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Riparian and Groundwater-Dependent Ecosystems of the Humboldt-Toiyabe National Forest: An Assessment of Current Conditions

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Abstract

This assessment provides information on the conditions of riparian and groundwater-dependent ecosystems in the Humboldt-Toiyabe National Forest (HTNF). We summarized dominant riparian community types and described riparian fish and wildlife habitat. We used peer-reviewed literature, data from the national forest and other partners, and site visits to inventory and map the distribution of riparian and groundwater-dependent ecosystems, as well as to evaluate the status of five key ecosystem characteristics: (1) surface water and groundwater fluctuations, (2) water quality, (3) channel and floodplain dynamics, (4) spring runout channel condition, and (5) composition and structure of riparian and groundwater-dependent ecosystems. Extensive riparian ecosystems were found in the Northern Mountains, Ruby Mountains, and Sierra Nevada. Springs are abundant across the forest, and the density of fens is greatest in the Sierra Nevada and Ruby Mountains. Streams in the HTNF likely maintain high water quality, despite widespread alteration of hydrologic fluctuations and channel dynamics. The composition and structure of riparian vegetation is consistent across the forest. Although expected species and communities are present, unsuitable levels of native and nonnative species occur. We determined that grazing and road infrastructure were primary stressors to riparian and groundwater-dependent ecosystems. Our results support the ecosystem assessment completed during the forest plan revision process and can help inform decision making related to the restoration and maintenance of riparian and groundwater-dependent ecosystems on the HTNF.

Keywords: forest plan, key ecosystem characteristic, riparian vegetation, flow regime, channel morphology, floodplain, natural range of variation

Cover: West Fork Carson River, photographed in October of 2019, in the Sierra Nevada geographical unit of the Humboldt-Toiyabe National Forest. USDA Forest Service photo by D. Max Smith.

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INTRODUCTION

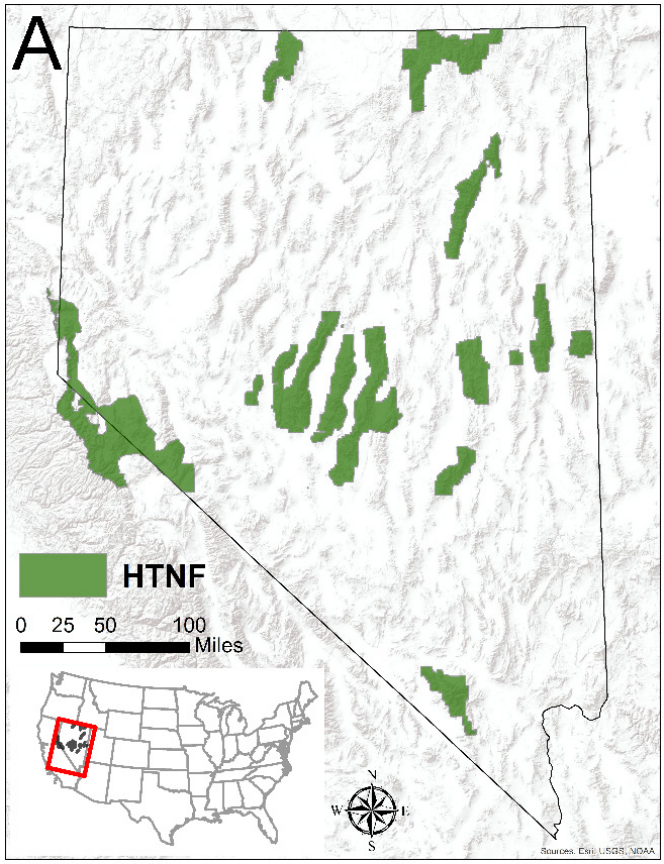
Background and Objectives

We completed an assessment of riparian and groundwater-dependent ecosystems (GDEs) in partial fulfillment of an agreement between the Forest Service, U.S. Department of Agriculture (hereafter, Forest Service) Intermountain Region and the Rocky Mountain Research Station. Our aim was to provide support during the revision of management plans for national forests under the 2012 Planning Rule (36 CFR 219; USDA FS n.d.a). Our methods meet the planning rule requirements for a rapid assessment of ecological integrity—"the quality or condition of an ecosystem when its dominant ecological characteristics occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influence"—while using only existing information and data (USDA FS n.d.a). We addressed the structure, function, composition, and connectivity of terrestrial and aquatic ecosystems, along with drivers and stressors. The planning rule uses an "all-lands approach" because study systems cross administrative boundaries. Additionally, it requires consideration of how actions by a national forest impact resources beyond the boundary and how conditions outside the national forest influence resources within the boundary.

We prepared the assessment to assist the Humboldt-Toiyabe National Forest (HTNF; the Forest) in understanding ecological conditions under the current land management plan. Assessments, as well as monitoring data, new information, changed conditions, or changed circumstances, can be used as preliminary identification of the need to change a forest plan (36 CFR 219.12; USDA FS n.d.a). The assessment includes descriptions of the dynamics and distribution of riparian ecosystems and GDEs and addresses several key ecosystem characteristics (KECs): surface water and groundwater fluctuations, water quality, channel and floodplain dynamics, spring runout channel condition, and composition and structure of riparian areas and GDEs.

Scale of Assessment

We completed our assessment of riparian ecosystems and GDEs at two spatial scales: the HTNF (fig. 1a) and seven ecological geographic units within the Forest: the Central Mountains, East Sierra, Eastern Mountains, Northern Mountains, Ruby Mountains, Sierra Nevada, and Spring Mountains National Recreation Area (SMNRA; fig. 1b). We further divided some geographic units into separate areas for spatial analyses. For this assessment, we conducted analysis within 12-digit hydrologic unit code (HUC) subwatersheds (i.e., watersheds roughly 36 square miles in area), evaluated KECs at the scale of the ecological geographic units, and summarized results for the Forest. Note that percentages may not sum to 100 due to rounding.



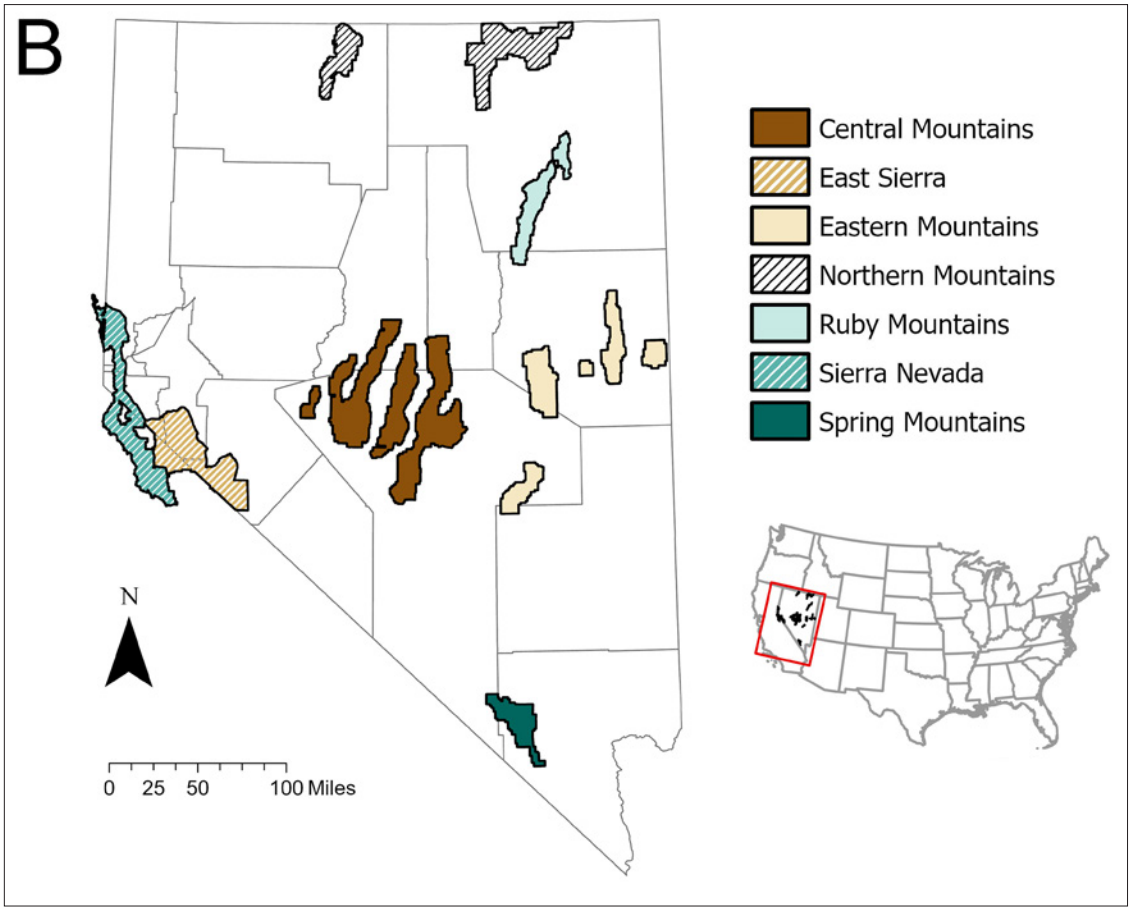


Figure 1—This assessment was completed at two spatial scales: (a) the Humboldt-Toiyabe National Forest and (b) seven ecological geographic units.

Study Area

The 6.3-million-acre HTNF is located throughout Nevada and extends into eastern California. Thirty-three level IV ecoregions are present on the Forest (table 1). These areas summarize ecosystems of differing geologies, landforms, soils, vegetation, climate, land use, wildlife, and hydrology, which ultimately influence the quality and integrity of terrestrial and aquatic ecosystems (Omernik 1987). The predominant ecoregions for each of the seven geographic units are described in the following sections.

Table 1—The percentage of each ecological geographic unit classified as different level IV ecoregions.

Ecological Geographic Unit	Central Mountains	East Sierra	Eastern Mountains	Northern Mountains	Ruby Mountains	Sierra Nevada	SMNRA	HTNF
Amargosa Desert	—	—	—	—	—	—	2	<1
Carbonate Sagebrush Valleys	—	—	8	—	2	—	—	1
Carbonate Woodland Zone	—	—	65	—	18	—	—	11
Central Nevada Bald Mountains	27	—	—	—	—	—	—	9
Central Nevada High Valleys	27	—	—	—	—	—	—	9
Central Nevada Mid-Slope Woodland and Brushland	45	—	—	—	—	—	—	14
Dissected High Lava Plateau	—	—	—	3	—	—	—	<1
Eastern Mojave Basins	—	—	—	—	—	—	<1	<1
Easern Mojave High Elevation Mountains	—	—	—	—	—	—	16	1
Eastern Mojave Low Ranges and Arid Footslopes	—	—	—	—	—	—	23	1
Eastern Mojave Mountain Woodland and Shrubland	—	—	—	—	—	—	59	3
Eastern Sierra Great Basin Slopes	—	—	—	—	—	4	—	1
High Elevation Carbonate Mountains	—	—	26	—	4	—	—	4

Table 1 continued.

Ecological Geographic Unit	Central Mountains	East Sierra	Eastern Mountains	Northern Mountains	Ruby Mountains	Sierra Nevada	SMNRA	HTNF
High Elevation Ruby Mountains	—	—	—	—	18	—	—	1
High Lava Plains	—	—	—	15	—	—	—	2
Lahontan Salt Shrub Basin	<1	6	—	—	—	—	—	1
Mid-Elevation Ruby Mountains	—	—	—	—	54	—	—	4
Northeastern Sierra Mixed Conifer-Pine Forests	—	—	—	—	—	38	—	5
Northern Sierra Subalpine Forests	—	—	—	—	—	11	—	1
Northern Sierra Upper Montane Forests	—	—	—	—	—	—	—	1
Partly Forested Mountains	—	—	—	6	—	—	—	1
Semiarid Uplands	—	—	—	72	—	—	—	11
Sierra Nevada-Influenced High Elevation Mountains	—	11	—	—	—	<1	—	2
Sierra Nevada-Influenced Ranges	—	53	—	—	—	12	—	8
Sierra Nevada-Influenced Semiarid Hills and Basins	—	23	—	—	—	16	—	5
Sierran Alpine	—	—	—	—	—	4	—	1
Southern Sierra Subalpine Forests	—	—	—	—	—	5	—	1
Tonopah Basin	<1	2	<1	—	—	—	—	<1
Tonopah Sagebrush Foothills	—	4	—	—	—	—	—	1
Tonopah Uplands	—	<1	—	—	—	—	—	<1

Table 1 continued.

Ecological Geographic Unit	Central Mountains	East Sierra	Eastern Mountains	Northern Mountains	Ruby Mountains	Sierra Nevada	SMNRA	HTNF
Upper Humboldt Plains	—	—	—	3	2	—	—	1
Upper Lahontan Basin	—	—	—	<1	—	—	—	<1
Wetlands	—	—	—	—	<1	—	—	<1

— Indicates ecoregion is not present within the HTNF unit.

Central Mountains

The Central Mountains unit is part of the Basin and Range Physiographic Province. These areas drain internally and tend to have intermediate temperature and moisture regimes compared to other Basin and Range systems (Bryce et al. 2003). Watersheds throughout the Central Mountains tend to be large, with wide valley bottoms (Board et al. 2020). Compared to other regions within Nevada, these lands receive relatively high annual precipitation, and the proportion of streams with perennial flow is higher (Board et al. 2020). Five level IV ecoregions are present within the Central Mountains unit, with most of the landscapes classified as Central Nevada Mid-Slope Woodland and Brushland, Bald Mountains, and High Valleys (table 1).

Central Nevada Mid-Slope Woodland and Brushland characterizes nearly half of the Central Mountains unit (figs. 2, 3), and is the most common ecoregion present on the HTNF, occupying 14 percent of the area. This ecoregion consists of pinyon-juniper woodland communities growing on mountain slopes and summits at elevations between 6,500 and 8,000 feet (Board et al. 2020; Bryce et al. 2003). Average January temperatures in the Mid-Slope Woodlands and Brushlands range from 17 °F daily minimum to 40 °F daily maximum, and average July temperatures range from 50 °F daily minimum to 84 °F daily maximum (Bryce et al. 2003). This ecoregion receives an average of 12 to 18 inches of annual precipitation. Perennial and intermittent streams in the Mid-Slope Woodlands and Brushlands tend to have moderate gradients and are fed by snowmelt and discharge from springs. Riparian vegetation communities include cottonwood (*Populus* spp.), aspen (*Populus tremuloides*), water birch (*Betula occidentalis*), chokecherry (*Prunus virginiana*), and coyote willow (*Salix exigua*) (Bryce et al. 2003).



Figure 2—The Mid-Slope Woodland and Brushlands ecoregion contains meadows surrounded by pinyon-juniper uplands. USDA Forest Service photo by Wendy Trowbridge.

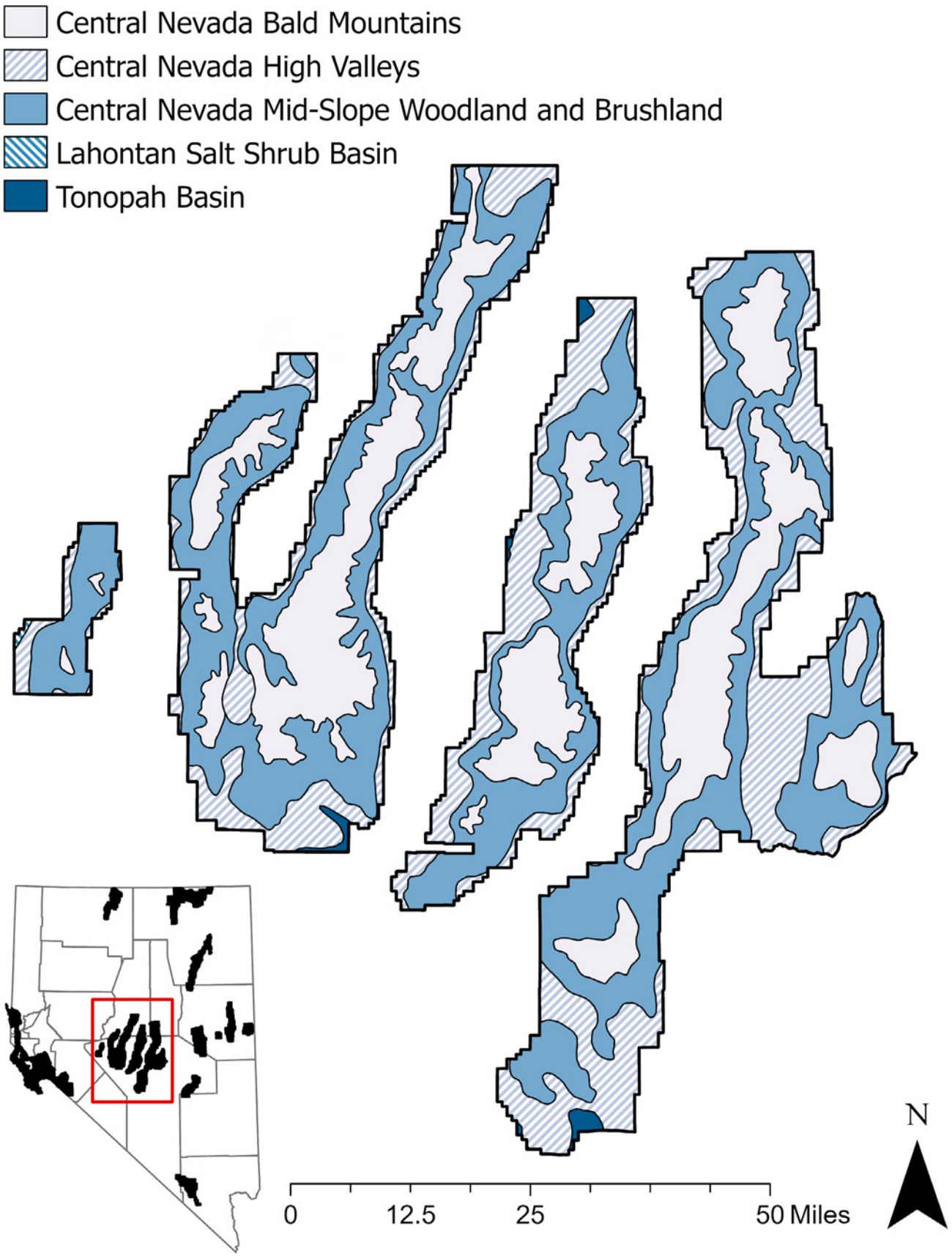


Figure 3—Level IV ecoregions of the Central Mountains unit.

The Central Nevada Bald Mountains and the Central Nevada High Valleys occupy about one-quarter of the Central Mountains unit. They also represent the fourth and fifth largest ecoregions present on the HTNF, respectively. The Bald Mountains consist of shrub communities including sagebrush (*Artemisia* spp.), bitterbrush (*Purshia tridentata*), snowberry (*Symphoricarpos* spp.), and mountain-mahogany (*Cercocarpus ledifolius*) growing on moderate to steep mountain slopes and ridges (Board et al. 2020; Bryce et al. 2003). Average January temperatures range from 18 °F daily minimum to 38 °F daily maximum and average July temperatures range from 48 °F daily minimum to 78 °F daily maximum (Bryce et al. 2003). These areas receive from 14 to over 25 inches of annual precipitation (Bryce et al. 2003). Moderate and high-gradient headwater streams throughout the Bald Mountains are fed by snowmelt and discharge from springs. Water temperatures in these systems can vary widely, providing both warm- and cold-water fishery habitat (Bryce et al. 2003).

The Central Nevada High Valleys are characterized by sagebrush and grassland communities in rolling valleys between 5,000 and 7,000 feet in elevation (Board et al. 2020; Bryce et al. 2003). The average January temperatures range from 12 °F daily minimum to 44 °F daily maximum and average July temperatures range from 48 °F daily minimum to 94 °F daily maximum (Bryce et al. 2003). These areas receive 8 to 20 inches of annual precipitation. Low gradient, spring- and snowmelt-fed intermittent streams occur in some locations within the High Valleys, though the ecoregion generally lacks riparian habitats (Bryce et al. 2003).

Two additional ecoregions are present in the Central Mountains unit (fig. 3); however, they occupy very small proportions of the landscape (table 1). Both the Lahontan Salt Shrub Basin and the Tonopah Basin are described in the next section, “East Sierra,” which covers the unit where these ecoregions are more prevalent.

East Sierra

Like the Central Mountains, the East Sierra unit is part of the Basin and Range features of Nevada. This area is composed of Great Basin hills, basins, and mountains that are influenced by the climate and biology of the Sierra Nevada (Bryce et al. 2003). The Sierra Nevada rain shadow has variable effects, with some of the high-elevation ranges likely to support perennial streams (Bryce et al. 2003). Seven level IV ecoregions are present in the East Sierra unit, with most of the landscape classified as Sierra Nevada-Influenced High Elevation Mountains, Ranges, and Semiarid Hills and Basins (table 1).

The Sierra Nevada-Influenced Ranges (fig. 4) occupy about half of the East Sierra unit and about 8 percent of the HTNF. These areas consist of pinyon, juniper, and sagebrush communities growing on mountain slopes, crests, ridges, and plateaus ranging from 6,500 to 9,000 feet in elevation (Bryce et al. 2003). Average January temperatures range from 19 °F daily minimum to 42 °F daily maximum and average July temperatures range from 49 °F daily minimum to 81 °F daily maximum (Bryce et al. 2003). This ecoregion receives 10 to 16 inches of annual precipitation. Small lakes, seasonal pools, and medium- to high-gradient, cold-water streams provide wildlife habitat throughout this ecoregion, with perennial streams tending to occur at higher elevations (Bryce et al. 2003).

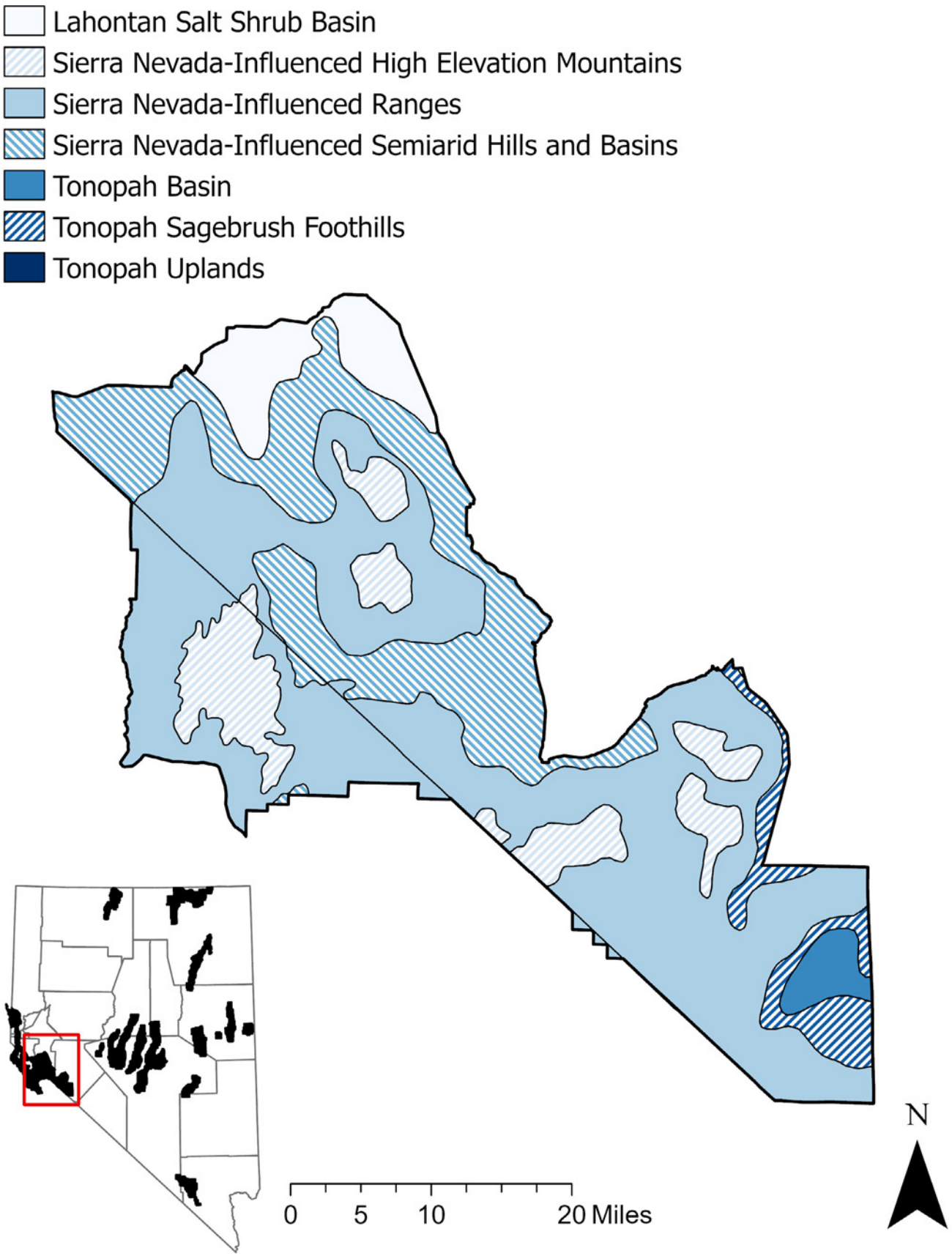


Figure 4—Level IV ecoregions of the East Sierra unit.

Almost one-quarter of the East Sierra unit is composed of the Sierra Nevada-Influenced Semiarid Hills and Basins ecoregion (fig. 4). These areas are characterized by Great Basin sagebrush communities growing on terraces, floodplains, hills, alluvial fans, bajadas, mountain flanks, and canyons between 4,000 and 6,400 feet in elevation (Bryce et al. 2003). Average January temperatures range from 16 °F daily minimum to 46 °F daily maximum and average July temperatures range from 48 °F daily minimum to 92 °F daily maximum. These areas receive 7 to 15 inches of annual precipitation. Snowmelt and spring discharge feed perennial streams with cold temperatures and moderate to high gradients (Bryce et al. 2003).

The third most common ecoregion present in the East Sierra unit is the Sierra Nevada-Influenced High Elevation Mountains (fig. 4). These areas consist of sagebrush and subalpine-alpine forb communities growing on mountains, ridges, hills, and plateaus at elevations above 9,000 feet (Bryce et al. 2003). Average January temperatures range from 16 °F daily minimum to 39 °F daily maximum and average July temperatures range from 45 °F daily minimum to 76 °F daily maximum. These areas typically receive 12 to more than 20 inches of annual precipitation. The streams present in the High Elevation Mountains tend to be high-gradient, cold-temperature headwaters fed by snowmelt and discharge from springs (Bryce et al. 2003).

Four additional ecoregions are present in the East Sierra unit: Lahontan Salt Shrub Basin, Tonopah Basin, Tonopah Sagebrush Foothills, and Tonopah Uplands (fig. 4); however, they occupy relatively small proportions of the landscape within the unit and across the HTNF (table 1). The Salt Shrub Basin is composed of internally draining rolling plains. The streams of this ecoregion can be perennial, intermittent, or ephemeral and generally are either medium-gradient with cobble substrates or low-gradient and sediment-laden (Bryce et al. 2003). Riparian vegetation communities in the Salt Shrub Basin are composed of Fremont cottonwood (*Populus fremontii*), coyote willow, silver buffaloberry (*Shepherdia argentea*), and Russian olive (*Elaeagnus angustifolia*). The aquatic systems of the Tonopah Basin, Sagebrush Foothills, and Uplands ecoregions are typically ephemeral, with scarce surface water flows supported by discharge from springs and infrequent precipitation events (Bryce et al. 2003).

Eastern Mountains

The Eastern Mountains are part of the Basin and Range systems located in the middle of the state. Watersheds in the Eastern Mountains tend to be smaller and have narrow valley bottoms compared to other ranges within Nevada (Board et al. 2020). The proportion of streams that flow perennially is high compared to other regions despite relatively moderate precipitation (Board et al. 2020). Much of the geology throughout this unit is porous and soluble—including limestone, dolomite, and other sedimentary rocks (Gregory Van Oosbree, USDA Forest Service, Elko, NV, personal communication, December 8, 2021)—which allows for rapid infiltration and supports a high number of springs and perennial streams (Board et al. 2020; Bryce et al. 2003). Four level IV ecoregions are present in the Eastern Mountains unit, with most of the landscape classified as Carbonate Woodlands or High-Elevation Carbonate Mountains (table 1).

The Carbonate Woodland Zone (figs. 5, 6) occupies 65 percent of the Eastern Mountains unit and about 11 percent of the HTNF. This woodland ecoregion is also prevalent in the Ruby Mountains unit. These areas are composed of pinyon-juniper woodland and Great Basin sagebrush communities that grow on moderate and steep mountains ranging from 6,000 to 9,000 feet in elevation (Board et al. 2020; Bryce et al. 2003). The average January temperatures range from 15 °F daily minimum to 38 °F daily maximum, and average July temperatures range from 51 °F daily minimum to 84 °F daily maximum (Bryce et al. 2003). Much of this ecoregion receives 9 to 15 inches of average annual precipitation, with some higher elevations receiving more than 20 inches. This part of Nevada receives more monsoonal moisture than the rest of the state, with substantial precipitation occurring in the summer months (Bryce et al. 2003). Streamflow in the Carbonate Woodlands varies seasonally, with cold, moderate- to high-gradient perennial and intermittent streams fed by discharge from springs and snowmelt (Bryce et al. 2003).

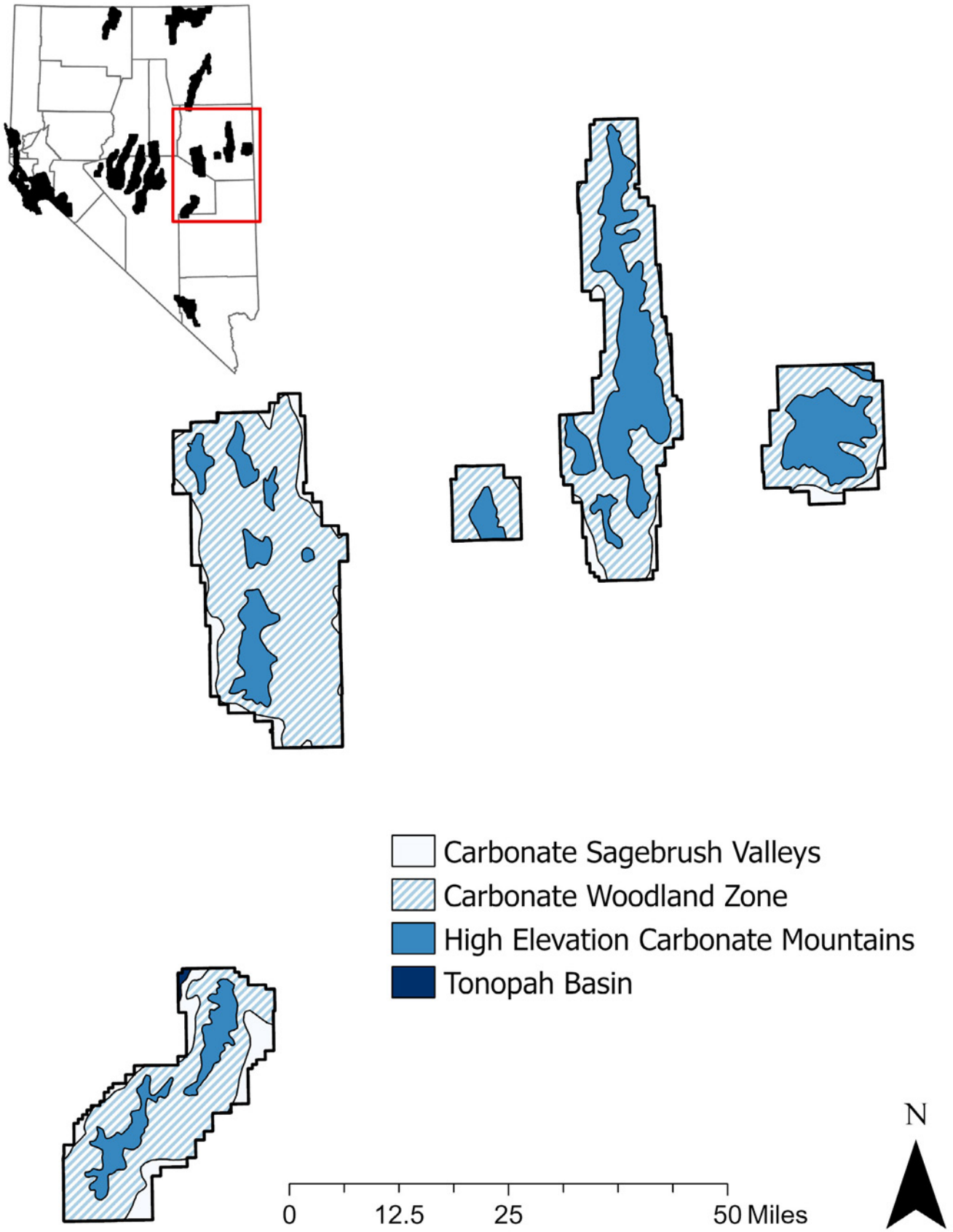


Figure 5—Level IV ecoregions of the Eastern Mountains unit.

