Chapter 7: Climate Change and Special Habitats in the Blue Mountains: Riparian Areas, Wetlands, and Groundwater-Dependent Ecosystems

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Introduction

In the Blue Mountains, climate change is likely to have significant, long-term implications for freshwater resources, including riparian areas, wetlands (box 7.1), and groundwater-dependent ecosystems (GDEs, box 7.2). Climate change is expected to cause a transition from snow to rain, resulting in diminished snowpack and shifts in streamflow to earlier in the season (Leibowitz et al. 2014, Luce et al. 2012; see chapter 3). Additional effects include changes in extreme high- and low-flow events; alteration of groundwater recharge rates; changes in the fate and transport of nutrients; sediments, and contaminants, and temporal and spatial shifts in critical ecosystem processes and functions (Johnson et al. 2012, Raymondi et al. 2013). Another consequence of climate change is higher frequency and severity of droughts (Seager et al. 2007), which will influence distribution of plant species, and likely increase susceptibility to insect attacks, as well as increase the frequency and severity of wildfires (see chapter 6).

In this chapter, we synthesize existing information and describe the potential effects of climate change on riparian areas, wetlands, and groundwater-dependent GDEs of the Malheur, Umatilla, and Wallowa-Whitman National Forests. We begin by defining riparian areas, wetlands, and GDEs, highlighting the considerable overlap among these ecosystems, as well as the numerous definitions for them. We briefly describe the range of plant communities that occur in these special habitats, partly to highlight the existing diversity of wetland/riparian vegetation, but also as a basis for discussing the potential influences of climate change. Much of this chapter is devoted to summarizing existing information on the current condition of special habitats in the Blue Mountains, with focus on wetland/riparian plant communities. Although we describe potential changes for different riparian/wetland vegetation groups, we also emphasize that there is considerable uncertainty about the rates

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Box 7.1—Climate change effects on riparian areas and wetlands in the Blue Mountains

Broad-scale climate change effects

- Higher air temperature
- Higher frequency and severity of droughts
- Decreased snowpack
- Increased rain-snow ratio
- Altered streamflow

Habitat and species

- Cottonwood-dominated riparian communities
- Wetland and riparian aspen communities
- Willow-dominated riparian communities
- Herbaceous-dominated riparian and wetland communities

Current condition, existing stressors

Cottonwood, aspen, and willow—
Condition:

- Decreased area owing to conversion and development of floodplains
- Degradation of stands owing to altered flow regimes (dams, diversions) and changes in hydrology owing to floodplain land use

Stressors:

- Structural simplification of channels (e.g., levee construction), roads, livestock and native ungulate browsing
- Intentional clearing/removal of native riparian woody species, e.g., to increase herbaceous forage or pasture area for livestock grazing

Herbaceous—
Condition:

- High cover and frequency of nonnative pasture grasses
- High cover of grazing-tolerant native species

Stressors:

- Heavy herbivory from livestock and native ungulates
- Increasing cover of invasive or noxious plant species
- Planting or seeding of nonnative pasture grasses

Box 7.1 (continued)

Sensitivity to climatic variability and change

Cottonwood, willow, and aspen—

- Decreased establishment of willow and cottonwood
- Displacement of wetland/riparian plant species with upland species
- Decreased riparian cover
- Decreased plant growth and increased mortality

Herbaceous—

- Further decreases in native species cover and richness
- Shift in community composition
- Increased success of nonnatives
- Loss of sensitive species

Expected effects of climate change

Cottonwood, willow, and aspen—

- Increased high flows in winter
- Decreased low flows in summer
- Increased demand for water (additional diversions, reservoir expansions)
- Increased browsing pressure

Herbaceous—

- Decreased low flows in summer
- Increased demand for water
- Increased demand for forage and grazing

Adaptive capacity

Cottonwood, willow, and aspen—

- Cottonwood and willow populations have evolved within the range of regional streamflow variability. They are highly dependent on natural flow characteristics for seed germination, seedling establishment, and stand persistence. They have limited adaptive capacity where flow regimes have been altered.
- Aspen and most willow species have high vegetative regenerative capacity following disturbance (fires, floods), which contributes to adaptive capacity. However, the ability to persist depends on site conditions, particularly soil moisture and depth to water table.

Box 7.1 (continued)

Herbaceous—

- Native, herbaceous wetland species have high soil moisture requirements. When water table elevations decline and soil moisture conditions become more limiting, these species are no longer competitive against more drought-tolerant species, and have limited adaptive capacity.
- Common, dominant native species (e.g., *Carex aquatilis*) can occur over a fairly wide range of soil moisture conditions, as well as grazing pressure and have some adaptive capacity. Less is known about the adaptive capacity of many native wetland sedge and forb species, but most occur within narrow ranges of soil saturation/soil moisture conditions. Where these conditions are not met, sensitive and uncommon herbaceous species will not persist.

Vulnerable geographic locations

Cottonwood, willow, and aspen—

- Cottonwood gallery forests along low-gradient river segments are extremely vulnerable, particularly in floodplains with flow diversions or groundwater pumping. More isolated stands along higher gradient stream segments are less vulnerable, but still require components of the natural flow regime for long-term persistence.
- Most willow stands at lower elevations along low-gradient stream segments have been affected by floodplain land use and are highly vulnerable. At higher elevations and along smaller streams, willow stands may be less vulnerable. However, willow stands may be comprised of two to eight species, and the requirements for establishment, growth, and persistence are largely unknown for some species. Willow stands may persist, but some species may not survive locally.
- Riparian aspen stands along low-gradient river segments are extremely vulnerable, particularly in floodplains with flow diversions or groundwater pumping. Some isolated aspen stands in uplands environments may be largely dependent on groundwater, so vulnerability depends on underlying lithology.

Herbaceous—

- The most vulnerable herbaceous communities are those that have already been extensively affected by grazing and other land and water uses.
- Alpine and subalpine herbaceous communities are highly vulnerable owing to decreases in amount and persistence of snow.
- Herbaceous communities at mid elevations will experience shifts in community composition, with increased cover of nonnatives and loss of uncommon or sensitive species, but will likely persist.

Box 7.1 (continued)

Risk assessment

Potential magnitude of climate change effects

- Cottonwood-dominated riparian communities: high magnitude of effects along major rivers, given that cottonwood forests are currently affected and declining in many locations.
- Willow-dominated riparian communities: moderate-high magnitude of effects for some species and communities. Highest risks are for communities located along stream segments already affected by grazing and flow alteration.
- Wetland and riparian aspen communities: high magnitude of effects, because many aspen populations are known to be declining.
- Herbaceous-dominated riparian and wetland communities: moderate magnitude of effects for communities; high magnitude of effects for rare and sensitive species that will not be competitive in drier environments.

Likelihood of climate change effects

- Cottonwood-dominated riparian communities: high likelihood of effects for cottonwood communities located along larger floodplains.
- Wetland and riparian aspen communities: high likelihood of effects given current (declining) condition.
- Willow-dominated riparian communities: high likelihood of effects given predictions of changes in streamflow, increases in air temperature and higher frequency and severity of droughts, increased human demands for water.
- Herbaceous-dominated riparian and wetland communities: moderate likelihood of effects given predictions of changes in streamflow and higher frequency and severity of droughts, increased human demands for water and other resource use.

Box 7.2—Summary of climate change effects on groundwater-dependent ecosystems (GDEs) in the Blue Mountains

Broad-scale climate change effects

- Higher air temperature
- Higher frequency and severity of droughts
- Higher groundwater temperature
- Decreased snowpack, especially at lower elevations
- Possible changes in groundwater recharge quantity and levels

Habitat and systems

- Springs and associated wetlands and fens, hyporheic zones, groundwater contribution to streamflow (baseflow)

Current condition, existing stressors

Current condition:

- Numerous springs developed for watering livestock
- GDEs used by livestock, and native ungulates (source of water and forage)

Stressors:

- Continued water development
- Grazing, browsing, and trampling by livestock and native ungulates

Sensitivity to climatic variability and change

- GDEs (springs, wetlands) and stream baseflows are supported by groundwater recharge from rain and annual snowpack, especially in more permeable lithologies
- GDEs may contract in size or dry out in summer
- Increased air and water temperatures and drought will stress moisture-dependent flora and fauna
- Small aquifer systems are generally more vulnerable than larger systems
- Groundwater resources may be less sensitive to climate change than surface water, depending on local and regional geology, and surrounding land and water use

Box 7.2 (continued)

Expected effects of climate change

- Reduced groundwater discharge to GDEs
- Reduced areas of saturated soil
- Perennial springs may become ephemeral
- Ephemeral springs may disappear, except during high-snow years
- For springs discharging to streams, local cooling influence on stream temperature may be reduced
- Increased stress from effects of grazing
- Shifts in aquatic flora and fauna communities
- Higher groundwater temperatures
- "Gaining" reaches of streams may contribute less or become "losing" reaches

Adaptive capacity

- Because GDEs and the biota they support depend on continued availability and volume of groundwater, they have limited adaptive capacity.
- Current information about the role of groundwater on water budgets at different scales is very limited for wildland watersheds. Although ongoing research may reveal adaptive capacity in some locations, current information suggests that groundwater resources are declining.

Vulnerable geographic locations

- Vulnerability largely depends on elevation and underlying lithology, which influence the storage and movement of groundwater.
- GDEs located at higher elevations are likely the most vulnerable, given predicted changes in snowpack volume and persistence. As snowpacks decrease, less water will infiltrate into subsurface aquifers, and the amount of groundwater discharge will decrease. High-elevation springs and other GDEs may be the first to become ephemeral, dry out, and eventually disappear.
- GDEs located at mid elevations may be the least vulnerable, depending on underlying geology and water demands. GDEs may persist in lithologies that support large aquifer systems.
- GDEs located at lower elevations, including many rheocrene springs or springbrooks, are extremely vulnerable to increasing water demands, pressure for increased diversion or water development, and other watershed-scale land use effects.

Box 7.1 (continued)

Risk assessment

Potential magnitude of climate change effects

- High magnitude of effects for GDEs, especially those located at higher elevations or occurring where underlying geology only supports small shallow aquifer systems.

Likelihood of climate change effects

- Moderate likelihood of some GDEs disappearing by 2050, but groundwater research and modeling are needed to identify most vulnerable aquifers and GDEs.

and direction of change, which depend on the physical watershed and stream channel conditions, past and present land use, and the reliability of climate-change predictions for a given area.

Definitions

Riparian Areas

Riparian areas have been ecologically defined as “three-dimensional zones of direct physical and biotic interactions between terrestrial and aquatic ecosystems, with boundaries extending outward to the limits of flooding and upward into the canopy of streamside vegetation” (Gregory et al. 1991). The first dimension of riparian areas is the longitudinal continuum from headwaters to the mouths of streams and rivers and ultimately the oceans (Vannote et al. 1980). The second is the vertical dimension that extends upward into the vegetation canopy and downward into the subsurface and includes hyporheic and belowground interactions for the length of the stream-riparian corridor (Stanford and Ward 1988, 1993). The third dimension is lateral, extending to the limits of flooding on either side of the stream or river (Stanford and Ward 1993). The dynamic spatial and temporal extent of each of these three dimensions depends on the watershed hydrologic regime, location within the stream network of the watershed (elevation, connectivity), and watershed physical characteristics and geomorphic processes, which in turn influence floodplain water availability and the distribution of different riparian communities. These physical characteristics and processes largely regulate the structure and function of riparian ecosystems (Gregory et al. 1991, Naiman and Décamps 1997, Naiman et al. 2005).

In the Blue Mountains, riparian ecosystems occur along low-gradient, U- and trough-shaped glacial valleys in alpine, high-elevation sites; along steep-gradient, low-order headwater streams; along montane channels flowing through segments of varying valley width; and along low-gradient, alluvial rivers in the wider reaches of the Grande Ronde and the John Day Rivers and their tributaries (Crowe and Clausnitzer 1997, Johnson 2004, Wells 2006). The diversity of stream sizes, landforms, valley widths and gradients, and hydrologic regimes determine the types of biotic communities that occur along streams in a given region; each of these communities could have distinct responses to changing climate.

To assist in managing riparian areas, numerous administrative definitions and various terms have been developed (USDA FS 2012c). In the Blue Mountains, riparian areas, wetlands, and intermittent streams are included within Riparian Habitat Conservation Areas (RHCAs), which specify minimum buffers from each side of the channel or stream edge: intermittent streams (15 m), wetlands and non-fish-bearing perennial streams (46 m), and fish-bearing streams (91 m). Active management within these buffers must comply with a number of riparian management objectives designed to improve habitat conditions for fish species that have been federally listed as threatened or endangered under the Endangered Species Act (USDA FS 1995). Along many stream segments, the dimensions of the riparian buffers differ from the ecologically defined riparian area described above.

Wetlands can be extremely diverse, exhibiting a wide range of vegetation, soil, and hydrologic characteristics.

Wetlands

Numerous definitions for wetlands have been developed for a range of administrative, academic, and regulatory delineation purposes (National Research Council 1995). For all federal regulatory activities, wetlands are ecosystems "that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (Federal Interagency Committee for Wetland Delineation 1989). Wetlands can be extremely diverse, exhibiting a wide range of vegetation, soil, and hydrologic characteristics (Cowardin et al. 1979, National Research Council 1995). However, all definitions emphasize hydrologic variables, particularly duration, seasonality, and depth of inundation and soil saturation, that result in distinctive hydric soils and wetland vegetation.

