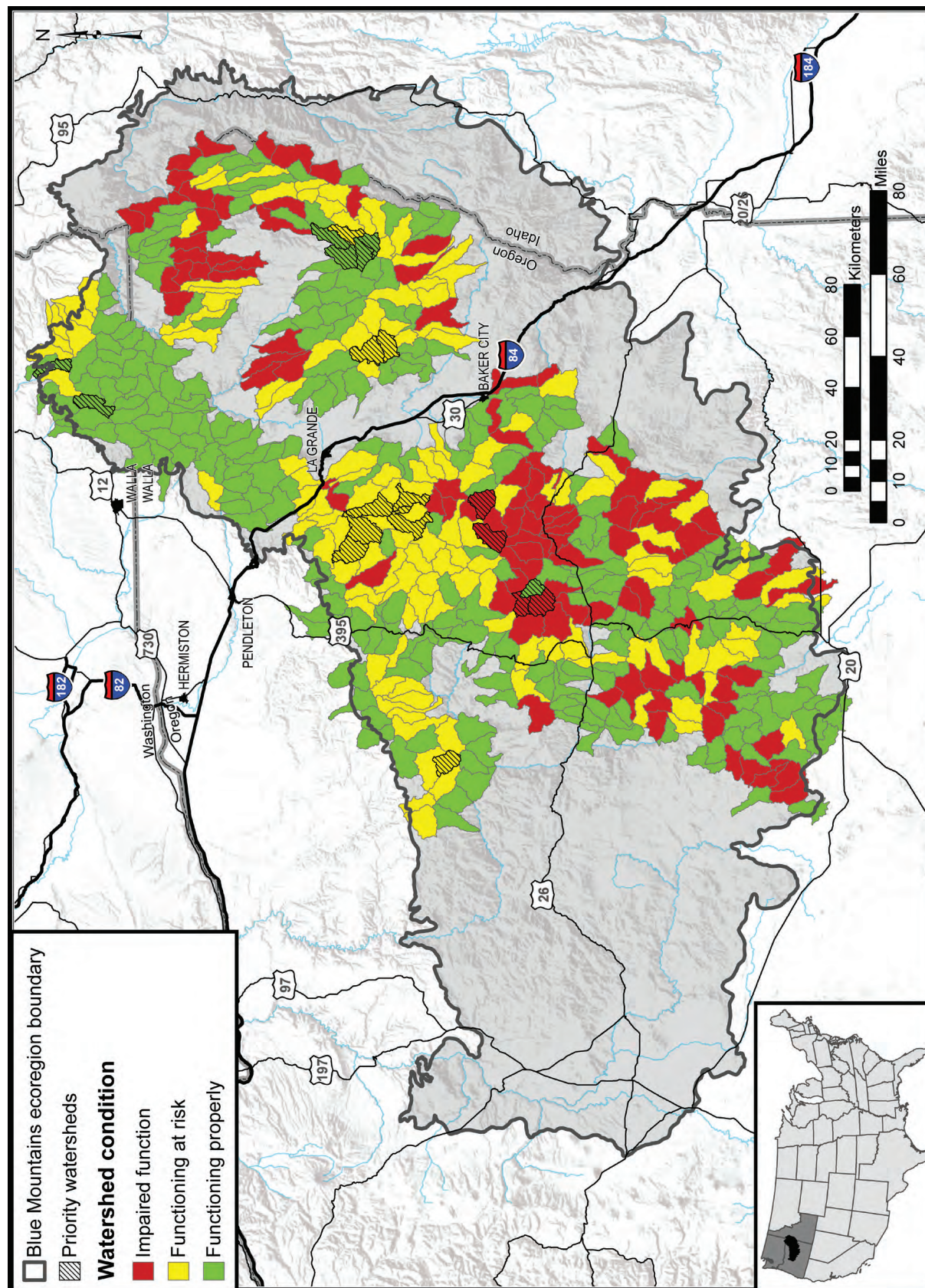


Figure 4.4—Magnitude of flow alteration by dams and diversions in the Blue Mountains region. Resource specialists in each national forest rated relative flow alteration of subwatersheds as part of the watershed condition classification in the Watershed Condition Framework (Potyondy and Geier 2011). A relatively high percentage of subwatersheds within the Burnt, Powder, Upper Grande Ronde, and Wallowa subbasins were rated as having impaired function for this indicator of watershed condition.

Umatilla, Burnt, Powder, Malheur, Silvies, and Silver Creek (Gecy 2014). Most of these areas are among those expected to experience the greatest changes in summer flows (fig. 4.3) and thus may be the most vulnerable from a water-use perspective.

Besides projected changes in streamflows and the magnitude of existing water diversions, the presence or absence of backup water systems is an important factor affecting the vulnerability of water supplies for human uses. Those systems with redundant supplies will generally be less vulnerable. Development of such systems, as well as increasing water conservation efforts, are key opportunities for adaptation.

Roads, Infrastructure, and Access

Roads, trails, bridges, and other infrastructure were developed in the Blue Mountains over more than a century to provide access for mineral prospectors, loggers, hunters, and recreationists. The national forests in the Blue Mountains were created to protect water supply, timber, range resources, and wildlife, and to provide multiple uses and enjoyment by the public. Providing access to accomplish these objectives largely determined where these activities historically occurred. Today, reliable and strategic access is critical for people to recreate, extract resources, monitor and manage resources, and respond to emergencies. Access to public lands promotes use, stewardship, and appreciation of their value as a vital resource contributing to quality of life (Louter 2006).

The three national forests combined contain 37 534 km of roads (table 4.1, fig. 4.5). Of the existing roads, 850 km of roads are paved, 17 800 km are gravel, and the remaining are native surface roads. Road density is higher at low elevations and adjacent to mountain passes, such as near major highways (fig. 4.5). Roads and trails cross many streams and rivers because of the rugged topography. Most

Reliable and strategic access is critical for people to recreate, extract resources, monitor and manage resources, and respond to emergencies.

Table 4.1—Kilometers of road by maintenance level on national forests in the Blue Mountains

Operational maintenance levels (ML)		National forests		
		Malheur	Umatilla	Wallowa-Whitman
Code	Description	Kilometers		
ML 1	Basic custodial care (closed)	6059	3543	7216
ML 2	High-clearance cars/trucks	8814	3131	6719
ML 3	Suitable for passenger cars	587	545	435
ML 4	Passenger car (moderate comfort)	0	114	29
ML 5	Passenger car (high comfort)	0	132	210
Total	All roads	15 460	7465	14 609