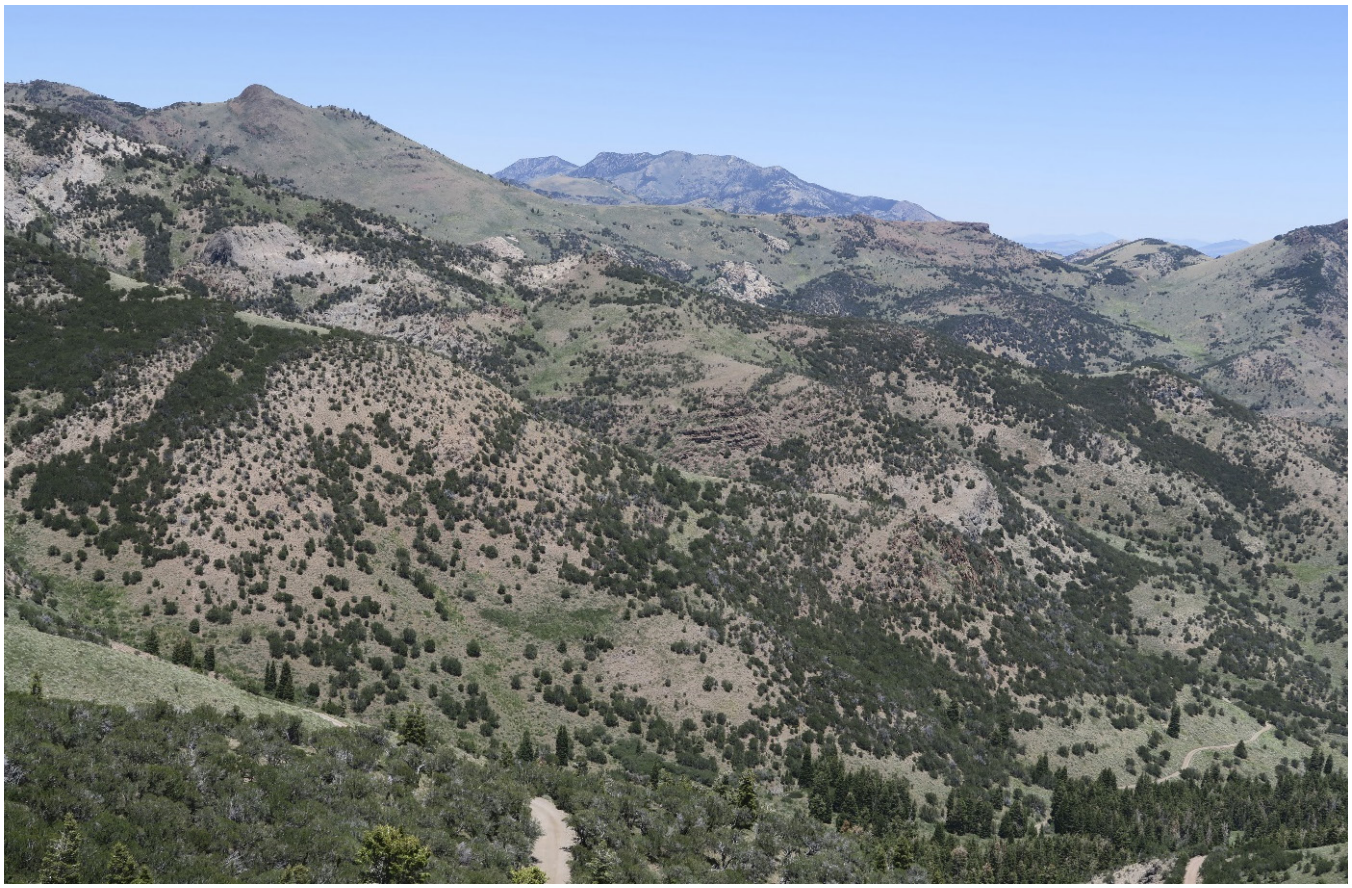


Figure 6—The Carbonate Woodland Zone is the largest ecoregion in the Eastern Mountains. The Schell Creek Range is pictured here. U.S. Geological Survey photo by Anna Knight.

The Tonopah Basin and the Carbonate Sagebrush Valleys represent relatively small proportions of the unit (table 1). We described the Tonopah Basin in the section "East Sierra." The Sagebrush Valleys are composed of internally draining basins, terraces, floodplains, and hillslopes (Bryce et al. 2003). The streams of this ecoregion can be perennial, intermittent, or ephemeral and generally have low or moderate gradients with substrates composed of cobble or fine sediment (Bryce et al. 2003).

Northern Mountains

The Basin and Range features of northern Nevada include scattered mountains, valleys, and dissected lava plains that are cooler and receive more moisture than similar features located farther south (Bryce et al. 2003). Watersheds in the western lava plains of the Northern Mountains unit are among the largest present on the HTNF (Board et al. 2020). These watersheds tend to have very broad valley bottoms, but relatively low proportions of perennial streams (Board et al. 2020). The watersheds of the uplands to the east are comparatively large (Board et al. 2020). These areas tend to have narrower valley bottoms and intermediate proportions of perennial streamflow compared to other regions within Nevada (Board et al. 2020). Six level IV ecoregions are present in the Northern Mountains, with most of the landscape classified as Semiarid Uplands and High Lava Plains (table 1).

The Semiarid Uplands ecoregion occupies nearly three-quarters of the Northern Mountains unit (figs. 7, 8) and is the second most prevalent ecoregion on the HTNF (table 1). These landscapes are characterized by sagebrush communities and grasslands growing on mountain slopes, volcanic cones, and buttes at elevations from 5,800 to 9,700 feet (Board et al. 2020; Bryce et al. 2003). Average January temperatures range from 16 °F daily minimum to 35 °F daily maximum, and average July temperatures range from 48 °F daily minimum to 80 °F daily maximum (Bryce et al. 2003). The Semiarid Uplands receive 12 to 18 inches of average annual precipitation (Bryce et al. 2003). Parts of this region can receive more than 25 inches of precipitation annually, according to Snow Telemetry (SNOTEL) data (Gregory Van Oosbree, USDA Forest Service, Elko, NV, personal communication, December 8, 2021). Streams tend to have moderate or high gradients and can be perennial, intermittent, or ephemeral (Bryce et al. 2003). Riparian vegetation communities are characterized by willows (*Salix* spp.) and chokecherry (Bryce et al. 2003).



Figure 7—The volcanic terrain of the Northern Mountains includes the Semi-arid Uplands ecoregion. U.S. Geological Survey photo by Anna Knight.

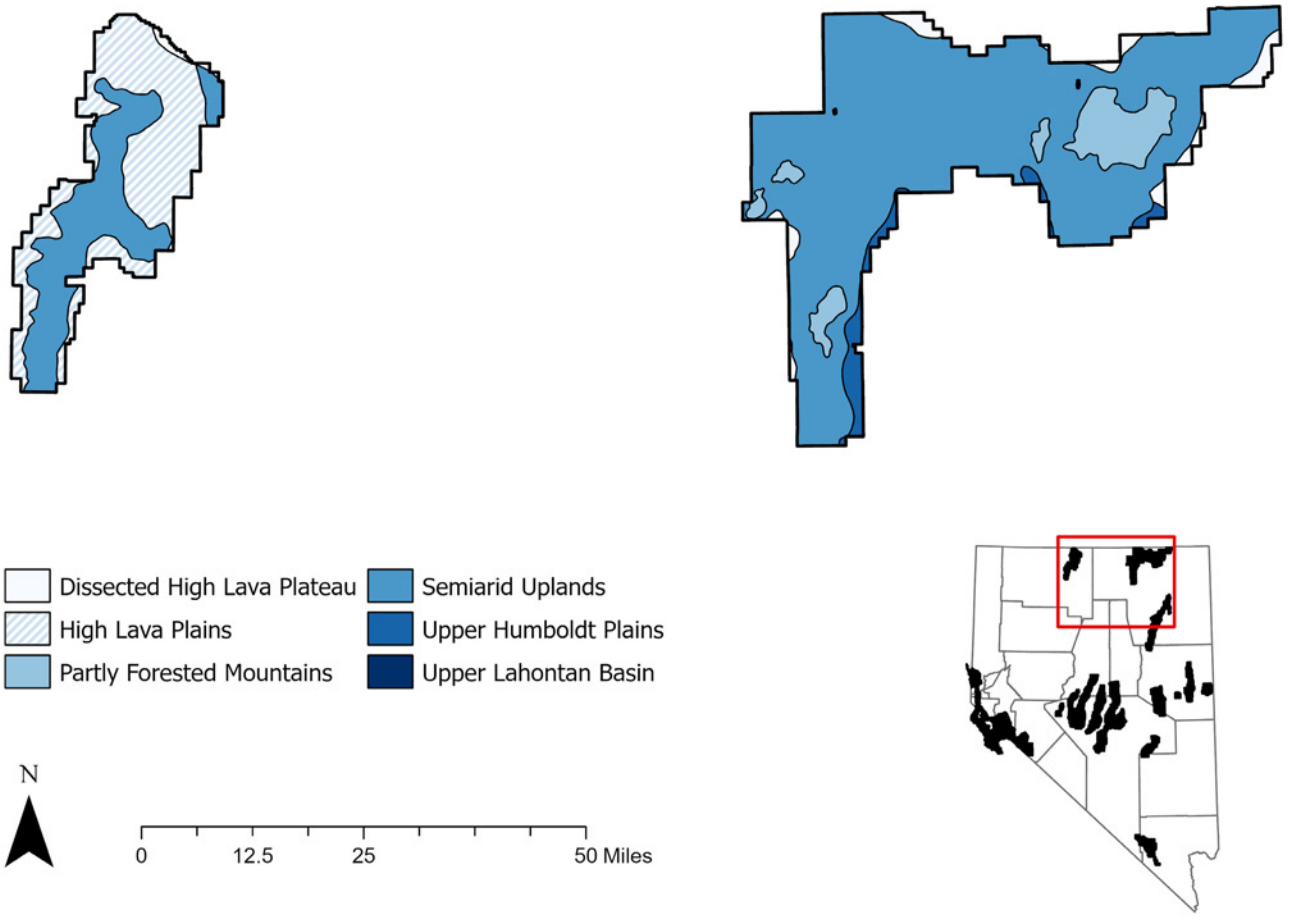


Figure 8—Level IV ecoregions of the Northern Mountains unit.

Fifteen percent of the Northern Mountains unit is composed of the High Lava Plains ecoregion (fig. 8). This area is characterized by sagebrush and grassland communities on internally draining flat and hilly volcanic plateaus ranging from 4,200 to 6,800 feet in elevation (Board et al. 2020; Bryce et al. 2003). Average January temperatures range from 12 °F daily minimum to 40 °F daily maximum, and average July temperatures range from 44 °F daily minimum to 92 °F daily maximum (Bryce et al. 2003). These areas receive between 8 and 16 inches of annual precipitation. Aquatic systems are limited in this ecoregion, with some lakes and ephemeral pools experiencing wide interannual and intra-annual variation in water levels (Bryce et al. 2003). These scattered lentic habitats provide critical habitat for unique fish species, including the Warner sucker (*Catostomus warnerensis*) and Wall Canyon sucker (*Catostomus* spp.) (Bryce et al. 2003).

Four additional ecoregions are present in the Northern Mountains unit (fig. 8); however, they occupy small proportions of the unit and the HTNF (table 1). The Dissected High Lava Plateau is composed of volcanic plateaus dissected by snowmelt- and spring-fed perennial, intermittent, and ephemeral streams and rivers that have carved

deep, shear-walled canyons (Bryce et al. 2003). The gradients, substrate, and flows of these systems are highly variable. The Partly Forested Mountains are high-elevation mountains that have been influenced by recent glaciation (Bryce et al. 2003). Fed by snowmelt and discharge from springs, streams in these areas can be perennial or intermittent and tend to have high gradients and cold temperatures. The Upper Humboldt Plains are rolling plains with perennial or intermittent, high-gradient streams that provide habitat for many fish species and the Columbia spotted frog (*Rana luteiventris*) (Bryce et al. 2003). The Upper Lahontan Basin is composed of broad valleys drained by perennial, intermittent, or ephemeral streams with medium to low gradients (Bryce et al. 2003). Some of these streams are critical fishery habitat (Bryce et al. 2003).

Ruby Mountains

The Ruby Mountains are a component of the Basin and Range features of central Nevada (Bryce et al. 2003). This area is internally drained and tends to be warmer and drier than Basin and Range features farther north. Watersheds located in these landscapes are generally smaller, with very narrow valley bottoms and a relatively high percentage of perennial streams compared to other regions in Nevada (Board et al. 2020). Seven level IV ecoregions are present in the Ruby Mountains unit, with most of the landscape classified as Mid- and High Elevation Ruby Mountains, as well as Carbonate Woodlands (table 1).

The Mid-Elevation Ruby Mountains ecoregion occupies about half of the Ruby Mountains unit (figs. 9, 10) and about 4 percent of the HTNF (table 1). These landscapes consist of pinyon-juniper woodlands and sagebrush communities growing on partly glaciated mountains and foothills that range from 6,500 to 8,500 feet in elevation (Board et al. 2020; Bryce et al. 2003). Average January temperatures range from 15 °F daily minimum to 35 °F daily maximum, and average July temperatures range from 50 °F daily minimum to 78 °F daily maximum (Bryce et al. 2003). This ecoregion receives 12 to more than 22 inches of average annual precipitation, including winter rainfall (Bryce et al. 2003). Parts of this region can receive more than 32 inches of precipitation annually, according to SNOTEL data (Gregory Van Oosbree, USDA Forest Service, Elko, NV, personal communication, December 8, 2021). Streams tend to be perennial, cold, high-gradient, and fed by snowmelt, springs, and small lakes (Bryce et al. 2003). Valley-bottom vegetation communities include cottonwood and aspen. Finally, many of the streams in this ecoregion are critical fishery habitats (Bryce et al. 2003).



Figure 9—This portion of Lamoille Canyon lies in the Mid-elevation Ruby Mountains ecoregion. U.S. Geological Survey photo by Anna Knight.

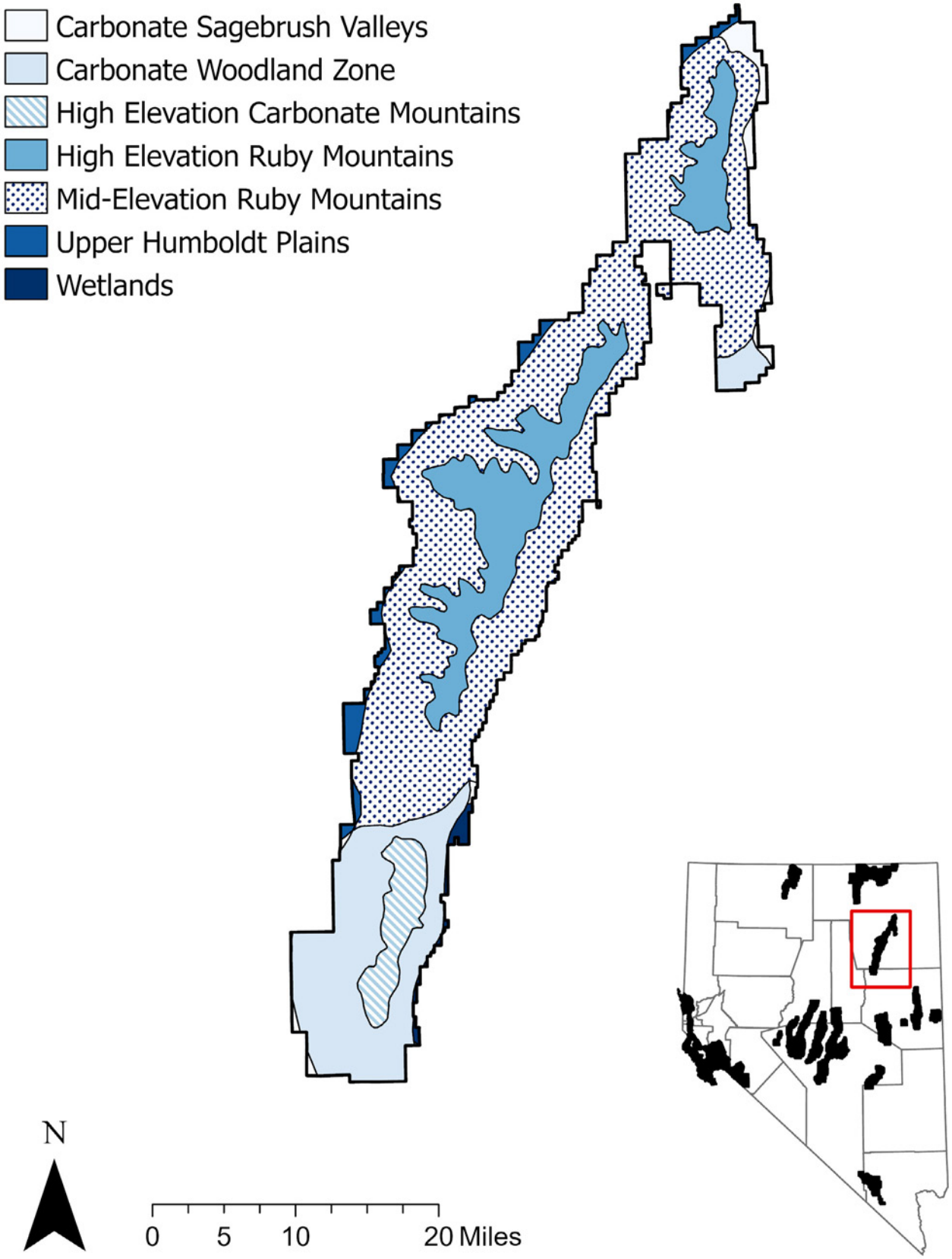


Figure 10—Level IV ecoregions of the Ruby Mountains unit.

Nearly one-fifth of the Ruby Mountains unit is classified as the High-elevation Ruby Mountains ecoregion (fig. 10). These areas are composed of limber pine (*Pinus flexilis*), whitebark pine (*Pinus albicaulis*), and shrubs and grasses that grow on heavily glaciated mountains ranging from 8,500 to 11,350 feet in elevation (Board et al. 2020; Bryce et al. 2003). Average January temperatures range from 16 °F daily minimum to 34 °F daily maximum and average July temperatures range from 47 °F daily minimum to 74 °F daily maximum. These landscapes receive 20 to more than 26 inches of average annual precipitation, including winter rainfall (Bryce et al. 2003). SNOTEL data within the area suggest some areas can receive 40 to 50 inches of annual precipitation (Gregory Van Oosbree, USDA Forest Service, Elko, NV, personal communication, December 8, 2021). Snowmelt and discharge from springs feed lakes and perennial streams throughout this ecoregion. Some of these aquatic habitats provide habitat to brook trout (*Salvelinus fontinalis*), Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*), and lake trout (*Salvelinus namaycush*). Additionally, high-elevation tarns (small mountain lakes formed in glacial cirques) that are rare throughout Nevada are present in this ecoregion (Gregory Van Oosbree, USDA Forest Service, Elko, NV, personal communication, December 8, 2021).

Five additional ecoregions are present in the Ruby Mountains unit (fig. 10). The most prevalent is the Carbonate Woodland Zone, which occupies 18 percent of the unit. The remaining four ecoregions compose relatively small proportions of the Ruby Mountains (table 1). We described the Carbonate Woodland Zone and the Carbonate Sagebrush Valleys in the section “Eastern Mountains”. We described the Upper Humboldt Plains in the section “Northern Mountains.” The High-Elevation Carbonate Mountains are partially glaciated rugged mountains with limited surface water systems (Bryce et al. 2003). The aquatic systems that do exist on these landscapes tend to be snowmelt- or spring-fed headwaters (Bryce et al. 2003).

The Ruby Mountains are the only unit on the HTNF that includes the Wetlands ecoregion (table 1). While wetlands occupy a small percentage of the unit and only 3,087 total acres of the HTNF, these are important systems for this assessment. The Wetlands ecoregion consists of flat landscapes with saline, brackish, or freshwater wetlands (Bryce et al. 2003). Wetlands fed by discharge from springs and groundwater systems tend to be perennial, while others are ephemeral and dependent on snowmelt. The vegetation communities present within the Wetlands ecoregion include bulrushes (*Scirpoides holoschoenus*), Baltic rush (*Juncus balticus*), cattails (*Typha* spp.), burreed (*Sparganium* spp.), reed grass (*Calamagrostis* spp.), inland saltgrass (*Distichlis spicata*), alkali sacaton (*Sporobolus airoides*), duckweed (*Lemnoideae* spp.), widgeongrass (*Ruppia maritima*), and iodine bush (*Allenrolfea occidentalis*), with nonnative tamarisk (*Tamarix* spp.) common in many areas (Bryce et al. 2003).

Sierra Nevada

The Sierra Nevada unit is a high-elevation, mountainous, and deeply dissected landscape (Bryce et al. 2003). These areas were influenced by Pleistocene glaciation and include features such as moraines, cirques, and small lakes. This unit influences others present on the HTNF by casting a rain shadow over landscapes to the east (Bryce et al. 2003). Eight ecoregions are present in the Sierra Nevada unit (fig. 11), with

the landscape dominated by Northeastern Sierra Mixed Conifer-Pine Forests, Sierra Nevada-Influenced Semiarid Hills and Basins, Sierra Nevada-Influenced Ranges, and Northern Sierra Subalpine Forests (table 1).

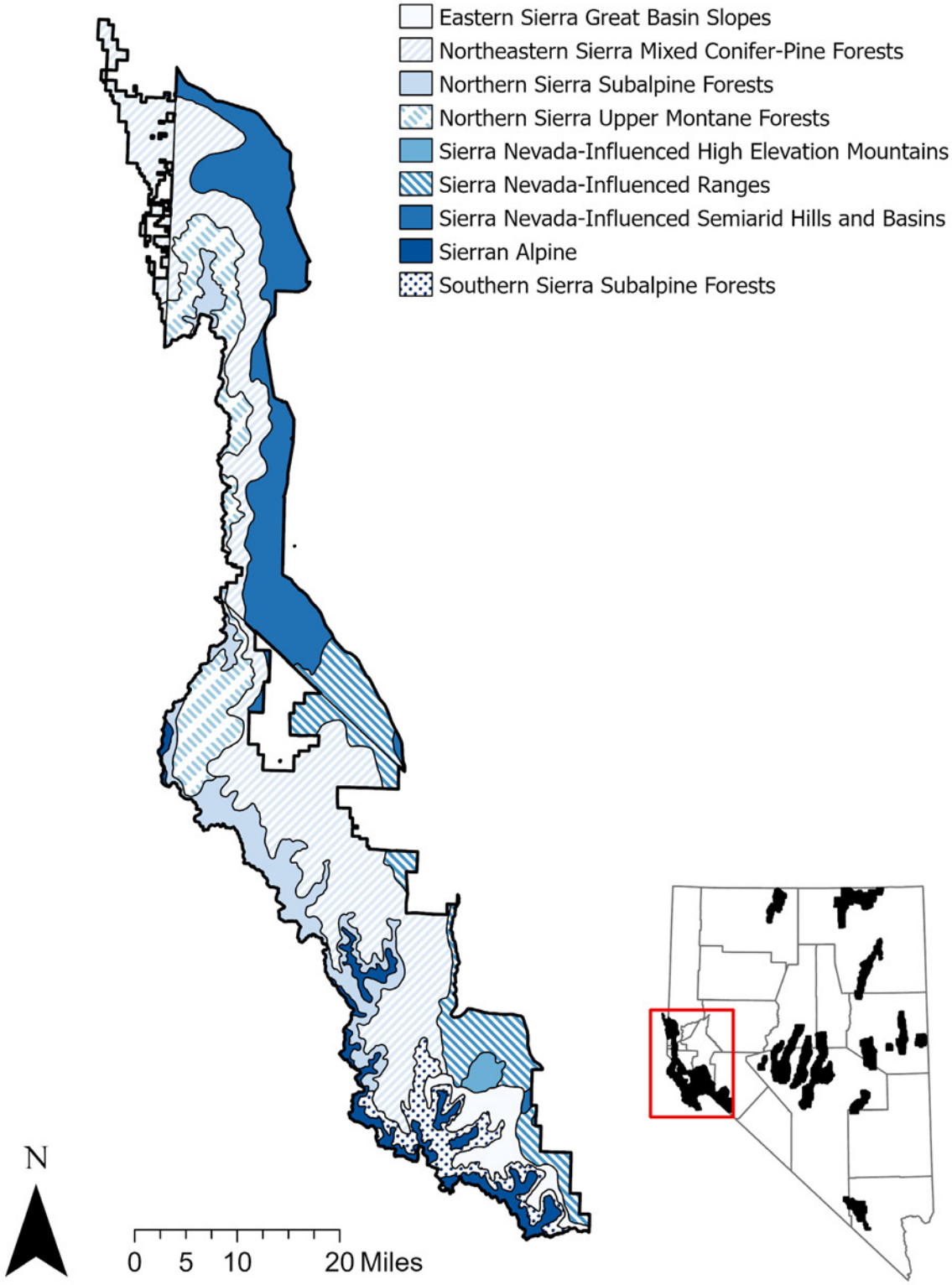


Figure 11—Level IV ecoregions of the Sierra Nevada unit.

We described the Sierra Nevada-Influenced Semiarid Hills and Basins, Ranges, and High-Elevation Mountains in the section “East Sierra.” The Southern Sierra Subalpine Forests, Sierran Alpine, and Eastern Sierra Great Basin Slopes all represent up to 5 percent of the unit, but in-depth information on these ecoregions is lacking (Griffith et al. 2016). The Northeastern Sierra Mixed Conifer-Pine Forests occupy 38 percent of the Sierra Nevada unit (fig. 12). These areas are characterized by dry forests between 5,000 and 8,000 feet in elevation (Griffith et al. 2016). The soil temperature regimes of this ecoregion tend to be frigid, and the moisture regimes are generally xeric (Griffith et al. 2016). The Northern Sierra Subalpine Forests occupy about one-tenth of the Sierra Nevada unit (table 1). These landscapes are characterized by lodgepole pine (*Pinus contorta*), whitebark pine, western white pine (*Pinus monticola*), and mountain hemlock (*Tsuga mertensiana*) growing at elevations from 8,000 to 10,000 feet. The Subalpine Forests have a cold climate and receive heavy snowfall (Griffith et al. 2016).



Figure 12—The Sierra Nevada Unit contains meadows and uplands within the Northeastern Sierra Mixed Conifer-Pine Forests ecoregion. USDA Forest Service photo by D. Max Smith.

Spring Mountains National Recreation Area

The Spring Mountains National Recreation Area (SMNRA) is part of the Mojave Basin and Range, which are lower, warmer, and drier than similar physiographic features in the central and northern sections of the state (Bryce et al. 2003). The Spring Mountains harbor unique flora and fauna and are often described as an island of endemism (Solem et al. 2013). The Eastern Mojave Mountain Woodland and Shrubland ecoregion occupies most of the landscape (fig. 13). These areas are characterized by pinyon-juniper woodlands, Gambel oak, mountain-mahogany, and sagebrush communities growing on mountain slopes, ridges, and hills at 6,000 to 8,000 feet in elevation (Bryce et al. 2003). Average January temperatures range from 26 °F daily minimum to 46 °F daily maximum and average July temperatures range from 62 °F daily minimum to 86 °F daily maximum (Bryce et al. 2003). These landscapes receive 10 to 16 inches of annual precipitation. Surface water systems are rare and tend to be ephemeral, with some springs present. Some riparian vegetation, including willow and cottonwood (*Populus balsamifera* ssp. *trichocarpa*), are present in canyon bottoms throughout the Woodlands and Shrublands (Bryce et al. 2003).

Nearly one-quarter of the SMNRA is classified as the Eastern Mojave Low Ranges and Arid Footslopes (figs. 13, 14), which consist of creosote bush (*Larrea tridentata*), white bursage (*Ambrosia dumosa*), Mojave yucca (*Yucca schidigera*), Joshua trees (*Yucca brevifolia*), blackbrush (*Coleogyne ramosissima*), winterfat (*Krascheninnikovia lanata*), and spiny menodora (*Menodora spinescens*) growing on low mountains, hills, and basalt flows at elevations between 2,800 and 6,200 feet (Bryce et al. 2003). Average January temperatures range from 20 °F daily minimum to 54 °F daily maximum and average July temperatures range from 58 °F daily minimum to 100 °F daily maximum (Bryce et al. 2003). This ecoregion receives between four and eight inches of annual precipitation (Bryce et al. 2003). Like the Mountain Woodlands and Shrublands, the Low Ranges and Arid Footslopes have limited surface water systems, with some springs and ephemeral streams present (Bryce et al. 2003).

The third most prevalent ecoregion in the SMNRA is the Eastern Mojave High Elevation Mountains (fig. 13). These landscapes include mountain-mahogany, sagebrush, ponderosa pine, and white fir forests growing on rugged mountains at elevations between 7,500 and 11,918 feet (Bryce et al. 2003). Average January temperatures range from 24 °F daily minimum to 41 °F daily maximum and average July temperatures range from 55 °F daily minimum to 78 °F daily maximum (Bryce et al. 2003). The Eastern Mojave High Elevation Mountains receive between 16 and more than 25 inches of annual precipitation (Bryce et al. 2003). Lastly, snowmelt-fed perennial streams are present but rare (Bryce et al. 2003).

Two additional ecoregions are present in the SMNRA (fig. 13); however, they occupy relatively small proportions of the landscape (table 1). The Amargosa Desert consists of internally draining valleys with floodplains, terraces, and playas at 2,000 to 4,200 feet in elevation (Bryce et al. 2003). Extensive groundwater systems discharge at seeps and springs, supporting intermittent and ephemeral streams and maintaining wetland oases that provide habitat for endemic plants (Bryce et al. 2003). The Eastern Mojave Basins are characterized by stream terraces and floodplains at elevations between 1,800 and

4,500 feet. Surface water is rare, however perennial and ephemeral low and medium gradient streams with warm temperatures do exist (Bryce et al. 2003). These systems are prone to flash flooding following precipitation events. Riparian areas in the Mojave Basins include desert willow (*Chilopsis linearis*), coyote willow, mesquite (*Prosopis glandulosa*), and tamarisk, which is rapidly replacing native vegetation (Bryce et al. 2003).

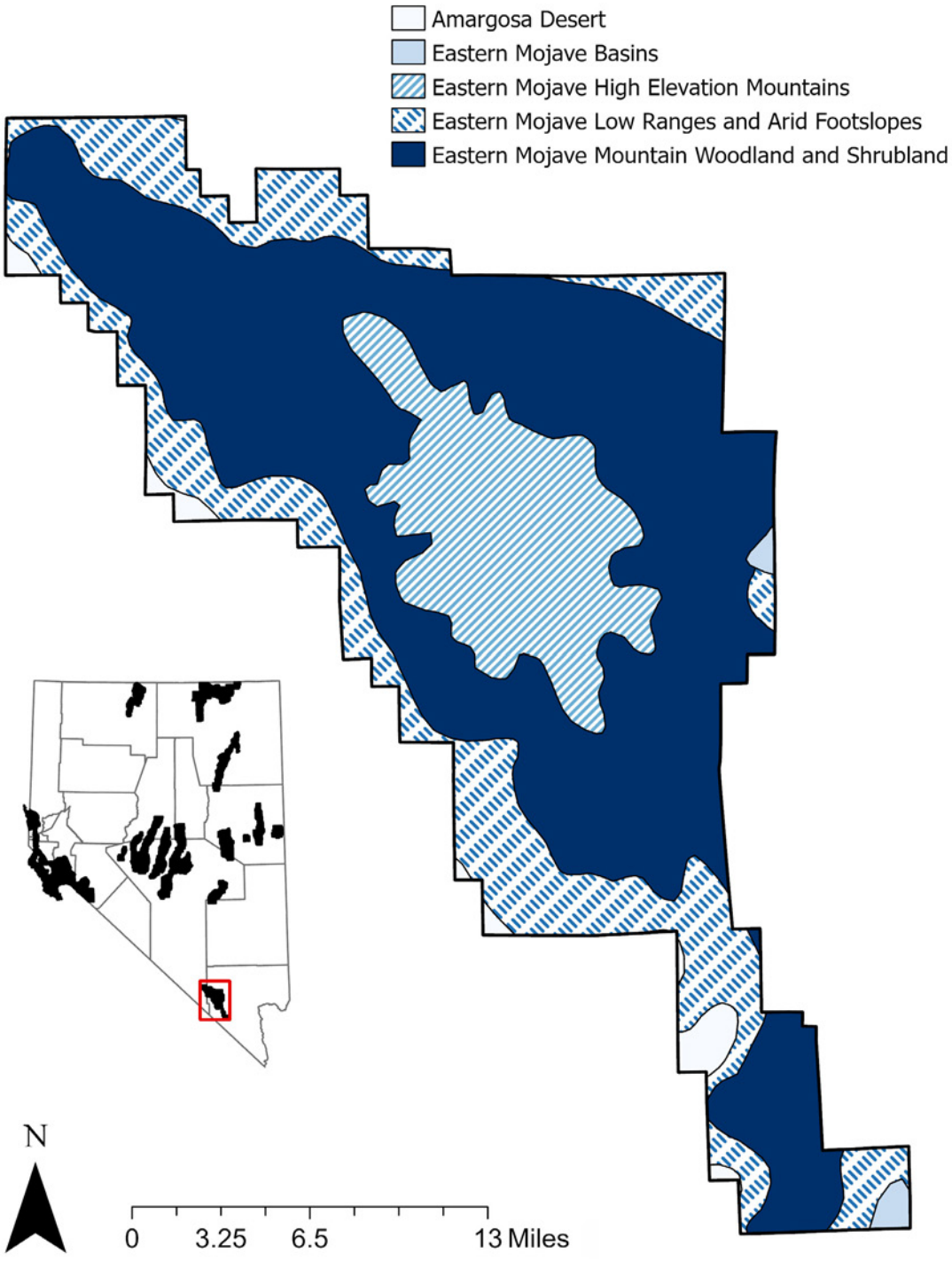


Figure 13—Level IV ecoregions of the Spring Mountain National Recreation Area Unit.