For the Blue Mountains, the Oregon Wetlands Geodatabase provides a summary map of wetlands (figs. 7.1 through 7.3), color-coded by wetland type, as classified by the U.S. Fish and Wildlife Service (http://oregonexplorer.info/wetlands/DataCollections/GeospatialData_Wetlands) (Cowardin et al. 1979). The maps were compiled from existing National Wetlands Inventory data and many additional sources, including local surveys and academic studies. Three broad categories of

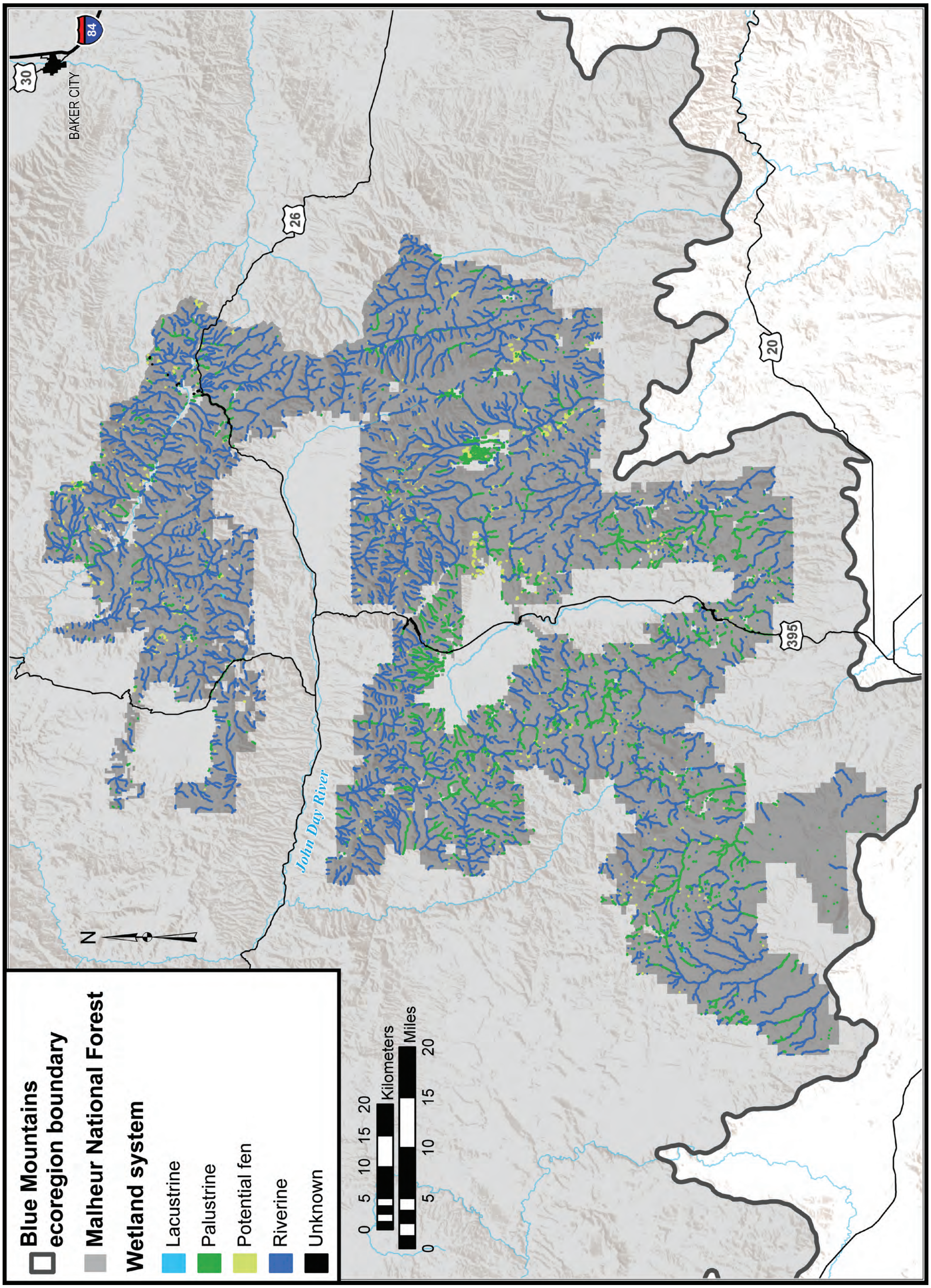

Figure 7.1—Wetlands in Malheur National Forest. Source: Oregon Wetlands Geodatabase.

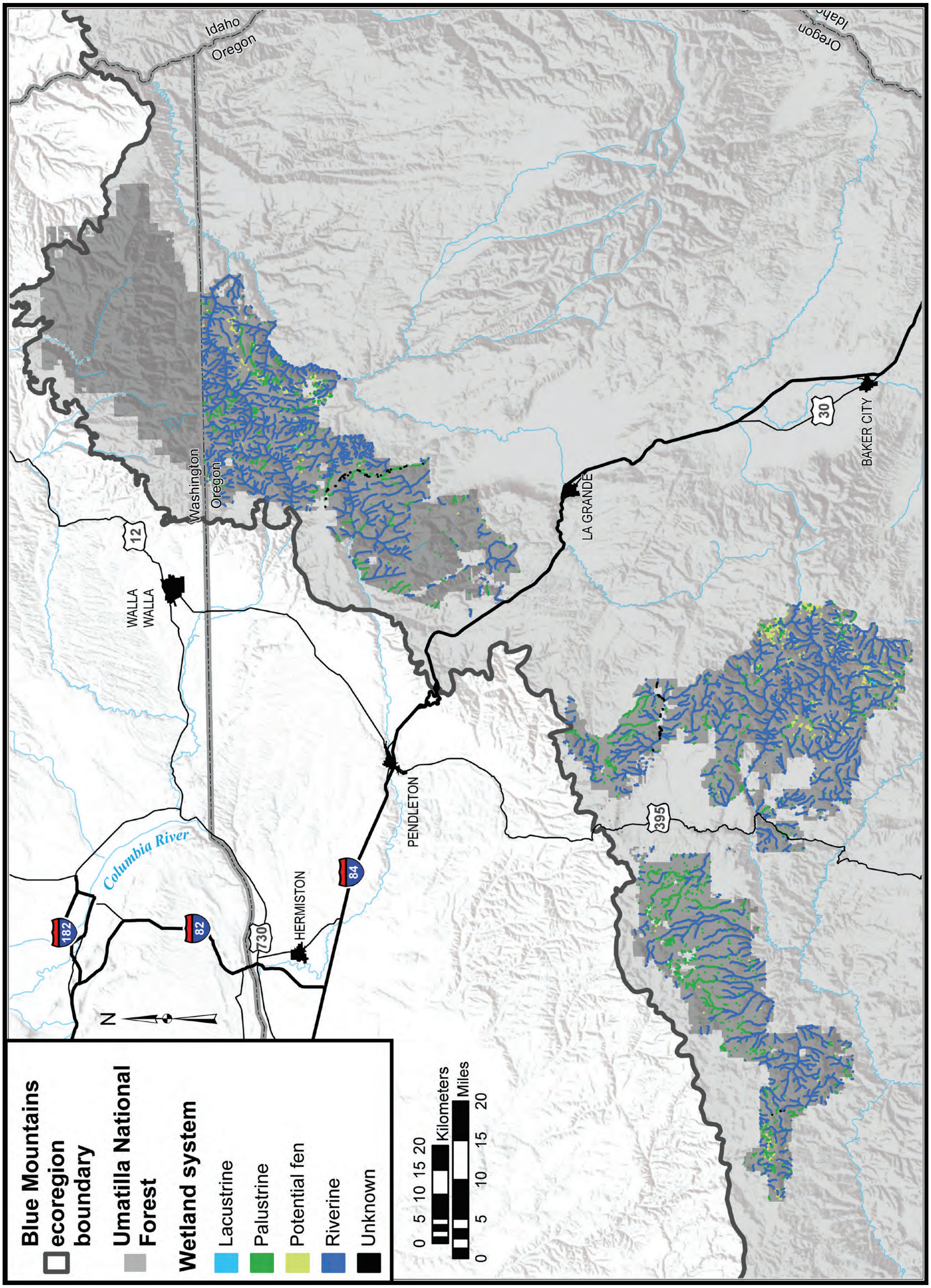

Figure 7.2—Wetlands in the Oregon portion of Umatilla National Forest. Source: Oregon Wetlands Geodatabase.

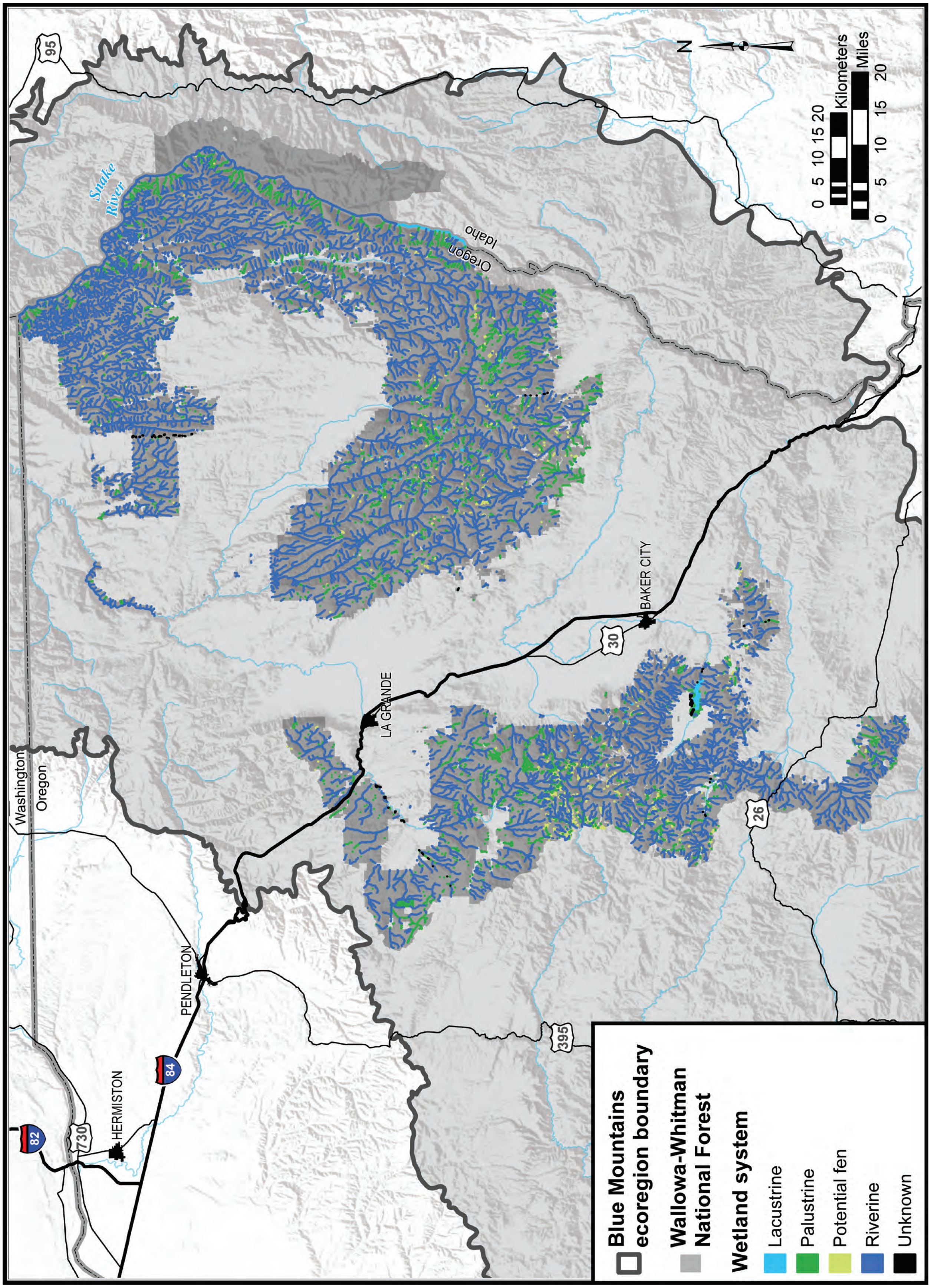

Figure 7.3—Wetlands in Wallowa-Whitman National Forest. Source: Oregon Wetlands Geodatabase.

wetlands occur in the Blue Mountains: palustrine, lacustrine, and riverine (Cowardin et al. 1979). Palustrine wetlands are freshwater wetlands that include marshes, wet meadows, and forested wetlands, and may be dominated by trees, shrubs, or emergent vegetation. Some palustrine wetlands may be associated with streams, particularly in headwaters, whereas many are isolated, occurring in basins, depressions, or wet meadows. Lacustrine wetlands border lake shores. Riverine wetlands are associated with streams and rivers, and occur along stream channels.

In this database, most riparian areas are treated as riverine wetlands (figs. 7.1 through 7.3), demonstrating the overlap in definitions of riparian areas and wetlands. This designation may result in an overestimate of wetland area, because some riparian areas may not qualify as jurisdictional wetlands (Federal Interagency Committee for Wetland Delineation 1989), but it does provide a basis for management, because all wetland and riparian areas in national forests in the Blue Mountains are managed as RHCAs (USDA FS 2012c). The mapped wetlands (shown in figs. 7.1 through 7.3) illustrate the extent and diversity of these resources in the three national forests of the Blue Mountains.

Although the Oregon Wetlands Geodatabase is an excellent resource for national forests in Oregon, it covers only wetlands that occur within the state's boundaries. The portion of the Umatilla National Forest in Washington is therefore excluded, as well as the small portion of the Wallowa-Whitman National Forest along the Snake River in Idaho. Wetland databases are not available for Washington and Idaho.

Groundwater-Dependent Ecosystems

Groundwater is broadly defined as "all water below the ground surface, including water in the saturated and unsaturated zones" (USDA FS 2012c). Groundwater-dependent ecosystems are "communities of plants, animals and other organisms whose extent and life processes are dependent on access to or discharge of groundwater" (USDA FS 2012a, 2012b), which can greatly contribute to local and regional biodiversity (Murray et al. 2006). The GDEs occur at aquifer discharge locations, such as springs, rheic, lentic or alluvial systems (Aldous et al. 2015), which are also referred to as surface/terrestrial GDEs (Bertrand et al. 2012, Goldscheider et al. 2006). Many wetlands, lakes, streams, and rivers receive inflow from groundwater, which can contribute substantially to maintenance of water levels, as well as water temperature and chemistry required by native biota (Lawrence et al. 2014, Winter 2007).

Groundwater is important to stream and river ecosystems… and most watersheds in northeastern Oregon.

Along stream segments referred to as "gaining reaches," groundwater enters the stream from the banks or the channel bed, and the volume of downstream streamflow is subsequently increased (Winter 2007, Winter et al. 1996). Groundwater can contribute substantially to late-summer streamflow (Gannett 1984) and is the source for cool-water upwellings that serve as refugia for coldwater aquatic species (Lawrence et al. 2014; Torgersen et al. 1999, 2012). Springbrooks, defined as "runout channels from springs, which may become a stream at some distance from the spring source" (USDA 2012a), may also contribute to the mediation of stream temperature. Groundwater is important to stream and river ecosystems in the John Day River basin (Gannett 1984) and most watersheds in northeastern Oregon (Brown et al. 2009).

In the Blue Mountains, GDEs include springs, springbrooks, certain high-elevation lakes, fens, streams, rivers (Brown et al. 2009, 2010), and riparian wetlands along gaining river reaches, all of which may provide habitat for rare flora and fauna. Fens are wetlands supported primarily by groundwater with a minimum depth (usually 30 to 40 cm) of accumulated peat (Chadde et al. 1998; USDA FS 2012a, 2012c). Springs are entirely supported by groundwater.

Five types of GDEs have been sampled in the Blue Mountains: helocrene, hillslope, hypocrene, mound, and rheocrene (USDA FS 2012a, 2012b; modified from Springer and Stevens 2009). Helocrene springs emerge diffusely from low-gradient wetlands, often discharging from indistinct or multiple sources. Hillslope GDEs are springs or fens located on hillslopes, usually on 20- to 60-degree slopes, often with indistinct or multiple sources of groundwater. Springs associated with mounds actually emerge near the top of elevated surfaces, i.e., mounds composed of peat or mineralized carbonate, and may be located within fens or wetland complexes near subsurface faults. Rheocrene springs emerge directly into stream channels, and are also referred to as springbrooks or spring runs. Other types of GDEs may occur in the Blue Mountains but have not yet been described or inventoried.