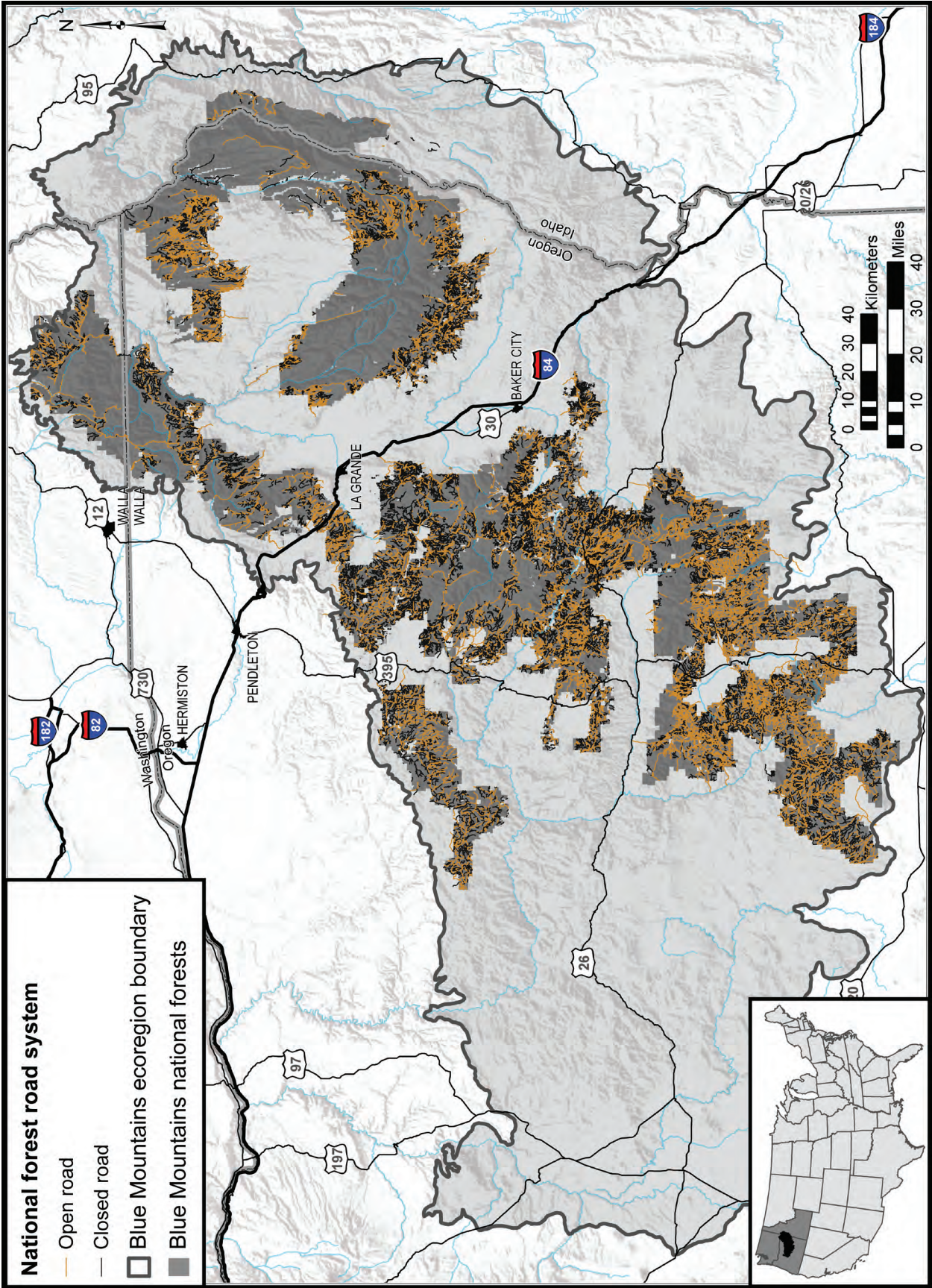


Figure 4.5—Distribution of roads and trails within the three national forests in the Blue Mountains region. The national forests cover a contiguous area of over 2 million ha and contain 37 534 km of roads. The density of roads is higher at low elevations.

(96 percent) known road-water crossings are culverts installed decades ago. Some crossings are being replaced, but many have not been inventoried and conditions are unknown. In many landscapes, the older the road, the more likely it is near or adjacent to streams, greatly increasing risks for road damage and degraded aquatic resources.

Historically, timber harvest was the primary purpose for development of the road system in national forests. Reduced harvesting during the past 20 years has decreased the need for roads for timber purposes. However, local population growth and tourism have increased demand for access for a diversity of recreation activities. Hiking and camping are the most popular activities, but visitors are staying for shorter duration, often only day use; more than 60 percent of trips to national forests last 6 hours or less (USDA FS 2010). Short visits concentrate human impacts on areas that are easily accessible. Demand is increasing for trail use by mountain bikes and motorized vehicles and for routes designated for off-highway vehicles, as well as for winter recreation (USDA FS 2010).

Road Management and Maintenance

The condition of roads and trails differs widely across the Blue Mountains, as do the impact of roads on watersheds and aquatic ecosystems. Culverts were typically designed to withstand a 25-year flood. Road construction has declined since the 1990s, with few new roads being added to the system. Road maintenance is primarily the responsibility of the Forest Service, but county road maintenance crews maintain some roads. The Federal Highway Administration is also involved with the management, design, and funding of roads within the national forests.

Roads vary in their level of environmental impact. They tend to accelerate runoff rates and decrease late-season flows, increase peak flows, and increase erosion rates and sediment delivery to the stream system. These impacts are generally greater from roads closer to rivers and streams; however, roads in uplands also affect surface and shallow groundwater flows, and erosion processes (Trombulak and Frissell 2000).

Each national forest develops a road maintenance plan for the fiscal year, primarily based on priorities by operational maintenance level, then by category and priority. Maintenance of forest roads subject to Highway Safety Act standards receive priority for appropriated capital maintenance, road maintenance, or improvement funds over roads maintained for high clearance vehicles. Activities that are critical to health and safety receive priority in decisions about which roads to repair and maintain, but are balanced with demands for access and protection of aquatic habitat.

Given current and projected funding levels, national forest staff are examining tradeoffs between providing access and maintaining and operating a sustainable transportation system that is safe, affordable, and responsive to public needs, and that causes minimal environmental impact. Management actions being implemented to meet these sometimes competing objectives include reducing road maintenance levels, storm-proofing roads, upgrading drainage structures and stream crossings, reconstructing and upgrading roads, decommissioning roads, converting roads to alternative modes of transportation, and developing more comprehensive access and travel management plans.

Planning for transportation and access on national forests is included in forest land management plans. The 2001 Road Management Rule (36 CFR 212, 261, and 295) requires national forests to use science-based analysis to identify a minimum road system that is ecologically and fiscally sustainable. The Malheur, Umatilla, and Wallow-Whitman National Forests are currently identifying a sustainable road network in accordance with the rule. The goals of transportation analysis are to assess the condition of existing roads, identify options for removing damaged or unnecessary roads, and maintaining and improving necessary roads without compromising environmental quality. Transportation analysis has four benefits: (1) increased ability to acquire funding for road improvement and decommissioning, (2) a framework to set annual maintenance costs, (3) improved ability to meet agreement terms with regulatory agencies, and (4) increased financial sustainability and flexibility. Consideration of climate change is not currently a formal part of the analysis.

Major road projects in national forests, such as reconstruction of roads and trails or decommissioning, must comply with the National Environmental Policy Act (NEPA) of 1969 (NEPA 1969) and require an environmental assessment and public involvement. Decommissioning roads is a process of restoring roads to a more natural state by reestablishing drainage patterns, stabilizing slopes, restoring vegetation, blocking road entrances, installing water bars, removing culverts, removing unstable fills, pulling back road shoulders, scattering slash on roadbeds, and completely eliminating roadbeds (36 CFR 212.5; Road System Management; 23 U.S.C. 101).

Spatial and terrain analysis tools developed to assess road risks, such as the Water and Erosion Predictive model (Flanagan and Nearing 1995), the Geomorphic Road Analysis and Inventory Package (GRAIP) (Black et al. 2012, Cissel et al. 2012), and NetMap (Benda et al. 2007), are often used to identify hydrologic impacts and guide management on projects. For example, the Wall Creek watershed GRAIP analysis on the Umatilla National Forest determined that 12 percent of the

road system contributed 90 percent of the sediment, and focused treatment plans to the most critical sites (Nelson et al. 2010).