Figure 14—This spring is located within the Eastern Mojave Low Ranges and Arid Footslopes ecoregion of the SMNRA. *Vitas arizonica* and other woody riparian species contrast with *Yucca brevifolia* and other upland desert species. Courtesy photo by the Spring Stewardship Institute.

Anthropogenic Influences on Water Resources in the Humboldt-Toiyabe National Forest

In contrast with current conditions, much of Nevada, including land in the present-day HTNF, was submerged 1,600 to 4,300 feet beneath the expansive (8,500 square miles) Lake Lahontan (Benson 1978). During this time (10,000 to 25,000 years ago), the climate of the Great Basin was much cooler and wetter than today (HTNF 2011).

Archaeological evidence suggests that Indigenous people have been in Nevada and California since 10,000 to 20,000 years before present. Cave dwellers left picture writings on rocks in southern Nevada. Basketmakers and ancestral Puebloans also flourished (Green 2015; Harrington 1927). Current evidence suggests that Numic-speaking ancestors of the Paiute and Shoshone began spreading into the Great Basin and Snake River Basin approximately 1,000 years ago (Magargal et al. 2017). Numic-speaking Indigenous groups lived nomadic lifestyles during the Quaternary Period, tracking changes in resource availability (Madsen 2002). The Washoe People occupied a smaller area, which now includes the Sierra Nevada and East Sierra units, for up to

9,000 years (Makley 2018). These groups established camps and agricultural areas along streams and lakes and near springs (Entrix 2008; Madsen 2002) (fig. 15). In what is now the SMNRA, springs were viewed as sacred features of the landscape by the Nuwuvi (Southern Paiute) and were stewarded by certain families (Spoon and Arnold 2009).



Figure 15—Petroglyphs near springs are indicative of the long relationship between people and these ecosystems in the Spring Mountains National Recreation Area. Courtesy photo by the Spring Stewardship Institute.

Explorers largely of European descent visited the area between 1826 and 1859 and were primarily of three different groups: (1) fur trappers and explorers (1826–1833), (2) sponsored exploration (1834–1853), and (3) emigration (1844–1859) (McBride 2002). The first group entered the area and took advantage of the abundant beaver pelt trade. The second group included expeditions sponsored by the U.S. Government and members of the Church of Jesus Christ of Latter-day Saints (Mormons) seeking new territories for colonization. The final group was dedicated mostly to emigration and settlement. The early visitors and settlers identified several Native American Tribes occupying land that is now part of the HTNF (table 2), including the southern and northern Paiute, western Shoshone, Washoe, and Mojave Tribes (Hulse 2012).

Table 2—Traditional territories and current tribal lands within or in close proximity to each of the National Forest's geographic units. Data from map viewers (Native Land Digital n.d.; USFS n.d.).

Geographic Unit	Traditional territories	Current tribal lands
Central Mountains	Newe (Western Shoshone), Northern Paiute	Yomba Reservation (Yomba Shoshone)
East Sierra	Northern Paiute, Washoe, Western Mono/Monache	Washoe Ranches Trust Land (Washoe Tribe)
Eastern Mountains	Goshute, Newe (Western Shoshone)	The Duckwater Reservation (Duckwater Shoshone Tribe), Ely Reservation (Ely Shoshone Tribe)
Northern Mountains	Newe (Western Shoshone), Northern Paiute, Shoshone-Bannock	Duck Valley Reservation (Shoshone-Paiute Tribes), Fort McDermitt Indian Reservation (Fort McDermitt Paiute and Shoshone Tribe)
Ruby Mountains	Newe (Western Shoshone)	South Fork Reservation (Te-Moak Tribe of Western Shoshone)
Sierra Nevada	Me-Wuk (Central Sierra Miwok), Northern Paiute, Washoe	Carson Colony, Stewart Community, and Washoe Ranches Trust Land (Washoe Tribe); Reno-Sparks Indian Colony (Paiute, the Shoshone and Washoe tribes)
SMNRA	Chemehuevi, Mojave, Newe (Western Shoshone), Southern Paiute	Las Vegas Indian Colony (Las Vegas Paiute Tribe)

Miners arrived soon after, discovering gold in the canyons of the Sierra Nevada in 1849. The Comstock Lode discovery of 1859 further boosted the region's mining industry (LaPointe and Price 2009). In recent decades, Nevada has led the United States in terms of gold production; the largest mines currently operate in the Carlin Trend, which is largely on non-Forest Service land between the Ruby Mountains and Santa Rosa geographic units (Plume 2005; Price 2011). Gold is not the only precious metal mined in Nevada. Silver has also been a significant metal, leading to the nickname the "Silver State," and copper mining is an important component of the economy in eastern Nevada (Hulse 2017). Mining these precious metals can be done in multiple ways. The rich ore was first extracted through surface diggings, but these were quickly exhausted, and miners had to tunnel underground to reach ore bodies. Unlike most silver ore deposits, which occur in long, thin veins, those of the Comstock Lode occurred in discrete masses, often hundreds of feet thick. Excavating buried mineral veins and bodies commonly required tunneling underground. Historically, tailings of extracted earth and minerals were deposited on the surface, where they often caused water pollution (Fashola et al. 2016; Navarro et al. 2008). Whether for gold or silver, water also found its way into and through underground passageways, again resulting in water pollution (Ngole-Jeme and Fantke 2017).

Grazing domestic livestock in the western United States has occurred for nearly 500 years, since the days of the Spanish explorer Coronado (Holechek et al. 2004; Winship 1904). Cattle arrived in San Diego, California in 1769, but it was the discovery of gold in California in 1849 that brought more than 300,000 people (Larson-Praplan 2014), and with them, a demand for meat that was met largely by sheep (Beck and Haase 1989)

and later by cattle (Jelinek 1999). Demand for beef changed the grazing paradigm from small herds to nearly a million head by 1860 (Larson-Praplan 2014). Cattle numbers remained limited in much of the western United States, including Nevada, until the end of the Civil War in 1865, which triggered rapid expansion of people and the associated livestock industry across the West, facilitated by railroads and favorable Federal policies toward homesteading (e.g., the Homestead Act of 1862) and grazing. The number of range cattle and sheep boomed between 1880 and 1890 (Stewart 1936), with most grazing unregulated and on public land. Land not claimed under the Homestead Act of 1862 was considered part of the public domain and was available for use by almost anyone for almost any legal activity; this became the "open range" (Larson-Praplan 2014). Ranchers were content to use the "public domain" because it was free and not subject to taxation. Because nobody owned the land, nobody was responsible for maintaining it, and public domain lands were severely abused and overgrazed (Alexander 1987).

The environmental effects of grazing livestock are tied primarily to the consumption and removal of plant cover that would otherwise protect the soil surface from the erosive forces of wind and water. Trampling by livestock may also physically disturb and compact the soil, disturb biological soil crusts, and cause failure of streambanks, thus increasing the likelihood of soil erosion, particularly at heavier stocking rates (USDA NRCS 2016; Thurow 1991).

In 1891, the Forest Reserve Act withdrew most unsettled tracts of forested land from the public domain and put them under the administration of what would become the U.S. Department of Agriculture, Forest Service for timber production, while some adjacent and intermixed parcels of rangeland were allocated for grazing. This division of land use continues to create no small degree of confusion, as the U.S. Grazing Service (now the U.S. Department of the Interior, Bureau of Land Management) became responsible for managing most rangeland and some lands that contain forest. To reverse a trend of declining range condition, the Department of the Interior began granting grazing permits in 1898 to try to limit the number of livestock on Federal land under its jurisdiction, and the Forest Service, established in 1905, initiated a system of grazing allotments for rangeland under its jurisdiction. Between 1910 and 1920, a series of laws were established to further regulate grazing on Forest Service lands. As the laws were established and enforced, the condition of grazed rangelands gradually improved. In the 1920s, the discipline of range management evolved, and several universities established departments of range management to train landowners and managers in ecological principles related to the management of rangelands subjected to grazing. In 1934, Congress passed the Taylor Grazing Act, which withdrew all remaining land from the public domain and placed it under the jurisdiction of what would become the Bureau of Land Management (Hurlburt 1935) in order to "stop injury to the public lands by preventing overgrazing and soil deterioration." Under the Taylor Grazing Act, ranchers could obtain long-term leases on public land for the purpose of livestock grazing. Stocking rates were established locally by the Bureau of Land Management.

Wallace and Silcox (1936), including a chapter written by Clapp (1936) indicated that rangelands occupied approximately 728 million acres or 40 percent of the total

land area of the coterminous United States. In 1948, the American Society of Range Management (now known as the Society for Range Management) was established as a professional organization dedicated to fostering proper management of rangelands (Howery 2015). Many changes have been implemented, including sharp reductions in stocking rates on many permits. While some lands continue to be severely overgrazed, the slow but generalized trend is toward improved rangeland condition (Mitchell 2000). Today, the Bureau of Land Management in the state of Nevada administers approximately 797 grazing allotments (USDOI BLM n.d.a).

Interactions between people and fire have influenced the HTNF landscape since the arrival of the first hunter-gatherers. Indigenous peoples frequently set fires to maintain resource production in forests and woodlands (Anderson 2018; Makley 2018; Spoon et al. 2015). Fires also occurred following ignitions from lightning strikes, especially at higher elevations (Van de Water and North 2010). After land was taken from Indigenous peoples, a century of fire suppression allowed the accumulation of biomass, increasing the risk of severe wildfire in upland forests and riparian areas (Busenberg 2004; Van de Water and North 2011). Under a changing climate, wildfires have increased in severity, extent, and duration (Malesky et al. 2018). Where firefighting activities require passage through streams, wetlands, and riparian areas, there is the risk of introducing sediment that may degrade those areas. In addition, the removal of upland vegetation by fire limits the ability of a watershed to store water, causing floods and debris flows during storms. These disturbances impact streams by altering features such as aquatic and riparian habitats, water quality, bank stability, channel shape, and channel gradient (Malesky et al. 2018).

Though intensive timber harvest has occurred in the past, it currently occurs on a much smaller scale than livestock grazing and other activities. Large amounts of timber were harvested along the eastern flank of the Sierra Nevada and Carson Range to support the mining industry from the 1860s to the 1880s (Kattelmann 2012; Zeier et al. 2004). During this time, logs were driven down streams to deliver timber to mills and mines. These log drives scoured riparian vegetation and eroded streambanks. Effects of timber harvest on riparian ecosystems also include the removal of streamside vegetation and alterations of stream dynamics resulting from roadbuilding (Fortino et al. 2004). Levels of timber harvest declined drastically beginning in the 1880s, because of a reduction in harvestable trees, establishment of forest reserves, and a scarcity of mills (Zeier et al. 2004). Logging drives ended in 1896, and, by the 1960s, there were no lumber mills operating near the Sierra Nevada or East Sierra geographic units (Loomis et al. 2007; Zeier et al. 2004). Since 1890, most of the timber harvested in Nevada has been shipped to mills in other states for processing (Alexander 1987). In recent years, most of the timber harvested in the HTNF has been used for fuelwood and is produced by logging standing dead trees (HTNF 2008; Menlove et al. 2016).

In addition to the effects of grazing and timber harvest, aquatic ecosystems have been impacted by diversion of water and harvest of fish and other foods. Streams, lakes, and springs have long been sources of food, water, and other cultural necessities. Indigenous people gathered foods from streams and lakes, sometimes altering aquatic and riparian communities in the process (Makley 2018). Some groups also diverted

water to irrigate their crops (Madsen 2002). Soon after arrival, Mormons and other settlers became proficient in building canals and diverting surface water to irrigate crops in several valleys (Hulse 2017). Following passage of the Newlands Reclamation Act in 1902 (The Reclamation Act of 1902), the Federal government took a lead role in the construction of dams, irrigation canals, and other structures, further modifying watersheds and expanding agricultural opportunities. Large-scale projects included the construction of Derby Dam on the Truckee River and Lahontan Dam on the Carson River. These structures provided water storage and delivery, but also altered streamflows and blocked fish passage from desert lakes to spawning grounds in the Forest (Berris et al. 2001; Gautam et al. 2013; Rood et al. 2003). Stream diversions have also increased the salinity of basin lakes, causing further declines or extirpations of threatened and endangered species (Lopes and Allander 2009). Several developments have disturbed waterways as well. Any linear disturbance that runs perpendicular to the natural flow of water has the potential to divert natural runoff and cause soil erosion and sediment pollution. Anthropogenic perturbations that fall into this category include roads, railroads, pipelines, irrigation canals, surface mining, and other unnatural features that divert runoff from its natural path. Careful planning may be able to lessen or alleviate such problems (Nevada Department of Transportation 2017).

A variety of recreational activities are permitted on the Forest. Permitted activities include bicycling, camping, climbing, fishing, hiking, horseback riding, hunting, nature viewing, all-terrain vehicle (ATV) riding, picnicking, rock hounding, scenic driving, water activities, and winter sports. In some areas, access requires parking near, or crossing, streams. Such access points disturb vegetation and introduce sediments into streams and wetlands, thus causing deterioration in the quality of riparian areas (Loomis et al. 2007; Zeier et al. 2004).

RIPARIAN AND GROUNDWATER-DEPENDENT ECOSYSTEMS: DESCRIPTIONS, DYNAMICS, AND DISTRIBUTIONS

In this section, we provide an overview of riparian ecosystems and GDEs of the HTNF. We first define the ecosystems selected for assessment and review the processes that characterize them. We then summarize their associated plant communities and discuss their importance to fish and wildlife. Finally, we use several datasets (Appendix A) to describe the known distribution of riparian ecosystems, springs, and fens in geographic units of the Forest.

Riparian Ecosystem Definitions

There are many definitions of riparian ecosystems, but three components are often included: (1) an interface of aquatic and terrestrial communities at a body of water, (2) landforms and organisms that are influenced by surface water and groundwater, and (3) plant communities differing in composition or structure (or both) from those in adjacent upland ecosystems (Dall et al. 1997; Gregory et al. 1991). At streams, riparian ecosystems are three-dimensional zones influenced by the movement of surface water and groundwater. The first dimension extends longitudinally from the headwaters of a stream to its mouth, the second extends vertically from the groundwater zone to the canopy of vegetation, and the third extends laterally from the streambed to the outer extent of the floodplain (Stanford and Ward 1988, 1993; Vannote et al. 1980). In the western United States, riparian ecosystems are also noted for supporting high levels of productivity and species richness, providing essential wildlife habitat, and covering a small percentage of the landscape (Hansen et al. 1995; Johnson et al. 2018).

Groundwater-dependent Ecosystem Definitions

The emergence of groundwater to the surface or near the surface creates unique ecosystems in the arid and semiarid regions of the western United States (Stevens and Meretsky 2008). Groundwater-dependent ecosystems are generally defined as biotic communities that rely on continuous or periodic access to groundwater to maintain their structure, composition, and function (Chiloane et al. 2022; Kløve et al. 2011). The Forest Service defines GDEs as “communities of plants, animals, and other organisms whose extent and life processes are dependent on access to or discharge of groundwater” (USDA FS 2012a,b). For the purposes of forest planning, GDEs include wetlands fed by groundwater; terrestrial vegetation and fauna sustained by shallow groundwater; ecosystems in streams and lakes fed by groundwater; caves and karst aquifers; aquifer systems; hyporheic zones (ecotones between surface water in a stream and groundwater) and hypolentic zones (ecotones between surface water in lakes and ponds and groundwater); and springs (USDA FS 2015). These ecosystems contribute to regional biodiversity by supporting specialized and endemic species, many of which are listed as threatened or endangered (Kreamer et al. 2015; Murray et al. 2006). Because many of their plant species rely on groundwater, some riparian areas are considered GDEs as well (Kløve et al. 2011).

Physical Settings

The dynamics of riparian areas and GDEs are driven in part by underlying geology, terrain, and land use. The legacy of bedrock formation and subsequent geologic events controls the dynamics of valley bottoms, streams, and groundwater in the HTNF watersheds (Heath 1983; Waring 2011). The HTNF is a collection of fault-block mountain ranges with varying geologies. These ranges are separated by valleys containing Basin and Range basin-fill aquifers, some of which overlie carbonate-rock and volcanic-rock aquifers (Heilweil and Brooks 2011). Each geographic unit of the Forest is, therefore, a unique combination of bedrock, unconsolidated deposits, and other features that influence surface flows, groundwater, and the development of ecosystems.

In the intermountain basins, deep layers of sand, gravel, and other unconsolidated materials were deposited during erosional processes following the uplift of mountain ranges beginning 17 million years ago (Morris and Stubben 1994). Unconsolidated deposits cover 4 to 28 percent of the area in geographic units (table 3). Most of these deposits are found at lower elevations in the form of alluvial fans and basin-fill (Chambers and Miller 2004). In general, the availability and conductivity of groundwater are greater in alluvial and basin-fill aquifers than in bedrock aquifers, making the former important sources of water for irrigation, municipal use, and domestic use (Welch et al. 2007). Basin-fill aquifers are adjacent to each of the geographic units, indicating the importance of the mountains and streams in the Forest to regional groundwater recharge. Where these aquifers discharge on valley floors, they can create extensive wetland complexes (Berger 2006). Basin-fill aquifers also exchange water with streams, supporting aquatic and riparian ecosystems (Huntington 2010).

Table 3—Hydrogeological characteristics and GDEs mapped in geographic units.

Geographic unit	Area	Acres of unconsolidated deposits (% of unit)	Acres of basaltic-rock aquifer (% of unit)	Acres of carbonate-rock aquifer (% of unit)	Acres of potential volcanic karst (% of unit)	Acres of potential carbonate karst (% of unit)	Springs in unit (springs per acre)	Acres of potential fens (% of unit)
Central Mountains	Monitor-Hot Creek	882,600.8 (21)	0	71,892.4 (8)	469.4 (0.1)	64,237.6 (7)	425 (0.0005)	359.2 (0.04)
	Paradise	70,756.2 (9)	0	0	1,844.5 (3)	16,506.7 (23)	39 (0.001)	0.6 (0.001)
	Toiyabe-Shoshone	743,244.4 (16)	0	0	15,429.9 (2)	71,315.2 (10)	692 (0.001)	98.8 (0.01)
	Toquima	437,141.1 (16)	0	25,349.9 (6)	0	59,642.2 (14)	269 (0.001)	45.2 (0.01)
East Sierra	NA	855,115.0 (25)	0	0	77,787.2 (9)	70,185.9 (8)	148 (0.0002)	233.7 (0.03)
Eastern Mountains	Quinn-Grant	219,856.7 (16)	0	82,555.1 (38)	125.6 (0.1)	73,859.7 (34)	80 (0.0004)	18.6 (0.01)
	Schell Creek	288,694.7 (11)	0	213,057.3 (74)	0	136,612.0 (47)	372 (0.001)	61.9 (0.02)
	Snake	119,428.0 (4)	0	72,411.9 9 (61)	0	71,080.8 (60)	59 (0.0005)	41.4 (0.03)
	Ward	40,329.4 (27)	0	31,741.8 (79)	0	25,611.4 (64)	19 (0.0005)	2.6 (0.01)
	White Pine	356,266.6 (28)	0	164,321.5 (46)	45.5 (0.01)	170,759.5 (48)	186 (0.001)	16.3 (0.005)
Northern Mountains	Jarbidge	761,111.9 (10)	34,595.6 (45)	0	0	105,032.4 (14)	606 (0.001)	280.5 (0.04)
	Santa Rosa	299,402.4 (4)	1,201.7(1)	0	38,639.0 (13)	8,819.7 (3)	540 (0.002)	207.4 (0.07)
Ruby Mountains	NA	438,956.2 (19)	0	81,953.3 (19)	0	290,007.6 (66)	353 (0.001)	326.1 (0.07)
Sierra Nevada	NA	866,382.9 (19)	0	0	8,053.8 (1)	9,118.0 (1)	405 (0.0005)	3,459.1 (0.4)
SMNRA	NA	321,572.5 (22)	0	247,226.1 (77)	0	202,263.9 (63)	182 (0.001)	0

NA: not applicable

Bedrock aquifers occur in consolidated rocks with primary openings, such as lava tubes or intergranular pores, or secondary openings, such as fractures and dissolution cavities (Heath 1983). Karst systems are specialized bedrock aquifers created by the chemical dissolution of carbonate bedrock, including limestone and dolostone. These systems, characterized by sinkholes, solution channels, and well-developed underground drainage paths, have the highest groundwater conductivity rates of the bedrock aquifers in the region (Maurer et al. 2004; USDA FS 2016). Extensive carbonate-rock aquifers and potential karst systems have been mapped at the Eastern Mountains, Ruby Mountains, and SMNRA geographic units (table 3). Smaller areas were mapped in the other geographic units. These aquifers recharge adjacent basin-fill aquifers and, where groundwater is discharged to springs and streams, support unique aquatic, riparian, and wetland communities (Fleishman et al. 2006; Heilweil and Brooks 2011).

Some extrusive igneous rocks have high groundwater conductivity as well. Basalt has the highest median conductivity, followed by breccia/tuff, rhyolite, and andesite (Maurer et al. 2004). Young basaltic lava flows are highly permeable and can transmit and discharge large volumes of groundwater, similar to carbonate karst systems (Jefferson et al. 2006). These types of flows have been mapped in the Central Mountains, Northern Mountains, East Sierra, Eastern Mountains, and Sierra Nevada, with the most extensive flows in the Santa Rosa area of the Northern Mountains (table 3). The Jarbidge and Santa Rosa areas of the Northern Mountains overlap portions of the Pacific Northwest basaltic-rock aquifers (table 3), indicating the importance of these units to recharge of these extensive groundwater systems. Basaltic-rock aquifers are important sources of groundwater for agricultural, municipal, and domestic uses (Frans et al. 2012).

Groundwater is transported and stored in fractured intrusive igneous rocks such as granite and in metamorphic rocks such as quartzite. Conductivity is generally low in these rocks relative to carbonate rocks and extrusive igneous rocks (Maurer et al. 2004). Large areas of intrusive and metamorphic rocks occur in the Eastern Mountains, Ruby Mountains, and Sierra Nevada.

The HTNF landscape consists of numerous mountain ranges and relatively few major streams. The mountains collect precipitation in the form of rain and snow, producing runoff for streamflows and groundwater recharge. Perennial streams are rare and unevenly distributed in this arid environment (Heilweil and Brooks 2011). Streams classified as perennial may be spatially intermittent because of infiltration of surface flows into permeable streambed substrates (Weixelman et al. 1996). Perennial flows often terminate at alluvial fans that have formed at the bases of mountain ranges (Chambers and Miller 2004). These mountain fronts are the primary zone of groundwater recharge for basin-fill alluvial aquifers (Berger 2006; Welch et al. 2007). Groundwater moving through permeable bedrock is also channeled to basin aquifers (Entrix 2008). The Truckee River, Carson River, and Walker River flow east from the Sierra Nevada and Carson Range into the basin valleys. The Humboldt River receives flows from tributaries originating in the Central Mountains, Northern Mountains, and Ruby Mountains as it flows west. These rivers terminate at sinks or valley lakes when

surface flows are not fully diverted for human use. Several perennial streams in the Northern Mountains flow northward from Nevada into the Snake River Basin.

Ecosystem Selection and Characterization

Riparian Ecosystems

Riparian ecosystems of the HTNF generally occur in mountain meadow complexes or narrow streamside corridors. Meadows have formed where fine-grained, unconsolidated materials accumulated in valley bottoms behind moraines, side valley fans, or other constrictions (Miller et al. 2001; Weixelman et al. 2011) (fig. 16). Meadow complexes can support expansive mosaics of riparian vegetation supported by surface flows and springs (Trowbridge et al. 2011). When in good functioning condition, meadows provide a variety of ecosystem services, including carbon sequestration and spring runoff storage (Hunt et al. 2018; Reed et al. 2020). In addition, the herbaceous- and shrub-dominated communities in meadows are critical habitats for several species of management concern (Fair et al. 2018).



Figure 16—Kingston Meadow is one of several extensive riparian meadow complexes in the Toiyabe-Shoshone area. USDA Forest Service photo provided by Jeanne Chambers.

Riparian corridors with narrower bands of vegetation occur along bedrock-confined reaches or along incised reaches in unconfined settings (Manning and Padgett 1995) (fig. 17). These corridors are characterized by a variety of woody plant communities, which provide wildlife habitat and shade for streams (Fuller et al. 2022; Wondzell et al. 2019).



Figure 17—Riparian corridors (a,b) occur along small streams in the Jarbidge area of the Northern Mountains, within the range of the federally threatened bull trout. Courtesy photos by PacFish/InFish Biological Opinion Monitoring Program.

A combination of physical and biotic processes influences the dynamics of riparian ecosystems. Through erosion, deposition, and dissolution, streams and groundwater work with the geologic material available to create and modify geomorphic features such as floodplains, gravel bars, terraces, and spring runout channels (Stanford et al.

2005). These geomorphic features are occupied by plant communities that may change in structure and composition over several successional pathways (Gregory et al. 1991). The composition of communities and the nature of successional pathways is determined by the complex interplay of geomorphology, surface water and groundwater movement, disturbances, wildlife, and anthropogenic use (Padgett et al. 1989; Youngblood et al. 1985).

In general, early successional riparian plants establish on newly deposited sediment or scoured floodplains. These species depend on flood disturbance and bare sediment for seedling establishment and require a connection with groundwater for survival and growth (Stromberg and Merritt 2016). As this vegetation stabilizes the sediment and streambanks, soil development proceeds rapidly, allowing establishment of late seral species (Winward et al. 2000; Youngblood et al. 1985). Late seral communities may persist on geomorphic features until a subsequent disturbance triggers the reestablishment of pioneer species and communities. Alternatively, potential natural communities (PNCs) may establish if successional pathways are completed without additional disturbance under current environmental conditions (Weixelman et al. 1996). In some riparian settings, however, attainment of late seral or PNC conditions may be rare or impossible given the frequency of natural or anthropogenic disturbances (Youngblood et al. 1985). Secondary succession occurs when natural or anthropogenic disturbances cause the gradual replacement of vegetation communities. For example, where surface flow diversions or stream incisions have lowered the groundwater table, shallow-rooted riparian vegetation is replaced by deep-rooted riparian trees, deep-rooted riparian shrubs, or desert plants (Chambers and Linnerooth 2001; Stromberg and Merritt 2016).

Beavers (*Castor canadensis*) exert a considerable influence on these dynamics in unconfined valley bottoms, including meadows. Beaver ponds and canals help to raise water tables and distribute surface water across meadows and valley bottoms, to the benefit of wetland plant communities (Gurnell 1998; Hunt et al. 2015; Naiman et al. 1988). In some areas, beaver dam complexes maintain perennial streamflows and increase the extent of riparian and aquatic habitats (Grudzinski et al. 2019; Pollock et al. 2014). Beaver dam complexes also influence the ecology and geomorphology of valley bottoms by accumulating valley-fill sediment and promoting the multichannel, biologically controlled stages of stream evolution processes (Castro and Thorne 2019; Powers et al. 2019; Westbrook et al. 2011).

Springs and Fens

Springs are ecosystems entirely supported by groundwater. Various types of springs occur within national forests of the Intermountain Region (National Forest System lands in western Wyoming, southern Idaho, Utah, and Nevada), each with features that promote regional biodiversity (Springer and Stevens 2009). Springs with surface pools provide lentic (still freshwater) habitat for plants, vertebrates, and other biota. Spring runout channels create unique lotic (moving freshwater) habitats with relatively uniform water temperatures and low oxygen concentrations (Springer and Stevens 2009) (fig. 18). These channels also increase connectivity across the landscape for organisms associated with surface water systems. Runout channels may connect with

streams or may terminate to subsurface flow while still supporting aquatic and riparian species. Spring mounds, composed of calcareous minerals, peat, and other substrates, provide specialized habitat features as well (Sikes et al. 2013). Plant and animal communities at springs often have greater species richness and structural diversity than adjacent upland areas (Fleishman et al. 2005). Springs are also a critical source of drinking water for wildlife and livestock (Young 1994). In arid landscapes, springs discharging from bedrock aquifers, such as karst systems, buffer streamflow volume and temperatures from the effects of climate warming and drought (Caldwell et al. 2020). By providing these ecosystem services, aridland springs function as both current biodiversity hotspots and future climate refugia (Cartwright and Johnson 2018).



Figure 18—Spring runout channels, such as Willow Creek, in the SMNRA support unique plant and animal assemblages. Courtesy photo by the Spring Stewardship Institute.

Springs are abundant in areas with high bedrock permeability, where surface flows can be limited. In areas with less-permeable intrusive igneous and metamorphic rocks, springs are scarce, and surface flows are a larger component of the water yield (Berger 2006). Springs are often clustered at faults, escarpments, or valley walls, where groundwater is forced to the surface, or aquifers are exposed (Cartwright and Johnson 2018; Junghans et al. 2016; Whiting and Stamm 1995). Due to their location at faults,

distribution of springs in this region can be influenced by seismic activity (Wood et al. 1985).

Fens are wetlands that are primarily supported by groundwater, have a minimum depth (9 to 12 inches) of accumulated peat, and support unique plant communities (Bedford and Godwin 2003; Chadde et al. 1998; USDA FS 2007, 2012a). Some fens occur in isolated conditions, surrounded by upland vegetation; others occur in valley bottoms, embedded within riparian corridors and wet meadow complexes (Weixelmann et al. 2011). Valley bottoms with wet meadows and fens are important wildlife habitats critical for groundwater storage and carbon sequestration (Bedford and Godwin 2003; Schimelpfenig et al. 2014; Wohl et al. 2018).

Fens develop in locations with little mineral sediment deposition and high rates of groundwater discharge. Over long periods of time, saturated organic soils accumulate with the slow decay of peat-forming plants (Sikes et al. 2013). In the Sierra Nevada Range, fens have developed on hillslopes composed of unconsolidated deposits such as glacial moraines and outwash channels, in cirques and basins where lakes and ponds have accumulated peat, at spring mounds, and within wet meadows (Chadde et al. 1998; Weixelman et al. 2011; Wolf and Cooper 2015) (fig. 19). In volcanic settings, fens can form at the contacts of bedrock layers where younger, permeable lava flows lie atop older, nonpermeable flows (Wolf and Cooper 2015).

Dynamics of GDEs are also influenced by regional climate and local weather patterns, particularly annual variation in snowpack and snow water equivalent. The persistence of GDEs relies on discharge from groundwater, which is primarily recharged by snowmelt (Drexler et al. 2013; Winograd et al. 1998). Recharge rates are affected by distribution, amount, and timing of precipitation; evapotranspirative losses; snow cover thickness; snowmelt rate; land use; and land cover (Cartwright and Johnson 2018; Kløve et al. 2014;). Areas receiving relatively high precipitation, particularly areas that accumulate a slowly melting snowpack, are the most important sources of recharge (Drexler et al. 2013). The climate of Nevada and eastern California is characterized by low humidity and prolonged dry periods, which typically limit the development of fens to high elevations, where the hydrology is suitable for peat formation (Chadde et al. 1998; Wolf and Cooper 2015).

Classification

Within each ecosystem, we identified riparian communities and dominance groups to describe its biotic characteristics. We compiled vegetation data from several sources: (1) Manning and Padgett's (1995) community type classifications based on the dominant overstory and understory species in HTNF measurement plots, (2) riparian plant communities used by Weixelman et al. (1996, 1999) to describe ecological types in the east Sierra Nevada and Central Nevada ranges, and (3) riparian communities reported by the ongoing HTNF vegetation monitoring program (Weixelman et al. 1997). We combined their lists of riparian community types and riparian communities into a single list of communities in the Forest (Appendix B: table B.1). To evaluate the conservation status of these communities, we searched for similar riparian associations in the NatureServe Explorer database. These associations have been given a global



Figure 19—Sedge-dominated fens often occur within Sierra Nevada wet meadows. USDA Forest Service photo by D. Max Smith.

conservation ranking by NatureServe (2020). Using riparian association rankings, we classified each community as critically imperiled, imperiled, vulnerable, apparently secure, secure, or unranked.

We grouped communities into dominance groups based on their overstory growth forms. Dominance groups are useful for describing vegetation structure and potential for wildlife habitat. This system of nesting communities within dominance groups follows Padgett et al.'s (1989) classification system for Utah and Manning and Padgett's (1995) classification system for Nevada. Our dominance groups are (1) coniferous tree, (2) tall deciduous tree, (3) low deciduous tree, (4) tall willow, (5) low willow, (6) nonwillow shrub, and (7) herbaceous.

In the next sections, we describe the characteristics of communities and dominance groups in the HTNF. Descriptions of sites, species composition, and successional status were obtained from Chambers et al. (2021), Manning and Padgett (1995), and Weixelman et al. (1996, 1999).