Dependence of Special Habitats on Different Water Sources

In contrast to surrounding upland ecosystems, the occurrence and characteristics of riparian areas, wetlands, and GDEs depend on the availability of abundant water. The fundamental hydrologic processes that influence these special habitats are (1) the amount, timing, and type of precipitation (rain or snow); (2) streamflow variables described by magnitude, frequency, timing, duration, and rate of change

(Nilsson and Svedmark 2002) and other characteristics of surface water runoff; (3) groundwater recharge; (4) groundwater discharge; and (5) evapotranspiration (Lins 1997).

Because precipitation is the ultimate source of water and directly influences streamflow characteristics and groundwater dynamics, it is expected that climate-induced changes in precipitation will affect riparian areas, wetlands, and GDEs. The availability of water to riparian areas, wetlands, or GDEs is also influenced by physical watershed characteristics that affect infiltration and surface and hill-slope runoff, including lithology, soil depth, and topography (Jencso et al. 2009). However, determining how climate-induced changes in hydrologic sources and processes will affect special habitats is complex and has not been directly studied in watersheds of the Blue Mountains. Here we draw on research that has been conducted in other locations in the Western United States with similar plant species or communities and infer potential climate-induced changes in riparian and wetland vegetation in northeast Oregon and southeast Washington.

Riparian ecosystems depend on the presence of flowing water, although streamflow may not be perennial along all stream segments and can vary considerably with season, physical features of the watershed, and water source. The volume of streamflow largely regulates the transport and deposition of sediment, influencing the creation and erosion of streambanks; floodplains; point bars; and meandering, braided, and abandoned channels. Depending on the physical characteristics of a given stream segment, the volume of streamflow can also drive the seasonal changes in water table elevation of the adjacent riparian area (Jencso et al. 2011). These hydrologic and fluvial processes and resulting geomorphic surfaces are essential for the establishment, development, and persistence of riparian vegetation, and strongly influence the local distribution of different plant species and communities (Naiman et al. 2005). Based on long-term daily flow data (from U.S. Geological Survey stream gauging stations), different streams in the Blue Mountains have been characterized as supported by perennial runoff, snow plus rain, and super-stable groundwater (Poff 1996).

As noted above, streamflow volume along gaining reaches increases with the inflow of groundwater to the channel. Stream water can also drain from the channel bed and banks to the groundwater system, resulting in a loss of downstream surface flow volume (Winter et al. 1996); these stream segments are referred to as "losing reaches." The extent and location of hyporheic and groundwater exchange along a channel segment is influenced by valley bottom features, including width, gradient, substrate size, and depth to bedrock, and can determine whether a reach is gaining or losing (Winter et al. 1996). Gaining and losing stream reaches result in different aquatic communities in the channels and different riparian plant communities on the floodplains. The extent to which specific reaches are gaining or losing may change in response to climate-induced changes in precipitation, streamflow characteristics, and groundwater discharge.

Wetlands can be supported by surface water, groundwater, and precipitation, or frequently by combinations of these sources that differ seasonally (Goslee et al. 1997, Winter 2001). Fens are primarily supported by springs or local aquifers and can maintain fairly stable water table elevations despite changes in timing and amounts of precipitation (Winter 1999). Other wetlands with different or multiple water sources will likely respond differently to climate-induced changes and variability (Winter 1999).

In wetlands and riparian ecosystems worldwide, hydrologic variables are consistently the strongest predictors of plant species distributions (Cooper and Merritt 2012, Franz and Bazzazz 1977, Lessen et al. 1999, Merritt and Cooper 2000, Shipley et al. 1991). Ordination and other analyses repeatedly show that riparian and wetland species and vegetation communities are distributed along gradients (usually elevational or microtopographic) relating to streamflow duration (Auble et al. 1994, 1998, 2005; Franz and Bazzazz 1977; Friedman et al. 2006); growing-season streamflow volume (Stromberg 1993); depth, duration, or timing of flooding (Richter and Richter 2000, Toner and Keddy 1997); inundation duration (Auble et al. 1994, Franz and Bazzazz 1977, Friedman et al 2006); and water table elevation or depth to groundwater (Busch and Smith 1995, Castelli et al. 2000, Cooper et al. 1999, Dwire et al. 2006, Rains et al. 2004, Scott et al. 1999). In wetlands, variables related to water table elevation and hydroperiod are the primary determinants of plant species distributions (Goslee et al. 1997, Magee and Kentula 2005, Weiher and Keddy 1995).

Current understanding of the water sources used by riparian/wetland plants is limited to a few indicator, keystone, and either highly valued or highly invasive species (mostly woody) (Cooper and Merritt 2012). However, it has been shown that riparian/wetland plant species use water from multiple sources (surface water, soil water, groundwater), depending on life stage and season (Busch and Smith 1995, Cooper et al. 1999, Goslee et al. 1997). In assessing the vulnerability of riparian/wetland species to climate-induced changes in streamflow or groundwater, the availability of water at all life stages must be considered, from plant recruitment and establishment, to reproducing adults, to persistence at later life stages (Cooper and Merritt 2012).

Lack of scientific information makes it difficult to directly infer climate change effects on riparian vegetation or to describe physical mechanisms regulating water availability to special habitats in the Blue Mountains. However, based on research from other locations, we assume that climate-induced changes in precipitation and streamflow will exert influences on the distribution of riparian vegetation via changes in local hydrologic regimes. Summer baseflows are predicted to decrease (Cayan et al. 2001, Luce and Holden 2009). If riparian water table elevation can be assumed to be in equilibrium with water levels in the stream, reduced baseflows could result in lower riparian water table elevations and subsequent drying of some streamside areas, particularly in wider valley bottoms. Increasing air temperature will result in increased evapotranspiration across the landscape, could reduce the hydrologic connectivity between uplands and riparian areas (Jencso et al. 2009, 2011), and subsequently could contribute to the drying of some streamside areas. Dominant wetland/riparian plant communities will respond to climate-induced changes in hydrologic variables differently owing to differences in their species composition (Merritt et al. 2010, Weltzin et al. 2000).

Current Resource Conditions

The Blue Mountains have a rich diversity of riparian and wetland plant associations and community types at mid-montane elevations (Crowe and Clausnitzer 1997) and at higher elevations and within deep canyons (box 7.3) (Johnson 2004, Wells 2006). Several quaking aspen (*Populus tremuloides* Michx.) communities and associations, which occur in upland locations as well as wetlands and riparian areas, have also been classified for the Blue Mountains (Swanson et al. 2010). Riparian and wetland aspen communities are highly valued throughout the Blue Mountains and are included here as special habitats.

Past land use and management activities have affected riparian and aquatic resources, but in different ways and to different extents, depending on valley setting, location within the watershed, and land use (Dwire et al 1999; Kauffman et al. 2004; Magee et al. 2008; McAllister 2008; McIntosh et al. 1994a, 1994b; Parks et al. 2005; Ringold et al. 2008). Streams, wetlands, and associated plant communities are possibly the most heavily impacted ecosystems in the Blue Mountains. In many cases, the effects of past land use and management activities may be considerably greater than the anticipated gradual influence of climate change. However, for these altered ecosystems, climate-induced changes will exert additional stress, possibly resulting in further degradation. In this section, we briefly describe the current condition of different riparian and wetland vegetation types and how they have been affected by past land use and management activities.

Box 7.3—Deep river canyons and climate change: the lower Snake River and its tributaries

The lower Snake River runs along the Idaho and Oregon state line and forms the deepest river gorge in North America, commonly referred to as Hells Canyon. From Hells Canyon Dam, one of three dams in the Hells Canyon Project, the river winds its way for 114 km to the northern boundary of Hells Canyon National Recreation Area (HCNRA), managed by Wallowa-Whitman National Forest. With river elevations of 512 m at the dam to 263 m at the northern boundary of HCNRA, this river canyon provides the warmest and driest environments in the Blue Mountains national forests.

The vegetation of the canyon is characterized by extensive bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] Á. Löve) and Idaho fescue (*Festuca idahoensis* Elmer) grasslands, with stringers of conifer forests at cooler aspects and higher elevation. Riparian communities are often confined to narrow strips along river corridors and moisture gradients are steep. The floodplains, rocky bars and terraces at elevations below 700 m support a number of unique riparian plant communities characterized by black cottonwood, white alder, netleaf hackberry (*Celtis reticula* [Torr.] L.D. Benson), and Barton's raspberry (*Rubus bartonianus* M. Peck), a narrow endemic shrub species of Hells Canyon and surrounding canyonlands (Wells 2006).

With the settlement of the canyon in the early 19th century came the introduction of many nonnative plant species, including tree of heaven (*Ailanthus altissima* [Mill.] Swingle), false indigobush (*Amorpha fruticosa* L.), and Himalayan blackberry (*Rubus armeniacus* Focke). The spread of Himalayan blackberry is of particular concern for the endemic Barton's raspberry, because Himalayan blackberry is able to occupy the same habitats but is a better competitor (Ferriel and Ferriel 2010).[1] Native *Rubus* species are restricted by drought conditions during summer, whereas Himalayan blackberry can store more water and achieves high growth and reproductive rates (Caplan and Yeakley 2010). Canes can grow up to 10 m long and produce over 700 fruits annually (Pojar and MacKinnon 1994). In Hells Canyon, Himalayan blackberry retains its leaves over winter, giving it an additional competitive edge over many native species.

Fire exclusion has affected Hells Canyon, with steep terrain and fast fire spread in dry canyon grasslands, less than other areas in the Blue Mountains. From 1980 to 2013, over 70 percent of all grass and shrublands of the HCNRA were within one or more mapped fire perimeters (S. Mellman-Brown, unpublished data on file at Wallowa-Whitman National Forest, Baker, OR). Many of these fires burned through riparian zones and replaced existing shrub and forest vegetation with early seral species. Himalayan blackberry, which resprouts readily from its root crown after fire, had covers of 80 percent near Pittsburg Creek one year after fire, an increase of 30 percent compared to measurements one decade earlier. On other sites, white alder (*Alnus rhombifolis*) Nutt., a tree with poor postfire sprouting abilities, appeared to be replaced by blackberry thickets after high-severity fire. Increasing fire frequencies with climate change will promote fire-adapted species like tree of heaven and Himalayan blackberry, potentially creating widespread novel plant communities with few native elements.

Warming climate with increasing fire frequencies may also facilitate the invasion and dominance of tamarisk in Hells Canyon (Kerns et al. 2009). Major population centers for tamarisk (*Tamarix* spp.) in the northwestern United States are the warmest and driest environments of the northern Basin and Range, Columbia Plateau, and central Snake River Plateau. Tamarisk is currently absent from the

Box 7.3 (continued)

HCNRA, but large populations exist nearby at Farewell Bend and with lower frequency along the Brownlee Reservoir. Large areas in the lower Snake River and upper John Day River drainages are also vulnerable to invasion by tamarisk (Kerns et al. 2009). Habitat suitability modeling by Kerns et al. (2009) suggests that tamarisk habitat will expand in the Northwest by the end of this century, which could dramatically change the composition and structure of many riparian corridors in the Blue Mountains.

[1] **Ferriel, J.; Ferriel, R. 2010.** *Rubus bartonianus* status review for Wallowa-Whitman National Forest, and Baker Resource Area, Vale District. Unpublished report on file with: USDA, Forest Service; USDI Bureau of Land Management. Baker City, OR. 10 p.

Riparian Areas

We utilize existing vegetation classifications to highlight the diversity and complexity of riparian areas in the Blue Mountains, and as a basis for discussing how different vegetation types might respond to climate-induced changes. We present information for distinct riparian/wetland potential vegetation types (PVTs), and potential vegetation groups (PVGs) that have been described for the Blue Mountains (Crowe and Clausnitzer 1997, Powell et al. 2007, Swanson et al. 2010, Wells 2006). These groupings are hierarchical, aggregated from fine-scale units to mid-scale units, and are explained in detail in Powell et al. (2007). Potential vegetation types are fine-scale hierarchical classification units that include plant associations and plant community types (Powell et al. 2007). They are aggregated into mid-scale plant association groups (PAGs) representing similar ecological environments as characterized by temperature and moisture regimes (Powell et al. 2007). The PAGs are then aggregated into PVGs with similar environmental regimes and dominant plant species; each PVG typically includes PAGs representing a predominant temperature or moisture influence (Powell 2000, Powell et al. 2007).

Riparian environments can be subject to frequent and unpredictable disturbances with a range of possible, but largely unstudied, successional trajectories.

Potential vegetation describes the plant species composition occurring under existing climatic conditions and in the absence of disturbance (Powell et al. 2007), implies some knowledge of successional pathways, and is most useful for well-studied upland vegetation. However, riparian environments can be subject to frequent and unpredictable disturbances with a range of possible, but largely unstudied, successional trajectories. Plant associations and community types are interspersed along stream-riparian corridors as a mosaic, sometimes co-occurring over short stream lengths, responding to valley bottom width, geomorphic surfaces, and local differences in hydrologic variables (Naiman et al. 2005). Although successional pathways cannot be reliably determined for these riparian classifications, the plant community/association descriptions provide detailed floristic information and a basis for assessing both current conditions and future changes in species composition in response to management, natural disturbance, and climate-induced changes. Below, we discuss broad riparian vegetation types and note the number of PAGs and PVTs and other groupings that have been classified for each.

Conifer-dominated riparian areas—

Many kilometers of streams in the Blue Mountains are bordered by conifer-dominated riparian communities. Conifer-dominated riparian areas are valued for maintenance of riparian microclimates, wildlife habitat, and a source of large wood for streams (table 7.1). Powell et al. (2007) describe a "cold riparian forest" PVG that includes three PAGs and 25 PVTs for conifer-dominated riparian areas. Depending on the PAG, dominant conifer species are subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), or lodgepole pine (*Pinus contorta* var. *latifolia* Engelm. ex S. Watson). The "warm riparian forest" PVG includes two PAGs with seven PVTs dominated by either Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) or grand fir (*A. grandis* [Douglas ex D. Don] Lindl.), and one PVT by western white pine (*Pinus monticola* Douglas ex D. Don). These conifer-dominated riparian vegetation types typically occur at high to moderate elevations, mostly along first- and second-order streams, and mostly in moderately to highly confined valley bottoms. Although several other PVTs have high cover of ponderosa pine (*P. ponderosa* Douglas ex P. Lawson & C. Lawson), grand fir, or Douglas-fir, they occur at lower elevations and are not consistently surrounded by conifer-dominated uplands (Powell et al. 2007).