Climate Change Effects on Transportation Systems

Altered hydrologic regimes are expected as a result of climate change, especially in the latter half of the 21st century (see chapter 3). Specifically, climate and hydrology will influence the transportation system on Blue Mountains national forests through reduced and earlier runoff of snowpack, resulting in a longer season of road use, higher peak flows and flood risk, and increased landslide risk on steep slopes associated with elevated soil moisture in winter (Strauch et al. 2014). Increased wildfire disturbance (see chapter 6), in combination with higher peak flows, may also lead to increased erosion and landslide frequency.

Changes in climate and hydrology can have both direct and indirect effects on infrastructure and access. Direct effects are those that physically alter the operation or integrity of transportation facilities. These include effects related to floods, snow, landslides, extreme temperatures, and wind. Indirect effects include secondary influences of climate change on access that can increase threats to public safety and change visitor use patterns. For hydrologic extremes such as flooding, the effect on access may be more related to weather events (e.g., the effects of a single storm) rather than climate trends, but the expansion of future extremes outside the historical range of frequency or intensity will likely have the greatest impacts (e.g., by exceeding current design standards for infrastructure).

Projected changes in soil moisture and precipitation form and intensity with climate change may locally accelerate mass wasting in the Blue Mountains. For example, in the deeply dissected northern Blue Mountains, shallow rapid debris slides may become more frequent, impacting infrastructure and access. Climate projections indicate that the conditions that trigger landslides will increase because more precipitation will fall as rain rather than snow, and more winter precipitation will occur in intense storms (Salathé et al. 2014). These effects will likely differ with elevation, because higher elevation areas typically have steeper slopes and more precipitation during storms. Flooding can also be exacerbated by increased basin size during rain events, as snow elevation is projected to move higher, and thus more of the basin will receive precipitation as rain rather than snow. Furthermore, reduced snowpack is expected to increase antecedent soil moisture in winter (Hamlet et al. 2013). Increasing trends in April 1 soil moisture have been observed in modeling studies as a result of warming, showing that soil moisture recharge is occurring earlier in spring and is now higher on April 1 than it was prior to 1947 (Hamlet et al. 2007).

Climate and hydrology will influence the transportation system on Blue Mountains national forests through reduced and earlier runoff of snowpack.

Elevated soil moisture and rapid changes in soil moisture can affect the stability of a slope and are responsible for triggering more landslides than any other factor (Crozier 1986). Antecedent moisture, geology, soil conditions, land cover, and land use also affect landslides (Kim et al. 1991, Strauch et al. 2014), and areas with projected increases in antecedent soil moisture (coupled with more intense winter storms) will have increased landslide risk. Although the VIC (see chapter 3) model does not directly simulate slope stability failures or landslides, projections of December 1 total column soil moisture from VIC can be used as an indicator of landslide risk. Projections from VIC indicate that December 1 soil moisture will likely be higher as the climate warms, and thus there will be higher landslide risk in winter on unstable land types at higher elevations.

The vulnerability of roads to hydrologic change (see chapter 3) varies based on topography, geology, slope stability, design, location, and use. To assess vulnerability of the transportation system in the Blue Mountains national forests, we identified the traits of the transportation system most sensitive to projected climate changes (box 4.3). This vulnerability assessment of the transportation system can inform transportation management and long-range planning.

Box 4.3—Sensitivities of the transportation system in national forests in the Blue Mountains

- Aging and deteriorating infrastructure increases sensitivity to climate impacts, and existing infrastructure is not necessarily designed for future conditions (e.g., culverts are not designed for larger peak flows).
- Roads and trails built on steep topography are more sensitive to landslides and washouts.
- A substantial portion of the transportation system is at high elevation, which increases exposure to weather extremes and increases the costs of repairs and maintenance.
- Roads built across or adjacent to waterways are sensitive to high stream-flows, stream migration, and sediment movement.
- Funding constraints, insufficient funds, or both limit the ability of agencies to repair damaged infrastructure or take preemptive actions to create a more robust system.
- Design standards or operational objectives that are unsustainable in a new climate regime may increase the frequency of infrastructure failure in the future.

Roads and trails built decades ago have increased sensitivity because of age and declining condition. Many infrastructure components are at or near the end of their design lifespan. Culverts were typically designed to last 25 to 75 years, depending on structure and material. Culverts remaining in place beyond their design life are less resilient to high flows and bed load movement and have a higher likelihood of structural failure. As roads and trails age, their surface and subsurface structure deteriorate and less intense storms can cause more damage than a high-intensity storm would have when the infrastructure was new.

Advanced design of materials, alignment, drainage, and subgrade that are required standards today were generally not available or required when much of the travel network was developed in the Blue Mountains. Consequently, new or replaced infrastructure is likely to have increased resilience to climate change, especially if climate change is considered in the design. New culverts and bridges are often wider than the original structures to meet agency regulations and current design standards. In the past 15 years, many culverts across the Blue Mountains have been replaced to improve fish passage and stream function using open-bottomed arch structures that are less constricted during high flows and accommodate aquatic organism passage at a range of flows. Natural channel design techniques that mimic the natural stream channel condition upstream and downstream of the crossing are being used at these crossings. In addition, culverts on non-fish-bearing streams are being upgraded.

The location of roads and trails can increase vulnerability to climate change. Many roads and trails were built on steep slopes because of the rugged topography of the region, so cut slopes and side-cast material have created landslide hazards. Past timber harvesting and its associated road network in national forests have contributed to the sensitivity of existing infrastructure by increasing storm runoff and peak flows that can affect road crossing structures (Croke and Hairsine 2006, Schmidt et al. 2001, Swanston 1971). Many roads and trails were also constructed in valley bottoms near streams to take advantage of gentle grades, but proximity to streams increases sensitivity to flooding, channel migration, bank erosion, and shifts in alluvial fans and debris cones. Most road-stream crossings used culverts rather than bridges, and culverts are generally more sensitive to increased flood peaks and associated debris. Roads that are currently in the rain-on-snow zone, typically in mid-elevation basins, may be increasingly sensitive to warmer temperatures.

Management of roads and trails (planning, funding, maintenance, and response) affect the sensitivity of the transportation system, and the condition of one road or trail segment can affect the function of connected segments. Major highways within the Blue Mountains, built to higher design standards and maintained more

frequently, will likely be less sensitive to climate change than their unpaved counterparts built to lower design standards in the national forests. Lack of funding can limit options for repairing infrastructure, which can affect the short- and long-term vulnerability of the transportation system. For example, replacing a damaged culvert with an “in-kind” culvert that was undersized for the current streamflow conditions leads to continued sensitivity to both the current flow regime and projected higher flows.

Current and Near-Term Climate Change Effects

Assessing the vulnerability of the transportation network in the Blue Mountains to climate change (boxes 4.3 and 4.4) requires evaluating projected changes in hydrologic processes (box 4.1). The integrity and operation of the transportation network in the Blue Mountains may be affected in several ways. Changes in climate have already altered hydrologic regimes in the Pacific Northwest, resulting in decreased snowpack, higher winter streamflow, earlier spring snowmelt, earlier peak spring streamflow, and lower streamflow in summer (Hamlet et al. 2007, 2010). Ongoing changes in climate and hydrologic response in the short term (in the next 10 years) are likely to be a mix of natural variability combined with ongoing trends related to climate change. High variability of short-term trends is an expected part of the response of the evolving climate system. Natural climatic variability, in the short term, may exacerbate, compensate for, or temporarily reverse expected trends in some hydroclimatic variables. This is particularly true for strong El Niño years (high El Niño Southern Oscillation index) and during warm phases of the Pacific Decadal Oscillation (as well as years with high Pacific Decadal Oscillation index), which may provide a preview of future climatic conditions under climate change.