Coniferous Tree Dominance Group

There are nine coniferous tree-dominated communities identified in the Forest (Appendix B: table B.1). These communities often resemble adjacent upland forests in structure and composition (Gregory et al. 1991) (fig. 20). Overstory trees include firs (*Abies lasiocarpa, Abies concolor*), Engelmann spruce (*Picea engelmannii*), pines (*Pinus contorta, Pinus flexilis*), gray alder (*Alnus incana*), and aspen (*Populus tremuloides*). Dominant understory plants include river birch (*Betula occidentalis*), red-osier dogwood (*Cornus sericea*), willows (*Salix* spp.), and several mesic forbs and graminoids. Geomorphic features are typically streamside terraces, but also include benches, floodplains, streambanks, drainageways, and meadows. Soils are recently deposited Entisols, intermediate-aged Inceptisols, or well-developed Mollisols that are rich in organic matter. Elevations range from 6,460 to 9,280 feet.



Figure 20—The Sierra Nevada geographic unit has many recreation sites near Reno, including Galena Creek. Riparian communities are dominated by coniferous trees and tall deciduous trees. USDA Forest Service photo by D. Max Smith.

In some areas, these communities develop through invasion by conifers of meadows or corridors previously dominated by graminoids, willows, cottonwoods, and other riparian plants. Composition of conifer-dominated types is stable in the absence of valley bottom disturbances, but high rates of water use by large conifers may lead to

loss of understory riparian species (Manning and Padgett 1995). Fires, insect outbreaks, and floods from runoff or beaver dams may promote a shift to dominance by shrubs, deciduous trees, or herbaceous plants. Understory dominance of Kentucky bluegrass (*Poa pratensis*) and Wood's rose (*Rosa woodsii*) in some communities indicates current or previous grazing pressure (Manning and Padgett 1995).

There are two conifer-dominated riparian associations with conservation rankings from NatureServe (2020). The *Pinus contorta*/*Cornus sericea* Swamp Woodland association is ranked as imperiled, and the *Pseudotsuga menziesii*/*Betula occidentalis* Riparian Woodland association is ranked as vulnerable.

Tall Deciduous Tree Dominance Group

There are 32 tall deciduous tree-dominated communities identified in the Forest (Appendix B: table B.1). Overstory trees include cottonwoods (*Populus angustifolia, Populus balsamifera* ssp. *trichocarpa*, *Populus fremontii*) and aspen. Elevations range from 5,030 to 9,850 feet. These communities are frequently found on terraces adjacent to or away from stream channels (fig. 20). They are also on streambanks, benches, bars, and other portions of the floodplain where water tables fluctuate but remain in contact with the rooting zone of trees. Aspen-dominated communities occur along streams or at springs. Dominant understory species of aspen communities include gray alder, currants (*Ribes* spp.), and snowberries (*Symphoricarpos* spp.). Cottonwood understories include willows, chokecherry (*Prunus virginianus*), skunkbush sumac (*Rhus trilobata*), red-osier dogwood, and sagebrush (*Artemisia* spp.). A variety of forbs and graminoids are also found in the understory of aspen and cottonwood stands.

Cottonwood-dominated communities quickly colonize sediment deposits or scoured floodplains. Cottonwoods are maintained on the landscape by disturbances, such as flood and fire, that create bare substrate for germination and induce sprouting (Kleindl et al. 2015; Wilding et al. 2014). Stands will most likely be replaced by late seral communities if disturbances are suppressed. Cottonwoods are likely to develop on recently formed Entisols and Inceptisols, whereas aspen-dominated types are frequently found in Mollisols, where soil development has had more time to occur (Manning and Padgett 1995). Some aspen communities are replaced by coniferous tree communities in the absence of disturbances, such as fire and beaver activity, from which aspens can rapidly recover. In some settings, aspen communities are persistent. Understory dominance of creeping bentgrass (*Agrostis stolonifera*), California brome (*Bromus carinatus*), Kentucky bluegrass, and Wood's rose in some communities indicates the effects of livestock grazing and stream incision (Manning and Padgett 1995).

Twelve tall deciduous-dominated associations have been ranked by NatureServe (2020). Rankings range from apparently secure to critically imperiled. The *Populus balsamifera*/*Salix exigua* Riparian Forest association is ranked as critically imperiled, the *Populus angustifolia*/*Rosa woodsii* Riparian Forest association is ranked as imperiled, and seven other associations are ranked as vulnerable.

Low Deciduous Tree Dominance Group

There are 13 low deciduous tree-dominated communities identified in the Forest (Appendix B: table B.1). Stands of gray alder, river birch, and other deciduous trees occur on benches, streambanks, and terraces in valley bottoms of various widths and gradients. Elevations range from less than 5,650 to 8,400 feet. Given their proximity to active stream channels, these pioneering communities establish following floods on newly deposited sediment or on scoured banks. The roots of gray alder and river birch are, therefore, helpful in stabilizing streambanks. Soils typically remain wet throughout the growing season, with aerated water moving rapidly through the soil column. Soils are Entisols, Inceptisols, Mollisols, or Histosols (which are primarily organic matter) showing a range of development. Depending on valley bottom characteristics, low deciduous-dominated communities can persist in the absence of disturbance such as fire or disease. In some areas, they are successional to late-seral shrub types or coniferous tree-dominated types. Communities with understory dominance by mesic forbs or mesic graminoids may be late seral or PNC. Communities with understory dominance of Kentucky bluegrass may represent grazing-induced states (Manning and Padgett 1995).

Seven low deciduous-dominated associations have been ranked by NatureServe (2020). All seven are ranked as vulnerable.

Tall Willow Dominance Group

There are 49 tall willow-dominated communities identified in the Forest (Appendix B: table B.1). These communities are found in a variety of settings and have understories dominated by various types of plants. Elevations range from 4,020 to 10,200 feet. This dominance group is further divided into cold willow and warm willow communities (Weixelman et al. 1996, 1999). Cold willow communities are dominated by *Salix geyeriana*, *Salix boothii*, *Salix lucida*, and other species. These often occur in wide valleys along low gradient streams at high elevations (fig. 21). Soils are often fine textured with abundant organic matter, mean soil temperatures of 41 °F at 20 inches depth, perennially high-water tables, and frequent ponding. Communities with Northwest Territory sedge (*Carex utriculata*) understories are often associated with beaver ponds. Cold willow communities may persist if soil conditions remain wet or mesic. Understory components may be affected by grazing if livestock can reach willow stands. Soil drying may lead to succession to coniferous tree-dominated communities.

Warm willow communities, dominated by *Salix exigua*, *S. lutea*, *S. lemmoni*, or *S. lasiolepis*, occupy active fluvial areas such as gravel bars in narrow and wide valleys across a range of elevations and stream gradients. A prolific root sprouter, *Salix exigua* can form extensive colonies in sites disturbed by flood or fire. Mean soil temperatures are 52 °F at 20 inches depth. These communities often establish on features where succession to other types may not occur due to frequent flood scour and deposition. At sites that are more stable, willows may persist or may be replaced by late seral vegetation, including coniferous tree-dominated communities. Understory dominance of Kentucky bluegrass and Wood's rose in some communities indicates effects of livestock grazing and stream incision (Manning and Padgett 1995).



Figure 21—Tahoe Meadows, in the Sierra Nevada geographic unit, contains herbaceous-, tall willow-, low willow-, and conifer-dominated riparian communities. USDA Forest Service photo by D. Max Smith.

Twenty-three tall willow-dominated associations have been ranked by NatureServe (2020). Rankings range from secure to imperiled. The *Salix exigua*/Mesic Forbs Wet Shrubland association is ranked as imperiled and 13 other associations are ranked as vulnerable.

Low Willow Dominance Group

There are five low willow-dominated communities identified in the Forest (Appendix B: table B.1). These communities are typically located in broad valley bottoms at elevations of 8,180 to 10,560 feet (fig. 21). These communities are often associated with subalpine mixed conifer forest. Dominant overstory willows include *Salix eastwoodiae*, *Salix orestera*, *Salix planifolia*, and *Salix wolfii*. Understory species include mountain sedge (*Carex scopulorum*). These communities have been found on Entisols, Inceptisols, Aridisols, Mollisols, and Histosols. Communities dominated by low willows on wet organic soils are persistent, but lowered water tables and drying of wet meadows may encourage encroachment by conifers. Understory components may be affected by soil

drying and grazing as well. Damage to willows from browsing encourages replacement by native or introduced species.

Three low willow-dominated associations have been ranked by NatureServe (2020). The *Salix wolfii*/Mesic Forbs Wet Shrubland association is ranked as vulnerable, and the two others are ranked as secure.

Nonwillow Shrub Dominance Group

There are 17 nonwillow shrub-dominated communities identified in the Forest (Appendix B: table B.1). This group includes several types that differ in site conditions. Red-osier dogwood-dominated communities are found in narrow to broad valley bottoms, often adjacent to active channels. Streams are low- to high-gradient, and elevation is between 5,040 and 8,840 feet. Red-osier dogwood is a pioneer species that colonizes stream bars and stabilizes banks. Soils are Entisols, Inceptisols, and Mollisols with fluctuating water tables and aerated water moving through coarse soil layers. In some settings, slow succession to coniferous or deciduous tree-dominated community types may occur.

Silver sagebrush (*Artemisia cana*), big sagebrush (*Artemisia tridendata* ssp. *tridentata*), and shrubby cinquefoil (*Dasiphora fruticosa*) dominate nonwillow shrub communities on a variety of geomorphic features in moderate to broad valley bottoms. Stream gradients are often low to moderate, and elevation ranges from 5,680 to 9,889 feet. These are late-seral riparian communities that can represent a transition between wetter willow and herbaceous communities and drier upland communities. Understory components are affected by succession, water availability, and grazing. These communities are usually found in well-developed Mollisols, but Entisols, Inceptisols, and clay-rich Alfisols have been noted as well. Water tables are at intermediate depths, and soils may dry during the growing season.

Nonwillow shrub communities dominated by other sagebrush species, rabbitbrush (*Ericameria nauseosa*), and Wood's rose are often indicative of water tables lowered by stream incision, as well as impacts of livestock grazing. These communities are at elevations ranging from 5,160 to 8,320 feet. Soils are typically Mollisols; Entisols, Inceptisols, and Aridisols are also noted.

Ten nonwillow shrub-dominated associations have been ranked by NatureServe (2020). Rankings range from secure to critically imperiled. The *Artemisia cana*/*Leymus cinereus* Wet Shrubland association is ranked as critically imperiled, the *Artemisia cana*/*Deschampsia cespitosa* Wet Shrubland and *Artemisia cana*/*Poa secunda* Wet Shrubland associations are ranked as imperiled, and the *Artemisia cana*/*Muhlenbergia richardsonis* Wet Shrub Meadow association is ranked as vulnerable.

Herbaceous Dominance Group

There are 54 herbaceous-dominated communities identified in the Forest (Appendix B: table B.1). Communities dominated by forbs and graminoids occur in a variety of settings ranging from 5,065 to 11,210 feet in elevation. Forb-dominated communities are often associated with narrow, high-gradient valley bottoms, whereas graminoid-

dominated communities often occur in broad valley bottoms along low-gradient streams in floodplains and riparian meadows (fig. 21). Forb and graminoid communities are also associated with springs and fens. Depending on characteristics such as depth to groundwater, herbaceous-dominated communities can include wet meadow vegetation, mesic meadow vegetation, or dry meadow vegetation (Castelli et al. 2000; Chambers et al. 2004). Northwest Territory sedge and other *Carex* species tend to occur in the wettest areas, such as beaver ponds. Most graminoid-dominated communities are found in well-developed Mollisols that have accumulated thick layers of organic matter. By accumulating deep layers of soil organic matter, fens and wet meadows provide the critical ecosystem service of carbon sequestration (Chimner et al. 2010; Wohl et al. 2012).

Herbaceous species such as sedges (*Carex aquatilis*, *Carex scopulorum*, and *Carex utriculata*), and tufted hairgrass (*Deschampsia cespitosa*) can colonize exposed soil and then form a dense stand that persists if water tables remain high and grazing disturbance is minimal. Other sedges, grasses, and forbs, such as *Carex douglasii*, *Carex nebrascensis*, *Hordeum brachyantherum*, *Iris missouriensis*, and J*uncus balticus*, are resistant to grazing and soil drying. Several herbaceous communities are dominated by introduced species, such as creeping bentgrass, cheatgrass (*Bromus tectorum*), and Kentucky bluegrass. These species colonize recently disturbed sites and withstand high levels of grazing, facilitating their displacement of analog sedge (*Carex simulata*), tufted hairgrass, and other native graminoids (Manning and Padgett 1995).

Twenty-four herbaceous-dominated associations have been ranked by NatureServe (2020). Rankings range from secure to critically imperiled. The *Danthonia californica* Valley Grassland association and *Leymus cinereus* Bottomland Wet Meadow association are ranked as critically imperiled, the *Danthonia intermedia* Grassland, *Hordeum brachyantherum* Lowland Wet Meadow, *Leymus cinereus* Alkaline Wet Meadow, and *Poa cusickii* Moist Meadow associations are ranked as imperiled. Four other associations are ranked as vulnerable.

Fish and Wildlife Habitat

Native Fishes

The HTNF contains streams that are part of the Great Basin, the Lower Colorado River Basin, and the Columbia River Basin. The native fish community of the HTNF includes three Federally threatened salmonids and one Federally threatened goodeid species (Appendix B: table B.2). The native range of Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*) covered much of northwestern Nevada, including streams and lakes in several of the geographic units. The subspecies now occurs in small, isolated populations in a subset of its native range. Important habitat features include canyons with deep pools and reaches receiving groundwater discharge (Boxall et al. 2008) (table 4). The Federally threatened Paiute cutthroat trout (*Oncorhynchus clarkia seleniris*) is native only to Silver King Creek and its tributaries, which are in the Carson River watershed in the Sierra Nevada geographic unit. This subspecies was inadvertently protected by sheepherders in 1912 when individuals were transplanted above Llewelyn Falls prior to the introduction of nonnative trout below the falls in the 1920s (US FWS

2004). Recent genetic analysis has shown that the population found upstream of its former range remains a distinct subspecies from Lahontan cutthroat trout (Saglam et al. 2017). The current range includes stream reaches in confined settings and reaches flowing through several meadows (Fair et al. 2018) (fig. 22).



Figure 22—Silver King Creek, in Upper Fish Valley, is one of the few streams within the current range of the Paiute cutthroat trout. Courtesy photo by the UC Davis Sierra Nevada Meadows Program.

In Nevada, the native range of the Federally threatened bull trout (*Salvelinus confluentus*) is limited to the Jarbidge River and its tributaries (Johnson and Weller 1994). This species occupies approximately 53 miles of streams in the Jarbidge area of the Northern Mountains geographic unit. Healthy populations of bull trout have been found in the East Fork Jarbidge River, the West Fork Jarbidge River, and their tributaries (Allen et al. 2010).

Cutthroat trout and bull trout require cold and clear water for spawning, as well as deep pools, cover from instream wood, and overhanging banks (USFWS 2004, 2015). Riparian ecosystems are instrumental in creating these features. Riparian vegetation filters sediment from overland flows, which helps to maintain water clarity (Correll 1997; Griffin et al. 2014). The root systems of sedges, willows, and other plants stabilize

Table 4—Total miles of perennial streams in the major river basins and total miles currently occupied by native trout in each geographic unit of the HTNF. Data were obtained from the National Hydrography Dataset and HTNF.

Geographic unit	Area	Columbia Basin stream miles	Great Basin stream miles	Lower Colorado Basin stream miles	Historical Lahontan cutthroat trout miles	Current Lahontan cutthroat trout miles	Current bull trout miles	Historic Paiute cutthroat trout miles	Paiute cutthroat trout miles
Central Mountains	Monitor-Hot Creek	0	134.5	0	0	0	0	0	0
	Paradise	0	1.1	0	0	0	0	0	0
	Toiyabe-Shoshone	0	539.9	0	133.8	24.5	0	0	0
	Toquima	0	88.6	0	0	0	0	0	0
East Sierra	NA	0	225.3	0	177.7	8.2	0	0	0
Eastern Mountains	Quinn-Grant	0	47.5	0	0	0	0	0	0
	Schell Creek	0	133.7	0	0	0	0	0	0
	Snake	0	40.9	0	0	0	0	0	0
	Ward	0	0	0	0	0	0	0	0
	White Pine	0	43.6	31.2	0	0	0	0	0
Northern Mountains	Jarbidge	694.1	124.4	0	193.2	44.5	52.9	0	0
	Santa Rosa	3.9	373.5	0	287.1	17.8	0	0	0
Ruby Mountains	NA	0	522.3	0	515.6	41.9	0	0	0
Sierra Nevada	NA	0	1059.6	0	402.8	63.2	0	8.8	24.3
SMNRA	NA	0	11.0	6.5	0	0	0	0	0

NA: not applicable.

soils, allowing the establishment of overhanging banks (Winward 2000). The roots of live trees and the fallen trunks and branches of dead trees provide cover and create pools (Cluer and Thorne 2014; Moore and Gregory 1988). Willows and low deciduous trees also shade stream channels, thereby maintaining cool water temperatures during summer months (Beschta 1997; Fuller et al. 2022; Wondzell et al. 2019). Beaver dams enhance habitat for trout and other native fishes by creating deep pools for overwintering habitat, regulating summer water temperatures, and encouraging the growth of riparian vegetation (McNeill et al. 1997; Weber et al. 2017).

Several relict and endemic fishes are supported by springs in valleys and ranges. Connections between precipitation, surface flows, and groundwater are critical to their conservation in this arid landscape (Davis et al. 2017). The Federally threatened Railroad Valley springfish (*Crenichthys nevadae*) is native to basins near the Eastern Mountains and has been introduced to sites in the Hot Creek watershed of the Central Mountains geographic unit (WAPT 2012). Populations have been maintained at these sites to protect the species. In the Great Basin and Lower Colorado Basin, several Federal- and State-listed fishes are found outside of the HTNF, but are dependent, in part, on streamflow and groundwater originating in the Forest (Appendix B: table B.2).

Aquatic Invertebrates

Springsnails in the genera *Pyrgulopsis* and *Tyronia* have recently received attention as a group in need of conservation and research (McKelvey et al. 2020). The Great Basin has the highest diversity of *Pyrgulopsis* species in the West, followed by the Colorado River Basin, making the HTNF and surrounding areas critical to their conservation (Hershler et al. 2014; McKelvey et al. 2020). A multistate agreement is in place to compile information about distribution, status, and habitat; to reduce threats to populations and habitats; and to maintain, enhance, and restore habitats in Nevada and Utah (Springsnail Conservation Team 2017).

Amphibians and Reptiles

Amphibians have declined throughout the Intermountain Region (Arkle and Pilliod 2015; Robinson et al. 1998). Two Federally-listed species and several State-listed species use streams, riparian areas, and GDEs of the HTNF as breeding sites, foraging sites, and movement corridors (Sikes et al. 2013; WAPT 2012) (Appendix B: table B.2). The Federally threatened Yosemite toad (*Anaxyrus canorus*) breeds in herbaceous- and low willow-dominated meadow communities (Kattelmann 2012; Morton and Pereyra 2010). Their eggs are laid in shallow, intermittent pools fed by snowmelt (Roche et al. 2012). Suitable habitat is located within the Carson River and Walker River watersheds of the Sierra Nevada geographic unit (Fair et al. 2018; Hunt et al. 2015; Liang and Stohlgren 2011). The Federally endangered Sierra Nevada yellow-legged frog (*Rana sierrae*) typically uses permanent ponds and lakes for breeding and overwintering sites (Knapp et al. 2003). Similar conditions are created by beaver ponds, fens, and low-gradient meadow streams (Brown et al. 2019; Sikes et al. 2013; Yarnell et al. 2019). Populations are currently found in high-elevation meadows of the Truckee River, Carson River, and Walker River watersheds (Fair et al. 2018; Greenwood et al. 2018; Hunt et al. 2018). In southwestern riparian ecosystems, reptile abundance and richness are greatest in

structurally complex stands with native trees and shrubs (Bateman and Merritt 2020). Riparian lizard communities include species with preferences for characteristics such as open understory, woody debris, and native trees, all of which can be altered by invasive species and streamflow reduction (Bateman and Ostoja 2012; Bateman and Riddle 2020; Bateman et al. 2008). Diverse snake communities, including terrestrial and semiaquatic species, are dependent on riparian and groundwater-dependent ecosystems as well (Bateman et al. 2009).

Birds

Many species of landbirds, including neotropical migrants, nest in the diverse plant communities associated with riparian ecosystems and GDEs (Appendix B: table B.2). Tall deciduous tree-dominated communities have high structural diversity and are among the most valuable habitats for birds and other wildlife (Smith and Finch 2014). The large size of mature cottonwood trees makes them attractive nest sites for diurnal raptors, owls, and other large birds. Cottonwoods and aspens are critical nesting trees for woodpeckers and other cavity-nesters (Hollenbeck and Ripple 2008; Saab and Vierling 2001). The canopies of tall deciduous trees are also frequently used as foraging sites by foliage-gleaning birds during the migration and nesting seasons.

Riparian-nesting birds rely on a variety of vegetation communities across elevations of the Forest. At lower elevations, stands of tall willows are especially important nesting habitats for the Federally endangered southwestern willow flycatcher (*Empidonax traillii extimus*) and other neotropical migrants (Olechnowski and Debinski 2008; Ostoja et al. 2013; Singer et al. 1994). At higher elevations, meadows and dense willow stands are habitat for the State-listed willow flycatcher subspecies (*Empidonax traillii brewsteri*) (Greenwood et al. 2018). Herbaceous- and shrub-dominated vegetation in fens and wet meadows are used for nesting by the Lincoln's sparrow (*Melospiza lincolnii alticola*), which specializes in these habitats (Cicero 1997). A variety of other migratory landbirds nest in high-elevation willow stands and wet meadows (Loffland 2019). By providing important cover, low willow-dominated communities benefit wildlife during their reproductive and migratory periods (Weixelman et al. 1999).

Greater sage-grouse (*Centrocercus urophasianus*) is a species previously considered for listing as Federally threatened. Priority areas for sage-grouse conservation are located within several geographic units (table 5). Though primarily associated with xeric sagebrush uplands, sage-grouse rely on willow, nonwillow shrub, and herbaceous-dominated riparian areas as summer brood-rearing habitat (Donnelly et al. 2016). Sage-grouse hens seek out these areas to forage on herbaceous vegetation and invertebrates while productivity in upland habitat is unsuitable (Atamian et al. 2010; Fischer et al. 1996). The maintenance of these habitats is, therefore, a critical component of sage-grouse conservation (Dzialak et al. 2011). Summer brood-rearing habitat was modeled in the region by Coates et al. (2014) using a habitat suitability index. The Northern Mountains, Ruby Mountains, and Central Mountains had the greatest amount of high-quality habitat among the geographic units. Using LANDFIRE and National Hydrography Dataset data, the HTNF estimated the amount of brood-rearing riparian habitat in each unit. The Jarbidge area of the Northern Mountains, Toiyabe-Shoshone

area of the Central Mountains, and the Sierra Nevada had the greatest extent of this habitat (table 5).

In addition to landbirds, a number of waterbirds rely on streams, wetlands, and lakes fed by water originating in geographic units of the HTNF (Appendix B: table B.2).

Table 5—Area of geographic units designated as greater sage-grouse priority areas for conservation (PACs), as summer brood-rearing habitat by the HTNF, and riparian zones suitable for foraging within summer brood areas. Riparian areas were delineated using the Valley Bottom Extraction Tool. Suitable riparian zones were identified using FS existing vegetation data.

Geographic unit	Area	Acres- PACs	Acres high quality summer brood habitat	Acres riparian foraging habitat
Central Mountains	Monitor-Hot Creek	438,019.7	72,228.1	7,834.2
	Paradise	0	0	306.5
	Toiyabe-Shoshone	506,190.0	149,254.9	13,492.9
	Toquima	203,192.9	16,458.5	4,938.9
East Sierra	NA	338,958.0	0	5,725.1
Eastern Mountains	Quinn-Grant	0	0	176.6
	Schell Creek	109,964.3	69,401.1	1,205.6
	Snake	0	9,754.7	76.5
	Ward	7,909.8	1,335.3	37.7
	White Pine	198,941.6	49,937.6	510.8
Northern Mountains	Jarbidge	573,833.1	463,778.3	38,490.8
	Santa Rosa	261,714.7	177,433.9	6,867.6
Ruby Mountains	NA	184,194.4	167,763.5	4,452.8
Sierra Nevada	NA	142,472.4	6,900.9	12,196.1
SMNRA	NA	0	0	0

NA: not applicable.

Mammals

Riparian ecosystems contain diverse and abundant communities of small mammals (Appendix B: table B.2). Rodents, shrews, mustelids, and lagomorphs inhabit dense patches of herbaceous riparian vegetation, which in many areas is enhanced by beaver activity (Frey 2018). Stream ecosystems contain many critical habitat components for bats, a group that is especially sensitive to the impacts of anthropogenic disturbances and climate change (Festa et al. 2023). A variety of bats forage for aquatic and terrestrial insects above streams and riparian vegetation (Fenton and Morris 1976; Hagen and Sabo 2014; Rogers et al. 2006). In riparian corridors, several species depend on large snags, cottonwoods, and other deciduous trees for nursery and roost sites (Andersen and Geluso 2018; Betts 1998; Chung-MacCoubrey 1999; Tye and Geluso 2019). Accessible drinking water, from sources such as streams and spring pools, is critical for survival and reproduction in arid environments (Adams and Hayes 2008; Lambert et al. 2018).

Distribution of Riparian and Groundwater-Dependent Ecosystems

To describe the distribution of areas that can be considered riparian ecosystems, we combined several geographic information systems (GIS) layers representing the extent of riparian vegetation (Appendix A). We used (1) shapefiles representing existing vegetation on the Forest (FS VEG), as mapped by the HTNF; (2) the Desert Research Institute's Map of Riparian Vegetation in Nevada (MARVN) shapefile (McGwire 2019); and (3) an existing vegetation type (LANDFIRE EVT) raster developed by the LANDFIRE program using its recently released 2016 Remap data (LANDFIRE 2019). We acknowledge that, given the narrow width of many riparian corridors in this arid region and the low resolution of these datasets (30 m; 100 feet), we are likely underestimating riparian extent. We also obtained shapefiles displaying the distribution of meadows in the Central Mountains geographic unit (Trowbridge et al. 2011) and the East Sierra and Sierra Nevada geographic units (Viers et al. 2013).

To map the potential distribution of GDEs, we obtained a shapefile of known spring locations from the Springs Stewardship Institute (SSI). We also obtained a shapefile of potential fens from the Colorado Natural History Program (CNHP). Using National Wetland Inventory data and aerial imagery, CNHP staff located wetlands that are potential fens and classified them as likely fens, possible fens, and low confidence fens based on the number of fenlike characteristics they observed using aerial imagery (Smith and Lemly 2019). To describe the influence of geologic setting on distribution of riparian ecosystems and GDEs, we created shapefiles showing the locations of faults and surficial geologic units obtained from the U.S. Geological Survey state geologic map compilation (Horton et al. 2017). We reclassified geologic units into hydrogeologic groups, following the methods of Maurer et al. (2004).

In the following sections, we summarize distribution patterns of riparian ecosystems and GDEs. Methods, maps, and descriptions of geographic units are provided in Appendix C.

Distribution of Riparian Ecosystems

The three vegetation mapping methods we summarized yielded fairly consistent results (table 6). The FS VEG shapefile, MRVN shapefile and LANDFIRE EVT raster show that the Northern Mountains, Ruby Mountains, and Sierra Nevada have the greatest extent of riparian vegetation, which is associated with perennial streams throughout these units. The smallest extents of riparian vegetation are in the Paradise area of the Central Mountains, the Ward area of the Eastern Mountains, and the SMNRA unit. In these smaller, drier areas of the Forest, riparian ecosystems occur in patches near springs or perennial and intermittent stream reaches.

We obtained shapefiles of meadows for the Central Mountains, East Sierra, and Sierra Nevada units (table 6). Though riparian meadows are likely present in all the other units, they have not been mapped to the same extent. The Sierra Nevada unit has the greatest area and percent area of mapped meadows, followed by the Toiyabe-Shoshone area of the Central Mountains. More than 300 meadows were mapped within the Sierra Nevada unit, whereas 54 were mapped in the Central Mountains. The East Sierra unit

has the smallest area of mapped meadows, with fewer than 10 meadows mapped on the western border.

Table 6—Characteristics of riparian ecosystem distribution, by geographic unit.

Geographic unit	Area	LANDFIRE riparian acres (% of total area)	FS VEG riparian acres (% of area)	MRVN riparian acres (% of unit)[a]	Riparian meadow acres[b]
Central Mountains	Monitor-Hot Creek	3394.4 (0.4)	6854.3 (0.8)	9330.0 (1.1)	97.3 (0.01)
	Paradise	62.3 (0.1)	25.3 (0.04)	186.0 (0.3)	—
	Toiyabe-Shoshone	6143.4 (0.8)	10934.5 (1.5)	14363.5 (1.9)	227.9 (0.03)
	Toquima	1329.7 (0.3)	2697.3 (0.6)	4708.6 (1.1)	81.4 (0.02)
East Sierra	NA	6665.6 (0.8)	5448.8 (0.6)	6751.1 (1.0)	41.2 (0.005)
Eastern Mountains	Quinn-Grant	363.4 (0.2)	998.9 (0.5)	1728.4 (0.8)	—
	Schell Creek	1020.1 (0.4)	3376.8 (1.2)	5891.5 (2.0)	—
	Snake	374.3 (0.3)	1213.4 (1.0)	2072.8 (1.7)	—
	Ward	17.1 (0.04)	103.6 (0.3)	75.4 (0.2)	—
	White Pine	765.5 (0.2)	804.7 (0.2)	2141.6 (0.6)	—
Northern Mountains	Jarbidge	17644.1 (2.3)	20834.0 (2.7)	27524.2 (3.6)	—
	Santa Rosa	3160.9 (1.1)	4575.2 (1.5)	15341.2 (5.1)	—
Ruby Mountains	NA	5984.0 (1.4)	8374.0 (1.9)	11153.7 (2.5)	—
Sierra Nevada	NA	31532.2 (3.6)	21248.0 (2.5)	6551.5 (2.0)	7842.2 (0.9)
SMNRA	NA	1309.2 (0.4)	—	473.4 (0.1)	—

[a] These data were only obtained for the Central Mountains, East Sierra, and Sierra Nevada geographic units
[b] These data were only obtained for the Central Mountains, East Sierra, and Sierra Nevada geographic units
— Indicates that ecosystems may be present, but had not been mapped.
NA: Not applicable.

Distribution of Springs

The distribution of springs is important for natural resource management, but spring inventories are often incomplete (Junghans et al. 2016). The SSI dataset shows a uniform effort to map the locations of springs across the units (Springs Stewardship Institute n.d.). An extensive study of riparian meadows yielded the locations of additional springs in the Monitor-Hot Creek, Toiyabe-Shoshone, and Toquima Ranges (Trowbridge et al. 2011). The Santa Rosa area of the Northern Mountains, which is largely composed of extrusive igneous rocks, has the greatest density of springs (table 3). Other areas with high densities are the Jarbidge area of the Northern Mountains, the Ruby Mountains, the Schell Creek and White Pine areas of the Eastern Mountains, the SMNRA, and the Paradise, Toiyabe-Shoshone, and Toquima areas of the Central Mountains. The surficial geologies of these units contain high percentages of extrusive igneous rocks

or carbonate sedimentary rocks. Throughout the Forest, large clusters of springs are associated with extrusive igneous bedrock and faulted sedimentary rocks.

Distribution of Fens

The CHNP mapping program identified potential fens in every geographic unit except for the SMNRA. A total of 2,436 potential fens were identified. Likely fens were mapped in the Central Mountains, East Sierra, Northern Mountains, Ruby Mountains, and Sierra Nevada. The Sierra Nevada unit has by far the highest density of potential fens and likely fens. Most of the likely fens (83 percent) occur between the elevations of 8,000 and 11,000 feet, and 54 percent were mapped between 9,000 and 10,000 feet. An estimated 48 percent of likely fens were in intrusive igneous rocks, which compose only 11 percent of the Forest (Smith and Lemly 2019). Of the 10 subwatersheds with the highest density of fens, nine were in the Walker River watershed in California, and one was in the Carson River watershed, also in California (Smith and Lemly 2019).

Summary

We summarized the dynamics and distribution of riparian ecosystems and GDEs, and their plant communities. There are several imperiled and critically imperiled communities within the conifer, tall deciduous, tall willow, nonwillow shrub, and herbaceous dominance groups. These communities are important habitats for fish and wildlife, including threatened, endangered, and sensitive species found in the Forest. Vegetation mapping indicates that the Northern Mountains, Ruby Mountains, and Sierra Nevada units have the greatest extent of riparian ecosystems. Springs and karst systems are important components of forest hydrology and habitat in areas where surface flows are limited in extent and duration. Mapped springs are abundant in several geographic units, with large clusters in areas with carbonate sedimentary and extrusive igneous geologies. Fen mapping from the CNHP indicates that the Sierra Nevada and Ruby Mountains units have the greatest densities of fens. Most fens were mapped in areas characterized by intrusive igneous bedrock at elevations of 8,000 feet and higher. These fen-mapping results are solely based on aerial imagery and should be validated by field surveys.

KEY ECOSYSTEM CHARACTERISTICS

Surface Water and Groundwater Fluctuations

The timing, frequency, duration, and magnitude of high and low flows, as well as the rate of change in surface water and groundwater levels, are important components of a freshwater ecosystem's natural flow regime (Poff et al. 1997). High flows connect the stream to its floodplain, allowing exchange of nutrients and organic matter, along with recharge of hyporheic and groundwater systems; these flows also reshape floodplain geomorphology (Junk et al. 1989; Poff et al. 1997; Stanford et al. 2005). Growth, survival, and distribution of native riparian plants, such as willows and cottonwoods, are highly influenced by natural flow regimes, requiring scoured alluvium to establish and access to groundwater to survive (Horton et al. 2001; Shafroth et al. 2000; Smith et al. 1998). In addition to native plants, the life cycles of several wildlife species associated with riparian areas depend on reliable and predictable fluctuations that are relatively unaltered from the system's natural flow regime (Lytle and Merritt 2004; Poff et al. 1997; Stanford et al. 2005).