Conifer-dominated riparian vegetation types have been affected by past forest harvest, mining, grazing, road building, fire exclusion, and to a lesser extent, invasive species (Wickman 1992) (table 7.2). Natural disturbances include wildfire, infestations by forest insects and fungal pathogens, landslides, and debris flows (Luce et al. 2012). In some locations at lower elevations, the ponderosa pine-common snowberry (*Symphoricarpos albus* [L.] S.F. Blake) community may be increasing in streamside areas previously dominated by deciduous woody species in response to channel incision and decreasing riparian soil moisture (table 7.2).

Riparian and wetland aspen plant communities—

Stands of quaking aspen are an uncommon, valued habitat type throughout the Blue Mountains region, and their sustainability has been a focus for management in uplands, riparian areas, and wetlands (Swanson et al. 2010). Classification of wetland and riparian aspen communities for the Blue Mountains region showed the largest

Table 7.1—Functions of riparian areas and key relationships to ecological services[a]

Riparian functions	Indicators of riparian functions	Onsite or offsite effects of functions	Goods and services provided	Relevant riparian plant communities
Hydrology and sediment dynamics				
Short-term storage of surface water	Connectivity of floodplain and stream channel	Attenuates downstream flood peaks	Reduces damage from floodwaters	Shrub (especially willow) and herbaceous dominated; all communities to some extent
Maintenance of high water table	Presence of flood-tolerant, hydrophytic, and mesic plant species	Maintains distinct vegetation, particularly in arid climates	Contributes to regional biodiversity through provision of habitat	Shrub (especially willow) and herbaceous dominated; all communities to some extent
Retention and transport of sediments; decreased streambank erosion	Riffle-pool sequences, point bars, floodplain terraces, and bank stability	Contributes to fluvial processes	Creates predictable yet dynamic channel and floodplain features	Shrub (especially willow) and herbaceous dominated; all communities to some extent
Biogeochemistry and nutrient cycling				
Riparian vegetation provides source of organic carbon (allochthonous inputs to streams; organic matter inputs to soils)	Healthy mosaic of riparian vegetation	Maintains aquatic and terrestrial food webs	Supports terrestrial and aquatic biodiversity	Highest quality inputs are from deciduous shrubs and herbaceous dominated; all communities to some extent
Transformation and retention of nutrients and pollutants	Water quality and biotic indicators	Intercepts nutrients and toxicants from runoff; water quality	Improves and maintains water quality	Retention and interception most likely in shrub (especially deciduous) and herbaceous-dominated communities; all communities to some extent
Sequestration of carbon in riparian soils	Occurrence, extent, and distribution of organic-rich soils	Contributes to nutrient retention and carbon sequestration	Potentially ameliorates climate change; provides source of dissolved carbon to streams via subsurface flow	Carbon sequestration in soils highest in herbaceous-dominated meadows; all communities to some extent

Table 7.1—Functions of riparian areas and key relationships to ecological services[a] (continued)

Riparian functions	Indicators of riparian functions	Onsite or offsite effects of functions	Goods and services provided	Relevant riparian plant communities
Distinctive terrestrial and aquatic habitat				
Contributes to overall biodiversity and biocomplexity	High species richness of plants and animals	Provides reservoirs for genetic diversity	Supports regional biodiversity	All communities, but especially those with multiple canopy strata, (e.g., cottonwood, aspen, and willow dominated)
Maintenance of streamside microclimate	Presence of shade-producing canopy; healthy populations of native terrestrial and aquatic biota	Provides shade and thermal insulation to stream; provides migratory corridors for terrestrial and aquatic species	Maintains habitat for sensitive species (e.g., amphibians, cold-water fishes)	All communities, but especially those with multiple canopy strata, (e.g., conifer, aspen, cottonwood, and willow dominated)
Contribution to aquatic habitat; provision of large wood	Aquatic habitat complexity (pool-riffle sequences, debris dams); maintenance of aquatic biota	Maintains aquatic biota	Maintains fisheries, recreation	Conifer, aspen, and cottonwood dominated
Provision of structural diversity	Availability of nesting/rearing habitat; presence of appropriate indicator wildlife species (e.g., Neotropical migrants)	Maintains biodiversity; provides migratory corridors for terrestrial and aquatic species	Provides recreation opportunities (e.g., birding, wildlife enjoyment, hunting)	All woody communities, but especially those with multiple canopy strata (e.g., conifer, aspen, cottonwood, and shrub dominated)

[a] Modified from Dwire et al. (2010), Naiman et al. (2005), NRC (2002).

Table 7.2—Stressors in riparian and wetland ecosystems which are likely to be exacerbated by climate change[a]

Stressor	Direct and indirect causes	Potential effects	Riparian and wetland plant communities and associations most affected by climate change
Changes in flow regime and dewatering	Surface water: dams, diversions, land use changes, climate change Groundwater: pumping, land use change, climate change	Water stress in vegetation Shifts in plant species composition Homogenization of riparian area and simplification of biota Isolation of floodplain from stream Altered stream-riparian organic matter exchange and trophic dynamics Altered floodplain biogeochemistry Altered channel structure Decreased lateral extent of riparian area	Cottonwood, aspen, willow, and herbaceous-dominated communities located along low-gradient, wide valley bottoms
Channelization	Bank hardening Levee construction Structural changes in channel-deepening Berm development Meander cutoff	Isolation of floodplain from stream Altered fluvial processes Altered hydraulics (aquatic habitat and channel forms) Altered floodplain biogeochemistry	Cottonwood, aspen, willow, and herbaceous-dominated communities located along low-gradient, wide valley bottoms
Conversion of floodplains to other uses	Removal of woody riparian vegetation	Elimination of local populations of cottonwood, aspen, willow, and herbaceous communities Reduced extent of riparian area, thus reducing ecosystem services (maintenance of water quality, wildlife habitat, recreation)	Cottonwood, aspen, willow, and herbaceous-dominated communities located along low-gradient, wide valley bottoms
Invasive species	Altered physical and ecological processes that facilitate establishment and spread (e.g., herbivory, changes in flow regime)	Displacement of native species Formation of monoculture Altered site characteristics (e.g., biogeochemistry, soil properties, water balance) Shifts in community composition Altered habitat structure	Nearly all riparian and wetland communities, especially those that occur in drier environments Potential increase in tamarisk in Hells Canyon

Table 7.2—Stressors in riparian and wetland ecosystems which are likely to be exacerbated by climate change[a] (continued)

Stressor	Direct and indirect causes	Potential effects	Riparian and wetland plant communities and associations most affected by climate change
Changes in sediment delivery to channel	Offroad vehicle use Roads (drainage, gravel application) Livestock and herbivore trampling Altered vegetative cover in watershed and along channel Direct mechanical effects on channel, dams, and diversions	Shifts in channel and floodplain form (through increased or decreased delivery to channel) Altered channel processes (e.g., incision and aggradation)	Nearly all riparian and wetland communities, although direct causes and severity will differ
Herbivory	Grazing by cattle and wild ungulates	Bank trampling and compaction Altered cover and composition of vegetation Stream capture Nutrient inputs	Aspen, cottonwood, willow and herbaceous communities are the most heavily affected, but most riparian and wetland communities are affected to some extent
Wildfire and fuels, fire suppression	Fuel buildup from invasive species and fire exclusion Reduced flooding Slower decomposition of organic material	Increased frequency and intensity of fires Loss of fire-intolerant taxa Altered structure of riparian vegetation and habitat quality and distribution, with subsequent shifts in composition	Conifer-dominated riparian plant associations with dominant tree species similar to adjacent uplands
Insects and disease	Fire exclusion and past harvest activities have resulted in susceptible stand structure	Altered fuel loads and distribution associated with increased canopy mortality	Conifer-dominated riparian plant associations with dominant tree species similar to adjacent uplands

Note: Although nearly all riparian and wetland plant associations are affected by each stressor, the most affected associations are noted in the last column.

[a] Modified from Theobald et al. (2010).

number of aspen community types (CT) were associated with herbaceous species in meadows (eight CTs), followed by associations with common snowberry (four CTs) and other tall shrubs (three CTs) in riparian areas (Swanson et al. 2010). One aspen CT was associated with Engelmann spruce, and another with tall shrub wetland types on slopes, likely occurring at points of groundwater emergence (Swanson et al. 2010).

Aspen CTs have been affected by fire suppression and herbivory by livestock and native ungulates (Baker et al. 1997, Bartos and Campbell 1998, Shinneman et al. 2013). They are currently threatened by herbivory and conifer encroachment, especially those occurring in meadows (Swanson et al. 2010) (table 7.2). Many stands are declining, without signs of regeneration, and are susceptible to a variety of insects and fungal pathogens (Swanson et al. 2010). Most aspen stands are less than 1 ha.

Black cottonwood is a keystone riparian species occurring along a variety of valley types in the Blue Mountains.

Cottonwood-dominated riparian areas—
Black cottonwood (*Populus trichocarpa* T. & G. ex Hook.) is a keystone riparian species occurring along a variety of valley types in the Blue Mountains, ranging from high-gradient, V-shaped valleys to moderately confined or open, low-gradient valleys (Crowe and Clausnitzer 1997). Powell et al. (2007) classified a "warm riparian forest" PVG that includes three PAGs dominated by black cottonwood.

Cottonwood-dominated riparian areas were among the earliest settled in the mid-1800s. Settlers quickly recognized the economic potential for raising livestock, especially along the wider valley bottoms at mid to low elevations with abundant forage and water resources (Dwire et al. 1999). The widespread decline of cottonwood and willows (*Salix* spp.) has been widely attributed to land management practices associated with livestock production (Beschta and Ripple 2005; McIntosh et al. 1994a, 1994b). Many floodplains formerly dominated by woody riparian species, including portions of the John Day River and its tributaries, were converted to cattle pastures and hay fields by modifying or relocating portions of the stream channels, removing woody species, and planting with introduced grasses (Dwire et al.1999). Other factors, such as use of cottonwood as a wood source, removal of streamside woody plants as "phreatophyte control," and hydrologic modification of streams and rivers for agricultural production and irrigation have contributed to a decrease in the distribution and abundance of deciduous riparian species, including cottonwoods and aspen, willows, and alders (*Alnus* spp.).

Several cottonwood species have been shown to depend on flood frequency and duration for recruitment and establishment (Mahoney and Rood 1998; Scott et al. 1996, 1997). Although recruitment of black cottonwood has not been studied relative to streamflow characteristics, germination and seedling survival depend on continuously moist conditions (http://plants.usda.gov/plantguide/pdf/cs_pobat.pdf), which are provided in part by high flows during spring runoff. Flow alteration of streams and rivers in the Blue Mountains may possibly have reduced the recruitment of new cottonwoods, thus contributing to the decline of existing stands. Limited recruitment has also been attributed to grazing of young cottonwood plants by livestock (Beschta and Ripple 2005) (table 7.2).

Willow-dominated riparian areas—
Willow-dominated riparian areas are found across elevation ranges, but are most extensive at mid to lower elevations. Willows provide numerous valued ecological functions, including shade and organic matter for streams, increased bank stability and sediment retention, and wildlife habitat for many resident and migratory vertebrate species, such as Neotropical migratory birds (Kauffman et al. 2001, Kelsey and West 1998) (table 7.1). Willow-dominated riparian areas also maintain water quality through trapping sediment and pollutants from upslope and upstream areas, thus reducing the volume or concentrations delivered to streams (Johnson and Buffler 2008).

Potential vegetation analysis for willow-dominated riparian areas of the Blue Mountains region resulted in the classification of a “cold riparian shrub” PVG that includes four PAGs and 10 PVTs (Powell et al. 2007). The cold riparian shrub PVG occurs at higher elevations or along channels with frequent cold air drainage at lower elevations (Crowe and Clausnitzer 1997). The dominant willow species include Booth’s willow (*Salix boothii* Dorn), undergreen willow (*S. commutata* Bebb.), and Drummond’s willow (*S. drummondiana* Barratt). The “warm riparian shrub” PVG includes three PAGs with eight PVTs dominated by willow species that generally occur in moderately confined or open valley bottoms, including unconfined and glaciated valleys with low slopes (less than 3 percent) in montane and subalpine settings (Powell et al. 2007). These warm riparian shrub PVTs are also referred to as the “alluvial bar” willow group, because they frequently occur on coarse-textured sands, gravel, and cobble bars. They are generally dominated by sandbar willow (*S. exigua* Nutt.), dusk willow (*S. melanopsis* Nutt.), and Pacific willow (*S. lasiandra* Benth.) (Powell et al. 2007).

In many streams throughout North America, the historical removal of American beaver (*Castor canadensis* Kuhl) has influenced the geomorphic and hydrologic characteristics of stream channels (Wohl 2001) as well as the distribution of woody riparian species, especially willows (Naiman et al. 1988). Dam building by beaver modifies local hydrology, thus expanding wetland area and contributing to retention of sediment and organic matter (Butler and Malanson 1995; Meentemeyer and Butler 1999; Westbrook et al. 2006, 2011). Willows are a preferred source of food and dam-building material for beaver and readily establish along the edges of beaver ponds and beaver-influenced stream reaches. In the Blue Mountains, the removal of beaver likely contributed to the reduction of willow-dominated riparian areas and abundance of aspen (Kay 1994, McAllister 2008, Swanson et al. 2010). Beavers and functioning beaver dams are still infrequent in the Blue Mountains (Swanson et al. 2010).

Willow-dominated riparian areas have been heavily affected by livestock use, including direct effects of grazing and browsing. Livestock grazing reduces cover and stem density of adult plants (Brookshire et al. 2002), and in many areas, has eliminated seedlings and saplings, thus reducing establishment of new plants. Elk (*Cervus elaphus* L.) utilize willows throughout the year (Singer et al. 1994, Zeigenfuss et al. 2002), and in floodplains with combined herbivory pressure from both livestock and native ungulates, willows can be highly affected. Flow alteration has also affected willow-dominated riparian areas; downstream of diversions, species composition tends to consist of more drought-tolerant species (Caskey et al. 2014).