Higher streamflow in winter (October through March) and higher peak flows, in comparison to historical conditions, increase the risk of flooding and impacts to structures, roads, and trails. Many transportation professionals consider flooding and inundation to be the greatest threat to infrastructure and operations because of the damage that standing and flowing water cause to transportation structures (MacArthur et al. 2012, Walker et al. 2011). Floods also transport logs and sediment that block culverts or are deposited on bridge abutments. Isolated intense storms can overwhelm the vegetation and soil water holding capacity and concentrate high-velocity flows into channels that erode soils and remove vegetation. During floods, roads and trails can become preferential paths for floodwaters, reducing operational function and potentially damaging infrastructure not designed to withstand inundation. If extreme peak flows become more common, they will have a major effect on roads and infrastructure.

Box 4.4—Exposure of access to climate change in the Blue Mountains

Current and short-term exposures (less than 10 years)

- Roads and trails are damaged by floods and inundation because of mismatches between existing designs and current flow regimes.
- Landslides, debris torrents, and sediment and debris movement block access routes and damage infrastructure.
- Traffic is affected by temporary closures to clean and repair damaged roads and trails.
- Frequent repairs and maintenance from damage and disruption incur higher costs and resource demands.

Medium-term exposures (intensifying or emerging in about 10 to 30 years)

- Flood and landslide damage will likely increase in late autumn and early winter, especially in mixed-rain-and-snow watersheds.
- Current drainage capacities may become overwhelmed by additional water and debris.
- Increases in surface material erosion are expected.
- Backlogged repairs and maintenance needs will grow with increasing damage.
- Demand for travel accommodations, such as easily accessible roads and trails, is projected to increase, which could increase travel management costs.
- Increased road damage will challenge emergency response units, making emergency planning more difficult.

Long-term exposures (emerging in 30 to 100 years)

- Fall and winter storms are expected to intensify, greatly increasing flood risk and infrastructure damage and creating a greater need for cool-season repairs.
- Higher streamflows will expand channel migration, potentially beyond recent footprints, causing more bank erosion, debris flows, and wood and sediment transport into streams.
- Changes in hydrologic response may affect visitation patterns by shifting the seasonality of use.
- Shifts in the seasonality of visitation may cause additional challenges to visitor safety, such as increased use in areas and during seasons prone to floods and avalanches.
- Managers will be challenged to provide adequate flexibility to respond to uncertainty in impacts to access.

Short-term exposures to changes in climate may affect safety and access in the Blue Mountains.

In the short term, flooding of roads and trails will likely increase, threatening the structural stability of crossing structures and subgrade material. Roads near perennial and other major streams are especially vulnerable (figs. 4.6 and 4.7), and many of these roads are located in floodplains and are used for recreation access. Increases in high flows and winter soil moisture may also increase the amount of large woody debris delivered to streams, further increasing damage to culverts and bridges, and in some cases making roads impassable or requiring road and facility closures. Unpaved roads with limited drainage structures or minimal maintenance are likely to experience increased surface erosion, requiring additional repairs or grading.

Increasing incidence of more intense precipitation and higher soil moisture in early winter could increase the risk of landslides in some areas. Landslides also contribute to flooding by diverting water, blocking drainage, and filling channels with debris (Chatwin et al. 1994, Crozier 1986, Schuster and Highland 2003). Increased sedimentation from landslides also causes aggradation within streams, thus elevating flood risk. Culverts filled with landslide debris can cause flooding, damage, or complete destruction of roads and trails (Halofsky et al. 2011). Landslides that connect with waterways or converging drainages can transform into more destructive flows (Baum et al. 2007). Roads themselves also increase landslide risk (Swanson and Dyrness 1975, Swanston 1971), especially if they are built on steep slopes and through erosion-prone drainages. In the Western United States, the development of roads increased the rate of debris avalanche erosion by 25 to 340 times the rate found in forested areas without roads (Swanston 1976), and Chatwin et al. (1994) and Montgomery (1994) found that the number of landslides is directly correlated with total kilometers of roads in an area. Consequently, areas with high road or trail density and projected increases in soil moisture that already experience frequent landslides may be most vulnerable to increased landslide risks.

Short-term exposures to changes in climate may affect safety and access in the Blue Mountains. Damaged or closed roads reduce agency capacity to respond to emergencies or provide detour routes during emergencies. Increased flood risk could make conditions more hazardous for river recreation and campers. More wildfires (see chapter 6) could reduce safe operation of some roads and require additional emergency response to protect recreationists and communities (Strauch et al. 2014). Furthermore, damaged and closed roads can reduce agency capacity to respond to wildfires.