Drivers

Fluctuations of surface water and groundwater in the Basin and Range features of the HTNF are highly influenced by climate (Belcher et al. 2013; Chambers and Miller 2011; Duffy and Al-Hassan 1988; Eakin et al. 1976; Jewett et al. 2004). Interannual and intra-annual temperature and precipitation patterns vary widely due to topographic differences within the study area (Chambers and Miller 2011; Duffy and Al-Hassan 1988; Eakin et al. 1976; Elias et al. 2015; Flaschka et al. 1987; Jewett et al. 2004). Average annual air temperature is inversely related to elevation, with higher temperatures occurring in the basins than in the adjacent mountain ranges (Chambers and Miller 2011). Additionally, large diurnal and seasonal temperature ranges are characteristic of the Great Basin region (Elias et al. 2015; Flaschka et al. 1987). Evapotranspiration potential is high in the intermontane basins and decreases at higher elevations in the mountain ranges (Chambers and Miller 2011). Average annual precipitation is orographically controlled (e.g., precipitation increases as air masses reach mountains and rise and cool) and highly variable throughout the study area (Chambers and Miller 2011; Eakin et al. 1976; Elias et al. 2015; Jewett et al. 2004). The majority of precipitation falls as snow at higher elevations, with high and broad mountain ranges collecting the most precipitation from the moist air masses that move across the Great Basin (Elias et al. 2015; Jewett et al. 2004). Due to the low temperatures, low evapotranspiration rates, and high precipitation, high-elevation areas are important water sources for both surface water and groundwater systems (Chambers and Miller 2011; Elias et al. 2015). Winter snowpack in these mountain ranges is the primary source of recharge and runoff (Elias et al. 2015; Flaschka et al. 1987; Jewett et al. 2004). Spring snowmelt and localized convective summer thunderstorms contribute to the highest surface water flows throughout the study area (Jewett et al. 2004). Discharge from groundwater sustains stream baseflows during late summer, fall, and winter months (Jewett et al. 2004).

Water fluctuations are also influenced by the geology and topography of the Great Basin (Belcher et al. 2013; Chambers and Miller 2011; Duffy and Al-Hassan 1988; Eakin et al. 1976). The study area is dominated by fault-block mountain ranges that trend from southwest to northeast and are separated by wide, alluvial-filled, internally draining intermontane basins (Banner 1992; Eakin et al. 1976; Jewett et al. 2004). These mountain ranges and the geologic features that form and underlie them strongly control patterns in regional water flow (Chambers and Miller 2011; Eakin et al. 1976). Surface waters often flow directly on top of bedrock in mountain ranges where evapotranspiration is low and inputs from rainfall, snowmelt, and springs are high (Chambers and Miller 2011). Bedrock units typically have low permeability and prevent infiltration to groundwater systems (Chambers and Miller 2011). Depending on the presence of bedrock channels, drainage basin area, local mean annual precipitation, and the percentage of a basin that is at high altitude, streams that originate in the HTNF deliver water to mountain fronts where the stream infiltrates into alluvial fill sediments in the valleys (Chambers and Miller 2011; Eakin et al. 1976; Maurer et al. 2004). Many of these intermontane basins that experience high evapotranspiration are composed of thick and permeable alluvial sediments that do not have major surface water networks but include playa lakes which capture all of the drainage from surrounding mountains (Chambers and Miller 2011).

Flow of groundwater throughout the Great Basin Region is also strongly influenced by geology (Belcher et al. 2013; Chambers and Miller 2011; Eakin et al. 1976; Maurer et al. 2004; Planert and Williams 1995; Plume 1996). Recharge to groundwater systems tends to occur at high elevations and the upper sections of alluvial fans (Belcher et al. 2013; Eakin et al. 1976; Elias et al. 2015; Maurer et al. 2004). Groundwater typically discharges in low elevations in the centers of alluvial valleys, as well as in perennial streams, springs, and wetlands (Chambers and Miller 2011; Eakin et al. 1976; Maurer et al. 2004). Flow paths and rates are strongly influenced by the types of geologic units; bedrock, intrusive igneous rocks, and metamorphic rocks often act as barriers with low permeability (Belcher et al. 2013; Chambers and Miller 2011; Maurer et al. 2004; Plume 1996). In contrast, highly fractured basalt, unconsolidated deposits, and sedimentary rocks can be highly permeable (Chambers and Miller 2011; Maurer et al. 2004). Finally, faults influence fluctuations in groundwater by restricting flow in unconsolidated formations and enhancing flow through bedrock (Belcher et al. 2013; Maurer et al. 2004).

Beavers impact water fluctuations by constructing dams that slow runoff, store water and sediment, raise the level of local surface water and groundwater, and increase aquifer recharge (Andersen and Shafroth 2010; Collen and Gibson 2001; Gibson and Olden 2014; Lowry 1993; Westbrook et al. 2006). These effects are particularly strong in streams with a series of dams built along the longitudinal gradient (Collen and Gibson 2001). Beaver ponds moderate high and low flows by collecting runoff during peak discharge and releasing it slowly throughout drier months of the year (Collen and Gibson 2001; Gibson and Olden 2014; Westbrook et al. 2006). These moderating effects can be sufficiently strong to transition intermittent streams to perennial when beaver dams are introduced to the system (Collen and Gibson 2001; Gibson and Olden 2014; Westbrook et al. 2006). In addition to the longitudinal impacts generated by beaver

activity, dams have lateral impacts, including greater frequency, extent, duration, and depth of overbank flooding (Gibson and Olden 2014; Westbrook et al. 2006).

Stressors

Stressors to surface water and groundwater fluctuations include activities or forces that alter connectivity between surface water and groundwater systems or that impact the timing, frequency, duration, magnitude, or rate of change in high and low flows. Stressors can be natural or anthropogenic and include wildfire, vegetation mortality, drought, dams, diversions, roads and trails, timber harvest, and livestock grazing (Ostoja et al. 2013) (table 7). Whether the stressor is natural or anthropogenic, any activities that alter the abundance of both surface and subsurface water can have major effects on the presence and persistence of riparian areas in the Great Basin (Belcher et al. 2013; Jewett et al. 2004; Ostoja et al. 2013).

Natural disturbances to surface water and groundwater fluctuations include wildfire, vegetation mortality due to insects and disease, and drought (Pendleton et al. 2013). Fires that burn large amounts of the landscape at high severity can have major hydrologic impacts such as flash flooding or severe sedimentation that reduces connectivity between ground and surface water systems (Doerr et al. 2006; Ice et al. 2004; Miller et al. 2013). Widespread vegetation mortality can alter the timing of water fluctuations by increasing infiltration to groundwater systems in late summer (Bearup et al. 2014). Rates of groundwater recharge in the Great Basin are closely linked to precipitation (Belcher et al. 2013; Harrill and Prudic 1998; Naumburg et al. 2005), and droughts throughout the study area are linked to lower water tables and reduced streamflow (Elias et al. 2015; Naumburg et al. 2005). While wildfire, vegetation mortality, and drought are natural stressors to surface water and groundwater fluctuations, their effects can be amplified by anthropogenic activities. Fire suppression has led to larger fuel loads compared to historical conditions (Parsons and DeBenedetti 1979; Schoennagel et al. 2004). These fuel conditions, combined with changes in climate, have lengthened the fire season and contributed to an increase in large and more severe wildfires throughout the western United States (Miller et al. 2013). Additionally, climatic changes that include warmer air temperatures and altered precipitation patterns could prolong drought and modify hydrology throughout the study area (Elias et al. 2015).

Anthropogenic stressors to surface water and groundwater fluctuations include dams, diversions, roads and trails, timber harvest, and livestock grazing (Pendleton et al. 2013). Dams and diversions reduce peak and base flows and release water at different times for different durations, with major impacts to the timing, magnitude, and frequency of a system's natural flow regime (Graf 1999; Magilligan and Nislow 2005; Winter et al. 1998). Roads and trails can reduce infiltration and increase surface runoff by altering the contour of hillslopes and adding impervious surfaces to the landscape (Forman and Alexander 1998). Additionally, these types of infrastructure are unnatural sources of fine sediment that, when washed into stream channels, can obstruct the natural flow paths that connect surface water and groundwater systems (Forman and Alexander 1998; Pickering et al. 2010; Reid and Dunne 1984). Impacts from timber harvest on the hydrology of an area depend on management, with clearcutting

associated with increased surface runoff and sedimentation that can disrupt natural surface water and groundwater networks (Bosch and Hewlett 1982). Lastly, grazing by livestock and some wildlife is associated with reduced upland and riparian vegetative cover, reduced stability, increased runoff, and stream incision (Chambers and Miller 2011; Jewett et al. 2004; Krueper 1993, 1996).

Climatic conditions are especially influential on water fluctuations. Warmer air temperatures and altered precipitation patterns, including smaller snowpacks, earlier snowmelt, and more precipitation in the form of rain, can alter the timing and magnitude of surface runoff and groundwater recharge (Belcher et al. 2013; Cayan 1996; Elias et al. 2015; Halofsky et al. 2018; Hamlet et al. 2005). Higher temperatures can also increase rates of evapotranspiration and alter the distribution of plants that rely on groundwater (Chen et al. 2011; Rind et al. 1990; Weiss et al. 2009). Within the study area, air temperatures have increased across the Forest, with particularly large increases in seasonal temperatures occurring in the Sierra Nevada and East Sierra units (Elias et al. 2015; Pendleton et al. 2013) (Appendix D; table D.1). Changes in seasonal precipitation across the HTNF tend to be small; however, in the dry climate present on the HTNF, a loss of an inch of winter precipitation can be equivalent to losing more than a quarter of annual precipitation (Appendix D: table D.1). Natural groundwater and surface water fluctuations are strained by these changes in air temperature and precipitation, with all other stressors acting cumulatively (Elias et al. 2015; Halofsky et al. 2018; Pendleton et al. 2013; USDA FS 2012a,b). Riparian areas and wetlands are particularly vulnerable to climatic changes on the HTNF, especially those at lower elevations where soils are already affected by drought (Halofsky et al. 2018).

Methods

We used five indicators to assess surface water and groundwater fluctuations: (1) conversion of riparian habitat to conifer cover, (2) conversion of riparian habitat to upland grass and shrub species, (3) the Watershed Condition Classification (WCC) water quantity indicator, (4) percentage of the unit in poor or very poor condition for deviation in winter air temperature, (5) percentage of the unit in poor or very poor condition for deviation in winter precipitation (Appendix D: table D.1). We used output from the Riparian Condition Assessment Toolbox (R-CAT; Macfarlane et al. 2017) to estimate the percentage of streams within each unit with moderate or significant conversion of riparian cover to conifers, grasses, or shrubs. These transitions in cover type from riparian vegetation to upland species are associated with altered flow regimes (Macfarlane et al. 2017). Additionally, encroachment of grasses, shrubs, and conifers can initiate positive feedbacks that reduce turnover in the landscape, modify water yield and fluctuation timing, and encourage more upland encroachment (Huxman et al. 2005; Macfarlane et al. 2017). R-CAT uses 30-meter (98-foot) LANDFIRE data to estimate conifer and upland encroachment, which can be too coarse to adequately map vegetation that occurs in some of the narrow riparian corridors within the study area. In these cases, R-CAT tends to overestimate conversion of riparian habitats to alternative habitat types. We acquired information on water quantity from the WCC indicator that addresses changes in timing, frequency, duration, or magnitude of natural flows (Potyondy and Geier 2011). We used data that captured

the deviation in winter air temperature and precipitation and condition classifications from the Terrestrial Condition Assessment version 2.0 (TCA; Cleland et al. 2017). These two indicators address climatic warming that is linked to alterations in snowpack and natural flow regimes throughout the western United States (Safeeq and Hunsaker 2016).

We used these indicators of groundwater and surface water fluctuations to determine whether evidence existed of moderate or substantial alteration. If more than 33 percent, but less than 67 percent, of streams had converted from riparian to conifer, grass, or shrub cover, we considered this evidence of moderate alteration from natural range of variation (NRV); if more than 67 percent of streams had converted to conifer, grass, or shrub cover, we considered this evidence of substantial alteration from NRV. If more than half of watersheds were classified by the WCC to be in functioning-at-risk condition, we considered this evidence of moderate alteration from NRV. If more than half of watersheds were classified in impaired condition, we considered this evidence of substantial alteration from NRV. If more than 33 percent, but less than 67 percent, of the unit was in poor or very poor condition for deviations in winter precipitation or winter air temperature, we considered this evidence of moderate alteration from NRV. If more than 67 percent of the unit was in poor or very poor condition for deviations in winter precipitation or winter temperature, we considered this evidence of substantial alteration from NRV. To estimate the NRV status of surface water and groundwater fluctuations within each unit, we evaluated whether the majority of indicators provided evidence of no, moderate, or substantial alteration.

We used surveys from the SSI database to identify disturbances present at GDEs on the HTNF. Some SSI reports provided information on whether impacts from avalanches, fire, flood, drought, diversions, horse and burro activity, cattle, recreation, or dredging were present. The Spring Ecosystem Assessment Protocol (SEAP), which provides information on the condition of aquifer functionality, water quality, geomorphology, human influence, habitat, and biotic integrity, was implemented at some springs on the Forest. We used the SEAP aquifer functionality parameter to evaluate water fluctuations at springs across the Forest. This parameter is a composite score that evaluates the amount of discharge, as well as whether the aquifer is in decline, flow is unnaturally reduced, or discharge is persistent. SEAP data were relatively rare across the assessment area, but we summarized SEAP results by site when these data were available.

Results

Water fluctuations on the HTNF were likely impacted by multiple interacting stressors. Based on indicators of water fluctuations, surface water and groundwater fluctuations were likely moderately altered from NRV in six units. The remaining unit, the Northern Mountains, was likely substantially altered (fig. 23). Conversion of riparian areas from native riparian vegetation to conifer species had occurred in all units, with extensive conifer encroachment occurring in the Central Mountains, East Sierra, Eastern Mountains, and Sierra Nevada. Encroachment of upland grasses and shrubs had occurred in all units as well, but was less extensive than conversion to conifers except in the Northern Mountains, where 66 percent of riparian corridor miles had

experienced conversion of riparian area to upland grasses or shrubs. See Appendix D for unit summaries.

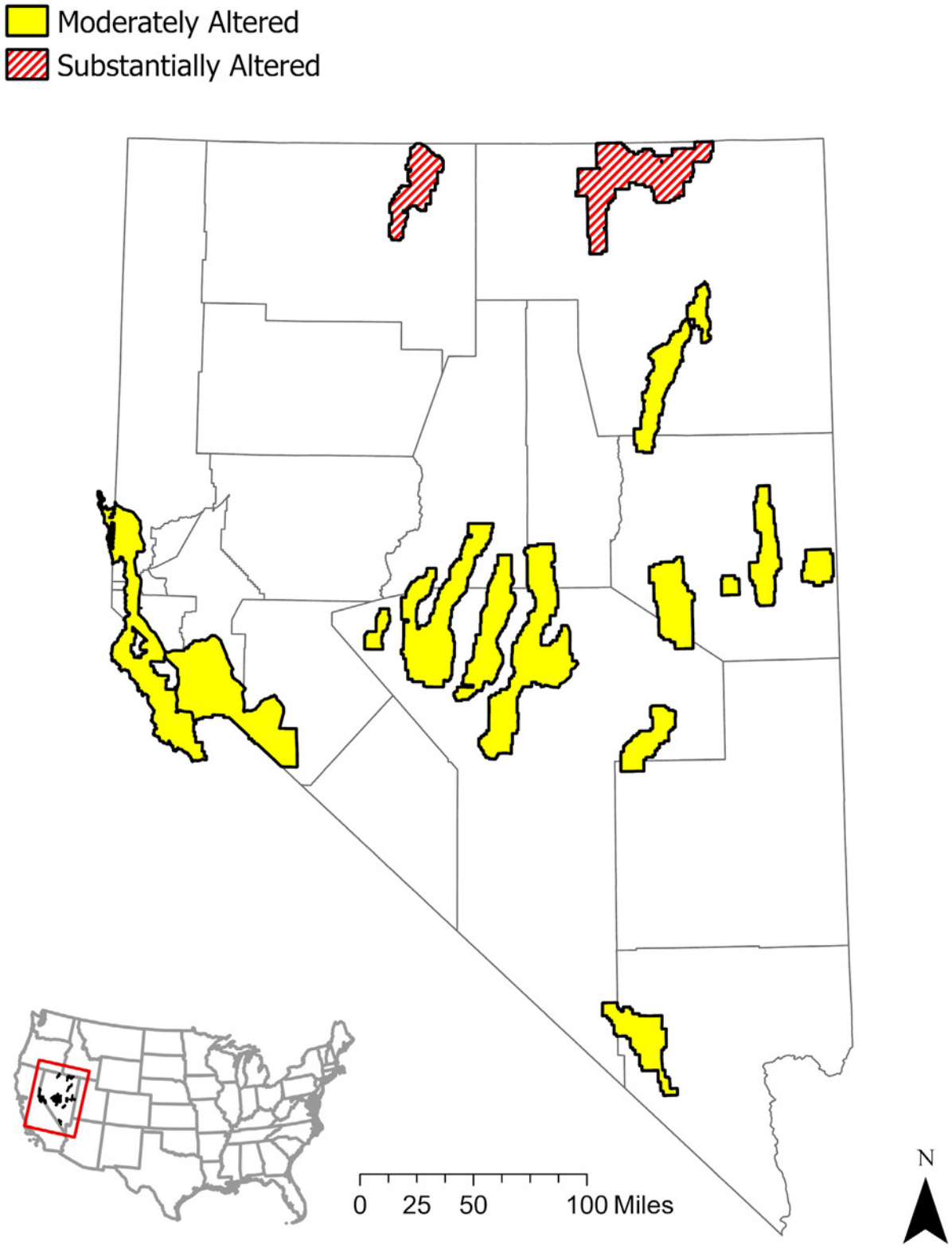


Figure 23—NRV status of groundwater and surface water fluctuations across the HTNF.

According to the WCC, the hydrologic regimes of nearly every watershed on the HTNF were moderately or substantially departed from natural flows. Average winter air temperatures of the last decade were greater than those of the previous century, ranging from increases of 1.5 °F in the Ruby Mountains to 3.3 °F in the East Sierra and Sierra Nevada. Winter precipitation, which is a major source of surface water runoff and groundwater recharge in the Great Basin, does not appear to have substantially changed across the HTNF. The timing of precipitation, however, had changed, with much of the Forest receiving more precipitation during fall and less precipitation during spring and summer. Together these indicators suggest a high likelihood of moderate alteration in surface water and groundwater fluctuations across the HTNF.

Discharge of groundwater is the primary water source that sustains baseflows throughout the Great Basin (Elias et al. 2015; Jewett et al. 2004). These groundwater systems are recharged by snow that falls at high elevations during winter (Elias et al. 2015; Jewett et al. 2004). On the HTNF, precipitation tends to be a major driver of water level fluctuations, with groundwater discharges varying across seasons and in response to storm events (Jewett et al. 2004). Water fluctuations at GDEs can be altered by diversions; groundwater pumping; soil compaction from roads, livestock, or wildlife; and climate change. Diversions and grazing by livestock and wildlife, specifically wild horses and burros, appear to have had extensive impacts to water fluctuations at GDEs across the HTNF. Both stressors were described as disturbing hydrologic processes at springs in every unit. Drought, recreation, and dredging had likely altered water fluctuations at GDEs in localized areas as well. Drought was recorded as a stressor to spring hydrologic processes in the Central Mountains and SMNRA. SSI reports described impacts from recreation at springs in the Central Mountains, Northern Mountains, and Sierra Nevada. Finally, dredging was cited in SSI reports to have altered water fluctuations at GDEs in the Ruby Mountains and Sierra Nevada. While there was evidence across the Forest of multiple interacting stressors that are known to alter hydrologic regimes, we did not locate sufficient data to assess the NRV status of water fluctuations at GDEs.

The most common stressors to groundwater and surface water fluctuations on the HTNF were roads, diversions, and grazing, each of which was identified as a stressor in all seven units. Tree mortality and drought were both indicated as stressors in four units. Less common stressors with likely localized impacts included fire and recreation.

According to the TCA, there were 5,874 miles of roads on the HTNF and 92 percent were unpaved and nongraveled. The largest road densities occurred in the Sierra Nevada, Northern Mountains, and East Sierra units, and the smallest road densities occurred in the Ruby Mountains and Eastern Mountains. Evidence of impacts from roads on hydrologic regimes was present in all units. Many riparian monitoring plots described roads as a disturbance, and the WCC showed moderate to high probability that roads had altered hydrologic regimes in nearly all watersheds on the HTNF. We identified 4,194 diversions and 58 dams present on the HTNF. The largest diversion densities occurred in the Sierra Nevada and Northern Mountains units. The smallest diversion densities occurred in the East Sierra, Central Mountains, and Eastern Mountains units (table 7). Of the 58 dams on the HTNF, 45 were in the Sierra Nevada unit. Evidence

of impacts to hydrologic regimes from dams and diversions was present in all units. This evidence included riparian plot data that described disturbance from diversions at many sites on the HTNF. The WCC also showed all watersheds on the Forest had moderate to significant departures from the natural hydrograph due to the operation of dams and diversion facilities. Grazing by livestock and wildlife, specifically wild horses and burros, was a widespread stressor. About 85 percent of the HTNF is located within a grazing allotment, and over 1.6 million acres of wild horse and burro territory is present on the Forest, much of which is in the SMNRA, Central Mountains, and Eastern Mountains. We found evidence of impacts to hydrologic regimes from altered rangeland conditions across most of the HTNF. Riparian plot data described disturbance from cattle and wildlife; the WCC showed nearly all rangelands on the HTNF had lost some hydrologic function.

Finally, minor disturbances to groundwater and surface water fluctuations included tree mortality, drought, wildfire, and recreation, which were identified as stressors in some units. Between 2009 and 2013, vegetation mortality impacted up to 5 percent of the Central Mountains, Eastern Mountains, Northern Mountains, Ruby Mountains, and Sierra Nevada units. Vegetation mortality tended to decrease in the units post-2014, except in the Sierra Nevada, where 10 percent of the unit was impacted between 2014 and 2018. Additionally, the WCC indicated loss of forest cover, including cut-over, denuded, or deforested forest land, had impacted at least 5 percent of NFS land in many watersheds of the Northern Mountains and Ruby Mountains. The TCA suggested drought had significantly impacted the ecological integrity within the Central Mountains, Eastern Mountains, Northern Mountains, Ruby Mountains, Sierra Nevada, and SMNRA. In addition to data provided by the TCA, drought was indicated as a disturbance at many springs across the Forest. Wildfire may have impacted areas within the Northern Mountains, Sierra Nevada, and SMNRA, where between 20 and 30 percent of the units were in poor or very poor condition due to uncharacteristic fire severity, according to the TCA. Furthermore, riparian plot data and spring surveys both described disturbance from fire to riparian ecosystems and springs throughout the Forest. Finally, trails and campsites across the HTNF may be contributing to altered hydrologic fluctuations in localized areas. Trail densities are highest in the Ruby Mountains and lowest in the Central Mountains (table 7), and there are several recreation sites located within the floodplains in the Sierra Nevada and SMNRA units. Spring surveys and local riparian plot data have captured disturbance to springs and riparian areas from trails, camping, off-highway vehicle (OHV) use, and other recreational activities.

Water Quality

Water quality is influenced by complex biogeochemical interactions that occur within and between aquatic and riparian ecosystems. Functional riparian and hyporheic zones provide the fundamental ecosystem service of nutrient transformation and biological filtration that results in drinking water for numerous communities (Boulton 2005). Additionally, as surface waters become increasingly polluted, sources of good water quality are important refugia for biodiversity and human consumption (Belcher et al. 2013). The condition of riparian ecosystems and GDEs can influence components of

water quality, including water temperature, dissolved oxygen content, pH, nutrient availability, and sediment loads, which in turn impact the metabolism and physiology of aquatic species, chemical reaction rates, bioavailability of nutrients and heavy metals, growth of algae and vascular plants, survival of aquatic species, and light availability (Cordone and Kelley 1961; Dodds and Welch 2000; Hauer and Hill 2007; Mesner and Geiger 2005; Newcombe and Macdonald 1991; Smith et al. 1999).

Drivers

The water quality of inland aquatic ecosystems is influenced by climate, precipitation chemistry, biological and biochemical processes, geology, and the duration of contact between water, soils, and rock (Hem 1985). The amount of water present in a system and, therefore, the concentrations of solutes and pollutants, is controlled by local patterns in precipitation and humidity (Hem 1985). Precipitation influences seasonal changes in stream discharge that drive changes in constituent concentrations (Amacher et al. 2004). Characteristics of precipitation, including temperature, amount, distribution, and chemical composition, drive weathering patterns that contribute sediment loads and dissolved solutes (Hem 1985). These precipitation properties vary widely across space and time due to reactions that occur in the atmosphere (Hem 1985).

Biological processes, including soil formation and subsurface reactions, further influence water quality (Hem 1985). Following infiltration, precipitation moves through soil and eventually becomes surface runoff or percolates to groundwater. During this process the water quality is influenced by dissolution of minerals, nitrogen fixation, selective removal of nutrients by plants, concentration of solutes by evapotranspiration, and biochemical processes that produce carbon dioxide (Hem 1985). Finally, aquatic biota drive diurnal fluctuations in stream metabolism, dissolved oxygen, and pH by producing oxygen, consuming carbon dioxide, and decomposing organic matter (Hem 1985).

The composition of rocks and geothermal activity within a watershed are additional drivers of water quality. Past studies of water quality in the Great Basin have identified significant differences in the chemical composition of streams draining catchments of different lithologies (Amacher et al. 2004). For example, streams draining igneous rock-dominated catchments differ significantly in concentrations of sodium, magnesium, calcium, silicon, chlorine, and phosphorus and in alkalinity compared to streams draining sedimentary-dominated basins (Amacher et al. 2004). In the Great Basin, water quality varies between basins and ranges from fresh to brine (Eakin et al. 1976; Planert and Williams 1995). Saline waters can occur near thermal springs and in areas where the geologic formations contain large amounts of soluble salts (Eakin et al. 1976; Planert and Williams 1995). In major internally drained terminal sinks, dissolved solid concentrations can exceed that of ocean water, but it is unlikely that waters in and under the playas of small closed valleys become as brackish (Eakin et al. 1976; Planert and Williams 1995). Local geologic formations may influence the chemical composition of water by introducing other constituents. For example, in the Tonopah subregion, extensive volcanic tuff contributes to fluoride concentrations that exceed water quality standards (Eakin et al. 1976).

Stressors

Water quality can be impacted by natural and anthropogenic activities that alter water temperature, sediment loading, or the concentration of nutrients, minerals, and pollutants (Bilotta and Brazier 2008; Dauer et al. 2000; Johnston 1991; Sánchez et al. 2007) (table 7). Nutrient, pollutant, and naturally occurring solute concentrations can be altered by increasing their inputs or changing the amount of water present in the system. Large nutrient loads can trigger algal blooms, which can lead to eutrophication and low dissolved oxygen (Anderson et al. 2002; Smith et al. 1999). Increase in sedimentation rates can impact stream temperatures by reducing waterbody depth (Einstein 1950) or by obstructing interstitial spaces that allow for exchange between surface water and groundwater systems (Richards and Bacon 1994; Wood and Armitage 1997). Shallower systems or those with reduced inputs of groundwater tend to have higher water temperatures (Poole and Berman 2001). Sedimentation can further degrade water quality by transporting pollutants that threaten aquatic biota and municipal water supplies (Gannon et al. 2022; Rust et al. 2019; Ryan and Dwire 2012). Finally, productivity and trophic relationships can be altered by suspended sediments that reduce light penetration in aquatic systems (Wood and Armitage 1997).

Natural stressors to water quality include drought and wildfires (Pendleton et al. 2013). Drought can influence water quality by reducing the amount of water in aquatic systems and increasing the concentration of nutrients and solutes (Mosley 2015). During dry periods, diminished flows allow for the accumulation of sediment and reduce the flushing rate of waterbodies (Mosley 2015). Additionally, stream temperatures tend to increase during drought, and thus impact rates of productivity and respiration, which drive dissolved oxygen content (Mosley 2015). Droughts also tend to reduce nutrient inputs from watersheds, potentially decreasing concentrations within streams, lakes, and GDEs. Following wildfire, sediment loads, nutrient concentrations, and water temperatures may be temporarily degraded (Benda et al. 2003; Bixby et al. 2015; Poole and Berman 2001; Rhoades et al. 2019; Rust et al. 2019; Shakesby and Doerr 2006; Spencer et al. 2003). Fires can consume riparian vegetation that shades aquatic systems, increasing solar inputs and the temperature of a waterbody (Poole and Berman 2001; Shakesby and Doerr 2006; Spencer et al. 2003). Ash flows tend to occur with the first precipitation event in a burned landscape. These runoff events provide a pulse of highly bioavailable nutrients that can contribute to hypoxic conditions and increased concentrations of ammonium, trace metals, and ferrocyanides (Bixby et al. 2015; Sanchez-Garcia et al. 2023). Depending on watershed characteristics, burn severity, and whether postfire treatments were applied, increased erosion and debris flows can deposit large amounts of sediment in streams, lakes, and GDEs (Benda et al. 2003; Shakesby and Doerr 2006).

Table 7A—Values of stressors present on the Humboldt-Toiyabe National Forest, organized by unit.

Unit	Road Density (miles/acre)	% Roads Unimproved	Trail Density (miles/acre)	Floodplain Road Density (miles/acre)	Floodplain Trail Density (miles/acre)
Central Mountains	0.0007	94	0.0003	0.0034	0.0013
East Sierra	0.0011	98	0.0004	0.0026	0.0013
Eastern Mountains	0.0006	99	0.0004	0.0032	0.0025
Northern Mountains	0.0011	94	0.0008	0.0030	0.0017
Ruby Mountains	0.0007	87	0.0014	0.0021	0.0034
Sierra Nevada	0.0011	76	0.0006	0.0010	0.0008
SMNRA	0.0010	90	0.0003	0.0061	0.0011

Table 7B—Values of stressors present on the Humboldt-Toiyabe National Forest, organized by unit.

Unit	% Unit Vegetation Mortality 2014-2018	% Unit in poor or very poor condition for uncharacteristic fire severity	% unit in poor or very poor condition for drought	Floodplain Recreation Site Density (sites/acre)	Diversion Density (points/acre)
Central Mountains	0	0	100	0.0000	0.0003
East Sierra	3	6	6	0.0000	0.0003
Eastern Mountains	1	0	100	0.0001	0.0002
Northern Mountains	1	23	28	0.0001	0.0011
Ruby Mountains	1	0	20	0.0001	0.0007
Sierra Nevada	10	28	19	0.0001	0.0015
SMNRA	0	20	100	0.0005	0.0005

Table 7C—Values of stressors present on the Humboldt-Toiyabe National Forest, organized by unit.

Unit	Dams per Stream Mile	% Unit RMU	% Unit Wild Horse & Burro Territory	% Floodplain burned by moderate/high severity Wildfire
Central Mountains	0.0001	98	49	0.004
East Sierra	0.0020	87	18	0.001
Eastern Mountains	0.0005	98	24	0.110
Northern Mountains	0.0005	90	0	0.781
Ruby Mountains	0.0009	92	6	0.157
Sierra Nevada	0.0169	55	0	0.025
SMNRA	0.0006	0	51	0.066

Anthropogenic factors that influence water quality include burning of fossil fuels, agriculture, diversions, mining, roads, recreation, timber harvest, spread of invasive species, and loss of riparian ecosystems (Brooks et al. 2013; Pendleton et al. 2013). High-intensity agriculture and combustion of fossil fuels are two sources of increased nitrogen loads in aquatic ecosystems (Carpenter et al. 1998; Pendleton et al. 2013). Nitrogen and phosphorus inputs can also be increased by runoff from fertilized fields or grazed areas (Carpenter et al. 1998). Activities such as diversions or groundwater pumping that remove water from a system can increase mineral and solute concentrations. Mining can also alter the amount of water in a system in addition to introducing trace metals or increasing phosphorus loading (Lines 1985). Roads, particularly those located within floodplains, are unnatural sources of sediment. These features can increase concentrations of heavy metals, salinity, and turbidity and alter dissolved oxygen levels (Forman and Alexander 1998). Other infrastructure, such as trails and campsites, can also increase sediment inputs and affect water quality through refuse disposal (Crabill et al. 1999; Varness et al. 1978). Livestock grazing can increase sedimentation rates and water temperatures when the animals trample banks and remove riparian vegetation that shades aquatic systems (Fleischner 1994). Furthermore, livestock waste can contribute to high nutrient loads (Carpenter et al. 1998). Timber harvest projects can increase sedimentation and nutrient loads of streams through erosion at the harvest site (Deval et al. 2021; Rashin et al. 2007). Nonnative vegetation, specifically nonnative tamarisk (Tamarix), can impact water quality by excreting salt and consuming large amounts of water (Barrows 1996). Finally, impacts of these stressors can be buffered by intact riparian zones that filter sediment and nutrients and modulate temperatures; however, loss of riparian areas and conversion to development, invasive species, or agriculture reduce the effects of this ecosystem service (Brooks et al. 2013; Clinton 2011).