Other woody-dominated riparian areas (deciduous shrubs and trees)— Geographic location, complex geology, and highly variable channel forms create a rich floristic diversity of woody riparian species in the Blue Mountains. Powell et al. (2007) describe a "warm riparian forest" with seven red alder (*Alnus rubra* Bong.) -dominated and two white alder (*A. rhombifolia* Nutt.) -dominated PVTs. In drier riparian areas, classified as "low soil moisture riparian shrub," 16 additional PVTs are described, dominated by 13 different shrub species that occur across a range of valley bottom types, including steep canyons. In a "warm riparian shrub" PVG, they describe the following PVTs, dominated by different riparian woody species:

- Mountain alder (*A. viridis* subsp. *crispa* [Chaix] DC.) (16 PVTs)
- Sitka alder (*A. v.* subsp. *sinuata* [Chaix] DC.) (3 PVTs)
- Water birch (*Betula occidentalis* Hook.) (3 PVTs)
- Red-osier dogwood (*Cornus sericea* L.) (3 PVTs)
- Currant (*Ribes* spp.) (3 PVTs)
- Twinberry (*Lonicera involucrata* [Richardson] Banks ex Spreng.) (1 PVT)
- Shrubby cinquefoil (*Dasiophora fruticosa* [L.] Rydb.) (1 PVT)
- Alderleaf buckthorn (*Rhamnus alnifolia* L'Hér.) (1 PVT)

In some locations, certain woody riparian plant associations are likely the result of land use, particularly hydrologic modification that has caused the conversion of willow-dominated areas to communities dominated by more dry-tolerant shrub species, such as shrubby cinquefoil, currant, and common snowberry. Woody-dominated riparian areas, including those with cottonwood, willow, and aspen, have also been affected by livestock grazing, herbivory pressure from native ungulates, and conversion to pastures and other agricultural uses (table 7.2).

Herbaceous-dominated riparian areas—
Several herbaceous-dominated riparian and wetland plant associations have been identified in the Blue Mountains, reflecting both environmental conditions and past land use. Herbaceous-dominated riparian and wetland communities occur over a wide elevation range from alpine to lower montane environments. Crowe and Clausnitzer (1997) identified 11 herbaceous plant associations and 17 plant CTs located in meadows, most of which were dominated by different sedge (*Carex, Eleocharis,* and other genera) species. In addition, they described seven herbaceous plant associations and six plant CTs that occurred along shaded streams or springs (GDEs). Herbaceous-dominated riparian areas occur most commonly in moderately confined to wide valley bottoms, usually along low-gradient stream segments.

At mid elevations, herbaceous-dominated meadows have been affected by heavy elk grazing. At nearly all elevations, meadows have also been affected by livestock use (Kauffman et al. 2004), with lasting impacts in many areas (Skovlin and Thomas 1995). At lower elevations, changes in species composition, density, and cover have resulted from either the complete or partial conversion of natural meadows to pasture along some floodplains. As with willow-dominated communities, hydrologic modifications, including water diversions and construction of ditches, and stream modifications (e.g., relocation or alteration of natural channels) have influenced channel characteristics, seasonal water supply and water table elevations (McIntosh et al. 1994a, 1994b). In riparian meadows, the distribution of herbaceous species is largely determined by seasonal water table elevation (Castelli et al. 2000, Dwire et al. 2006, Loheide and Gorelick 2007), which can be influenced by patterns of streamflow runoff. In many meadows, a combination of hydrologic alteration and livestock grazing has resulted in drier conditions and increased dominance by nonnative grasses and grazing-tolerant native species (Johnson et al. 1994) (table 7.2).

Subalpine and alpine riparian areas and wetlands—
Wells (2006) described 13 wetland alpine/subalpine plant associations:

- Three are dominated by willow species and generally occur in low-gradient, U-shaped glacial cirques, U- or trough-shaped glacial valleys, and higher gradient glaciated valleys.

- Two low shrub associations are identified:
  i. "Alpine laurel (*Kalmia microphylla* [Hook.] A. Heller)/black alpine sedge (*Carex nigricans* C.A. Mey) plant association" that occurs in low-gradient, U- and trough-shaped valleys, and
  ii. "Pink mountainheath (*Phyllodoce empetriformis* [Sm.] D. Don) mounds plant association" that occurs in the upper terminus of glacial valleys.
- Four wet graminoid associations are described, all of which occur most frequently in U-shaped, low-gradient valleys. They are dominated by the following sedge species:
  i. Water sedge (*Carex aquatilis* Wahlenb.),
  ii. Northwest Territory sedge (*C. utriculata* Boott),
  iii. Blister sedge (*C. vesicaria* L.), and
  iv. Few-flower spikerush (*Eleocharis quinqueflora* [Hartmann] O. Schwarz). The "few-flower spikerush plant association" is found in fens (GDEs) near springs at high elevations (2067 to 2348 m) in the Eagle Cap and Elkhorn Mountains.
- Three moist graminoid associations are described, dominated by the following sedge species:
  i. Holm's Rocky Mountain sedge (*C. scopulorum* T. Holm),
  ii. Woodrush sedge (*C. luzulina* Olney) and,
  iii. Black alpine sedge (*C. nigricans* C.A. Mey)
- A fourth moist graminoid plant association is a sedge-forb mix, most commonly associated with headwater springs in the Strawberry Mountains. Referred to as the "northern singlespike sedge (*C. scirpoidea* Michx.)/brook saxifrage (*Micranthes odontoloma* [Piper] A. Heller)-spring plant association," it is considered an indicator for GDEs (Wells 2006).

Although alpine wetlands and meadows have been affected by past livestock grazing and ungulate browsing, they are typically in better condition than their low-elevation counterparts.

PACFISH INFISH Biological Opinion Effectiveness Monitoring—
The PACFISH INFISH Biological Opinion (PIBO) Effectiveness Monitoring was developed as a response to declining populations of steelhead trout (*Oncorhynchus mykiss* Walbaum) and bull trout (*Salvelinus confluentus* Suckley) in the upper Columbia River basin (http://fsweb.r4.fs.fed.us/unit/nr/pibo/index.shtml). Its main objective is to monitor biological and physical components of aquatic and riparian habitats (Meredith et al. 2011). As part of the Columbia River Basin Project,

191 monitoring sites were established in randomly located watersheds across the Blue Mountains. Sites have been designated as ”reference” or ”managed” and are sampled on a 5-year rotation. Reference sites (18 of the 191) are located mostly in wilderness areas at somewhat higher elevations and with more annual precipitation. No reference sites are available for the Malheur National Forest, which complicates comparisons between reference and managed sites in the Blue Mountains. However, PIBO monitoring data are the primary source of quantitative information on the condition of riparian areas occurring along “response reaches.”

PIBO monitoring provides a regional evaluation of the condition of riparian vegetation for both reference and managed sites (Archer et al. 2012a[2], Meredith et al. 2011). At each site, plant species cover is sampled along the densely vegetated streamside zone, or “greenline” (Winward 2000), and along cross-sectional transects established perpendicular to the channel or valley bottom. For each site, “wetland ratings” are calculated based on relative abundance of wetland indicator species (Coles-Ritchie et al. 2007). For Blue Mountain PIBO sites, the Wilcoxon rank sum test was used to compare managed vs. reference sites, and the Wilcoxon signed rank test was used for comparisons between measurement cycles.

Data from 2007 to 2011 showed lower total cover ($p = 0.04$) and woody cover (including conifers; $p = 0.01$) along the greenline for managed sites compared to reference (fig. 7.4). Nonnative species cover, however, was significantly higher at managed sites relative to reference sites ($p < 0.001$, fig. 7.4). A comparison of data from 2003 to 2006 to the later sampling cycle (2007–2011) showed no detectable change in greenline total cover ($p = 0.83$), cross-section wetland rating ($p = 0.30$), and native species richness ($p = 0.79$). Greenline woody cover appears to have increased slightly at both managed and reference sites ($p < 0.001$ and $p = 0.03$, respectively) while nonnative cover has decreased (managed sites $p = 0.03$, reference sites $p = 0.002$). There is evidence that wetland ratings along the greenline have decreased on managed sites ($p < 0.001$). Definitive trends in vegetation and habitat quality will likely take more than two 5-year sampling cycles to detect.

Invasive weed species occurred in 109 of 178 managed sites (61 percent), compared to 8 of 18 reference sites (44 percent). The five most commonly encountered invasive plant species for the Blue Mountains PIBO monitoring sites were Canada thistle (*Cirsium arvense* [L.] Scop.), reed canarygrass (*Phalaris arundinacea* L.),

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[2] Archer, E.K.; Van Wagenen, A.R.; Coles-Ritchie, M. [et al.] [N.d.]. 2012a. Effectiveness monitoring for streams and riparian areas: sampling protocol for vegetation parameters. Unpublished report. On file at: http://www.fs.fed.us/biology/fishecology/emp. (8 January 2015).

oxeye daisy (*Leucanthemum vulgare* Lam.), tall buttercup (*Ranunculus acris* L.), and bull thistle (*Cirsium vulgare* [Savi] Ten.), similar to findings for the entire Columbia River basin (Archer et al. 2012b). Archer et al. (2012b) concluded that invasive plant species are widespread across the interior Columbia River basin, consistent with results reported by others (Magee et al. 2008, Ringold et al. 2008). The continued spread of invasive species could contribute to future degradation of riparian plant communities.

The continued spread of invasive species could contribute to future degradation of riparian plant communities.

Wetlands

The number of wetlands in national forests of the Blue Mountains, as derived from the Oregon Wetlands Geodatabase, is shown in table 7.3 (wetlands for the portion of the Umatilla National Forest in Washington are not shown). Depending on the national forest, 42 to 51 percent of the mapped wetlands are classified as "riverine" or riparian wetlands associated with streams, indicating the overlap in definitions of riparian areas and wetlands (table 7.3). Riverine wetlands account for the largest area among all wetland types on the Wallowa-Whitman National Forest (table 7.3). Other important wetland types in the Blue Mountains are: palustrine wetlands (freshwater wetlands including marshes and forested wetlands) and lacustrine wetlands (bordering lake shores). In Malheur National Forest, palustrine wetlands account for the largest area among all wetland types (table 7.4). The Oregon Wetlands Geodatabase also identified "potential fens" if a wetland, usually palustrine, occurred near a spring (tables 7.3 and 7.4; figs. 7.1 and 7.3). All fens are GDEs, defined and discussed in more detail below. In the National Wetlands Inventory database, fens are frequently classified as a type of palustrine wetland, again indicating overlap in definitions for riparian areas, wetlands, and GDEs. In the Cowardin et al. (1979) system, fens typically fall into the Palustrine Emergent Class (PEM) with a saturated water regime. However, because characterization based on remotely sensed information is sometimes inaccurate, fens may remain undetected or be classified as other wetland types (Aldous et al. 2015, Werstak et al. 2012).

Comparing riparian and wetland conditions—

The current condition of riparian and wetland ecosystems differs considerably depending on location within the watershed, valley configuration, and past and current land use. The riparian and wetland communities at low to mid elevations have been the most altered by land use, including grazing, development of water infrastructure (dams, diversions), road building along floodplains, and conversion of floodplains to agricultural uses (Crowe and Clausnitzer 1997; McIntosh et al. 1994a,

Table 7.3—Number of springs (named and unnamed) and wetlands for the Malheur, Umatilla, and Wallowa-Whitman National Forests[a]

	Springs			Wetlands				
National forest	Named	Unnamed	Total	Palustrine	Lacustrine	Riverine	Total	Potential fens
Malheur	389	2,462	2,851	4,405	8	4,648	9,061	1,132
Umatilla	268	381	649	2,472	5	1,780	4,257	568
Wallowa-Whitman	273	1,635	1,908	5,419	77	4,886	10,382	1,037
Total	930	4,478	5,408	12,296	90	7,314	23,700	2,737

Note: The number of springs was derived from the National Hydrography Database. The number of wetlands was derived from the Oregon Wetlands Geodatabase, and excludes national forest land in Washington (Umatilla) and Idaho (Hells Canyon Natural Recreation Area, Wallowa-Whitman).

[a] This database identified "potential fens" if a wetland, usually palustrine, occurred near a spring, so overlap exists between the number of palustrine wetlands and number of potential fens.

Table 7.4—Area of different wetland types[a] and percentage of forest area for the Malheur, Umatilla, and Wallowa-Whitman National Forests

	Wetland type								
National forest	Area	Palustrine		Lacustrine		Riverine		Potential fens[b]	
	Hectares	*Hectares*	*Percent*	*Hectares*	*Percent*	*Hectares*	*Percent*	*Hectares*	*Percent*
Malhuer	696 895	4552	0.7	62	<0.001	1963	0.3	967	0.15
Umatilla	442 428	2091	0.5	104	<0.001	1669	0.4	556	0.001
Wallowa-Whitman	914 115	3897	0.4	1447	0.01	4458	0.5	619	0.06
Total		10 540		1613		8090		2142	

[a] Wetland area was derived from the Oregon Wetlands Geodatabase and excludes national forest land in Washington (Umatilla) and Idaho (Wallowa-Whitman, Hells Canyon National Recreation Area).

[b] Potential fens are classified primarily as palustrine wetlands and are included in the area calculated for palustrine wetland area.

1994b) (table 7.2). Riparian and wetland communities that occur in wide, accessible valley bottoms have been more heavily affected than higher elevation, narrow, conifer-dominated riparian corridors. Effects of climate change on precipitation and streamflow, combined with agricultural and municipal demands for water, will continue to affect river segments and riparian areas in lower portions of watersheds (Theobald et al. 2010). Wetlands and riparian areas that have been affected by land use are more vulnerable to natural disturbances like flooding or wildfire (Dwire and Kauffman 2003). Less degraded wetlands and riparian areas may be more resilient to climate-related stressors (Luce et al. 2012).

Groundwater-Dependent Ecosystems

Steep-elevation gradients, varied bedrock, and glacial landforms in the Blue Mountains influence the distribution, characteristics, and water chemistry of GDEs.

Although the U.S. Forest Service recognizes that groundwater is a key component of the water resources on National Forest Systems lands (USDA FS 2007), existing information on the condition and distribution of GDEs in national forests of the Blue Mountains is limited. Here, we again rely on data compiled by The Nature Conservancy (Brown et al. 2010), the National Hydrology Dataset (http://nhd.usgs.gov), and the Oregon Wetlands Geodatabase (http://oregonexplorer.info/wetlands/DataCollections/GeospatialData_Wetlands) to assess the current condition of GDEs in the Blue Mountains.

Springs—

The number of currently mapped springs for Malheur, Umatilla, and Wallowa-Whitman National Forests is shown in table 7.3. The percentage of named springs, which implies a known perennial water source, ranges from 9 percent of mapped springs in Umatilla National Forest (Oregon portion) to 14 percent in both Malheur and Wallowa-Whitman National Forests. Most springs are unnamed, and many may not be perennial, especially during drier years. The number of springs is presented here to document the currently known occurrence of spring GDEs in the Blue Mountains. Although many more springs likely exist, such as rheocrene springs discharging directly to streams, they are not yet mapped.

Springs play a key role as groundwater discharge zones that deliver cool water to warming streams and support late-season streamflows in summer, and may deliver relatively warm water during winter months (Lawrence et al. 2014, Winter 2007). Using criteria developed by The Nature Conservancy, most streams and rivers in the Blue Mountains are at least partially groundwater dependent. Santhi et al. (2008) estimated that 59 percent of annual streamflow in the semiarid mountains of eastern Oregon is attributable to groundwater discharge. Locations of groundwater discharge to streams have been identified using remote sensing (Torgersen et al. 1999) and field techniques (Torgersen et al. 2012) but have not been systematically mapped (see chapter 4). The focus on stream temperature in relation to salmonid habitat has increased awareness of the ecological relevance and importance of groundwater discharge to streams and rivers.