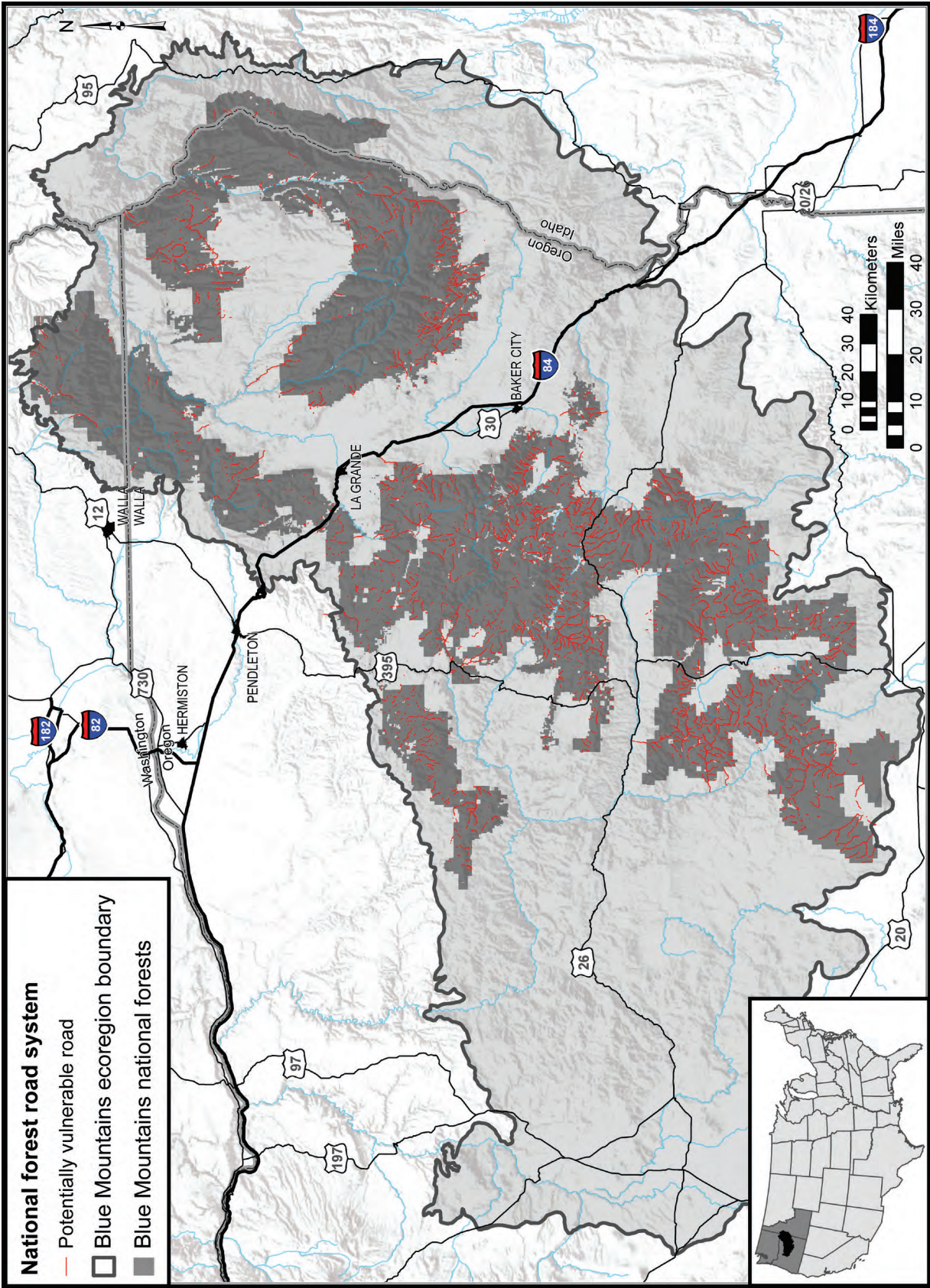


Figure 4.6—National forest roads located within 90 m of major rivers and streams. These roads, which are considered vulnerable to increased flooding, comprise 3300 km in the Blue Mountains (940 km in maintenance level (ML) 1 [basic custodial care; closed], 1915 km in ML2 [high-clearance cars and trucks], 377 km in ML3 [suitable for passenger cars], 21 km in ML4 [passenger cars; moderate comfort], and 98 km in ML5 [passenger cars; high comfort]). Note that not all vulnerable roads are represented; some roads also interrupt smaller intermittent streams and vice versa.

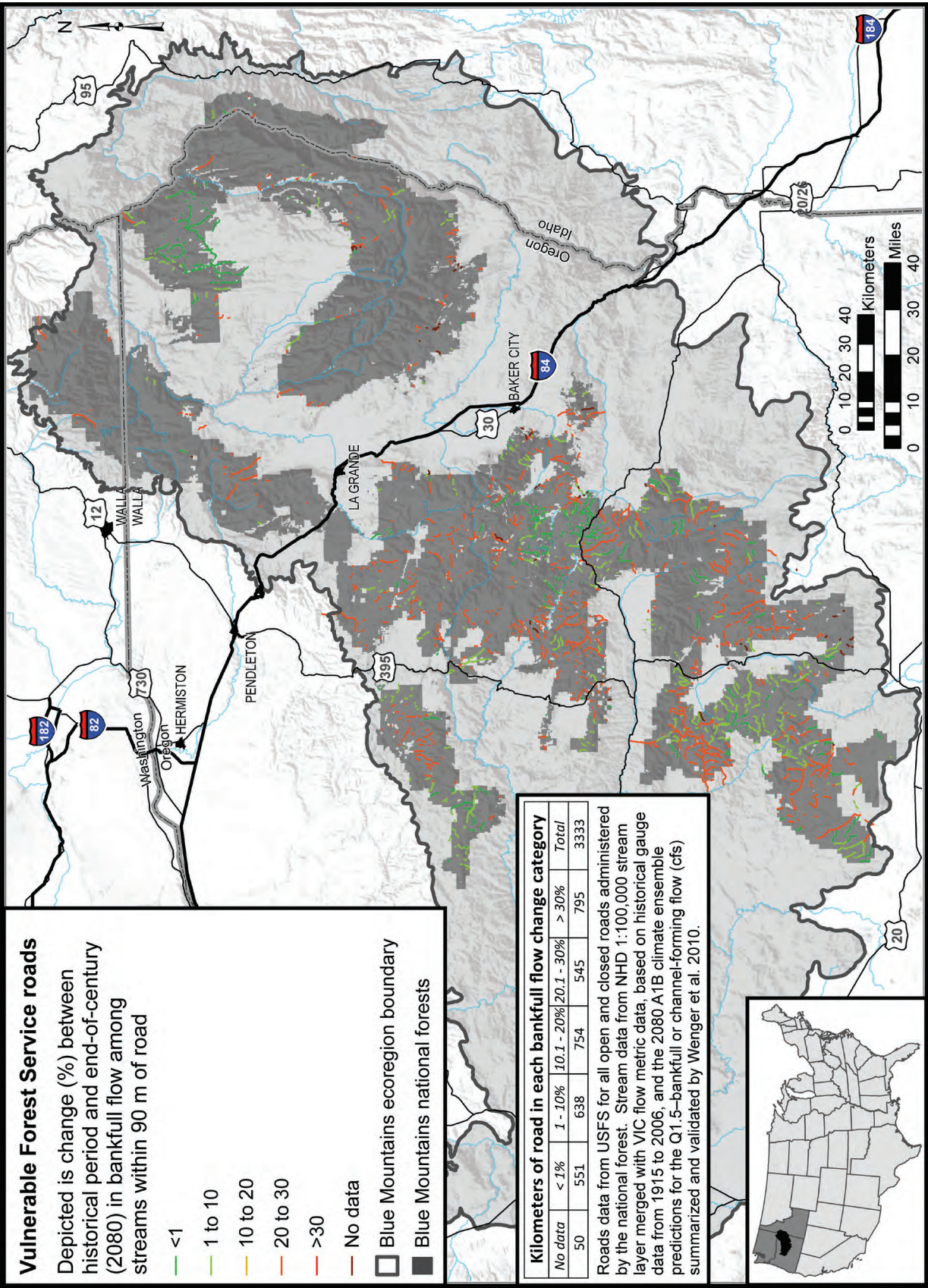


Figure 4.7—Projected percentage change in bankfull flow in 2080 for roads within 90 m of a major river or stream (bankfull flow refers to the flow that just fills the channel to the top of its banks and at a point where the water begins to overflow onto a floodplain). Projections were calculated using flow data from the Variable Infiltration Capacity (VIC) model, based on historical data for 1915–2006 and the Q1.5-bankfull or channel-forming flow simulated for a global climate model ensemble for the A1B emission scenario (from Wenger et al. 2010). Note that not all vulnerable roads are represented; some roads also interrupt smaller intermittent streams and vice versa.

Emerging and Intensifying Exposure in the Medium and Long Term

Many of the observed exposures to climate change in the short term are likely to increase in the medium (10 to 30 years) and long term (greater than 30 years) (box 4.4). In the medium term, natural climatic variability may continue to affect outcomes in any given decade, whereas in the long term, the cumulative effects of climate change may become a dominant factor, particularly for temperature-related effects. Conditions thought to be extreme today may be averages in the future, particularly for temperature-related changes (MacArthur et al. 2012).

Flooding in autumn and early winter is projected to continue to intensify in the medium and long term, particularly in mixed-rain-and-snow basins, but direct-rain-and-snow events may diminish in importance as a cause of flooding (McCabe et al. 2007). At mid to high elevations, more precipitation falling as rain rather than snow will continue to increase winter streamflow. By the 2080s, peak flows are anticipated to increase in magnitude and frequency (fig. 4.8; see chapter 3). In the long term, higher and more frequent peak flows will likely continue to increase sediment and debris transport within waterways. These elevated peak flows could affect stream-crossing structures downstream as well as adjacent structures because of elevated stream channels. Even as crossing structures are replaced with wider and taller structures, shifting channel dynamics caused by changes in flow and sediment may affect lower elevation segments adjacent to crossings, such as bridge approaches.