Methods

We evaluated seven indicators of water quality conditions on the HTNF: (1) the WCC condition of riparian and wetland vegetation, (2) the WCC impaired waters attribute, (3) the WCC water quality problems attribute, (4) conversion of riparian habitat to development or agriculture, (5) condition and (6) trend at sites monitored by the Nevada Department of Environmental Protection (NDEP), and (7) the percentage of streams and waterbodies classified by the State as impaired (Appendix E, table E.1). The WCC riparian and wetland vegetation indicator addresses function of native riparian vegetation and whether adequate cover exists to dissipate stream energy, reduce erosion, filter sediment, stabilize streambanks, buffer stream temperature, and improve water quality (Potyondy and Geier 2011). We calculated the percentage of streams and waterbodies listed by Nevada and California on the 303(d) list—each State's list of impaired and threatened waters based on the Clean Water Act Section 303(d) (Clean Water Act of 1977)—and considered the WCC impaired waters attribute, which is rated based on the percentage of stream miles or lake area within each watershed that appear on the 303(d) list. The WCC water quality problems attribute evaluates whether evidence exists of excessive sediment, nutrients, chemical pollution, or other water quality issues above natural or background levels (Potyondy and Geier 2011). We used output from R-CAT to determine the percentage of stream miles with riparian areas

that have converted from native vegetation to agriculture or development (Macfarlane et al. 2017). We acquired water quality data from NDEP for sites monitored on the Forest. Each site has been rated by the Nevada Multi-metric Index (MMI) as "reference," "impaired," or "undetermined," using methods established by Vander Laan (2012). We considered whether most sites within a unit were classified as reference (near natural conditions) or impaired (an index distribution that is significantly different from reference conditions with impacts of poor water quality to the biota). We also assessed whether NDEP data suggested water quality was declining over time at multiple sites within a unit.

We used these indicators to determine whether evidence existed of moderate or substantial alteration. If more than half of watersheds were classified by the WCC to be in functioning-at-risk condition, we considered this evidence of moderate alteration from NRV. If more than half of watersheds were classified by the WCC to be in impaired condition, we considered this evidence of substantial alteration from NRV. If more than 33 percent, but less than 67 percent, of riparian areas had converted to agriculture or development, we considered this evidence of moderate alteration from NRV. If more than 67 percent of riparian areas had converted to agriculture or development, we considered this evidence of substantial alteration from NRV. If more than 33 percent, but less than 67 percent, of NDEP sites were rated as impaired, we considered this evidence of moderate alteration. If more than 67 percent of NDEP sites were rates as impaired, we considered this evidence of substantial alteration. If NDEP data suggested a decline in water quality over time, we considered this evidence of alteration. Finally, if more than 33 percent, but less than 67 percent, of streams and waterbodies were listed by the State as impaired, we considered this evidence of moderate alteration. If more than 67 percent of streams and waterbodies were listed by the State as impaired, we considered this evidence of substantial alteration. It is possible for indicators to provide contradictory evidence of alteration. For units in which a similar number of indicators suggested water quality was both altered and unaltered, we considered the WCC rating for water quality, which is provided by local experts on the Forest and provides the most direct measure of condition for this KEC.

We used surveys from the SSI database to identify disturbances present at GDEs on the HTNF. Some SSI reports provided information on whether impacts from avalanches, fire, flood, drought, diversions, horse and burro activity, cattle, recreation, or dredging were present. The SEAP, which provides information on condition of aquifer functionality, water quality, geomorphology, human influence, habitat, and biotic integrity, was implemented at some springs on the Forest. We used the SEAP "aquifer functionality and water quality" parameter to evaluate water quality at GDEs across the Forest. This parameter is a composite score that evaluates water quality and algal/periphyton cover, as well as hydrologic metrics. SEAP data were rarely available throughout the assessment area, but we summarized SEAP results when they were available.

Results

Water quality on the HTNF appears to be resistant to multiple interacting stressors. Based on indicators of water quality, all units except for the Sierra Nevada were

estimated to be within the NRV for water quality (fig. 24). We estimated water quality conditions in the Sierra Nevada were moderately altered. These results are consistent with other studies of water quality on the HTNF. Amacher et al. (2004) found that the chemical composition of streams on national forest lands in central Nevada were not sensitive to land use and that water quality had not been impaired. The authors of this study attributed the generally high water quality of the HTNF to remoteness and low population density that drive relatively light use of resources (Amacher et al. 2004). The overall driving factors of chemical composition in streams were catchment lithology and discharge (Amacher et al. 2004); therefore, it possible that water quality could become impaired in response to changes in land use or disturbance regimes.

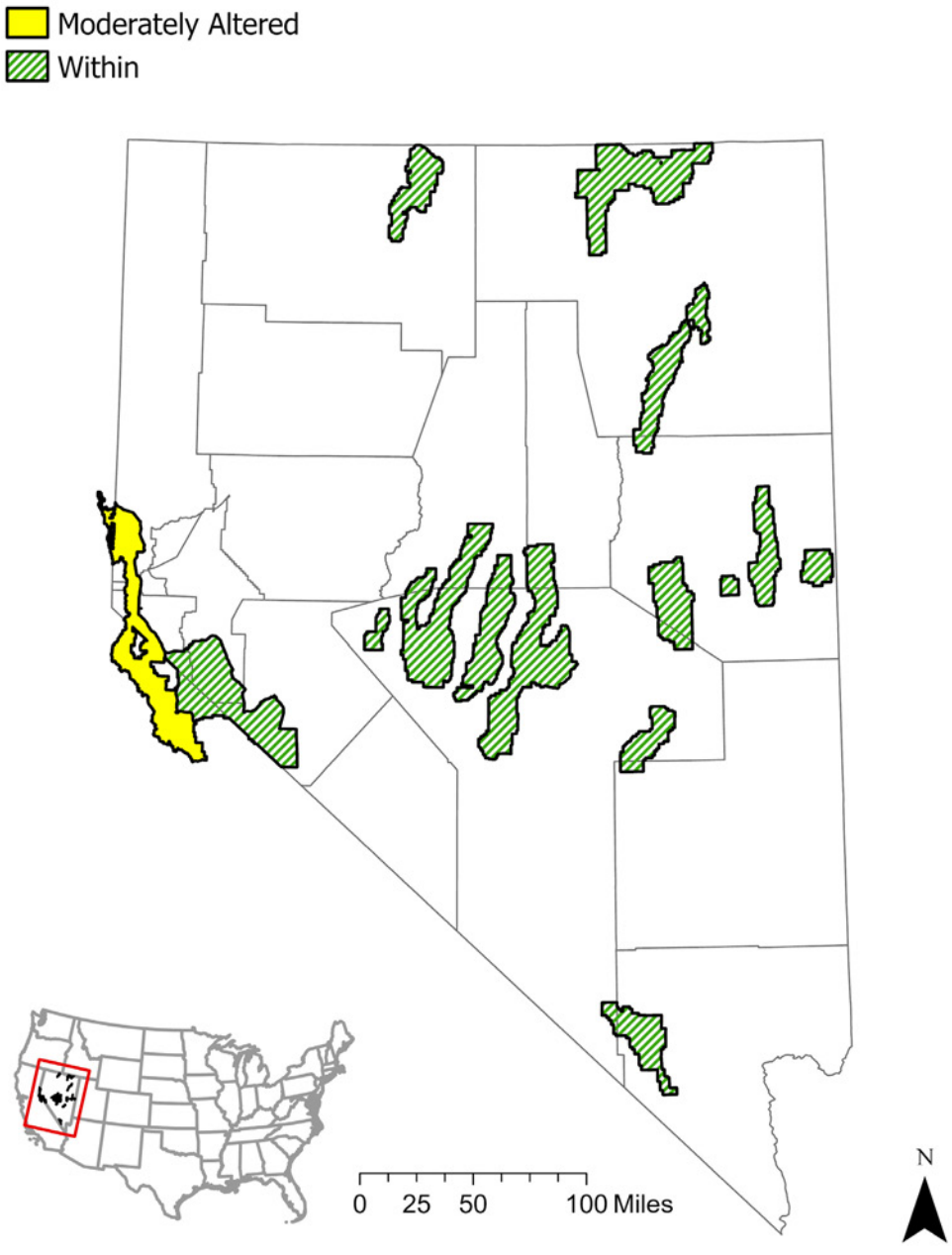


Figure 24—NRV status of water quality across the HTNF.

Although most of the HTNF is likely within the NRV for water quality, there was evidence of impacts from stressors in all units. Only small percentages of riparian areas have converted from native plant cover to development or agriculture, but according to the WCC, the condition of riparian vegetation is impacted and likely not capable of improving water quality in many watersheds. Native riparian and wetland vegetation in all units except SMNRA had lost at least some functional capacity to reduce erosion, buffer stream temperatures, allow for biological filtering, or improve water quality. The distribution of 303(d)-listed impaired waters is limited throughout the study area; however, watersheds across the HTNF, and especially in the Central Mountains, Eastern Mountains, and East Sierra, appear to be impacted by excessive sediment, nutrients, or chemical pollution (or combination thereof) beyond natural levels, according to the WCC. Based on the Northwest Stream Temperature (NorWeST) dataset (Isaak et al. 2017), we expect that stream temperatures across the Forest are increasing and are likely to exceed water quality standards in at least some locations. According to NDEP data, it appears water quality conditions at many stations monitored on the HTNF are stable. Several NDEP stations, particularly in the East Sierra unit, have identified impaired water quality conditions; however, in many cases, stations have been sampled only once, and these conditions need to be confirmed with additional monitoring.

The most common stressors to water quality on the HTNF included roads, diversions, grazing, and soil conditions, which were identified as stressors in all seven units. As mentioned earlier, there were 5,874 miles of roads on the HTNF and 92 percent were unpaved and nongraveled. The WCC indicates that roads are frequently located near streams and that maintenance of these features by applying best management practices is often lacking, increasing the likelihood of waterbody pollution. Nevertheless, the WCC mass wasting attribute suggests that most of these roads are on stable landforms, and there is generally no danger of large quantities of debris being delivered to streams from mass wasting. The impacts of diversions to hydrologic regimes are described in the section “Surface Water and Groundwater Fluctuations.” We expect these altered flow regimes to negatively affect water quality, with similar observations made for the Great Basin as a whole (Chambers et al. 2008). Large percentages of every unit, except SMNRA, are within grazing allotments, and wild horse and burro territory occurs within large sections of the SMNRA, Central Mountains, Eastern Mountains, and East Sierra units. The WCC suggests rangelands in nearly all watersheds have lost at least some capacity to limit redistribution of nutrients and organic matter, suggesting that grazing has likely impacted water quality across the Forest. Lastly, the WCC suggests that soil nutrient cycling processes are impaired, and evidence of extensive soil erosion is present in nearly all watersheds on the HTNF.

Secondary stressors to water quality on the HTNF that exist in localized areas include drought, nitrogen deposition, recreation, and fire. We expect that drought has exacerbated water quality problems across the Forest, but especially in the Eastern Mountains, SMNRA, and Central Mountains, where the TCA suggested moisture deficits had impacted the ecological integrity of the entire unit. Nitrogen deposition appears to impact ecological integrity in at least some parts of every unit, except the Sierra Nevada. Impacts from this stressor are particularly extensive in the Ruby Mountains and East Sierra. As described in the preceding section, recreational facilities, including

trails and campgrounds, occur throughout the Forest. Local riparian monitoring and spring surveys indicate disturbances from camping and OHV use may contribute to degraded water quality in specific locations. High-severity fires may impact water quality in areas within the Northern Mountains, Sierra Nevada, and SMNRA. We did not find any studies or reports that directly linked impacts of common stressors to water quality on the HTNF; however, Chambers et al. (2008) suggested that point and nonpoint source pollution of nutrients, metals, sediment, temperature, and dissolved solids have degraded water quality throughout the Great Basin. These water quality problems in Great Basin watersheds can be exacerbated by drought, flooding, loss of wetlands and riparian zones, diversion, development and other land-use change, overgrazing, mining, and roads (Chambers et al. 2008).

Channel and Floodplain Dynamics

Channel and floodplain dynamics, including the condition of spring runout channels, support complex aquatic and terrestrial habitats that are productive, biodiverse, resilient, and resistant (Hauer et al. 2016; Junk et al. 1989; Ward et al. 1999). The shape of the channel and its floodplain, as well as the distribution of habitats across the landscape, is driven by flooding, channel avulsion, cut and fill alluviation, recruitment of large wood, and regeneration of vegetation (Stanford et al. 2005). These patterns operate across space and time, with streamflow as a master variable influencing channel and floodplain structure (Poff et al. 1997). In contrast, spring runout channels are "groundwater-fed streams that emerge from springs or within groundwater-fed wetlands" (USDA FS 2012a,b). They are distinguished from the runoff-dominated channels by flow regime and sediment input (Griffiths et al. 2008). These unique downstream reaches of GDEs can support endemic aquatic and wetland biota that are particularly vulnerable to spring development.

Drivers

Channel and floodplain dynamics are ultimately driven by supplies of water and sediment and whether these supplies are balanced over time. Geology, topography, climate, and beaver activity are major influences on the amount and balance of water and sediment present within a system. The shape of stream channels and whether a system is aggrading is controlled by watershed characteristics, including the erodibility of underlying bedrock and channel-forming materials, relief, and valley attributes such as gradient and width (Chambers and Miller 2011). Mountains in the Basin and Range Physiographic Province tend to be deeply dissected as a result of both past incision into uplifting ranges, and high relief between ranges and adjacent basins that produces steep potential energy gradients and increases incision (Chambers and Miller 2011). This geologic and topographic setting tends to produce narrow, steep, fluvial V-shaped valleys where erosion exceeds deposition (Chambers and Miller 2011; Jewett et al. 2004; Minshall et al. 1989). The sediments eroded from mountain reaches are generally transported to the alluvial basins at the base of each mountain range (Chambers and Miller 2011; Minshall et al. 1989).

In addition to geology and topography, climate contributes to channel and floodplain dynamics by driving changes in water availability and in vegetation cover, which

influences erosion and sediment supply. During dry periods, vegetation cover tends to be diminished, and water is scarce, which allows for increased erosion and lower streamflow. For this reason, stream channels tend to aggrade and form new floodplains during dry climatic periods. In contrast, wet climates are associated with downcutting of streams and terrace formation. Fluvial processes within Great Basin watersheds continue to be influenced by a major drought that occurred within the study area about 2,000 years ago (Chambers and Miller 2011; Chambers et al. 2004; Jewett et al. 2004). During this drought, large amounts of erosion from hillslopes occurred, with sediments deposited on valley floors and in alluvial fans (Chambers and Miller 2011; Miller et al. 2001). Over the past 400 years, a wetter and warmer climate has led to increased vegetative cover, reduced hillslope erosion, and higher rates of stream incision throughout Great Basin watersheds (Chambers and Miller 2011; Miller et al. 2001). Increased intense incision has occurred over the last 150 years in response to episodic high-flow events, with significant channel downcutting following high precipitation in the mid-1970s, 1983, 1995, 1998, and 2005 (Chambers and Miller 2011).

Lastly, beaver activity can drive channel and floodplain dynamics through the construction of dams that slow runoff, trap sediment, and build wide, low gradient, alluvial valleys (Gurnell 1998; Naiman et al. 1988). Meadows created by beavers tend to generate a step pattern along a stream's longitudinal profile. Beaver dams also influence the lateral profile of a stream and its floodplain by increasing variation in channel width, depth, and geomorphologic diversity. In general, beaver activities tend to stabilize channels and build channels and floodplains of greater complexity (Gurnell 1998).

Stressors

Activities or forces that alter the balance between water and sediment supplies or limit lateral movement of a channel across its floodplain are stressors to channel and floodplain dynamics. Stressors to this KEC can be natural or anthropogenic and include drought, wildfire, roads, recreation, diversions, dams, grazing, and timber harvest (table 7).

Natural stressors to channel and floodplain dynamics include drought and wildfire. Both can reduce upland and riparian vegetative cover, allowing for greater erosion and sedimentation of channels. During drought, stream power is reduced, sediments are not flushed from the system, and channels aggrade (Chambers and Miller 2011; Chambers et al. 2004; Miller et al. 2001). Additionally, drought can interact with other stressors, such as livestock grazing, and amplify the impacts on channel and floodplain condition (Emmerich and Heitschmidt 2002). Depending on burn severity, wildfires can increase both runoff and sediment inputs from uplands with an overall impact on channel geomorphology (Doerr et al. 2006; Inbar et al. 1998; Johansen et al. 2001; Shakesby and Doerr 2006). Following fire, infiltration may be reduced by hydrophobic soils. Lower infiltration results in greater overland and stream flow, which can remove sediment and downcut the channel (Ice et al. 2004; Neary et al. 2003). In contrast, postfire erosion and debris flows can contribute large amounts of sediment to channels, ponds, lakes, and wetlands (Shakesby and Doerr 2006).

Roads and recreation infrastructure such as trails and campgrounds can impact channel and floodplain dynamics by physically altering or constraining a channel or by providing an unnatural source of sediment. Roads that parallel streams often confine channels and limit lateral migration (Forman and Alexander 1998; Jones et al. 2000; Trombulak and Frissell 2000). Culverts or armored stream crossings are often installed at locations where roads cross streams. These structures can restrict channel movement and result in downstream scouring and plunge pools (Abt et al. 1985). Crossings that do not occur at bridges can cause streams to become wider and shallower with flattened banks (Forman and Alexander 1998; Jones et al. 2000; Trombulak and Frissell 2000). Like roads, campgrounds and trails can also increase sediment inputs and lead to trampled streambanks (Cole 2004; Green 1998; Kidd et al. 2014). Finally, streams can be simplified and disconnected from their floodplains by riprap or other artificial banks installed to protect roads and recreation structures (Forman and Alexander 1998; Jones et al. 2000; Trombulak and Frissell 2000).

Channels and their floodplains are impacted by dams and diversions that alter water and sediment supplies. These features tend to reduce the magnitude of floods, which connect the stream to its floodplain, move sediment downstream, and reshape the channel (Winter et al. 1998). Additionally, dams tend to trap sediments and starve downstream systems of their sediment supply (Kondolf 1997). This process can lead to downcutting of channels and coarser substrates (Kondolf 1997). River regulation is linked to a 37 percent decrease in floodplain complexity, with interior rivers of the western United States most vulnerable to these impacts (Graf 1999). Additionally, regulation of streams is associated with a 79 percent reduction in the area of active floodplain, and inactive floodplain area of regulated streams is 3.6 times larger than comparable unregulated reaches (Graf 1999).

Grazing and timber harvest both remove vegetative cover from watersheds, which can contribute to erosion in uplands and sedimentation of channels. Timber harvest does not appear to be a significant stressor on the HTNF. No projects were identified in any units except the Sierra Nevada, where less than 1 percent of the unit was located within a project area. In contrast, grazing is a major stressor to channel and floodplain dynamics across the HTNF. Grazing livestock and wild horses and burros can impact channels and floodplains by trampling banks, overwidening streams, and contributing sediment from cattle trails, in addition to removing vegetation. Overgrazing occurred extensively throughout the western United States following Euro-American settlement. Erosion and overland flow often increased in response to the removal of stabilizing vegetation and soil compaction (Armour et al. 1994; Fleischner 1994; Krueper 1993). Channels eventually became incised and disconnected from their floodplains (Armour et al. 1994; Krueper 1993). Although there does not appear to be direct evidence that links overgrazing in the Great Basin to extensive stream incision, Chambers and Miller (2011) concluded it has unquestionably affected stream channels on the local scale.

Methods

We evaluated six indicators that provide information related to the condition of channels and floodplains on the HTNF: (1) the WCC channel shape and function attribute, (2) the WCC large woody debris attribute, (3) condition of confined reaches,

(4) condition of unconfined reaches, (5) uncharacteristic fire in floodplain, and (6) the WCC habitat fragmentation attribute (Appendix F: table F.1). The WCC channel shape and function attribute considers whether width-to-depth ratios are within an expected range, channels are vertically stable, and channels remain connected to their floodplains (Potyondy and Geier 2011). For stream systems that evolved with wood near the stream, the WCC large woody debris attribute provides information on whether large woody debris is present and recruited to channels at near natural rates. The WCC habitat fragmentation attribute provides data on whether aquatic habitats have become disconnected due to changes in temperature, blockages, or dewatering. We used output from R-CAT to determine the condition of confined and unconfined stream segments (Macfarlane et al. 2017). R-CAT summarizes riparian conditions as confined-impacted, confined-unimpacted, unconfined-good, unconfined-intact, unconfined-moderate, unconfined poor, or unconfined-very poor using departure of riparian vegetation from historical conditions, intensity of land use, and disconnection of the stream and its floodplain imposed by transportation infrastructure (Macfarlane et al. 2017). Lastly, we used classifications from the TCA uncharacteristic fire disturbance indicator within the 50-year floodplain map to characterize whether fire frequency or severity is altered within riparian areas.

We used these indicators of channel and floodplain dynamics to determine whether evidence existed of moderate or substantial alteration. If more than half of watersheds were classified by the WCC to be in functioning-at-risk condition, we considered this evidence of moderate alteration from NRV. If more than half of watersheds were classified by the WCC to be in impaired condition, we considered this evidence of substantial alteration from NRV. If more than 33 percent, but less than 67 percent, of streams were classified as confined-impacted, we considered this evidence of moderate alteration from NRV. If more than 67 percent of streams were classified as confined-impacted, we considered this evidence of substantial alteration from NRV. If more than half of unconfined streams were classified as moderate condition, we considered this evidence of moderate alteration. If more than half of unconfined streams were classified as poor, we considered this evidence of substantial alteration. Finally, if more than 33 percent, but less than 67 percent, of floodplains were in poor or very poor condition for uncharacteristic fire disturbance, we considered this evidence of moderate alteration from NRV. If more than 67 percent of floodplains were in poor or very poor condition for uncharacteristic fire disturbance, we considered this evidence of substantial alteration from NRV. To determine the NRV status of channel and floodplain dynamics within each unit, we evaluated the number of indicators that provided evidence of no, moderate, or substantial alteration. It is possible for indicators to provide contradictory evidence of alteration. For units in which a similar number of indicators suggested channel and floodplain dynamics were both altered and unaltered, we considered the WCC rating for channel shape and function, which is provided by local experts on the Forest and provides the most direct measure of condition for this KEC.

Results

Channel and floodplain dynamics on the HTNF appear to have been impacted by multiple interacting stressors (Appendix F). Based on indicators of channel and floodplain dynamics, 100 percent of the HTNF was moderately altered from the NRV for channel and floodplain dynamics.

Most indicators in all units showed evidence of altered channels and floodplains. According to the WCC, most watersheds in all units have channels with increased width-to-depth ratios, evidence of channel degradation or aggradation (or both), and evidence of downcutting to the extent that some streams were no longer connected to their floodplain. While many confined valley segments appear to be unimpacted, between one-third and more than half of unconfined valleys are moderately impacted. Large woody debris is not recruited at natural rates in many systems and is lacking in many more. Additionally, streams in most watersheds had experienced increased fragmentation due to dewatering or other stressors. These results are consistent with those reported by Chambers and Miller (2011) which suggested that many channels in the upland watersheds of the Great Basin have been degraded as a result of ongoing stream incision. The authors of that report identified many streams that had experienced significant changes in channel form and were disconnected from their floodplains (Chambers and Miller 2011).

The most common stressors to channel and floodplain dynamics on the HTNF were roads, diversions, and grazing, with localized impacts from drought, dams, recreation, and loss of forest cover. Roads were identified as a stressor in all units. These transportation features are linked to stream incision and degradation of riparian areas throughout the Great Basin. Chambers and Miller (2011) suggested that roads located in valley bottoms are potentially the major anthropogenic cause of altered channel dynamics. Based on the WCC, it appears significant road length is located within 300 feet or otherwise hydrologically connected to streams and waterbodies across the HTNF. Additionally, best management practices have been applied to less than 75 percent of roads in water crossings in nearly all watersheds. Finally, riparian monitoring plots throughout the Forest repeatedly indicated that roads were disturbances impacting conditions. These results suggest a high likelihood that roads have contributed to altered channel and floodplain dynamics in many HTNF watersheds.

Diversions were also identified as a stressor in all units. Chambers et al. (2008) described extensive impacts on most Great Basin aquatic and riparian ecosystems from diversions, including dams, channelization, and spring boxes with pipes. These structures have altered flow regimes in streams and springs and impacted channels by adding gabions and other hard structures to armor streambanks (Chambers et al. 2008). The WCC indicates dams and diversions in every watershed on the HTNF have altered flow regimes such that one or more characteristics—timing, frequency, duration, magnitude, rate of change—of at least mid-range discharges, if not peak and base flows, are not consistent with the natural hydrograph. Riparian monitoring plots and spring surveys confirm these impacts, with many indicating diversion of flow as a disturbance. Like roads, these results suggest that diversions across the HTNF are likely to have contributed to altered stream channels and floodplain dynamics.

Grazing was identified as a stressor in all units except the SMNRA, where the WCC did not evaluate rangeland vegetation conditions. Nevertheless, it appears grazing impacts channel and floodplain dynamics in SMNRA as local riparian plot data have recorded impacts from livestock and wild horses and burros. Although Chambers and Miller (2011) stated there is no direct evidence linking overgrazing with increased stream incision, it is well documented that grazing throughout the western United States alters sediment regimes and contributes to degraded channel conditions (Chambers et al. 2008; Fleischner 1994; Krueper 1993). According to the WCC, rangelands throughout the entire Forest (apart from the SMNRA, which was not rated) are in fair or poor condition. This rating means that soils in these systems are likely to be compacted and allowing increased overland flow, which contributes to stream incision and bank erosion. These impacts are confirmed by riparian monitoring and spring surveys that note livestock grazing, as well as wild horse and burro activity, as disturbances in many areas across the HTNF.

It appears that altered channel and floodplain conditions impact riparian ecosystems on the HTNF (Chambers and Miller 2011; Chambers et al. 2004, 2008). Significant extensive and ongoing channel incision has disconnected many streams from their floodplains and lowered the water table (Chambers and Miller 2011; Chambers et al. 2004). As a result, the structure and composition of riparian communities with groundwater-dependent vegetation have changed (Chambers and Miller 2011; Chambers et al. 2004). The WCC supports these findings, with a strong correlation (Spearkman rank order correlation coefficient = 0.9) between the channel shape and function and the riparian vegetation condition attributes. This association suggests watersheds with functional channels and floodplains tend to have riparian ecosystems in good condition, but that watersheds with channels in poor condition typically have a noticeable loss of vigor, reproduction, and growth in native riparian vegetation, as well as changes in composition.

Spring Runout Channel Condition

Drivers

Spring runout channels are streams fed by groundwater that emerge from a spring or within a GDE wetland (USDA FS 2012a,b). The hydrology, geomorphology, and sediment regimes of these channels are distinct from systems dominated by runoff (USDA FS 2012a,b). The primary drivers of spring runout channel dynamics are discharge and sediment inputs (Griffiths et al. 2008; Whiting and Stamm 1995). Discharge from springs tends to be less variable than flow that occurs in runoff-dominated systems (Whiting and Moog 2001). Spring-dominated channels tend to lack fine-grained sediment inputs (USDA FS 2012a,b), but otherwise tend to have substrates of variable size (Whiting and Moog 2001; Whiting and Stamm 1995). The muted hydrograph and limited sediment inputs that are characteristic of springs lead to channels that are typically straight or lack regular sinuosity (USDA FS 2012a,b). Additionally, runout channels tend to lack bars, but can have islands or downed timber within the channel (USDA FS 2012a,b). These unique features provide groundwater that is deoxygenated and of relatively uniform temperature, which often allows them to support flora and fauna that are not found in other lotic waters (USDA FS 2012a,b).

Stressors

Forces or activities that alter spring discharge regimes, sediment inputs, or channel structure are considered stressors to spring runout channels (table 7; USDA FS 2012a,b). Spring development, diversions, or regulation can influence the timing and amount of discharge in the channel (Gurrieri 2020; Kendy and Bredehoeft 2006; Sophocleous 2002). Livestock grazing, recreation, and roads can contribute sediment loads that overwhelm the spring runout channel with deposits that cannot be cleared. These activities can lead to trampled banks, shallower or entrenched channels, ditching, redirected flow, overall degradation, or the loss of the runout channel (Ostoja et al. 2013).

Methods

We used surveys from the SSI database to identify disturbances present at GDEs on the HTNF (Appendix F). Some SSI reports provided information on whether impacts from avalanches, fire, flood, drought, diversions, horse and burro activity, cattle, recreation, or dredging were present. The SEAP, which provides information on condition of aquifer functionality, water quality, geomorphology, human influence, habitat, and biotic integrity, was implemented at some springs on the Forest. We used the SEAP geomorphology parameter to evaluate spring runout channel condition at GDEs across the Forest. This parameter is a composite score that evaluates geomorphic functionality, runout channel geometry, soil integrity, geomorphic diversity, and natural physical disturbance on a scale from 0 (poor condition) to 6 (pristine condition). SEAP data were collected at few springs across the Forest, but we summarized SEAP results by site when they were available.

Results

Although many springs on the HTNF have been documented in the SSI, very few surveys of condition have been completed. The primary stressors to spring runout channel condition appear to be diversions and grazing by livestock, wild horses, and wild burros. Impacts from these stressors were identified at springs in every unit (Appendix F). Dredging and recreation were secondary stressors that had impacts in the Northern Mountains, Ruby Mountains, and Sierra Nevada. Springs in the SMNRA had been impacted by many stressors, including avalanches, fire, flood, drought, dredging, diversions, horse and burro activity, cattle, and recreation (Solem et al. 2013). SEAP surveys describing condition of spring runout channels were rare across the HTNF; however, the few that were completed suggested at least mild impacts to geomorphology. There was insufficient information to evaluate spring runout condition in all units of the Forest.

Composition and Structure of Riparian and Groundwater-Dependent Ecosystems

In this section, we assess the composition and structure of riparian ecosystems and GDEs of the HTNF. This KEC is a response to the processes evaluated in the previous sections. We describe the current characteristics of riparian vegetation using data from field surveys and GIS analyses. We also describe flora and fauna observed at springs

and groundwater-supported wetlands. We use this information to determine the status of composition and structure in relation to the NRV (Appendix G).

Riparian vegetation is fundamentally coupled to the hydrogeology and habitat quality of valley bottoms. The composition and the structure (both vertical and horizontal) of vegetation are influenced by and have an influence on streamflows and geomorphology (Cluer and Thorne 2014). Certain plant species, such as water sedge (*Carex aquatilis*) and coyote willow, have extensive root systems and numerous shoots that trap sediment and stabilize streambanks during high flows, thus creating and maintaining features that benefit aquatic and terrestrial communities (Griffin et al. 2014; Winward 2000). Willows such as *Salix boothii* and deciduous trees such as gray alder stabilize banks and buffer streams from climate warming by providing shade (Fuller et al. 2022; Hough-Snee et al. 2013; Wondzell et al. 2019). Cottonwoods, boxelders (*Acer negundo*), and other tall deciduous trees provide nest sites and seasonal foraging opportunities for wildlife, including dozens of bird species (Smith and Finch 2014). As living plants and instream wood, cottonwoods and other trees stabilize streambanks and maintain floodplain connectivity (Zeier et al. 2004). By maintaining a connection with groundwater, deep-rooted trees and shrubs transport this resource to aboveground communities throughout a floodplain (Smith and Finch 2017). Sedges, rushes, and grasses provide cover and forage for amphibians, reptiles, waterbirds, and small mammals (Frey and Malaney 2009; Medin and Clary 1990, 1991). An evaluation of riparian vegetation is, therefore, critical to assessing the condition of riparian ecosystems.

The current composition of plants, animals, and other biota must be evaluated to inform management decisions affecting springs, fens, and other GDEs (Kreamer et al. 2015). The GDEs of the HTNF support relatively high richness of plants, aquatic invertebrates, and terrestrial invertebrates; many species in these communities are endemic or narrowly distributed (Fleishman et al. 2005; Sada et al. 2005; Spence et al. 2012). For example, more than 250 plant and animal species have been documented at springs in the SMNRA geographic unit, indicating the importance of GDEs to regional biodiversity (Sada and Pohlmann 2006). Many of these springs, however, have been modified for anthropogenic use (Sada et al. 2005). An understanding of composition relative to reference conditions is therefore needed to identify the need for change.

Drivers

The composition and structure of riparian vegetation vary among settings, with physical processes acting at multiple scales to shape the communities adjacent to streams and other bodies of water. Elevation, climate, geology, and biotic communities interact to form geomorphic features along streams, which influence the vegetation types that can establish in meadows and riparian corridors (Engelhardt et al. 2015; Hough-Snee et al. 2015; Youngblood et al. 1985). The progression of sediment deposition, stream meanderings, and streambed incision results in the creation of floodplains, benches, and terraces. These features are colonized by cottonwood-, willow-, and herbaceous-dominated community types (Gregory et al. 1991; Gruell 1980). Such processes are limited in narrow, bedrock-confined valley bottoms, which typically contain coniferous tree-, low deciduous tree-, and tall deciduous tree-dominated community types.