Fens—

The Oregon Wetlands Geodatabase identified “potential fens” if a wetland, usually palustrine, occurred near a spring. To determine if these wetlands are indeed fens, each would require a field visit to determine that the wetland is supported (at least in part) by groundwater and that a minimum depth of peat (30 to 40 cm) has accumulated within the wetland (Chadde et al. 1998; USDA FS 2012a, 2012c). Fens occupy less than 1 percent of the Blue Mountains landscape (table 7.4), but they contribute substantially to regional biodiversity of plants and animals (Blevins and Aldous 2011). In an otherwise arid region, perennially saturated fens are critical habitat for invertebrate and amphibian species. Although not explicitly differentiated as fen vegetation, several herbaceous-dominated plant associations frequently occur in fens. These are underlain by organic soils and dominated by different sedge species, including Northwest Territory sedge, Cusick's sedge (*Carex cusickii* Mack. ex Piper & Beattie), Holm's Rocky Mountain sedge, and woodrush sedge (Crowe and Clausnitzer 1997).

Current condition of groundwater-dependent ecosystems—
Since 2008, 133 GDEs, mostly springs, have been inventoried and documented in the Blue Mountains national forests using draft and final versions of the Groundwater-Dependent Ecosystems Level I and Level II inventory methods (USDA FS 2012a, 2012b). The Level I guide (USDA FS 2012a) describes basic methods for assessing GDEs within a given area (e.g. national forest, ranger district, or specific project area) and is intended to qualitatively document the location, size, and basic characteristics of each GDE site. It also presents a "management indicator tool," described in more detail below. The Level II guide presents more detailed inventory (USDA FS 2012c) in addition to protocols for more comprehensive characterization of the vegetation, hydrology, geology, and soils at a given site.

In Malheur and Wallowa-Whitman National Forests, these inventories targeted strategically selected sites, because of concerns about disturbance and management, proposals for water development, and the high value of the resource. The GDE inventories in Umatilla National Forest targeted portions of grazing allotments and watersheds with specific management concerns. Most inventories in all three national forests used the Level 1 inventory protocol (USDA FS 2012b). As of 2014, eight Level II inventories have been conducted, including collection of quantitative vegetation data suitable for monitoring.

In Umatilla National Forest, Level I inventories were conducted at 102 GDEs. Nearly 72 percent of these GDEs were identified as rheocrene springs that discharge directly into stream channels (table 7.5). Helocrene springs were the second most common GDE type and typically support a larger, low-gradient wetland (0.1 to greater than 1 ha). Water diversions that withdrew emerging water away from the spring habitat or adjacent stream were observed at 46 of the inventoried springs (table 7.5). The amount of water diverted away from the GDE was estimated at 20 sites, averaging 93 percent of the available water at the time of sampling. Information on diverted water and other variables was not recorded at two of the 102 GDEs ("missing data"; table 7.5).

Table 7.5—Number of different types of groundwater-dependent ecosystems (GDEs) affected by water diversion for 102 GDEs in Umatilla National Forest

	GDEs[a]						
	Helocrene	Hillslope	Hypocrene	Mound	Rheocrene	Unclassified	Total
No permanent diversion	8	2	1	1	39	3	54
Permanent diversion[b]	5	2	0	1	33	5	46
Missing data	0	1	0	0	1	0	2
Total	13	5	1	2	73	8	102

[a] See text for definitions of GDE types.

[b] Permanent diversion includes some types of infrastructure that withdrew emerging water away from the spring habitat.

In the GDE Level I protocol (USDA FS 2012a), a series of 25 management indicator statements assist in identifying potential concerns and needs for management action based on observations recorded during field inventories. Information for the following three management indicators is presented for GDEs in Umatilla National Forest (table 7.6). Assessments for each of these are described in more detail in USDA FS (2012a):

- Aquifer functionality—There is no evidence to suggest that the aquifer supplying groundwater to the site is being affected by groundwater withdrawal or loss of recharge.
- Soil integrity—Soils are intact and functional; for example, saturation is sufficient to maintain hydric soils, if present, and erosion or deposition is not excessive.
- Vegetation composition—The site includes anticipated cover of plant species associated with the site environment, and upland species are not replacing hydric species.

Over 56 percent of the GDEs had evidence that aquifer functionality was compromised in some way, usually through groundwater extraction (table 7.6). Soil alterations in the form of ground disturbance, soil compaction, or soil pedestaling affected 24 percent of inventoried sites (soil integrity; table 7.6). Upland species cover was higher than expected in nearly 18 percent of the GDEs, suggesting that hydric species may have been replaced as a result of altered local hydrology.

Trails created by animals or people were noted in 44 percent of the sites, grazing/browsing by livestock was noted in 36 percent of sites, and grazing/browsing by wildlife was observed in 16 percent of sites. Thirty-one percent of the sites were disturbed through animal trampling. Disturbances were severe enough to question

Table 7.6—Selected management indicators for 62 groundwater-dependent ecosystem sites in Umatilla National Forest[a]

Management indicator	No concern	Issue of concern	Not applicable
Aquifer functionality	20	35	7
Soil integrity	42	15	5
Vegetation composition	47	11	4

[a] Sensu USDA FS 2012c. See text for explanation of management indicators.

the long-term functioning of the most severely impacted GDEs. In summary, the inventoried GDEs in Umatilla National Forest showed significant resource impacts through water diversion, soil disturbance, and livestock impacts on vegetation composition (table 7.6). The GDE inventories for Malheur and Wallowa-Whitman National Forests documented similar trends (data not shown).

In an assessment of GDEs in Oregon, Brown et al. (2009, 2010) examined existing data to determine distribution of GDEs and associated threats, focusing on water quantity and quality. They used the National Hydrography Dataset to identify locations of GDEs at the scale of hydrologic unit code 6 (HUC6), and focused their assessment on watersheds containing two or more types of GDEs (e.g., wetlands and rivers), which they termed "GDE clusters." To evaluate threats to water quantity supporting GDEs, they examined the extent of water extraction or pumping through permitted wells used primarily for irrigation, industrial, and municipal uses, and unregulated (exempt) wells, which are used for livestock and domestic purposes. Where possible, they incorporated pending groundwater pumping permits and projections of residential growth to assess future threats from groundwater extraction. They found that GDE clusters in the Grande Ronde Valley, which is largely surrounded by Wallowa-Whitman National Forest, are threatened by diminished groundwater quantity (Brown et al. 2009).

To evaluate threats to groundwater quality supporting GDEs, Brown et al. (2009, 2010) examined contamination by nitrogen and phosphorus (high levels of fertilizer use), pesticides, and other toxic chemicals, using the compiled information to locate where GDEs (and GDE clusters) may be threatened by contaminated groundwater. Based on location and type of surrounding industrial and agricultural land use, they estimated that 22 to 40 percent of the GDE clusters in the John Day, Malheur/Owyhee, and northeast Oregon HUCs were potentially at risk by groundwater contamination from pesticides or nutrients. Although most of the threatened GDE clusters they identified were located in agricultural valleys, not in national forests, contaminated groundwater may influence water quality in other portions of these basins, depending on physical features of the aquifers.

Potential Climate Change Effects

Riparian Areas and Wetlands

Changing climate in the Pacific Northwest is projected to alter streamflow in rivers and streams in a number of ecologically significant ways (see chapters 3 and 5). Warmer temperatures will influence changes in precipitation, evapotranspiration, and snow accumulation, timing, and rate of melt (chapter 3). Earlier spring snowmelt will affect the timing and magnitude of peak flows, leading to higher peak flows in winter (Mote et al. 2005). Summer low flows are projected to decrease throughout the West (Cayan et al. 2001, Luce and Holden 2009).

In this section, we describe the potential effects of climate change in special habitats in the Blue Mountains, based on research that has examined responses of riparian vegetation to hydrologic alteration, primarily dams and diversions, as described above. However, there is considerable uncertainty in our projections, because empirical data are lacking on specific mechanisms through which climate change will influence riparian and wetland plant communities in the Blue Mountains. Climate change is likely to affect diverse riparian/wetland plant communities differently, depending on elevation, location within the watershed, land use, and species composition. Shifts in riparian vegetation and reduction in riparian area will probably occur in response to changes in streamflow characteristics, direct effects of higher temperatures, and seasonal and spatial distributions of soil moisture independent of streamflow (atmospheric and non-alluvial groundwater) (box 7.1).

Reduced riparian extent could result in direct losses in quantity and quality of ecosystem services provided by riparian vegetation, such as wildlife habitat, recreational value, shade over streams, and buffer capacity for maintenance of stream water quality. Less quantifiable are the loss of aesthetic values associated with reduced riparian cover and changes in streamside species composition, vegetation and age-class structure. Reduced width of riparian areas associated with projected changes in streamflow characteristics (see chapter 3), increased severity and frequency of drought, and higher agricultural and municipal demands for water could result in lower buffer capacity between aquatic and upland habitats.

Conifer-dominated riparian areas—

In headwater portions of forested watersheds, riparian areas are frequently dominated by the same species as surrounding uplands, although stands may differ in age, stem density, and relative proportions of different species or size classes (Dwire et al. 2015). With progression of climate change, conifer-dominated riparian forests are increasingly subject to disturbances occurring in upland forests, including more numerous and severe fires and more frequent incidence of insect infestations.

In the Blue Mountains, Olson (2000) compared the fire history of upland and riparian forests, dominated by ponderosa pine, Douglas-fir, and grand fir. In these dry forest types, characterized by a low-severity fire regime, fires in riparian areas were slightly less frequent than in uplands of the same forest types, although, differences were not significant. Williamson (1999) studied fuel characteristics and potential for crown fire initiation (torching) in paired upland-riparian stands of ponderosa pine, Douglas-fir, grand fir, and subalpine fir in the Blue Mountains. The potential for torching was high in both upland and riparian forests of all forest types, suggesting that high-severity fire could extend downslope into the valley bottoms. With projected changes in fire intensity and severity, fuel conditions in riparian areas may not differ sufficiently from those in uplands to stop or reduce the intensity of large wildfires during hot, dry weather (Luce et al. 2012).

Increases in air temperature and changes in precipitation may result in drier streamside conditions, leading to stress in riparian trees.

Recent warmer climate has been associated with frequent and extensive insect outbreaks, as well as outbreaks in places where historical insect activity was low or unknown (Logan and Powell 2009; see chapter 6). Warming temperatures are projected to promote insect outbreaks in forested areas by increasing water stress in host trees while conferring physiological advantages to insects (Bale et al. 2002). Riparian trees, which grow in moist soils and cool microclimatic conditions, may be more resistant to insect infestation. However, climate-induced increases in air temperature and changes in precipitation may result in drier streamside conditions, leading to stress in riparian trees. In addition, high insect densities may overwhelm local resistance to attack, making host trees vulnerable despite location along a stream channel. Wildfire, an important forest disturbance that is directly influenced by climate change (Peterson et al. 2014, Westerling et al. 2006), can reduce the resistance of surviving trees to insect attack. In addition, insect-caused canopy mortality alters the amount, composition, and arrangement of fuels (Jenkins et al. 2008, 2012). As fire- and insect-caused mortality transform the structure of dry forests, effects on associated riparian forests may also become more prominent.

In a vulnerability assessment of forest trees in the Pacific Northwest, tree species were ranked by risk factors: distribution, reproductive capacity, habitat affinity, adaptive genetic variation, and threats from insects and disease (Devine et al. 2012). Each risk factor incorporated several variables evaluating the vulnerability of each species to climate change. Authors found that subalpine fir and Engelmann spruce, dominant conifer species in many high-elevation, forested riparian areas in the Blue Mountains, were rated as highly vulnerable to climate change (Devine et al. 2012).

Although some riparian conifer species could decline in cover, others may increase. For example, at lower elevations, ponderosa pine, grand fir, and Douglas-fir could increase in cover and density along drier floodplains.

Riparian and wetland aspen plant communities—

Quaking aspen is one of the few broadleaf deciduous trees in northeastern Oregon, providing vegetative diversity in the Blue Mountains region (Swanson et al. 2010). Its relative rarity, high value for wildlife, and colorful autumn foliage contribute to its aesthetic value. Over the last 25 years, many aspen stands in the Blue Mountains have been declining in number, area, and stem density (Swanson et al. 2010); similar dieback has been observed in other locations in western North America (Worrall et al. 2013). The reasons for broad-scale decline remain uncertain but may be related to low soil moisture in severely affected stands (Worrall et al. 2013; see chapter 6). In the Blue Mountains, aspen communities will likely continue to decrease in extent if climate-related changes reduce water availability, thus affecting streamflow characteristics, available groundwater, and drought conditions (see chapter 6).

Cottonwood-dominated riparian areas—

Black cottonwood is a fairly short-lived tree (Braatne et al. 1996) that likely depends on seasonal flooding for recruitment and stand replacement (Lytle and Merritt 2004, Mahoney and Rood 1998, Merigliano 2005, Shafroth et al. 1998), and on baseflow for stand maintenance (Lite and Stromberg 2005). Relationships between streamflow and aspects of cottonwood ecology have been described for different species, geomorphic settings, and regions in western North America, mostly in response to dams and other flow alterations (Auble et al. 1994, Braatne et al. 1996, Merritt and Cooper 2000). Research results have also indicated that numerous cottonwood populations are in serious decline, and that nonnative woody riparian species, notably tamarisk (*Tamarix* spp.), are expanding in distribution and displacing native cottonwoods throughout the Western United States, particularly along rivers with altered flow regimes (Friedman et al. 2005, Merritt and Poff 2010).

Although tamarisk is not currently an issue in national forests of the Blue Mountains, habitat suitability modeling suggests that riparian habitat for tamarisk will increase throughout the Pacific Northwest over the next century (Kerns et al. 2009), which could have negative consequences for native cottonwoods. Decreases in distribution and declines in the condition of cottonwood stands are likely for cottonwood-dominated riparian areas in the Blue Mountains in response to climate-related changes in availability of stream and groundwater, and increased frequency and severity of droughts. Many cottonwood stands are already compromised by limited recruitment, livestock grazing (Beschta and Ripple 2005), and floodplain conversion and development. Additional stress from climate-related changes in the hydrologic regime could have negative effects on the distribution and abundance of cottonwood.

Willow-dominated riparian areas—

Throughout the Western United States, willow-dominated riparian areas occur in broad valley bottoms, including unconfined and glaciated valleys with low slopes in montane and subalpine landscapes (Patten 1998, Rocchio 2006). Floods, streamflow, shallow subsurface drainage, and American beaver activities all contribute to maintenance of high water tables and willow dominance (Demmer and Beschta 2008, Gage and Cooper 2004). The relative importance of streamflow and hillslope discharge for maintenance of willow ecosystems depends on elevation, geology, season, and other factors (Westbrook et al. 2006, 2011; Wolf et al. 2007).