Projected increases in flooding in autumn and early winter will shift the timing of peak flows and affect the timing of maintenance and repair of roads and trails. More repairs may be necessary during the cool, wet, and dark time of year in response to damage from autumn flooding and landslides, challenging crews to complete necessary repairs before snowfall. If increased demand for repairs cannot be met, access may be restricted until conditions are more suitable for construction and repairs.

In the long term, low streamflows in summer may require increased use of more expensive culverts and bridges designed to balance the management of peak flows with providing low-flow channels in fish-bearing streams. Road design regulations for aquatic habitat will become more difficult to meet as warming temperatures hinder recovery of cold-water fish populations, although some streams may be buffered by inputs from snowmelt or groundwater in the medium term.

Over the long term, higher winter soil moisture may increase the risk of landslides in autumn and winter. Landslide risk may increase more in areas with tree mortality from fire and insect outbreaks, because tree mortality reduces soil root

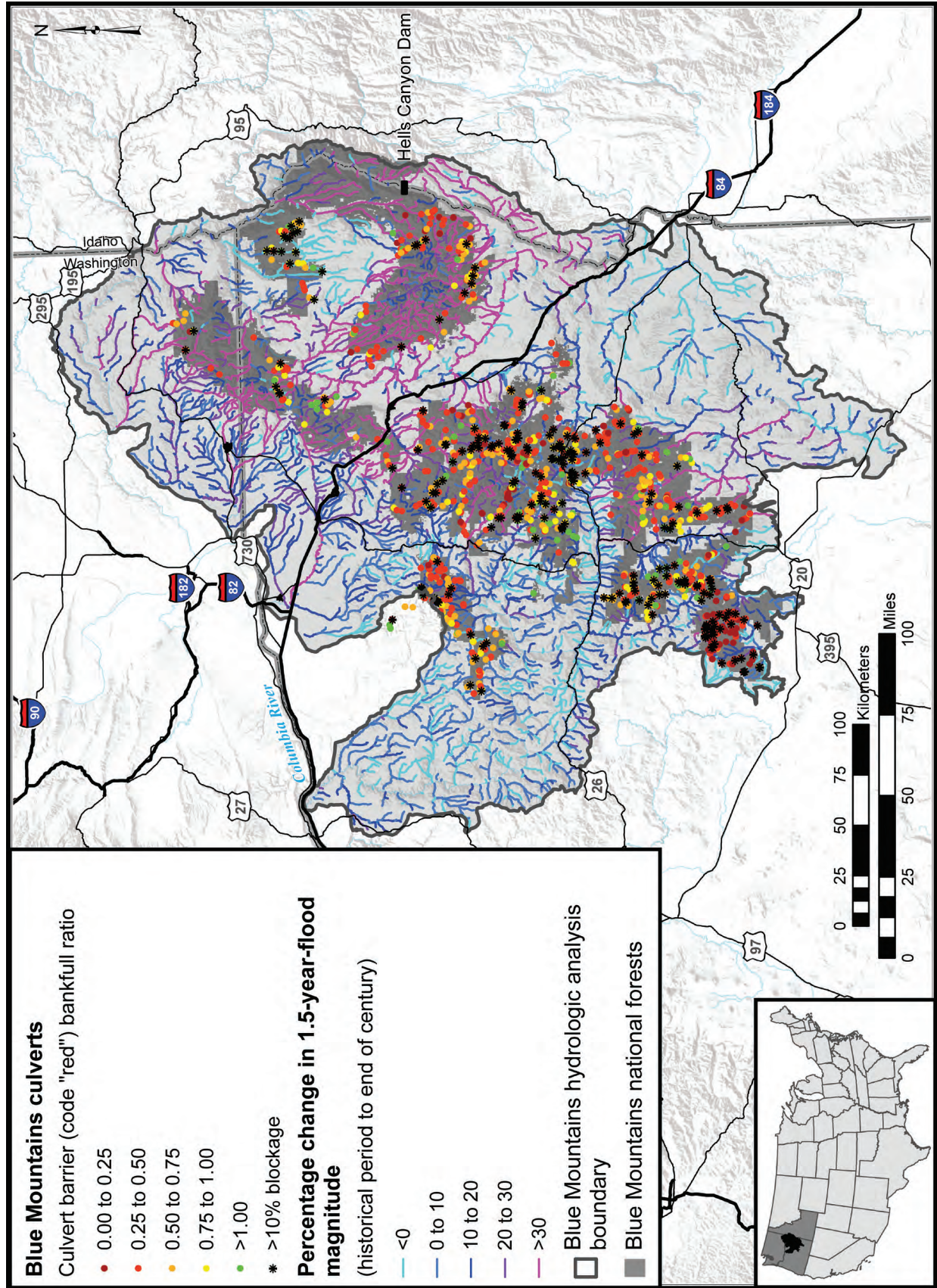


Figure 4.8—Projected percentage change in Q1.5-bankfull flow in 2080, with culvert barriers indicated based on the ratio of culvert width to bankfull width. Projections were calculated using flow data from the Variable Infiltration Capacity model, based on historical data for 1915–2006 and the Q1.5-bankfull, or channel-forming flow, simulated for a global climate model ensemble under the A1B emission scenario (from Wenger et al. 2010).

cohesion and decreases interception and evaporation, further increasing soil moisture (Martin 2006, Montgomery et al. 2000, Neary et al. 2005, Schmidt et al. 2001). Thus, soils will likely become more saturated and vulnerable to slippage on steep slopes during the wet season. Although floods and landslides will continue to occur near known hazard areas (e.g., because of high forest road density), they may also occur in new areas (e.g., those areas currently covered by deep snowpack in mid-winter) (MacArthur et al. 2012). Thus, more landslides at increasingly higher elevations (with sufficient soil) may be a long-term effect of climate change. Coinciding exposures in space and time may be particularly detrimental to access.

Climate change effects on access may create public safety concerns for national forests. A longer snow-free season may extend visitor use in early spring and late autumn at higher elevations (Rice et al. 2012). Lower snowpack may lead to fewer snow-related road closures for a longer portion of the year, allowing visitors to reach trails and campsites earlier in the season. However, warmer temperatures and earlier snowmelt may encourage use of trails and roads before they are cleared. Trailheads, which are located at lower elevations, may be snow-free earlier, but hazards associated with melting snow bridges, avalanche chutes, or frozen snowfields in shaded areas may persist at higher elevations along trails. Relatively rapid warming at the end of the 20th century coincided with greater variability in cool season precipitation and increased flooding (Hamlet and Lettenmaier 2007). If this pattern continues, early-season visitors may be exposed to more extreme weather than they have encountered historically, creating potential risks to visitors. In summer, whitewater rafters may encounter unfavorable conditions from lower streamflows in late summer (Mickelson 2009) and hazards associated with deposited sediment and woody debris from higher winter flows. Warmer winters may shift river recreation to times of year when risks of extreme weather and flooding are higher. These activities may also increase use of unpaved roads in the wet season, which can increase damage and associated maintenance costs.

Climate change may also benefit access and transportation operations in the Blue Mountains over the long term. Lower snow cover will reduce the need for and cost of snow removal, and earlier snow-free dates projected for the 2040s suggest that low- and mid-elevation areas will be accessible earlier. Earlier access to roads and trails will create opportunities for earlier seasonal maintenance and recreation. Temporary trail bridges installed across rivers may be installed earlier in spring as spring flows decline. A longer snow-free season and warmer temperatures may allow for a longer construction season at higher elevations. Less snow may increase access for summer recreation, but it may reduce opportunities for winter recreation particularly at low and moderate elevations (Joyce et al. 2001, Morris and

More landslides at increasingly higher elevations (with sufficient soil) may be a long-term effect of climate change.