Riparian and wetland ecosystems are also shaped by current surface water and groundwater dynamics. Growth and survival of deep-rooted plants such as cottonwoods and willows are dependent on stable groundwater connections (Bilyeu et al. 2008). These connections are maintained by processes such as floods, springs, beaver dams, and accumulation of instream wood (Montgomery et al. 2003; Pollock et al. 2014; Stromberg 2001). Herbaceous-dominated community types establish in riparian meadows where groundwater levels (down to 13 feet) are maintained by springs or streamflow and geomorphic conditions allow the accumulation of fine sediments (Weixelman et al. 1997). Depth to groundwater is often the most important driver of plant composition in meadows (Castelli et al. 2000; Gross and Coppoletta 2013). Where present, karst systems influence surface flows through storage and transport of groundwater (Godfrey 1985; Mills and Huntoon 1989). By raising water tables and distributing surface flows, beaver dams encourage the establishment of herbaceous- and willow-dominated community types (Gibson and Olden 2014; Marshall et al. 2013) (fig. 25).

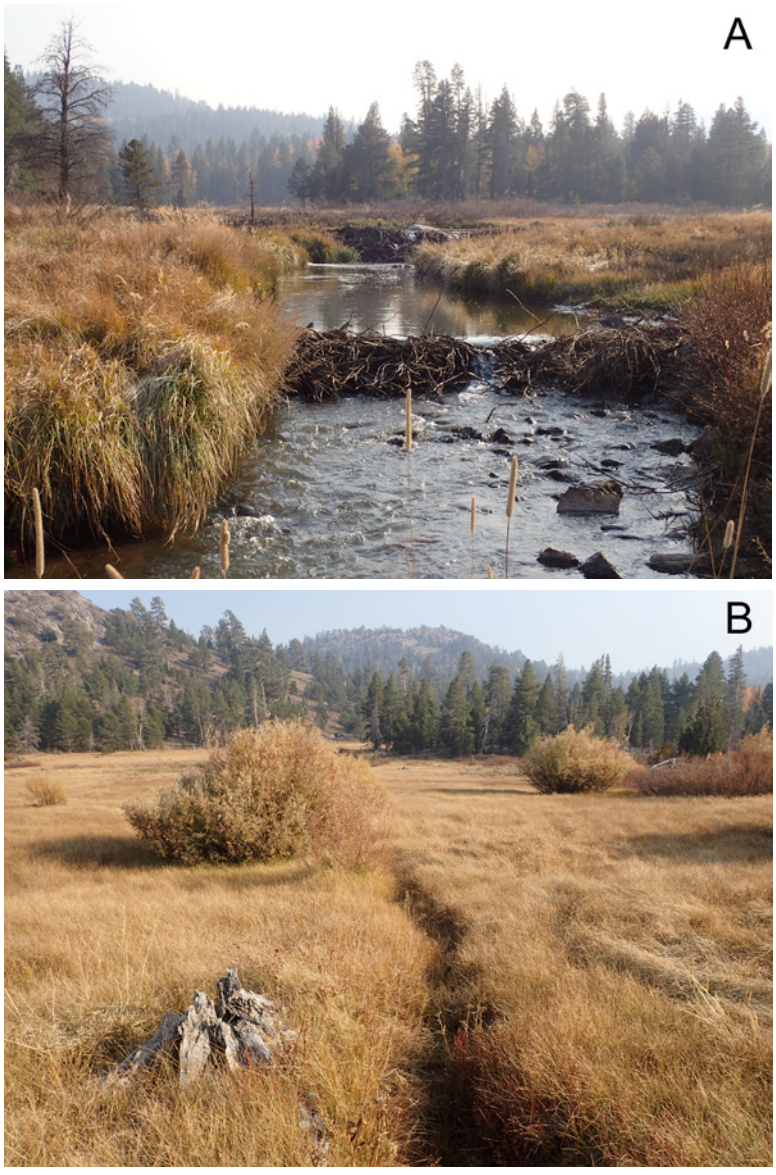


Figure 25—Beaver dams and springs help to maintain a) herbaceous- and b) willow-dominated communities in Upper Red Lake Creek meadows. USDA Forest Service photo by D. Max Smith.

A variety of disturbances influence the composition and structure of riparian communities in meadows and corridors. In high-order streams, reproduction of cottonwoods, willows, and other pioneering species occurs in response to valley bottom scour and sediment deposition. These conditions occur during years with heavy precipitation and spring runoff (Baker 1990; Dykaar and Wigington 2000). In low-order streams at higher elevations, flood disturbance is typically less severe. Late seral vegetation, which includes sedges and willows, stabilizes streamside soils, creating overhanging banks and narrow stream channels (Winward 2000). Moderate- to high-severity wildfire results in aboveground mortality of trees and shrubs, but can encourage establishment of deciduous species through sprouting or germination (Dwire and Kauffman 2003; Gruell 1980; Smith et al. 2009; Wolf et al. 2007). Fire, which was used as a management tool by Indigenous peoples, helped to maintain the dominance of herbaceous plants in riparian meadows (Gross and Coppoletta 2013). Flooding, beaver activity, and ice flows can also cause a reduction of height and clonal sprouting of willows and cottonwoods (Wilding et al. 2014).

Water availability and geomorphic setting are the primary bottom-up drivers of GDE composition (Cooper and Merritt 2012; Magee and Kentula 2005; Stevens and Meretsky 2008). Climate and geology interact to shape the volume and chemistry of groundwater, which are determinants of plant and animal community composition at springs and fens (Chimner et al. 2010; Lemly and Cooper 2011; Sada et al. 2001). Macroinvertebrate diversity in springs was correlated with flow permanence, calcium concentration, specific conductance, pH, magnesium, and alkalinity in the Sierra Nevada (Sada and Pohlmann 2006). In fens of the Mountain West, vegetation composition and structure are largely influenced by physical and chemical characteristics (Chimner et al. 2010; Lemly and Cooper 2011; Wolf and Cooper 2015). Peatland plant communities vary among geomorphic settings, such as sloping fens, patterned fens, and floating mat fens. This variation is driven by gradients in water table depth and duration of surface inundation (Cooper and Andrus 1994). Vegetation also varies along microtopographic gradients within fens (Sikes et al. 2013). Fens are typically dominated by herbaceous vegetation, particularly sedges and mosses, but shrubs and trees are present in some situations (Hansen et al. 1995; Lemly and Cooper 2011). Because they are not rooted in mineral soil, plants in fens receive mineral nutrients from the water in saturated soils (Sikes et al. 2013). Groundwater chemistry is, therefore, an important driver of species composition. Rich fens, fed by high-pH water from carbonate bedrock, have high species richness, whereas poor fens, with low-pH water from granitic bedrock, are dominated by fewer species, such as *Sphagnum* mosses and *Vaccinium* shrubs (Chimner 2011; Chimner et al. 2010).

Stressors

Numerous stressors, both natural and anthropogenic, affect the structure and composition of riparian ecosystems and GDEs (table 7). Because of high productivity and frequently exposed soil, these areas are especially vulnerable to colonization by invasive plants (Richardson et al. 2007). Plants with the potential to spread into riparian areas include herbaceous thistles, forage grasses, and woody species such as Russian olive (*Elaeagnus angustifolia*) and nonnative tamarisk (*Tamarix* spp.) (Brooks et al.

2013). Following disruption of natural processes, these invasive plants replace native species, but they often provide poor habitat and continue to alter the natural dynamics of floodplains (Frey and Malaney 2009; Smith and Finch 2014).

In coniferous tree-dominated landscapes, fire helps to maintain natural riparian vegetation by preventing encroachment and dominance by conifers and other late-successional species (Kleindl et al. 2015). Widespread suppression of wildfire has, therefore, altered riparian composition in landscapes adapted to frequent fire (Gruell 1980; Hall 1971). In low-elevation floodplains, fire can result in mortality of native deciduous trees and facilitate replacement by invasive and upland species (Smith et al. 2009). This loss of native vegetation can impede restoration of prefire stream channel dynamics, causing further degradation to aquatic habitats (Leonard et al. 2017). In the Sierra Nevada, forested riparian areas have high wildfire hazard risk following decades of fire suppression (Van de Water and North 2011). A warming and drying climate will also alter wildfire risk in riparian ecosystems, but the nature of these changes remains uncertain (Riley et al. 2019).

Dams, diversions, and roads can disrupt surface flows that shape a stream's geomorphology and connect the channel to its floodplain. Additionally, these structures disrupt natural processes of scour and deposition. By altering the volume and timing of surface flows or removing them altogether, dams and diversions reduce the extent of riparian vegetation in affected areas (Dewine and Cooper 2007). Roads and other forms of development restrict the movement of stream channels, thereby limiting the horizontal structure of riparian vegetation to a subsection of the historical floodplain (Forman and Alexander 1998; Jones et al. 2000; Salo and Theobald 2016; Trombulak and Frissell 2000) (fig. 26). Valley bottom roads have been linked to increasing rates of stream incision and associated changes in riparian vegetation in the Central Mountains geographic unit (Chambers and Miller 2011).



Figure 26—Roads, like this one along Big Creek in the Toiyabe-Shoshone area of the Central Mountains, increase confinement of streams and riparian areas, contribute sediment, and help to accelerate rates of stream channel incision in meadows. USDA Forest Service photo by Jeanne Chambers.

Livestock and wildlife herbivory influence the composition, vertical structure, and coverage of riparian vegetation. Grazing is the primary land use in riparian meadows of central Nevada (Trowbridge et al. 2011). Riparian meadows in the Sierra Nevada were grazed by sheep in the early 1900s and some have been grazed by cattle since the 1940s (Overton et al. 1994). Impacts of cattle grazing include decreased cover of native plants and increased cover of introduced plants (Hansen et al. 1995; Platts and Nelson 1989). Grazing has also been shown to reduce the cover of herbaceous vegetation, increase cover of woody shrubs, and reduce bank stability (Overton et al. 1994; Rickart et al. 2013). Composition and structure are also affected by wild ungulate browsing, beaver herbivory, and flooding behind beaver dams (Gruell 1980). Where beavers were present prior to Euro-American settlement, their removal has resulted in stream incision, lowering of water tables, and disconnection of streams from floodplains (Pollock et al. 2014; Wohl 2021). These changes prompt the loss of willow and herbaceous communities and encourage the encroachment of conifers and upland plants into valley bottoms (Marshall et al. 2013). Recreational use of riparian areas creates additional stressors in the form of direct damage to vegetation and the introduction of invasive species (Loomis et al. 2007). Natural stream migration also causes a shift from mesic to xeric riparian types or to upland types (Manning and Padgett 1995). Stressors to riparian ecosystems in the Snake Range include sheep and cattle grazing, mining, and recreation (Beever et al. 2005). Stressors to riparian ecosystems and GDEs in the SMNRA include recreation and use by livestock, wild horses and burros, and an introduced population of elk (*Cervus elaphus*) (Entrix 2008; Sada et al. 2005).

Springs are among the ecosystems most threatened by anthropogenic activities in the western United States (Stevens and Meretsky 2008). Spring developments for irrigation and livestock include the installation of headboxes, diversion of flows to troughs and other structures, and construction of ponds within GDEs (Sada et al. 2001). These activities have adverse effects on plant and animal assemblages, but spring-dependent species can persist if spring developments are planned correctly (Unmack and Minckley 2008). For example, if the volume of springbrook diversions and depth of groundwater declines are kept below certain thresholds, losses of carbon storage capacity and spring-dependent species can be avoided (Gurrieri 2020).

Livestock and wildlife directly affect GDEs through grazing and browsing of vegetation (fig. 27). Grazing and browsing can also cause soil compaction, hummocking, headcutting, and other disturbance (Sada et al. 2001). Effects of recreation include vegetation trampling, soil compaction, and modification of natural runout channels for soaking pools. Natural stressors include wildfire, drought cycles, and geologic events, such as earthquakes (Wood et al. 1985). Conifer and sagebrush encroachment, which results from fire suppression, reduces the extent of willows and wetlands at springs (Gruell 1980). In fens and other wetlands, disturbances such as ditch and trail development and stream incision cause oxidation and degradation of peat soils (Chimner and Cooper 2003; Patterson and Cooper 2007).



Figure 27—This spring in the Central Mountains has a long runout channel that has been heavily grazed and trampled by livestock. Water has been diverted from the stream as well. Courtesy photo by the Spring Stewardship Institute.

Many of these stressors have been observed in Nevada, where greater than 85 percent of surveyed springs were moderately or highly disturbed by livestock or diversion (or both) (Sada and Pohlmann 2006). Increases in water temperatures and levels of dissolved solids have affected water quality and spring biota (Sada and Pohlmann 2006). Alterations to spring ecosystems for recreation (soaking), livestock use (impoundments and diversions, grazing effects), irrigation, municipal use, and domestic use have resulted in a complete population loss of organisms such as springsnails (Hershler et al. 2014).

Methods

We reviewed the scientific literature to identify drivers and stressors that influence the composition and structure of riparian ecosystems and GDEs. Given the available datasets, we selected indicators of current composition and structure in relation to the NRV. We quantified stressors and indicators at the scale of the geographic unit. Stressors, indicators, and data sources are described in Appendix A. To determine the current status of composition and structure in each geographic unit, we used our

synthesis of literature and data to determine whether components of this key ecosystem characteristic are operating within the NRV, operating outside of the NRV, or are moderately altered (table 8).

We used data from several sources to evaluate the composition and structure of riparian ecosystems in each geographic unit. Descriptions of datasets and analyses are detailed in Appendix G. Using a combination of field survey data, GIS data, and photo analysis, we identified vegetation communities and dominance groups present in riparian ecosystems and GDEs. We calculated several indicators, including measures of problem vegetation cover, vegetation condition (successional status), vegetation departure, disturbance, and invasion (table 8).

Table 8—Indicator scores and status of composition and structure of riparian corridors and meadows in the HTNF geographic units.

Indicator	Central Mountains	East Sierra	Eastern Mountains	Northern Mountains	Ruby Mountains	Sierra Nevada	SMNRA
Number of riparian corridor plots	4	0	7	30	7	8	0
Number of wet meadow plots	39	4	57	110	38	62	3
Dominance groups and plant species similar to those expected under NRV?	Yes	Insufficient information	Yes	Yes	Yes	Yes	Yes
% of riparian corridor plots with unsuitable cover of problem vegetation	0	—	0	20	14	25	—
% of wet meadow plots with unsuitable cover of problem vegetation	74	100	75	93	61	84	100
% of Riparian corridor plots with vegetation condition rated as moderate or high	67	—	57	40	43	63	—
% of wet meadow plots with vegetation condition rated as moderate or high	58	50	48	59	48	67	0
% of stream miles with moderate or significant departure from expected riparian vegetation	58	61	48	76	43	60	37
% of stream miles with moderate or significant expansion of riparian vegetation	1	7	2	1	8	23	0
% of riparian plots with livestock disturbance	90	25	89	91	81	75	100
% of riparian plots with road disturbance	70	25	53	67	69	26	100
% of riparian plots impacted by noxious weeds	8	0	26	33	44	12	67
Status of riparian corridors	Moderately altered	Insufficient information	Moderately altered	Moderately altered	Moderately altered	Moderately altered	Moderately altered
Status of wet meadows	Moderately altered	Insufficient information	Moderately altered	Moderately altered	Moderately altered	Moderately altered	Moderately altered

— Indicates that data were unavailable.

Results

Current Conditions at Riparian Ecosystems

We found that the status of riparian composition and structure did not vary widely among geographic units. For the most part, the expected dominance groups, communities, and species were present in riparian corridors and meadows (appendix G), but a high percentage of plots had unsuitable levels of vegetation (native and nonnative species) that were indicative of management problems, especially in meadow plots (table 8). Of the riparian vegetation present, condition was moderate or high at 40 to 70 percent of plots. Riparian departure was more than 50 percent at most units and is driven by the encroachment of conifers and upland shrubs, including *Artemisia tridentata*, on riparian ecosystems (fig. 28). Disturbance from livestock or wildlife was the most frequently observed impact to riparian vegetation in each unit. Damage from wild horses, wild burros, and elk is widespread in the SMNRA, whereas impacts from cattle are apparent in the other units. Effects of roads, recreation, and noxious weeds are widespread as well. Impacts from other disturbances, such as mining and wildfire, are more localized. We determined that the composition and structure of riparian corridors and meadows are moderately altered at each unit except for the East Sierra, where there is insufficient information. Based on indicator values (table 8), composition and structure are closest to the NRV in the Ruby Mountains and Sierra Nevada geographic units.

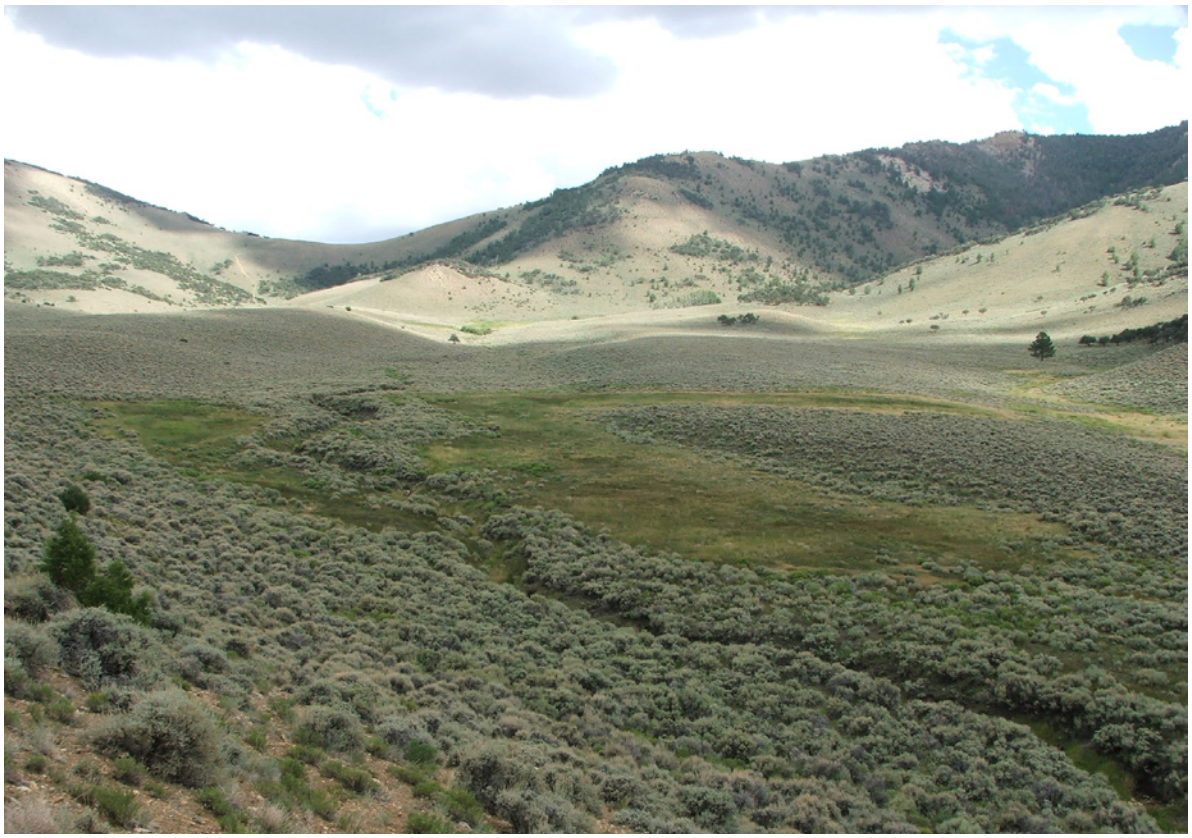


Figure 28—N Wadsworth Meadow, in the Monitor-Hot Creek area of the Central Mountains, shows signs of stream channel incision and resulting encroachment of sagebrush along the channel. Photo by Wendy Trowbridge, USFS.

Current Conditions at Springs

Spatial data and field surveys indicate that springs are critical to sustaining riparian vegetation in arid landscapes such as the SMNRA (Coles-Ritchie 2013; Solem et al. 2013). Springs sustain riparian communities, herbaceous wetland communities, and shrub wetland communities throughout the Forest (figs. 29, 30). As with riparian ecosystems, we found consistent results for the status of springs. In each unit, native wetland vegetation and native aquatic animals were present at most springs, despite impacts from livestock, feral ungulates, and diversions (table 9). Overall, the Northern Mountains had the lowest percentage of springs with disturbances noted. We determined that the composition and structure of spring ecosystems were moderately altered in four geographic units (Central Mountains, Eastern Mountains, Northern Mountains, and SMNRA), but there was insufficient information to determine the status at three units (East Sierra, Ruby Mountains, and Sierra Nevada). Based on values of indicators (table 9), composition and structure are closest to the NRV at the Northern Mountains.



Figure 29—At higher elevations of the SMNRA, springs are dominated by forbs including *Dodecantheon redolens*. Courtesy photo by the Spring Stewardship Institute.



Figure 30—Many springs in the Jarbidge area of the Northern Mountains support dense stands of herbaceous vegetation dominated by *Veratrum californicum*. Courtesy photo by the Spring Stewardship Institute.

Table 9—Value of indicator scores and status of composition and structure of spring ecosystems in the HTNF geographic units.

Unit	Number spring survey reports	% sites with nonnative vegetation	% sites with aquatic invertebrates	% sites with diversions	% sites with cattle disturbance	% sites with feral ungulate disturbance	% sites rated as pristine or good	Status of springs
Central Mountains	59	29	22	25	58	4	67	Moderately altered
East Sierra	22	—	59	50	60	6	—	Insufficient information
Eastern Mountains	79	80	57	34	46	5	48	Moderately altered
Northern Mountains	110	69	64	3	13	2	89	Moderately altered
Ruby Mountains	5	—	80	33	33	0	—	Insufficient information
Sierra Nevada	16	—	64	36	7	0	—	Insufficient information
SMNRA	156	65	58	30	7	31	50	Moderately altered

— Indicates that data were unavailable.

Current Conditions at Fens

We could not find results from field surveys specific to fens in the HTNF. Fens in other forests of the Sierra Nevada Range in California have been affected by changes in sediment dynamics and surface flows where watersheds were historically overgrazed (Wolf and Cooper 2015). In some areas, use of meadows by cattle and pack stock results in trampling and grazing of fen vegetation (Sikes et al. 2013). Surface water diversions, groundwater pumping, and timber harvest alter water tables in fens, thereby influencing species composition. Roads disrupt surface water and groundwater flow paths and can exacerbate sedimentation. Sierra Nevada fens are also impacted by OHVs and other forms of recreation (Sikes et al. 2013). Drexler et al. (2013) observed a reduction in vegetation that is characteristic of fens at several sites in the Sierra Nevada Range. This contraction appears to be associated with rising temperatures, a decrease in snow water equivalent, and a reduction in groundwater recharge. These stressors are likely affecting the composition and structure of fens in the HTNF, but field-based surveys are needed to assess the impacts.

Summary

In this section we combined results from GIS analysis and several field research projects to describe the vegetation associated with streams and GDEs. We present a snapshot of current vegetation and habitats, but it is difficult to determine whether composition and structure are currently within the NRV, given the lack of reference data and the variability among riparian areas and GDEs across a forest spanning considerable latitudinal and elevational gradients (Kattelmann and Embury 1996). Because of the widespread introduction of nonnative vegetation, extensive networks of roads, and past and ongoing livestock effects, we determined that composition and structure are moderately altered from the NRV in the units we could assess. By combining measurements of desirable and problem vegetation with observations of disturbance, we concluded that stressors have most likely resulted in a shift from the NRV, but composition and structure of riparian corridors, meadows, and springs could be brought closer to or within the NRV with changes in management.

These changes include the installation of livestock and wildlife exclosures, upgrade or decommissioning of forest roads, and reintroduction of beaver in areas where populations have been reduced, such as the Northern Mountains and Sierra Nevada.

CONCLUSIONS

Overall Patterns and Trends

By summarizing results from field studies and GIS analyses (Appendix H), we found that riparian vegetation types cover small percentages of the valley bottoms in most geographic units. The Northern Mountains, Ruby Mountains, and Sierra Nevada units have the greatest extent of riparian ecosystems. Arid mountain ranges in the Central Mountains, Eastern Mountains, and SMNRA have the smallest extents. Given their relative scarcity in this landscape, maintenance of riparian ecosystems could be prioritized to protect biological diversity and species of concern.

Springs maintain perennial streamflow and support aquatic and riparian habitats throughout the Forest. Spring ecosystems are widespread and abundant in several geographic units, as would be expected given the presence of geologic features, such as faults, that create contacts among sedimentary and igneous rocks which can transmit large volumes of groundwater. Fens are not as widespread as springs in this forest. Most of the wetlands identified as likely fens are within the Sierra Nevada unit, where they are concentrated in the Walker River watershed.

As a source of surface flows and groundwater recharge, the HTNF plays an outsized role in maintaining populations of imperiled fishes and other aquatic organisms, both within and outside of the Forest's boundaries. We identified 33 fish species of greatest conservation need that are at least partially dependent on water from the HTNF. Of these species, 19 are Federally listed as endangered or threatened. The habitat needs of this diverse assemblage vary, from species such as coldwater-dependent bull trout in the Northern Mountains, to fishes restricted to thermal springs in the Mojave Desert near the SMNRA. In addition to fish, dozens of wildlife species are dependent on streams, springs, riparian corridors, and wetlands that are sustained by surface water and groundwater originating in the Forest. Management actions that protect the volume and quality of water in the HTNF are therefore likely to benefit aquatic and riparian ecosystems throughout Nevada and in neighboring states.

Our results indicate that, overall, condition of riparian ecosystems and GDEs varies little among geographic units and that KECs have been moderately altered from the NRV. Grazing and road impacts are ubiquitous in the geographic units. Dams and diversions are most prevalent in the Sierra Nevada unit. Localized impacts from recreation are reported in several areas. At springs, riparian vegetation is vulnerable to grazing and browsing, whereas aquatic invertebrates are most vulnerable to diversions. These stressors have been documented in all the units, but impacts on springs are likely minimal in the Northern Mountains.

Data Gaps and Management Issues

In conducting this assessment, we found recurring issues for riparian areas and GDEs. To maintain the ecological integrity of these ecosystems, several issues could be addressed through additional research and changes in management.

Beavers

Beaver dam complexes maintain potential natural conditions in unconfined valley bottoms. These complexes include willow stands and herbaceous-dominated wetlands that are critical habitat for fish and wildlife. The current status of beaver populations is unknown for much of the Forest, and there is conflicting information about the historical distribution of beavers in California and Nevada. Additional investigation is therefore needed to determine where beaver dams are functioning, where reintroductions are succeeding, and where dams could best be used to maintain or restore perennial flows to benefit aquatic and riparian species.

Highways, Roads, and Recreation

The construction of roads and highways has likely influenced riparian ecosystems in each unit. Given the popularity of several units for recreation, including motorized vehicle use, managers may consider protecting additional sensitive areas from disturbance caused by OHVs.

Livestock Use

Impacts from livestock or wild horses and burros were reported at streams and springs in each geographic unit. The nature of these impacts varies among units. Ecosystems in the Sierra Nevada are still recovering from the long-term effects of historical overgrazing. Springs and streams in the SMNRA are currently affected by feral ungulate disturbance. Springs and streams in the other units are modified for livestock use. Consistent monitoring efforts among riparian corridors, meadows, and GDEs could improve understanding of current conditions and the capacity for resistance and recovery from these impacts.

Climate Change

Characteristics of riparian ecosystems and GDEs are, overall, moderately altered in the Forest, but climate change is likely to shift conditions farther from the NRV. Increases in air temperature have been observed in each unit and are expected to amplify the influence of wildfire, raise water temperatures, reduce streamflows and groundwater discharge, and trigger extreme events, such as floods and debris flows. Damage to aquatic and riparian habitats is likely to be greatest where droughts and floods interact with roads, livestock, and other stressors.

Data Collection

Riparian meadows have been well-studied in the Central Mountains and Sierra Nevada units. HTNF monitoring plots have also produced valuable data on riparian ecosystems throughout the Forest, but additional plot data are needed in the East Sierra, Paradise, and Toiyabe-Shoshone areas of the Central Mountains, and the SMNRA. Additional study of woody riparian corridors is needed across the Forest, to complement the information gathered on riparian meadows.

Numerous spring surveys have been conducted in the SMNRA and portions of other geographic units. Additional surveys that focus on vegetation condition are needed in the East Sierra, Ruby Mountains, and Sierra Nevada units. These surveys are also

needed within the Santa Rosa area of the Northern Mountains, the Paradise area of the Central Mountains, and the Quinn-Grant, Snake, and Ward areas of the Eastern Mountains. Several methods have been used to survey springs in the HTNF. Protocols have differed among the units, making it difficult to summarize results across the Forest. A spatially and temporally consistent system of surveys could be applied to future projects, using standardized protocols such as the Forest Service's GDE level I or level II.

REFERENCES

Abt, S.R.; Ruff, J.F.; Doehring, F.K. 1985. Culvert slope effects on outlet scour. Journal of Hydraulic Engineering. 111(10): 1363–1367. https://doi.org/10.1061/(ASCE)0733-9429(1985)111:10(1363).

Adams, R.A.; Hayes, M.A. 2008. Water availability and successful lactation by bats as related to climate change in arid regions of Western North America. Journal of Animal Ecology. 77(6): 1115–1121. https://doi.org/10.1111/j.1365-2656.2008.01447.x.

Alexander, T.G. 1987. The rise of multiple-use management in the Intermountain West: A history of Region 4 of the Forest Service. FS-399. Washington, D.C.: U.S. Government Printing Office. 267 p.

Allen, M.B.; Connolly, P.J.; Mesa, M.G.; [et al.]. 2010. Distribution and movement of bull trout in the upper Jarbidge River watershed, Nevada. Open-File Report 2010-1033. Reston, VA: U.S. Department of the Interior, Geological Survey. 80 p. https://pubs.usgs.gov/of/2010/1033/pdf/ofr20101033.pdf. [Accessed 28 June 2024].

Amacher, M.C.; Kotuby-Amacher, J.; Grossl, P.R. 2004. Effects of natural and anthropogenic disturbances on water quality. In: Chambers, J.C.; Miller, J.R., eds. Great Basin riparian ecosystems: Ecology, management, and restoration. Washington, D.C.: Island Press: 162-195.

Andersen, B.R.; Geluso, K. 2018. Roost characteristics and clustering behavior of western red bats (*Lasiurus blossevillii*) in southwestern New Mexico. Western North American Naturalist. 78(2): 174–183. https://scholarsarchive.byu.edu/wnan/vol78/iss2/7.

Andersen, D.C.; Shafroth, P.B. 2010. Beaver dams, hydrological thresholds, and controlled floods as a management tool in a desert riverine ecosystem, Bill Williams River, Arizona. Ecohydrology. 3(3): 325–338. https://doi.org/10.1002/eco.113.

Anderson, D.M.; Glibert, P.M.; Burkholder, J.M. 2002. Harmful algal blooms and eutrophication: Nutrient sources, composition, and consequences. Estuaries. 25(4): 704–726. https://doi.org/10.1016/j.hal.2008.08.017.

Anderson, M.K. 2018. The use of fire by Native Americans in California. In: van Wagtendonk J.W.; Sugihara, N.G.; Stephens, S.L.; [et al.], eds. Fire in California's ecosystems. Berkeley, CA: University of California Press. 381–398.

Arkle, R.S.; Pilliod, D.S. 2015. Persistence at distributional edges: Columbia spotted frog habitat in the arid Great Basin, USA. Ecology and Evolution. 5(17): 3704-3724. https://doi.org/10.1002/ece3.1627.

Armour, C.; Duff, D.; Elmore, W. 1994. The effects of livestock grazing on western riparian and stream ecosystem. Fisheries. 19(9): 9-12. https://doi.org/10.1577/1548-8446(1994)019<0009:TEOLGO>2.0.CO;2.

Atamian, M.T.; Sedinger, J.S.; Heaton, J.S.; [et al.]. 2010. Landscape-level assessment of brood rearing habitat for greater sage-grouse in Nevada. The Journal of Wildlife Management. 74(7): 1533–1543. https://doi.org/10.1111/j.1937-2817.2010.tb01281.x.

Baker, W.L. 1990. Climatic and hydrologic effects on the regeneration of *Populus angustifolia James* along the Animas River, Colorado. Journal of Biogeography. 17(1): 59-73. https://doi.org/10.2307/2845188.

Banner, R.E. 1992. Physiographic provinces and surface geology of Utah. Rangelands. 14(2): 106–109. http://hdl.handle.net/10150/638862.

Barrows, C.W. 1996. Tamarisk control and common sense. In: Lovich, Jeff; Randall, John; Kelly, Mike, eds. Proceedings: California Exotic Pest Plant Council Symposium, Volume 2; October 4-6, 1996; Handlery Hotel; San Diego, CA. https://www.cal-ipc.org/wp-content/uploads/2017/12/1996_symposium_proceedings1826.pdf. [Accessed 28 June 2024].

Bateman, H.L.; Chung-MacCoubrey, A.; Snell, H.L. 2008. Impact of non-native plant removal on lizards in riparian habitats in the Southwestern United States. Restoration Ecology. 16(1): 180–190. https://doi.org/10.1111/j.1526-100X.2007.00361.x.

Bateman, H.L.; Chung-MacCoubrey, A.; Snell, H.L.; [et al.]. 2009. Abundance and species richness of snakes along the Middle Rio Grande riparian forest in New Mexico. Herpetological Conservation and Biology. 4(1): 1-8. https://www.herpconbio.org/Volume_4/Issue_1/Bateman_etal_2009.pdf. [Accessed 28 June 2024].

Bateman, H.L.; Merritt, D.M. 2020. Complex riparian habitats predict reptile and amphibian diversity. Global Ecology and Conservation. 22: e00957. https://doi.org/10.1016/j.gecco.2020.e00957.