Climate-induced changes in precipitation could affect both streamflow characteristics and groundwater discharge and may result in the spatial contraction of willow communities and in local loss of species near limits of their distribution. Similar to most cottonwood species, many willow species are thought to be reproductive specialists, requiring open substrates with certain particle size distributions that are able to maintain soil moisture levels for germination and establishment (Karrenberg et al. 2002). Hydrologic modification of streams has altered flood frequency and duration along many riparian corridors, which has likely influenced the local recruitment and persistence of willows and contributed to the decline of some willow species and communities, particularly those in the “cold riparian shrub” PVG (table 7.2; see also Stromberg et al. 2010). Willow communities in the “warm riparian shrub” PVG tend to be dominated by clonal willow species that frequently establish and spread via vegetative propagules. However, clonal willow species depend on flow characteristics for creation and reworking of sand and gravel bars, where they frequently establish. In addition, drying of willow-dominated plant communities, in combination with higher air temperature and projected decreases in stream baseflow could reduce soil and foliar moisture and limit their ability to serve as fuel breaks during wildfires.

Other shrub-dominated riparian areas—

Depending on the species, some shrub-dominated riparian areas could increase in areal extent and displace more moisture-dependent vegetation, including willow communities and sedge-dominated meadow communities. Conifers could encroach into shrub-dominated riparian areas, particularly at lower elevations.

Herbaceous-dominated riparian areas—

Wetland herbaceous species are highly sensitive and responsive to water table elevation, which could become more variable and less predictable with changes in streamflow characteristics and increased frequency and severity of drought. In some locations, wet meadows could contract in area, and vegetation could shift from sedge-dominated communities to more drought-tolerant native and nonnative grasses and possibly shrubs. Changes in species composition and cover of riparian vegetation could have cascading effects on water quality by reducing infiltration of runoff, and on stream channel morphology by weakening bank stability.

Summary—

As noted above, climate change could influence riparian and wetland vegetation in the Blue Mountains in various ways (box 7.1), depending on species composition and physical setting, specifically valley bottom width and geometry and location within the stream network and watershed. Some riparian plant communities and associations could contract in area, many could change in species composition over time, and others could increase in cover. The following trends are expected:

- **Conifer-dominated riparian areas** will become more susceptible to drought, wildfire, and insect infestations. Shifts in latitudinal and altitudinal distribution of dominant conifers will likely track trends in uplands (see chapter 6). Conifer-dominated communities will increase in cover, particularly at lower elevations, encroaching on shrub-dominated riparian areas and herbaceous-dominated meadows.
- **Riparian and wetland aspen** plant communities will likely continue to decrease in extent and decline in vigor owing to drought and decreased water availability. Some populations (e.g., those associated with springs) may be lost because of altered local hydrology.
- **Cottonwood-dominated riparian areas** will decrease in extent. Reductions in late summer baseflows will likely compromise the persistence of existing stands. Changes in timing and magnitude of spring runoff could influence the recruitment and establishment of new individuals, thus affecting the replacement of existing stands.
- **Willow-dominated riparian areas** will decrease in extent as riparian width contracts in response to changes in frequency and magnitude of flooding, and lower water table late in the growing season as a result of lower baseflows. Changes in timing and magnitude of spring runoff could influence recruitment and establishment of new individuals, thus affecting

replacement of existing stands. Species composition of willow communities will likely shift, favoring the most drought-tolerant willows and other shrub species.

- **Other woody-dominated riparian areas** will increase in extent in some riparian areas, displacing more mesic willow species and communities, and favoring more drought-tolerant species. In communities dominated by more drought-tolerant species, encroachment of conifers could increase, possibly replacing some shrub species over time.
- **Herbaceous-dominated riparian areas** will decrease in extent as riparian width contracts in response to decreased water availability owing to lower baseflows, and changes in the magnitude, duration, and extent of flooding. Some sedge species will be replaced by more drought-tolerant (and grazing tolerant) native and nonnative grass species, and invasive species will likely increase in cover.

Increased warming will influence the amount, timing, and distribution of runoff, as well as groundwater recharge and discharge.

Groundwater-Dependent Ecosystems

Climatic variables affect hydrological processes, and in the Pacific Northwest, increased warming will influence the amount, timing, and distribution of runoff, as well as groundwater recharge and discharge (Elsner et al. 2010, Waibel et al. 2013). In the Blue Mountains, air temperatures are projected to become warmer during all seasons, with the largest increases occurring in summer (chapter 3), which will increase evapotranspiration in all ecosystems, including the special habitats discussed in this chapter. Snowpack is the main source of groundwater recharge in mountainous terrain (Winograd et al. 1998).

Higher minimum temperatures can reduce the longevity of snowpack, and decrease the length of time aquifer recharge can occur, potentially leading to faster runoff and less groundwater recharge. Groundwater recharge has been examined in only a few locations (Tague and Grant 2009), and little is known about groundwater recharge processes in many watersheds, including those that may be shifting from snow-dominated to more rain-dominated hydrologic regimes (Safeeq et al. 2013, 2014; see chapter 3). Snowmelt is generally considered a more efficient recharge agent than rainfall, so snow-to-rain shifts could potentially drive declines in groundwater recharge in snow-dominated areas (Earman and Dettinger 2011). Depending on elevation and the hydrogeologic setting, however, slowly infiltrating precipitation that includes both rain and snow may recharge some groundwater aquifers as effectively as rapid, seasonal snowmelt runoff. Although rain-on-snow zones are expected to shift upwards in elevation (see chapter 3), the influence of these shifts on groundwater recharge is unknown.

In the Blue Mountains, annual precipitation is projected to remain within the natural range of variability (see chapter 3). However, summers will be drier, the onset of snowmelt will be earlier (Luce et al. 2012), the rate of snowmelt will be more rapid, and the snow water equivalent (SWE) of snowpack will decrease (Folland et al. 2001; see chapter 3), all of which will influence snowpack volume. The biggest declines in snowpack persistence and April 1 SWE are projected to occur in mid elevations (see chapter 3). Although effects will differ considerably depending on local physical features and land use, these changes will likely affect groundwater recharge rates and, in turn, influence groundwater levels and the amount of groundwater available to support springs, groundwater-dependent wetlands, stream baseflows, and soil moisture (Ludwig and Moench 2009).

When assessing potential climate-induced changes to groundwater resources, recharge, and GDEs, it is critical to consider the hydrogeologic setting. Geologic units respond differently to changes in precipitation because of differences in hydraulic conductivity, transmissivity, primary vs. secondary porosity, and fracture patterns. In a study that combined examination of aerial photography (over 50 to 80 years) and climate analysis, Drexler et al. (2013) showed that five fens in the Sierra Nevada (California) decreased 10 to 16 percent in area. This decrease in GDE area occurred over decades with documented increases in annual mean minimum air temperature and decreases in SWE and snowpack longevity. However, two fens in the southern Cascade Range, underlain by different geology than the Sierra Nevada, did not change in area, suggesting that the hydrogeologic setting plays an important role in mediating changing climate variables on GDEs.

In the Blue Mountains, several different hydrogeologic categories can be delineated, including igneous/metamorphic, basalt, sedimentary, and older volcanic units (Gonthier 1985). Igneous and metamorphic rocks that exhibit low permeability and porosity, low-volume-groundwater discharges to GDEs, and are recharged only during large infrequent precipitation or snowmelt events, may not be very vulnerable to changes in temperature and precipitation regimes. However, aquifers in sedimentary or basalt formations, which generally have high permeability and porosity, larger volume discharges to GDEs, and are recharged more frequently, may be more sensitive to altered climate.

Small, unconfined aquifers, especially surficial and shallow aquifers, are more likely to have renewable groundwater on shorter time scales and may respond rapidly to changes in climate (Healy and Cook 2002, Lee et al. 2006, Sophocleous 2002, Winter 1999). Larger, deeper, and confined aquifers are more likely to have nonrenewable groundwater, may be less sensitive to the direct effects of climatic variability and change, and are projected to have a slower response (Wada et al. 2012). Hydrogeologic units in the Blue Mountains exhibit both confined and unconfined conditions. The deeper basalt units and older volcanic aquifers tend to be more confined (Gonthier 1985).

Groundwater storage can act as a moderator of surface water response to precipitation (Maxwell and Kollet 2008), and changes to groundwater levels can alter the interaction between groundwater and surface water (Hanson et al. 2012). Climate-induced changes in connectivity between groundwater and surface water could directly affect stream baseflows and associated wetlands and other GDEs (Candela et al. 2012, Earman and Dettinger 2011, Kløve et al. 2012, Tujchneider et al. 2012). Simulation modeling shows that short flow-path groundwater systems, including many that provide baseflow to headwater streams, could change substantially in the timing of discharge in response to changes in seasonality of recharge (Waibel et al. 2013). By contrast, regional-scale aquifer systems with flow paths on the order of tens of kilometers, are much less affected by shifts in seasonality of recharge (Waibel et al. 2013). These effects may be highly variable, and largely depend on local hydrogeology. In wetlands, changes in groundwater levels can lead to reduced groundwater inflow, leading to lower water table levels and altered wetland water balances. For local- and intermediate-scale systems, the spatial extent of some GDEs will likely contract in response to decreasing surface water and groundwater and increasing temperatures. Changes in groundwater and surface water will also vary depending on location within the watershed and stream network, as well as future land use.

Effects of changing climate on the ecology of GDEs will depend on changes in groundwater levels and recharge rates, as influenced by the size and position of groundwater aquifers (Aldous et al. 2015). The GDEs supported by small, local groundwater systems tend to exhibit more variation in temperature and nutrient concentrations than regional systems (Bertrand et al. 2012). Larger systems will likely be more resilient to climate change. Freshwater springs are dependent on continuous discharge of groundwater and form ecotones between subsurface-surface water and aquatic-terrestrial environments, which contribute to local and regional aquatic biodiversity (Ward and Tockner 2001). Springs and springbrooks are physically stable environments that support locally unique biological communities (Barquin and Death 2006). However, climate-induced changes in recharge rates may be reflected in decreased summertime flows with possible drying, as well as increased winter flow and associated flooding that could have negative impacts on biological communities (Green et al. 2011).

Taylor and Stefan (2009) estimated that groundwater temperatures would rise by up to 4 °C in a temperate region under a doubling of carbon dioxide. Because many biogeochemical processes are temperature dependent, climate-induced changes in groundwater temperature may negatively affect the quality of groundwater and, in turn, influence aquatic communities (Figura et al. 2011). However, because the thermal regime of groundwater systems is less dependent on air temperature patterns than surface waters, the effects of rising air temperatures are likely to be less pronounced in springs and other GDEs.

For fens, peat accumulating processes will be influenced by increasing temperatures and local and regional changes in hydrologic regime. Reduced groundwater levels tend to promote soil aeration and organic matter oxidation. Generation and maintenance of peat soils over time depend on stable hydrological conditions. In recent studies of peatlands exposed to groundwater lowering, responses such as soil cracking, peat subsidence, and secondary changes in waterflow and storage patterns have been observed (Kværner and Snilsberg 2011). Wetland plant species can respond to even slight changes in water table elevation (Magee and Kentula 2005, Shipley et al. 1991, Vitt et al. 1984), and shifts in composition of both vascular and bryophyte species could occur in fens with lowered water tables.

Land-use changes can alter watershed conditions and generate responses in biological communities and ecological processes, and in some cases, may override hydrologic modifications caused by large-scale climate shifts. As noted above for wetland and riparian ecosystems, effects of land use and management activities may have more immediate and detectable impacts on GDEs and the species they support than changing climate. For example, a recent study on spring-channel water diversion indicated that substantial decreases in physical and aquatic habitat occur with relatively small (10 to 20 percent) discharge reductions (Morrison et al. 2013). In the Umatilla National Forest, approximately 45 percent of inventoried springs undergo water withdrawals from the spring habitat (table 7.5). However, some spring organisms appear to be resilient to human-induced disturbances. Ilmonen et al. (2012) showed that invertebrate communities in springs affected by logging about 30 years prior to sampling did not differ appreciably from those in unaffected reference springs.

Management Context

Current Management Objectives and Desired Outcomes

Riparian areas and wetlands are protected under the Clean Water Act, which regulates the development and modification of floodplains; minimizes the destruction, loss, and degradation of wetlands; and enhances the natural and beneficial value of wetlands. Current management objectives for riparian areas in eastern Oregon are mainly informed by the aquatic strategies PACFISH and INFISH (USDA FS 1995, USDA FS and USDI BLM 1995) that were developed and adopted by the U.S. Forest Service and Bureau of Land Management. These strategies were considered short-term interim direction to protect native fish populations and their aquatic habitat. They will be revised by desired riparian conditions and management objectives with the adoption of new land management plans for all three national forests in the Blue Mountains.

Riparian goals in PACFISH and INFISH address water quality, stream channel integrity, instream flow, natural timing and variability of water-table elevation, diversity and productivity of riparian plant communities, and other riparian and aquatic habitat qualities necessary to support populations of inland native and anadromous fish. Riparian vegetation is to be maintained or restored to provide instream and riparian large wood, thermal regulation (including stream shading), and protection of floodplain surfaces and banks against uncharacteristic erosion. PACFISH and INFISH interim direction establishes riparian management objectives (RMOs) for all watersheds that include inland native or anadromous fish. These RMOs describe habitat conditions as a range of features that need to be met or exceeded. The key feature is pool frequency that varies by channel width. Supporting features include maximum water temperature, instream large wood, width-depth ratios, and measures of bank stability and bank angle. In the absence of site-specific watershed analysis, the RMOs provide a benchmark for all management actions and apply to all Riparian Habitat Conservation Areas (RHCAs), including streams with and without fish, wetlands, and intermittent streams.

The U.S. Forest Service groundwater management program has made progress in increasing awareness of the importance and vulnerability of groundwater resources, and providing guidance on identify, assessing, and analyzing of GDEs (USDA FS 2012a,c). National forests in the Blue Mountains are still in the early stages of identifying and understanding the extent of groundwater resources, as well as potential threats. However, resource managers are increasingly considering GDEs in watershed assessments and project-level planning.

Management Practices

The establishment of RHCAs has altered management priorities to put primary emphasis on riparian-dependent resources. Management activities in RHCAs are subject to specific standards and guidelines that limit timber harvest (including fuelwood cutting). Consequently, fuel management, timber sales, and forest restoration projects commonly exclude RHCAs from any treatment. This management approach may be creating uncharacteristic fuel conditions within some riparian corridors (Messier et al. 2012, Meyer et al. 2012). Avoiding active management within RHCAs that have been altered by fire suppression and streamflow regulation (dams, roads, culverts, diversions) could further influence disturbance regimes and contribute to more uniform, late-seral forest structure, or to increased fire hazard. This management approach could also affect postdisturbance conditions, resulting in decreased riparian plant diversity over time.