Walls 2009). The highest elevations of the Blue Mountains may retain relatively more snow than other areas, which may create higher localized demand for winter recreation and river rafting in summer over the next several decades.

Adapting Management of Water Use and Roads in a Changing Climate

Through a workshop and subsequent dialogue, scientists and resource managers worked collaboratively to identify adaptation options that can reduce the adverse effects of climatic variability and change on water use and roads in the Blue Mountains. The workshop included an overview of adaptation principles (Peterson et al. 2011) and regional examples of agency efforts to adapt to climate change. Options for adapting hydrologic systems, transportation systems, and access management were identified, as well as potential barriers, opportunities, and information needs for implementing adaptation.

Adaptation Options for Water Use

Climate change adaptation options for water use on national forests must be considered within the broader context of multiownership watersheds, where most of the traditional consumptive uses occur off the forest but the forests are relied on for a majority of the supply. Many of the resource sensitivities addressed here already exist to some extent, but are expected to intensify as the climate warms. Adaptation options focusing on national forests were developed after consideration of the collective effects of several climate-related stressors: lower summer streamflow, higher winter peak streamflow, earlier peak streamflow, lower groundwater recharge, and higher demand and competition for water by municipalities and agriculture (table 4.2). The following adaptation strategies were developed to address these stressors: (1) restore function of watersheds, (2) connect floodplains, (3) support groundwater-dependent ecosystems, (4) reduce drainage efficiency, (5) maximize valley storage, and (6) reduce fire hazard (table 4.2). The objective of most of these adaptation strategies is to retain water for a longer period of time at higher elevations and in riparian systems and groundwater of mountain landscapes. These strategies will likely help maintain water supplies to meet demands, especially during the summer, and reduce loss of water during times when withdrawals are low. This diversity of adaptation strategies requires an equally diverse portfolio of adaptation tactics that address different biophysical components of hydrologic systems and timing of uses, among other considerations (table 4.2).

The adaptation tactic of using a “climate change lens” when developing plans and projects provides an overarching context for managing and conserving water

Table 4.2—Adaptation options that address climate change effects on water use in the Blue Mountains

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
Sensitivity to climatic variability and change: lower summer flows, higher winter peak flows, earlier peak flows, lower groundwater recharge, higher demand and competition for water by municipalities and agriculture.				
Adaptation strategy: Restore function of watersheds, connect floodplains, support groundwater-dependent ecosystems, reduce drainage efficiency, maximize valley storage, reduce fire hazard.				
• Add wood to streams and increase beaver populations		Collaboration with other agencies	Concerns about effects of beavers on private property	Identification of priority areas
• Use a “climate change lens” during project analysis		Use the Climate Project Screening Tool for analysis of projects		
• Improve livestock management to reduce water use (e.g., shutoff valve on stock ponds)	Some <10 years, some >30 years	Collaboration with range managers	Minimal technology available for operations	Improved technology to reduce water use
• Reduce surface fuels and stand densities in low-elevation forest	<10 years, ongoing	Collaboration with fire managers	Opposition to active management, prescribed burning	
• Restore meadows	Ongoing		Interactions with roads Elk herbivory	Inventory and classification of meadows
Adaptation strategy: Address demands for water (including water rights); improve water conservation.				
• Conduct integrated assessment of water and local effects of climate change	Ongoing, opportunistic	Case by case	Concerns about property rights High existing workload	Updated water resource use assessments at priority sites
• Implement vegetation treatments in high water-retention areas (e.g., snow retention)	Ongoing	Enabled by national forest land management plan	Lack of funding for long-term collection of gage data	Centralized source of data and metadata on water resources
• Improve efficiency of drainage and ditches	10 to 30 years			
• Encourage communication and full disclosure of information	Ongoing	Existing management plans		Identification of key messages
• Conduct vulnerability assessments by community	10 to 30 years	Communication between line officers and local communities Source water assessments in some cases		
• Treat roads where needed to retain water and maintain high water quality	<10 years	Collaboration with road engineers	Lack of support for treatments	Development of effective road treatments

supply (tables 4.1 and 4.2). Including climate change in decisionmaking generally reinforces practices that support sustainable resource management. Potential risk and uncertainty can be included in this process by considering a range of climate projections (based on different models and emission scenarios) (see chapter 3) to frame decisions about appropriate responses to climate change. In addition, user awareness of vulnerability to shortages, reducing demand through education and negotiation, and collaboration among users can support adaptation efforts.

Many adaptation tactics to protect water supply are current standard practices, or “best management practices (BMP),” for water quality protection. In 2012, the Forest Service implemented a national BMP program to improve management of water quality consistently with the Federal Clean Water Act and state water quality programs (USDA FS 2012; <http://www.fs.fed.us/biology/watershed/BMP.html>). The BMPs are specific practices or actions used to reduce or control impacts to water bodies from nonpoint sources of pollution, most commonly by reducing the loading of pollutants from such sources into storm water and waterways. The BMPs are required on all activities with potential to affect water quality, including road management and water developments. A related tactic is improving roads and drainage systems to maintain high-quality water as long as possible within hydrologic systems in national forests. Although these tactics may be expensive, they significantly affect water retention and erosion control. Actions are typically needed at specific locations at key times even under normal conditions, and climate change will likely force more frequent maintenance and repair.

Several adaptation tactics related to biological components of mountain landscapes can reduce the effects of climate change on water resources. Reducing stand density and surface fuels in low-elevation coniferous forest reduces the likelihood of fires that severely affect soils, accelerate erosion, and degrade water quality in streams. Vegetation treatments in high-snow areas may enhance snow retention and soil moisture, and may extend water yield into the summer, at the catchment scale, for a few years following treatment.

Similarly, restoration techniques that maintain or modify biophysical properties of hydrological systems to be within their presettlement historical range of variability can increase climate change resilience. Stream restoration techniques that improve floodplain hydrologic connectivity increase water storage capacity. Meadow and wetland restoration techniques that remove encroaching conifers can improve hydrologic function and water storage capacity. Adding wood to streams improves channel stability and complexity, slows water movement, improves aquatic habitat, and increases resilience to both low and high flows. Similarly,

increasing American beaver (*Castor canadensis* Kuhl) populations will create more ponds, swamps, and low-velocity channels that retain water throughout the year.

Lower soil moisture and low flows in late summer, combined with increasing demand for water, will likely reduce water availability for aquatic resources, recreation, and other uses. However, water conservation measures within national forests can potentially reduce water use. For example, resource managers can work with permittees to implement livestock management practices that use less water (e.g., install shutoff valves on stock water troughs). Over the long term, increasing water conservation and reducing user expectations of water availability (e.g., through education) are inexpensive and complementary adaptation tactics for maintaining adequate water supply.

At a broader level, it will be valuable to engage in and contribute to integrated assessments, such as the Oregon Integrated Water Resource Strategy, for water supply and availability and local effects of climate change. Vulnerability assessments for individual communities will provide better information on where and when water shortages may occur, leading to adaptation tactics customized for each location. Because discussions of water use and water rights are often contentious, it will be important to help foster open dialogue and full disclosure of data and regulatory requirements so that proactive, realistic, and fair management options can be developed.

Adaptation Options for Roads and Infrastructure

Climate change adaptation options for roads and infrastructure were developed after consideration of the collective effects of several climate-related stressors: sensitivity of road design and maintenance to increasing flood risk, effects of higher peak streamflows on road damage at stream crossings, and safety hazards associated with an increase in extreme disturbance events (table 4.3, box 4.2).