In upland forest watersheds where fuel treatments are implemented, it might be beneficial to include adjacent riparian areas for treatments.

In upland forest watersheds where fuel treatments are implemented, it might be beneficial to include adjacent riparian areas for treatments (Meyer et al. 2012) to avoid concentration of fuels in streamside areas. Although treating fuels in riparian areas can potentially affect desired functions and ecosystem services (Dwire et al. 2010) (table 7.1), research has indicated that effects of prescribed fire are largely short term (Arkle and Pilliod 2010, Béche et al. 2005). However, the effects of other fuel reduction treatments (e.g., mechanical thinning or various treatment combinations) on stream and riparian attributes have not been evaluated.

The RHCA standards and guidelines require adjustment or elimination of grazing practices that are inconsistent with attainment of RMOs but appear to have a smaller effect on management practices compared to timber management. The requirements have resulted in increased fencing of sensitive riparian and wetland resources within grazing allotments. Other management actions include active movement of cattle out of riparian zones, and placement of cut conifers to discourage access to treated aspen stands and streamside meadows. To monitor the effects of grazing practices and ensure that they do not prevent the attainment of RMOs, national forests have implemented riparian monitoring protocols such as Multiple Indicator Monitoring (Burton et al. 2011) in addition to PACFISH/INFISH effectiveness monitoring.

Adapting Special Habitats to Climate Change in the Blue Mountains

Management strategies and tactics for increasing resilience of vegetation in the Pacific Northwest to a warmer climate are well documented (e.g., Gaines et al. 2012; Halofsky et al. 2011; Littell et al. 2012, 2014; Raymond et al. 2013, 2014; see chapter 6). Although adaptation options for habitats associated with special hydrologic conditions are a small part of this knowledge base, these habitats have a disproportionately large effect on biological diversity in the region. Adaptation options for water resources (Dalton et al. 2013, Halofsky et al. 2011, Strauch et al. 2014; see chapter 4) are often synonymous with, or related to, adaptation options relevant for special habitats (e.g., maintaining and restoring instream flows). These sources of information, combined with feedback from resource specialists, contributed to a summary of climate change adaptation options for special habitats in the Blue Mountains (tables 7.7, 7.8, and 7.9). Implementation of climate-smart management actions and restoration objectives will benefit from a strategic approach to ensure that the most important work is occurring in the most important places (Hughes et al. 2014). Because special habitat conservation is at the interface of vegetation and stream restoration, opportunities exist for coordination of restoration programs and on-the-ground actions.

Riparian Areas and Wetlands

The productivity of wetland and riparian ecosystems could decrease in the future as a result of increased evapotranspiration and reduced snowpack, causing lower water supply during the growing season and more variable streamflow. Maintaining appropriate densities of native species, propagating drought-tolerant native species, and controlling or eliminating nonnative species are strategies that may increase riparian resilience to a warmer climate (tables 7.7 and 7.8). It would also be beneficial to plant species that have a broad range of moisture tolerances, such as Lewis' mock orange (*Philadelphus lewisii* Pursh) and choke cherry (*Prunus virginiana* L.), which are resistant to variable water availability during the growing season. Finally, removing infrastructure (e.g., campsites, utility corridors, spring houses, and spring boxes) from riparian areas and wetlands will reduce soil compaction and other physical damage, thus allowing natural physical processes to occur and improving hydrologic function. Opposition by the public to facilities removal is likely, so relocation (rather than removal) of some facilities to areas with less environmental impact can be considered.

Improving soil health and bank stability to reduce erosion and enhance native vegetation is an adaptation strategy that would improve riparian conditions (Kauffman et al. 2004). The most important measure is to reduce degradation of riparian areas by livestock through fencing and rest-rotation grazing. Livestock grazing has caused considerable damage to riparian systems over many decades, and efforts to repair and reduce this damage will improve resilience, although opposition from range permittees is likely if changes are instituted. Along stream segments with highly valued deciduous riparian vegetative cover, fencing to exclude native ungulates could also be considered. Elk and deer are frequently able to enter enclosures or riparian areas that have been fenced to exclude cows.

Table 7.7a—Adaptation responses to climate change for riparian and wetland systems in the Blue Mountains

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
Sensitivity to climatic variability and change: Shifts in hydrologic regime include changes in timing and magnitude of flows, lower summer flows and higher, more frequent winter peak flows. Reduced snowpack will decrease water supply during growing season and lead to more variable streamflow, thus reducing productivity in riparian ecosystems.				
Adaptation strategy: Maintain appropriate densities of native species, and propagate more drought-tolerant native species.				
Plant species that have a broader range of moisture tolerance (e.g., mock orange, choke cherry)	10 to 30 years, >30 years	Collaborate with Idaho Power, range permittees, and private landowners	High cost Limited availability of local plant material	Identify segments along stream-riparian corridors with need for shade that meet growth requirements of desirable woody species
Eradicate and control invasive species where possible (especially after fire)	<10 years, 10 to 30 years	Collaborate with range permittees, private landowners, counties, and Idaho Power	High cost	Identify riparian areas (stream segments) with high cover of most noxious nonnative species; prioritize treatment areas
Remove infrastructure where appropriate (e.g., campsites, utility corridors, springhouses, and spring boxes)	<10 years	Various management plans	High cost Public opposition; constraints of existing water rights for modifying spring developments	Identify infrastructure that can be removed; prioritize decommissioning and removal
Adaptation strategy: Maintain or restore natural flow regime to buffer against future changes.				
Develop integrated, interdisciplinary tactics to maintain or restore natural flows; purchase and obtain instream flow rights where possible	<10 years	Collaborate with nongovernmental organizations, other federal and state agencies, and private landowners	Competing priorities; lack of funding	Using watershed analysis, watershed condition framework, or other approaches to identify priority watersheds and stream segments

Table 7.7a—Adaptation responses to climate change for riparian and wetland systems in the Blue Mountains (continued)

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
Restore riparian areas and beaver populations to maintain summer baseflows and raise water table	<10 years to >30 years	Collaborate with states, range permittees, and private landowners regarding beaver reentry Use range allotment management, riparian shrub planting and protection, riparian aspen restoration and management, road infrastructure planning, and valley form analysis to assess potential sites for beaver colonies and channel migration	Effects on infrastructure (culverts and diversions) Adequate food supply for growing beaver colonies and dispersing individuals Public and private landowner acceptance of beaver colonies Effects of rising water levels on streamside roads and camping grounds	Improve geographic information system (GIS) layer for distribution of riparian community types relative to valley bottom classification Identify watersheds and stream reaches with highest potential for successful establishment Monitor beaver populations Inventory riparian vegetation and stream morphology status and trends
Address water loss at points of water diversion and along ditches	<10 years	Coordinate with the water district managers, water master, and water users	Competing priorities Lack of funding Water law does not address ditch water loss, inefficiencies, and other impacts on forest resources	Identify diversions/and ditches with water losses or other impacts on forest resources
Anticipate new proposals for development of water infrastructure (additional diversions or reservoir expansions)	<10 years	Develop approach for protection of streamflow and maintenance of water levels in wetlands	Competing priorities Constraints of water laws	Identify priority watersheds and stream reaches; define flows required for sediment transport, and maintenance of riparian and wetland vegetation and aquatic habitat
Reconnect and increase off-channel habitat and refugia in side channels and channels supported by sideslope wetlands	<10 to >30 years	Collaborate with partners	Competing priorities Lack of funding	Identify potential watersheds and stream reaches

Table 7.7a—Adaptation responses to climate change for riparian and wetland systems in the Blue Mountains (continued)

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
Revegetate; fence to exclude livestock; acquire water rights	<10 years	Collaborate with partners to fence or acquire or lease water rights Revegetate and protect riparian areas Restore aspen	Competing priorities Lack of funding Difficulty of maintaining livestock and ungulate exclusions	Investigate baseline vs. desired conditions in riparian corridors Conduct effectiveness monitoring Identify water rights holders willing to collaborate
Adaptation strategy: Improve soil health (including bank stability) and increase resilience of native vegetative communities to maintain natural water storage.				
Reduce degradation by livestock; fence riparian areas, and use rest rotation	Ongoing	Adjust range allotment management where possible; collaborate with range permittees and private landowners	Public opposition	Identify stream-riparian reaches for fencing, or changes in grazing management
Manage fuel loads through various prescriptions (prescribed fire, mechanical treatments)	10 to 30 years	Forest plans for fire and fuels management	High cost Logistical challenges of prescribed fire use in riparian areas	Quantify riparian fuel loads (relative to uplands) and effectiveness of various fuel reduction treatments

Table 7.7b—Adaptation responses to climate change for high-elevation riparian systems in the Blue Mountains

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
Sensitivity to climatic variability and change: Reduced snowpack will decrease water supply during growing season and lead to more variable streamflow, thus reducing productivity in riparian systems in alpine and subalpine ecosystems.				
Adaptation strategy: Reduce stresses such as conifer encroachment, livestock grazing, and ungulate browsing.				
Consider riparian fuel reduction strategies in forested subalpine areas, including small-scale fuel breaks	<10 years	Coordination with other fuels management and restoration projects	Logistical constraints	Assessment of riparian fuel characteristics Identify strategic locations for fuel breaks
Reduce degradation by livestock	Ongoing	Adjust range allotment management where possible; collaborate with range permittees and private landowners	Public opposition	Identify stream-riparian reaches for fencing, or changes in grazing management

Table 7.7c—Adaptation responses of groundwater-dependent ecosystems (GDEs) to climate change in the Blue Mountains

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
Sensitivity to climatic variability and change: Reduced snowpack will decrease water supply during growing season, thus reducing productivity in groundwater-dependent systems, including springs and wetlands.				
Adaptation strategy: Manage for resilience of springs and wetlands by considering the broader forest landscape including uplands.				
Consider impacts and potential benefits of vegetation management treatments (prescribed fire, mechanical thinning)	<10 years	Coordination with other fuels management and restoration projects	Lack of scientific and site-specific information on spring ecology	Inventory and characterization of springs, other GDEs and surrounding forest conditions
Protect groundwater recharge areas	<10 years	Explore opportunities with range permittees, nongovernmental organizations, and others	Limited information on locations of springs, recharge areas, and groundwater input to stream channels Lack of funds to address sites affected by livestock Competing priorities	Locate and characterize GDE and spring influences
Adaptation strategy: Manage water to maintain springs and wetlands; improve soil quality and stability.				
Decommission roads and reduce road connectivity to encourage interception and retention of water	<10 years	Incorporate into forest plans as watershed improvement strategy	High cost Public opposition Competing priorities	Identify and prioritize project areas
Reduce ungulate trampling with fencing	<10 years	Work with range permittees, watershed councils, and other partners to fund or install fencing	High cost Need for maintenance	Identify and prioritize springs and wetlands for fencing Monitor effectiveness of fencing projects
Maintain water on site through water conservation techniques such as float valves, diversion valves, and hose pumps	<10 years	Incorporate into forest plans as watershed improvement strategy; specify in allotment management plans	Range permittees do not like these practices	Identify permittees and water users who are willing to collaborate
Encourage spring development project designs that will ensure environmental flows for native species and habitat	<10 years	Proposed, new, or redeveloped livestock watering projects		Conduct environmental flow/level analysis

Table 7.7c—Adaptation responses of groundwater-dependent ecosystems (GDEs) to climate change in the Blue Mountains (continued)

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
• Collect no more water than is sufficient to meet the intended purpose of the spring development	<10 years	Proposed, new, or redeveloped livestock watering projects		Conduct environmental flow/level analysis
• Include implementation and effectiveness monitoring to evaluate success of the project in meeting design objectives and avoiding or minimizing unacceptable impacts to spring ecology	<10 years	Incorporate into forest plans as watershed improvement strategy		
• Use suitable measures to maintain desired downstream temperatures, dissolved oxygen levels, and aquatic habitats when water is released from a pond trough or impoundment.	<10 years	Proposed, new, or redeveloped livestock watering projects		
• Use float valves or other flow control devices to provide flow only when a demand is present	<10 years	Incorporate into forest plans as watershed improvement strategy		
• Use a flow-splitting device to retain as much flow in the spring and associated habitat as possible	<10 years	Proposed, new, or redeveloped livestock watering projects		
• Consider discontinuing use of a water resource in critical habitats	<10 years	Allotment management plan revision		Ecological assessment
Relocate water troughs away from springs and riparian areas to limit trampling.	<10 years	Proposed, new, or redeveloped livestock watering projects		
Change the duration, season, or intensity of grazing if the current grazing strategy inhibits natural recovery at a given site	<10 years	Allotment management plan revision		Determine the duration, season, and intensity of grazing with the least impact for a given site

Riparian areas and wetlands are important components of alpine and subalpine ecosystems. In these systems, an important adaptation strategy is to reduce existing stresses, such as conifer encroachment, livestock grazing, and ungulate browsing (table 7.8). Specific adaptation tactics include controlling livestock grazing and removing nonnative species where feasible, especially following wildfire. Collaboration with range permittees, fire and fuels managers, and coordination with ongoing restoration activities, will enhance the effectiveness of adaptation actions.

Groundwater-Dependent Ecosystems

Reduced snowpack could decrease water supply, potentially reducing productivity in all types of GDEs. The primary strategy for increasing resilience in GDEs is to manage for their functionality in the spatial context of the broader forest landscape (table 7.9), because the structure and function of GDEs are largely influenced by surrounding vegetation and hydrology. An adaptation strategy is to maintain GDEs by maintaining water supply and improving soil quality and stability. This can be accomplished through three different tactics. First, decommissioning roads and reducing road connectivity is likely to increase interception of precipitation and local retention of water. Second, trampling of GDEs by domestic livestock and native ungulates can be better managed with fencing. Third, water can be maintained at developed spring sites through improved engineering, including use of float valves, diversion valves, and pumps. These tactics require significant costs, and there may be opposition to road removal and grazing restrictions by the public and range permittees.

As ecosystems, GDEs are understudied, primarily because subterranean systems are difficult to access. The scientific community is in early stages of research and management of these ecosystems and faces important knowledge gaps. The current lack of knowledge on groundwater has limited the consideration of groundwater resources in integrated forest planning, inventory, monitoring, and permitting. A framework for managing groundwater resources in national forests is needed, one that includes a more consistent approach for evaluating and monitoring the effects of management actions on groundwater. With respect to conservation of GDEs, guidance on how groundwater resources are considered in agency activities is needed, and will require evaluation of potential effects of groundwater withdrawals on national forest resources. Guidance should also provide a strategy through which groundwater and vegetation can be jointly managed, thus facilitating management of riparian areas, wetlands, and GDEs in a warmer climate.

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