The following adaptation strategies were developed to address these stressors: (1) increase resilience of stream crossings, culverts, and bridges to higher streamflow; and (2) increase the resilience of the road system to higher streamflows and associated damage by stormproofing and reducing the road system.

The Forest Service travel analysis process (USDA FS 2005) and BMPs provide an overarching framework for identifying and maintaining a sustainable transportation system in national forests in the Blue Mountains, and climate change provides a new context for evaluating current practices (Raymond et al. 2014, Strauch et al. 2014). Incorporating climate change in the travel-analysis process, which is already addressing some vulnerabilities by decommissioning and stormproofing roads,

Vulnerability assessments for individual communities will provide better information on where and when water shortages may occur.

Table 4.3—Adaptation options that address climate change effects on roads and infrastructure in the Blue Mountains

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
Sensitivity to climatic variability and change: Road design and maintenance are sensitive to increasing flood risk; higher peak flows lead to increased road damage at stream crossings (because of insufficient culvert capacity, more culvert blockage, and low bridges); safety is compromised by more extreme events (e.g., landslides and debris flows).				
Adaptation strategy: Increase resilience of stream crossings, culverts, and bridges to higher peak flows.				
• Replace culverts with higher capacity culverts or other appropriate drainage (e.g., fords or dips) in high-risk locations	<10 years, opportunistic	Structure failures, especially at fish crossings	Funding	Database of projects and upgrades
			Current backlog of deferred maintenance and upgrades	Safety priorities
			Historical use patterns	Campground analysis
• Complete geospatial database of culverts and bridges	<10 years, opportunistic	Recording of geospatial locations as projects are completed	Funding	Database of projects and upgrades
			Incomplete culvert survey information	
Adaptation strategy: Facilitate response to higher peak flows by reducing the road system and thus flooding of roads and stream crossings; disconnect roads from streams.				
• Continue to decommission roads with high risk and low access	Opportunistic, >30 years	Partnerships and collaboration with other agencies that are also disconnecting roads from waterways	High cost of decommissioning roads	Implementation of Geomorphic Road Analysis and Inventory Package for decisionmaking
• Convert use to other transportation modes (e.g., from vehicle to bicycle or foot)	Opportunistic, >30 years	Transportation planning, travel management plans, land and resource management plans	High cost of decommissioning roads	
• Invoke Travel Analysis Process to prioritize road management	<10 to 30 years	Travel Analysis Process and Minimum Roads Analysis are underway		
• Use drains, gravel, and outslowing of roads to disperse surface water	Ongoing, 10 to 30 years	National forest land management plan	High cost of road management Priorities unclear in some cases	Implementation of Geomorphic Road Analysis and Inventory Package for decisionmaking

culverts, and bridges, will enhance resilience to higher streamflows. Improving and updating geospatial databases of roads, culverts, and bridges will provide a foundation for continuous evaluation and maintenance. If vulnerable watersheds, roads, and infrastructure can be identified, then proactive management (e.g., use of drains, gravel, and outsloping of roads to disperse surface water) can be implemented to reduce potential damage and high repair costs.

National forests in the Blue Mountains have a large backlog of culverts and road segments in need of repair, replacement, or upgrade, even under current hydrologic regimes. Limited funding and staff hinder current efforts to upgrade the system to current standards and policies, so the additional cost of upgrades to accommodate future hydrological regimes could be a barrier to adaptation. However, extreme floods that damage roads and culverts can be opportunities to replace existing structures with ones that are more resilient to higher peak flows. These replacements, called “betterments,” can be difficult to fund under current Federal Highway Administration Emergency Relief for Federally Owned Roads program eligibility requirements when used to fix damage from extreme events, because the current policy is to replace in kind. In some cases, matching funds can be raised or betterments can be funded with sufficient justification and documentation of the environmental impacts. Justification for betterments based on the latest climate change science would facilitate this approach.

Increasing resilience to higher peak flows will not be possible for all road segments because of limited funding for maintenance. Adapting road management to climate change in the long term may require further reductions in the road system. Road segments that are candidates for decommissioning are typically those with low demand for access, high risks to aquatic habitat, a history of frequent failures, or combinations of the three. National forest road managers also consider use of roads for fire management (fire suppression, prescribed fire, and hazardous fuel treatments).

Engineers may consider emphasizing roads for decommissioning that are in basins with higher risk of increased flooding and peak flows, in floodplains of large rivers, or on adjacent low terraces. Information on locations in the transportation system that currently experience frequent flood damage (Strauch et al. 2014) can be combined with spatially explicit data on projected changes in flood risk and current infrastructure condition to provide indicators of where damage is most likely to continue and escalate with changes in climate (e.g., figs. 4.7 and 4.8). Optimization approaches (e.g., linear programming) can be used to compare the tradeoffs associated with competing objectives and constraints while minimizing the overall costs of the road system.

In the long term, protecting infrastructure in place will be more difficult as flood risk continues to increase.

Reducing the road system in national forests presents both barriers and opportunities (table 4.3). Decommissioning roads or converting roads to trails is expensive and must be done properly to reduce adverse effects on water quality and aquatic habitat. Furthermore, reductions to the road system are often met with opposition from the public accustomed to using roads for recreational access, but public involvement in road decisions can also be an opportunity to increase awareness and develop “win-win” adaptation options. Thus, one adaptation tactic is to adjust visitation patterns and visitor expectations by actively involving the public in road decisions related to climate change. This has the added benefit of raising political support and possibly funding from external sources to help maintain access. Partnerships with recreation user groups will be increasingly important for raising public awareness of climate change threats to access and for identifying successful adaptation options.

Increased risk of flooding in some basins may require modification to current management of facilities and historical and cultural resources. In most cases, the high cost of relocating buildings and inability to move historical sites from floodplains will require that adaptation options focus on resistance through prevention of flood damage. Stabilizing banks reduces risk to infrastructure, and using bioengineering rather than riprap or other inflexible materials may have less environmental impact. In the long term, protecting infrastructure in place will be more difficult as flood risk continues to increase. Long-term adaptation strategies may require removing (or not rebuilding) infrastructure in the floodplain to allow river channels to migrate and accommodate the changing hydrologic regime. National forest land and resource management plans, which have relatively long planning horizons, are opportunities to implement these long-term adaptation tactics for management of facilities and infrastructure.

More frequent failures in the road and trail system may increase risks to public safety. Limited resources and staff make it difficult for national forests to quickly repair damage, yet the public often expects continuous access. In response to climate change, managers may consider implementing and enforcing more restrictions on access to areas where trails and roads are damaged and safe access is uncertain. Greater control of seasonal use, combined with better information about current conditions, especially during early spring and late autumn, before and after active maintenance, will ensure better public safety. Partnerships with recreation user groups may generate opportunities to convey this message to a larger audience, thus enhancing public awareness of hazards and the safety of recreation users.

Managers may consider adapting recreation management to changes in visitor use patterns in early spring and late autumn in response to reduced snowpack and warmer temperatures. An expanded visitor season would increase the cost of operating facilities (e.g., campgrounds), but revenue from user fees may also increase. Land management plans and transportation planning provide opportunities to address anticipated changes in the amount and timing of visitation. Limitations on staff because of funding or other constraints may also present obstacles to an expanded visitor season. Adaptive management can be used to monitor changes in the timing, location, and number of visitors, thus providing data on where management can be modified in response to altered visitor patterns.

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