Bateman, H.L.; Ostoja, S.M. 2012. Invasive woody plants affect the composition of native lizard and small mammal communities in riparian woodlands. Animal Conservation. 15(3): 294–304. https://doi.org/10.1111/j.1469-1795.2011.00517.x.

Bateman, H.L.; Riddle, S.B. 2020. Reptile community responses to native and non-native riparian forests and disturbance along two rivers in Arizona. River Research and Applications. 36(3): 492–502. https://doi.org/10.1111/j.1526-100X.2007.00361.x.

Bearup, L.A.; Maxwell, R.M.; Clow, D.W.; [et al.]. 2014. Hydrological effects of forest transpiration loss in bark beetle-impacted watersheds. Nature Climate Change. 4(6): 481–486. https://doi.org/10.1038/nclimate2198.

Beck, W.A.; Haase, Y.D. 1989. Historical atlas of the American West. Norman, OK: University of Oklahoma Press. 156 p.

Bedford, B.L.; Godwin, K.S. 2003. Fens of the United States: Distribution, characteristics, and scientific connection versus legal isolation. Wetlands. 23(3): 608-629. https://doi.org/10.1672/0277-5212(2003)023[0608:FOTUSD]2.0.CO;2.

Beever, E.A.; Pyke, D.A.; Chambers, J.C.; [et al.]. 2005. Monitoring temporal change in riparian vegetation of Great Basin National Park. Western North American Naturalist. 65(3): 382-402. https://scholarsarchive.byu.edu/wnan/vol65/iss3/10.

Belcher, W.R.; Moran, M.J.; Rogers, M.E. 2013. Water and water use in southern Nevada [Chapter 3]. In: Chambers, J.C.; Brooks, M.L.; Pendleton, B.K.; Raish, C.B. eds. The Southern Nevada Agency Partnership Science and Research Synthesis: Science to support land management in Southern Nevada. Gen. Tech. Rep. RMRS-GTR-303. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. P. 37-58. https://research.fs.usda.gov/treesearch/44308.

Benda, L.; Miller, D.; Bigelow, P.; [et al.]. 2003. Effects of post-wildfire erosion on channel environments, Boise River, Idaho. Forest Ecology and Management. 178(1): 105–119. https://doi.org/10.1016/S0378-1127(03)00056-2.

Benson, L. 1978. Fluctuation in the level of pluvial Lake Lahontan during the last 40,000 years. Quaternary Research. 9(3): 300-318. https://doi.org/10.1016/0033-5894(78)90035-2.

Berger, D.L. 2006. Hydrogeology and water resources of Ruby Valley, northeastern Nevada. Scientific Investigations Report 2005-5247. Carson City, NV: U.S. Department of the Interior, Geological Survey. 39 p. https://pubs.usgs.gov/sir/2005/5247/sir2005-5247.pdf

Berris, S.N.; Hess, G.W.; Bohman, L.R. 2001. River and reservoir operations model, Truckee River Basin, California and Nevada, 1998. Water-Resources Investigations Report 01-4017. Carson City, NV: U.S. Department of the Interior, Geological Survey. 148 p. https://doi.org/10.3133/wri014017.

Beschta, R.L. 1997. Riparian shade and stream temperature: An alternative perspective. Rangelands. 19(2): 25-28. http://hdl.handle.net/10150/640452.

Betts, B.J. 1998. Roosts used by maternity colonies of silver-haired bats in northeastern Oregon. Journal of Mammalogy. 79(2): 643–650. https://doi.org/10.2307/1382994.

Bilotta, G.S.; Brazier, R.E. 2008. Understanding the influence of suspended solids on water quality and aquatic biota. Water Research. 42(12): 2849–2861. https://doi.org/10.1016/j.watres.2008.03.018.

Bilyeu, D.M.; Cooper, D.J.; Hobbs, N.T. 2008. Water tables constrain height recovery of willow on Yellowstone's Northern Range. Ecological Applications. 18(1): 80-92. https://doi.org/10.1890/07-0212.1.

Bixby, R.J.; Cooper, S.D.; Gresswell, R.E.; [et al.]. 2015. Fire effects on aquatic ecosystems: An assessment of the current state of the science. Freshwater Science. 34(4): 1340–1350. https://doi.org/10.1086/684073.

Board, D.I.; Dilts, T.E.; Weisberg, P.J.; [et al.]. 2020. Characterizing ecoregions and montane perennial watersheds of the Great Basin. Gen. Tech. Rep. RMRS-GTR-419. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 51 p. https://research.fs.usda.gov/treesearch/61573.

Bosch, J.M.; Hewlett, J.D. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology. 55(1–4): 3–23. https://doi.org/10.1016/0022-1694(82)90117-2.

Boulton, A.J. 2005. Chances and challenges in the conservation of groundwaters and their dependent ecosystems. Aquatic Conservation: Marine and Freshwater Ecosystems. 15(4): 319-323. https://doi.org/10.1002/aqc.712

Boxall, G.D.; Giannico, G.R.; Li, H.W. 2008. Landscape topography and the distribution of Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*) in a high desert stream. Environmental Biology of Fishes. 82: 71-84. https://doi.org/10.1007/s10641-007-9254-1.

Brooks, M.L.; Ostoja, S.M.; Chambers, J.C. 2013. Invasive species in southern Nevada [Chapter 4] (Executive Summary). In: Chambers, J.C.; Brooks, M.L.; Pendleton, B.K.; Raish, C.B., eds. The Southern Nevada Agency Partnerhsip Science and Research Synthesis: Science to support land management in Southern Nevada – Executive Summary. Gen. Tech. Rep. RMRS-GTR-304. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. P. 19-24. https://research.fs.usda.gov/treesearch/44312.

Brown, C.; Wilkinson, L.R.; Wilkinson, K.K.; [et al.]. 2019. Demography, habitat, and movements of the Sierra Nevada yellow-legged frog (*Rana sierrae*) in streams. Copeia. 107(4): 661-675. https://doi.org/10.1643/CE-19-196.

Bryce, S.A.; Woods, A.J.; Morefield, J.D.; [et al.]. 2003. Ecoregions of Nevada (color poster with map, descriptive text, summary tables, and photographs). Reston, VA: U.S. Department of the Interior, Geological Survey (map scale 1:1,350,000). https://gaftp.epa.gov/epadatacommons/ORD/Ecoregions/nv/nv_front.pdf.

Busenberg, G. 2004. Wildfire management in the United States: The evolution of a policy failure. Review of Policy Research. 21(2): 145-156. https://doi.org/10.1111/j.1541-1338.2004.00066.x.

Caldwell, T.G.; Wolaver, B.D.; Bongiovanni, T.; [et al.]. 2020. Spring discharge and thermal regime of a groundwater dependent ecosystem in an arid karst environment. Journal of Hydrology. 587: 124947. https://doi.org/10.1016/j.jhydrol.2020.124947.

Carpenter, S.R.; Caraco, N.F.; Correll, D.L.; [et al.]. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications. 8(3): 559–568. https://doi.org/10.1890/1051-0761(1998)008[0559:NPOSWW]2.0.CO;2.

Cartwright, J.; Johnson, H.M. 2018. Springs as hydrologic refugia in a changing climate? A remote-sensing approach. Ecosphere. 9(3): e02155. https://doi.org/10.1002/ecs2.2155.

Castelli, R.M.; Chambers, J.C.; Tausch, R.J. 2000. Soil-plant relations along a soil-water gradient in Great Basin riparian meadows. Wetlands. 20: 251-266. https://doi.org/10.1672/0277-5212(2000)020[0251:SPRAAS]2.0.CO;2.

Castro, J.M.; Thorne, C.R. 2019. The stream evolution triangle: Integrating geology, hydrology, and biology. River Research and Applications. 35(4): 315-326. https://doi.org/10.1002/rra.3421.

Cayan, D.R. 1996. Interannual climate variability and snowpack in the Western United States. Journal of Climate. 9(5): 928–948. https://doi.org/10.1175/1520-0442(1996)009<0928:ICVASI>2.0.CO;2.

Chadde, S.W.; Shelly, J.S.; Bursik, R.J.; [et al.]. 1998. Peatlands on National Forests of the Northern Rocky Mountains: Ecology and conservation. Gen. Tech. Rep. RMRS-GTR-11. Ogden, UT: U.S. Department of Agriculture, Forest Service Rocky Mountain Research Station. 80 p. https://doi.org/10.2737/RMRS-GTR-11.

Chambers, J.C.; Devoe, N.; Evenden, A., eds. 2008. Collaborative management and research in the Great Basin - examining the issues and developing a framework for action. RMRS-GTR-204. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 66 p. https://doi.org/10.2737/RMRS-GTR-204.

Chambers, J.C.; Linnerooth, A.R. 2001. Restoring riparian meadows currently dominated by *Artemisia* using alternative state concepts - the establishment component. Applied Vegetation Science. 4(2): 157-166. https://doi.org/10.1111/j.1654-109X.2001.tb00484.x.

Chambers, J.C.; Miller, J.R. 2004. Restoring and maintaining sustainable riparian ecosystems: The Great Basin ecosystem management project. In: Chambers, J.C.; Miller, J.R., eds. Great Basin riparian ecosystems: Ecology, management, and restoration. Washington, D.C.: Island Press: 1-23.

Chambers, J.C.; Miller, J.R., eds. 2011. Geomorphology, hydrology, and ecology of Great Basin meadow complexes - implications for management and restoration. Gen. Tech. Rep. RMRS-GTR-258. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 125 p. https://doi.org/10.2737/RMRS-GTR-258.

Chambers, J.C.; Miller, J.R.; Lord, M.L.; [et al.]. 2021. Geomorphic sensitivity and ecological resilience of Great Basin streams and riparian ecosystems. Part I. Sensitivity and resilience concepts, components, and categories. Part II. Assessment protocol. Gen. Tech. Rep. RMRS-GTR-426. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 159 p. https://doi.org/10.2737/RMRS-GTR-426.

Chambers, J.C.; Tausch, R.J.; Korfmacher, J.L.; [et al.]. 2004. Effects of geomorphic processes and hydrologic regimes on riparian vegetation. In: Chambers, J.C.; Miller, J.R., eds. Great Basin riparian ecosystems: Ecology, management, and restoration. Washington, D.C.: Island Press. 320 p.

Chen, I.C.; Hill, J.K.; Ohlemüller, R.; [et al.]. 2011. Rapid range shifts of species associated with high levels of climate warming. Science. 333(6045): 1024–1026. https://doi.org/10.1126/science.1206432.

Chiloane, C.; Dube, T.; Shoko, C. 2022. Impacts of groundwater and climate variability on terrestrial groundwater dependent ecosystems: A review of geospatial assessment approaches and challenges and possible future research directions. Geocarto International. 37(23): 6755-6779. https://doi.org/10.1080/10106049.2021.1948108.

Chimner, R.A. 2011. Restoring sedges and mosses into frost heaving iron fens, San Juan Mountains, Colorado. Mires and Peat. 8(7): 1-9. http://www.mires-and-peat.net/pages/volumes/map08/map0807.php.

Chimner, R.A.; Cooper, D.J. 2003. Carbon dynamics of pristine and hydrologically modified fens in the Southern Rocky Mountains. Canadian Journal of Botany. 81(5): 477-491. https://doi.org/10.1139/b03-043.

Chimner, R.A.; Lemly, J.M.; Cooper, D.J. 2010. Mountain fen distribution, types and restoration priorities, San Juan Mountains, Colorado, USA. Wetlands. 30(4): 763–771. https://doi.org/10.1007/s13157-010-0039-5.

Chung-MacCoubrey, A. 1999. Maternity roosts of bats at the Bosque Del Apache National Wildlife Refuge: A preliminary report. In: Finch, D.M.; Whitney, J.C.; Kelly, J.F.; [et al.]. Rio Grande ecosystems: Linking land, water, and people: Toward a sustainable future for the Middle Rio Grande Basin. Proceedings RMRS-P-7. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 187-190. https://research.fs.usda.gov/treesearch/35787.

Cicero, C. 1997. Boggy meadows, livestock grazing, and interspecific interactions: Influences on the insular distribution of montane Lincoln's sparrows (*Melospiza lincolnii alticola*). The Great Basin Naturalist. 57(2): 104-115. https://scholarsarchive.byu.edu/gbn/vol57/iss2/2. [Accessed 28 June 2024].

Clapp, E.H. 1936. The major range problems and their solution: A resumé. In: Wallace, H.A.; Silcox, F.A., eds. The western range. Washington, D.C.: U.S. Government Printing Office: 1–69.

Cleland, D.; Reynolds, K.; Vaughan, R.; [et al.]. 2017. Terrestrial condition assessment for national forests of the USDA Forest Service in the continental US. Sustainability. 9(11): 2144. https://doi.org/10.3390/su9112144.

Clinton, B.D. 2011. Stream water responses to timber harvest: Riparian buffer width effectiveness. Forest Ecology and Management. 261(6): 979–988. https://doi.org/10.1016/j.foreco.2010.12.012.

Cluer, B.; Thorne, C. 2014. A stream evolution model integrating habitat and ecosystem benefits. River Research and Applications. 30(2): 135-154. https://doi.org/10.1002/rra.2631.

Coates, P.S.; Casazza, M.L.; Brussee, B.E.; [et al.]. 2014. Spatially explicit modeling of greater sage-grouse (*Centrocercus urophasianus*) habitat in Nevada and northeastern California: A decision-support tool for management. Open-File Report 2014-1163. Reston, VA: U.S. Department of the Interior, Geological Survey. 83p. https://doi.org/10.3133/ofr20141163.

Cole, D.N. 2004. Impacts of Hiking and Camping on Soils and Vegetation: a Review. In: Buckley, R., ed. Environmental impacts of ecotourism. Cambridge, MA: CABI Publishing: 41-60. https://doi.org/10.1079/9780851998107.0041.

Coles-Ritchie, M. 2013. Report on SMNRA riparian inventory 2012. Report on file U.S. Forest Service [USFS], Spring Mountains National Recreation Area, Las Vegas, NV. 51 p.

Collen, P.; Gibson, R.J. 2001. The general ecology of beavers (*Castor* spp.), as related to their influence on stream ecosystems and riparian habitats, and the subsequent effects on fish – a review. Reviews in Fish Biology and Fisheries. 10: 439–461. https://doi.org/10.1023/A:1012262217012.

Cooper, D.J.; Andrus, R.E. 1994. Patterns of vegetation and water chemistry in peatlands of the west-central Wind River Range, Wyoming, USA. Canadian Journal of Botany. 72(11): 1586-1597. https://doi.org/10.1139/b94-196.

Cooper, D.J.; Merritt, D.M. 2012. Assessing the water needs of riparian and wetland vegetation in the Western United States. Gen. Tech. Rep. RMRS-GTR-282. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 125 p. https://doi.org/10.2737/RMRS-GTR-282.

Cordone, A.J.; Kelley, D.W. 1961. The influences of inorganic sediment on the aquatic life of streams. California Game and Fish. 47(2): 189-228. https://www.waterboards.ca.gov/water_issues/programs/tmdl/records/region_1/2003/ref2075.pdf. [Accessed 28 June 2024].

Correll, D.L. 1997. Buffer zones and water quality protection: General principles. In: Haycock, N.E.; Burt, T.P.; Goulding, K.W.T.; [et al.], eds. Buffer zones: Their processes and potential in water protection. Hertfordshire, England: Quest Environmental: 7-20.

Crabill, C.; Donald, R.; Snelling, J.; [et al.]. 1999. The impact of sediment fecal coliform reservoirs on seasonal water quality in Oak Creek, Arizona. Water Research. 33(9): 2163–2171. https://doi.org/10.1016/S0043-1354(98)00437-0.

Dall, D.; Elliott, C.; Peters, D. 1997. A system for mapping riparian areas in the Western United States. Lakewood, CO: U.S. Department of the Interior, Fish and Wildlife Service, National Wetlands Inventory. 16 p. https://www.fws.gov/sites/default/files/documents/a-system-for-mapping-riparian-areas-in-the-western-united-states-2019.pdf. [Accessed 28 June 2024].

Dauer, D.M.; Weisberg, S.B.; Ranasinghe, J.A. 2000. Relationships between benthic community condition, water quality, sediment quality, nutrient loads, and land use patterns in Chesapeake Bay. Estuaries and Coasts. 23(1): 80-96. https://doi.org/10.2307/1353227.

Davis, J.A.; Kerezsy, A.; Nicol, S. 2017. Springs: Conserving perennial water is critical in arid landscapes. Biological Conservation. 211(B): 30-35. https://doi.org/10.1016/j.biocon.2016.12.036.

Deval, C.; Brooks, E.S., Gravelle, J.A.; Link, T.E.; Dobre, M.; Elliot, W.J. 2021. Long-term response in nutrient load from commercial forest management operations in a mountainous watershed. Forest Ecology and Management. 494(80): 119312. https://doi.org/10.1016/j.foreco.2021.119312.

DeWine, J.M.; Cooper, D.J. 2007. Effects of river regulation on riparian box elder (*Acer negundo*) forests in canyons of the Upper Colorado River Basin, USA. Wetlands. 27(2): 278-289. https://doi.org/10.1672/0277-5212(2007)27[278:EORROR]2.0.CO;2.

Dodds, W.K.; Welch, E.B. 2000. Establishing nutrient criteria in streams. Journal of the North American Benthological Society. 19(1): 186-196. https://doi.org/10.2307/1468291.

Doerr, S.H.; Shakesby, R.A.; Blake, W.H.; [et al.]. 2006. Effects of differing wildfire severities on soil wettability and implications for hydrological response. Journal of Hydrology. 319(1–4): 295–311. https://doi.org/10.1016/j.jhydrol.2005.06.038.

Donnelly, J.P.; Naugle, D.E.; Hagen, C.A.; [et al.]. 2016. Public lands and private waters: Scarce mesic resources structure land tenure and sage-grouse distributions. Ecosphere. 7(1): e01208. https://doi.org/10.1002/ecs2.1208.

Drexler, J.Z.; Knifong, D.; Tuil, J.; [et al.]. 2013. Fens as whole-ecosystem gauges of groundwater recharge under climate change. Journal of Hydrology. 481: 22-34. https://doi.org/10.1016/j.jhydrol.2012.11.056.

Duffy, C.J.; Al-Hassan, S. 1988. Groundwater circulation in a closed desert basin: Topographic scaling and climatic forcing. Water Resources Research. 24(10): 1675–1688. https://doi.org/10.1029/WR024i010p01675.

Dwire, K.A.; Kauffman, J.B. 2003. Fire and riparian ecosystems in landscapes of the Western USA. Forest Ecology and Management. 178(1-2): 61-74. https://doi.org/10.1016/S0378-1127(03)00053-7.

Dykaar, B.B.; Wigington Jr., P.J. 2000. Floodplain formation and cottonwood colonization patterns on the Willamette River, Oregon, USA. Environmental Management. 25(1): 87-104. https://doi.org/10.1007/s002679910007.

Dzialak, M.R.; Olson, C.V.; Harju, S.M.; [et al.]. 2011. Identifying and prioritizing greater sage-grouse nesting and brood-rearing habitat for conservation in human-modified landscapes. PLoS ONE. 6(10): e26273. https://www.doi.org/10.1371/journal.pone.0026273.

Eakin, T.E.; Price, D.; Harrill, J.R. 1976. Summary appraisals of the nation's ground-water resources-Great Basin region. Professional Paper 813-G. Arlington, VA: U.S. Department of the Interior, Geological Survey. 46 p. https://doi.org/10.3133/pp813G.

Einstein, H.A. 1950. The bed-load function for sediment transportation in open channel flows. Technical Bulletin 1026. Washington, D.C.: U.S. Department of Agriculture Soil Conservation Service. 74 p.

Elias, E.; Steele, C.; Havstad, K.; [et al.]. 2015. Southwest Regional Climate Hub and California Subsidiary Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies, T. Anderson, Ed., United States Department of Agriculture, 76 p. https://www.climatehubs.usda.gov/sites/default/files/FINAL%20Southwest%20and%20California%20Vulnerbility%20Assessment%20Final.pdf. [Accessed 28 June 2024].

Emmerich, W.E.; Heitschmidt, R.K. 2002. Drought and grazing: II. Effects on runoff and water quality. Journal of Range Management. 55(3): 229–234. https://doi.org/10.2307/4003128.

Engelhardt, B.M.; Chambers, J.C.; Weisberg, P.J. 2015. Geomorphic predictors of riparian vegetation in small mountain watersheds. Journal of Plant Ecology. https://doi.org/10.1093/jpe/rtv002.

Entrix, Inc. 2008. Characterization of the Spring Mountains National Recreation Area. Prepared for: USDA Forest Service Spring Mountains National Recreation Area Humboldt-Toiyabe National Forest. Contract No. AG-9360-C-06-0003. Las Vegas, NV: Entrix, Inc. 72 p. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm9_025920.pdf. [Accessed 28 June 2024].

Fair, J.; Hunt, L.; Hanley, M.; [et al.]. 2018. Restoring Carson meadows: Assessment and prioritization. A report by American Rivers submitted to the National Fish and Wildlife Foundation. 39 p. https://meadows.ucdavis.edu/sites/g/files/dgvnsk10941/files/2021-05/Carson%20Assessment%20Report_Updated%201.30.19.pdf. [Accessed 28 June 2024].

Fashola, M.O.; Ngole-Jeme, V.M.; Babalola, O.O. 2016. Heavy metal pollution from gold mines: Environmental effects and bacterial strategies for resistance. International Journal of Environmental Research and Public Health. 13(11): 1047. https://doi.org/10.3390/ijerph13111047.

Fenton, M.B.; Morris, G.K. 1976. Opportunistic feeding by desert bats (*Myotis* spp.). Canadian Journal of Zoology. 54(4): 526–530. https://doi.org/10.1139/z76-059.

Festa, F.; Ancillotto, L.; Santini, L.; [et al.]. 2023. Bat responses to climate change: A systematic review. Biological Reviews Cambridge Philosophical Society. 98(1): 19-33. https://doi.org/10.1111/brv.12893.

Fischer, R.A.; Reese, K.P.; Connelly, J.W. 1996. Influence of vegetal moisture content and nest fate on timing of female sage grouse migration. The Condor. 98(4): 868-872. https://doi.org/10.2307/1369875.

Flaschka, I.; Stockton, C.W.; Boggess, W.R. 1987. Climatic variation and surface water resources in the Great Basin region. Journal of the American Water Resources Association. 23(1): 47–57. https://doi.org/10.1111/j.1752-1688.1987.tb00783.x.

Fleischner, T.L. 1994. Ecological costs of livestock grazing in Western North America. Conservation Biology. 8(3): 629–644. https://doi.org/10.1046/j.1523-1739.1994.08030629.x.

Fleishman, E.; Murphy, D.D.; Austin, G.T. 2005. Biodiversity patterns of spring-associated butterflies in a Mojave Desert mountain range. Journal of the Lepidopterists' Society. 59(2): 89-95. https://images.peabody.yale.edu/lepsoc/jls/2000s/2005/2005(2)89-Fleishman.pdf. [Accessed 28 June 2024].

Fleishman, E.; Murphy, D.D.; Sada, D.W. 2006. Effects of environmental heterogeneity and disturbance on the native and non-native flora of desert springs. Biological Invasions. 8: 1091-1101. https://doi.org/10.1007/s10530-005-7564-9.

Forman, R.T.T.; Alexander, L.E. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics. 29: 207–231. https://doi.org/10.1146/annurev.ecolsys.29.1.207.

Fortino, K.; Hershey, A.E.; Goodman, K.J. 2004. Utility of biological monitoring for detection of timber harvest effects on streams and evaluation of Best Management Practices: A review. Journal of the North American Benthological Society. 23(3): 634–646. https://doi.org/10.1899/0887-3593(2004)023<0634:UOBMFD>2.0.CO;2.

Frans, L.M.; Rupert, M.G.; Hunt Jr., C.D.; [et al.]. 2012. Groundwater quality in the Columbia Plateau, Snake River Plain, and Oahu basaltic-rock and basin-fill aquifers in the Northwestern United States and Hawaii, 1992-2010. Scientific Investigations Report 2012-5123. Reston, VA: U.S. Department of the Interior, Geological Survey. 98 p. https://doi.org/10.3133/sir20125123.

Frey, J.K. 2018. Beavers, livestock, and riparian synergies: Bringing small mammals into the picture. In: Johnson, R.R.; Carothers, S.W.; Finch, D.M.; [et al.], tech. eds. Riparian research and management: Past, present, future: Volume 1. Gen. Tech. Rep. RMRS-GTR-377. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 85-101. https://doi.org/10.2737/RMRS-GTR-377-CHAP6.

Frey, J.K.; Malaney, J.L. 2009. Decline of the meadow jumping mouse (*Zapus hudsonius luteus*) in two mountain ranges in New Mexico. The Southwestern Naturalist. 54(1): 31–44. https://doi.org/10.1894/MLK-07.1.

Fuller, M.R.; Leinenbach, P.; Detenbeck, N.E.; Labiosa, R.; Isaak, D.J. 2022. Riparian vegetation shade restoration and loss effects on recent and future stream temperatures. Restoration Ecology. 30(7): e13626. https://doi.org/10.1111/rec.13626.

Gannon, B.M.; Wei, Y.; Thompson, M.P.; Scott. J.H.; Short, K.C. 2022. System analysis of wildfire-water supply risk in Colorado, USA with Monte Carlo wildfire and rainfall simulation. Risk Analysis. 42(2): 406-424. https://doi.org/10.1111/risa.13762.

Gautam, M.R.; Chief, K.; Smith, W.J. 2013. Climate change in arid lands and Native American socioeconomic vulnerability: The case of the Pyramid Lake Paiute Tribe. Climate Change. 120: 585-599. https://doi.org/10.1007/s10584-013-0737-0.

Gibson, P.P.; Olden, J.D. 2014. Ecology, management, and conservation implications of North American beaver (*Castor canadensis*) in dryland streams. Aquatic Conservation: Marine and Freshwater Ecosystems. 24(3): 391–409. https://doi.org/10.1002/aqc.2432.

Godfrey, A.E. 1985. Karst hydrology of the south slope of the Uinta Mountains, Utah. In: Picard, M.D., ed. Geology and energy resources, Uinta Basin of Utah. Salt Lake City, UT: Utah Geological Association Guidebook: 277-294.

Graf, W.L. 1999. Dam nation: A geographic census of American dams and their large-scale hydrologic impacts. Water Resources Research. 35(4): 1305–1311. https://doi.org/10.1029/1999WR900016.

Green, D.M. 1998. Recreational impacts on erosion and runoff in a central Arizona riparian area. Journal of Soil and Water Conservation. 53(1): 38-42. https://www.jswconline.org/content/53/1/38. [Accessed 28 June 2024].

Green, M.S. 2015. Nevada: A history of the Silver State. Reno, NV: University of Nevada Press. 496 p.

Greenwood, M.; Fair, J.; Hanley, M.; [et al.]. 2018. Restoring Truckee meadows: Assessment and prioritization. A report by American Rivers submitted to the National Fish and Wildlife Foundation. 35 p.

Gregory, S.V.; Swanson, F.J.; McKee, W.A.; [et al.]. 1991. An ecosystem perspective of riparian zones. BioScience. 41(8): 540–551. https://doi.org/10.2307/1311607.

Griffin, E.R.; Perignon, M.C.; Friedman, J.M.; [et al.]. 2014. Effects of woody vegetation on overbank sand transport during a large flood, Rio Puerco, New Mexico. Geomorphology. 207: 30-50. https://doi.org/10.1016/j.geomorph.2013.10.025.

Griffith, G.E.; Omernik, J.M.; Smith, D.W.; [et al.]. 2016. Ecoregions of California (poster). Open-File Report 2016–1021. U.S. Department of the Interior, Geological Survey (map scale 1:1,100,000). https://doi.org/10.3133/ofr20161021.

Griffiths, R.E.; Anderson, D.E.; Springer, A.E. 2008. The morphology and hydrology of small spring-dominated channels. Geomorphology. 102(3-4): 511–521. https://doi.org/10.1016/j.geomorph.2008.05.038.

Gross, S.; Coppoletta, M. 2013. Historic range of variability for meadows in the Sierra Nevada and South Cascades. U.S. Department of Agriculture, Forest Service. 64 p. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5434345.pdf. [Accessed 24 June 2024].

Grudzinski, B.P.; Cummins, H.; Vang, T.K. 2019. Beaver canals and their environmental effects. Progress in Physical Geography: Earth and Environment. 44(2): 189-211. https://doi.org/10.1177/0309133319873116.

Gruell, G.E. 1980. Fire's influence on wildlife habitat on the Bridger-Teton National Forest, Wyoming. Volume 1: Photographic record and analysis. Research Paper INT-235. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 207 p.

Gurnell, A.M. 1998. The hydrogeomorphological effects of beaver dam-building activity. Progress in Physical Geography: Earth and Environment. 22(2): 167–189. https://doi.org/10.1177/030913339802200202.

Gurrieri, J.T. 2020. Rangeland water developments at springs: Best practices for design, rehabilitation, and restoration. Gen. Tech. Rep. RMRS-GTR-405. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 21 p. https://doi.org/10.2737/RMRS-GTR-405.

Hagen, E.M.; Sabo, J.L. 2014. Temporal variability in insectivorous bat activity along two desert streams with contrasting patterns of prey availability. Journal of Arid Environments. 102: 104–112. https://doi.org/10.1016/j.jaridenv.2013.11.016.

Hall, H.H. 1971. Ecology of a subalpine meadow of the Aquarius Plateau, Garfield and Wayne Counties, Utah. Salt Lake City: University of Utah. Dissertation.

Halofsky, J.E.; Peterson D.L.; Ho, J.J.; Little, N.J. Joyce, L.A., eds. 2018. Climate change vulnerability and adaptation in the Intermountain Region. Gen. Tech. Rep. RMRS-GTR-375. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Part 1. pp. 1-197. https://doi.org/10.2737/RMRS-GTR-375PART1.

Hamlet, A.F.; Mote, P.W.; Clark, M.P.; [et al.]. 2005. Effects of temperature and precipitation variability on snowpack trends in the Western United States. Journal of Climate. 18(21): 4545–4561. https://doi.org/10.1175/JCLI3538.1.

Hansen, P.L.; Pfister, R.D.; Boggs, K.; [et al.]. 1995. Classification and management of Montana's riparian and wetland sites. Missoula, MT: Montana Forest and Conservation Experiment Station, School of Forestry, The University of Montana.

Harrill, J.R.; Prudic, D.E. 1998. Aquifer systems in the Great Basin region of Nevada, Utah, and adjacent states - summary report. Professional Paper 1409-A. Denver, CO: U.S. Department of the Interior, Geological Survey. 75 p. https://doi.org/10.3133/pp1409A.

Harrington, M.R. 1927. A primitive Pueblo city in Nevada. American Anthropologist. 29(3): 262-277. https://www.jstor.org/stable/661149.

Hauer, F.R.; Hill, W.R. 2007. Temperature, light, and oxygen. In: Hauer, F.R.; Lamberti, G.A., eds. Methods in stream ecology. Second edition. Cambridge, MA: Academic Press: 103-117.

Hauer, F.R.; Locke, H.; Dreitz, V.J.; [et al.]. 2016. Gravel-bed river floodplains are the ecological nexus of glaciated mountain landscapes. Science Advances. 2(6): e1600026. https://doi.org/10.1126/sciadv.1600026.

Heath, R.C. 1983. Basic ground-water hydrology. Water-Supply Paper 2220. Reston, VA: U.S. Department of the Interior, Geological Survey. 86 p. https://doi.org/10.3133/wsp2220.

Heilweil, V.M.; Brooks, L.E. 2011. Conceptual model of the Great Basin carbonate and alluvial aquifer system. Scientific Investigations Report 2010-5193. Reston, VA: U.S. Department of the Interior, Geological Survey. 191 p. https://pubs.usgs.gov/sir/2010/5193/. [Accessed 24 June 2024].

Hem, J.D. 1985. Study and interpretation of the chemical characteristics of natural water. Water-Supply Paper 2254. Alexandria, VA: U.S. Department of the Interior, Geological Survey. 272 p. https://doi.org/10.3133/wsp2254.

Hershler, R.; Liu, H.P.; Howard, J. 2014. Springsnails: A new conservation focus in Western North America. BioScience. 64(8): 693-700. https://doi.org/10.1093/biosci/biu100.

Holechek, J.L.; Pieper, R.D.; Herbel, C.H. 2004. Range management: Principles and practices. Fifth edition. Upper Saddle River, NJ: Prentice Hall. 607 p.

Hollenbeck, J.P.; Ripple, W.J. 2008. Aspen snag dynamics, cavity-nesting birds, and trophic cascades in Yellowstone's Northern Range. Forest Ecology and Management. 255(3-4): 1095–1103. https://doi.org/10.1016/j.foreco.2007.10.016.

Horton, J.D.; San Juan, C.A.; Stoeser, D.B. 2017. The State Geologic Map Compilation (SGMC) geodatabase of the conterminous United States. Data Series 1052. Reston, VA: U.S. Department of the Interior, Geological Survey. 46 p. https://doi.org/10.3133/ds1052.

Horton, J.L.; Kolb, T.E.; Hart, S.C. 2001. Physiological response to groundwater depth varies among species and with river flow regulation. Ecological Applications. 11(4): 1046-1059. https://doi.org/10.1890/1051-0761(2001)011[1046:PRTGDV]2.0.CO;2.

Hough-Snee, N.; Roper, B.B.; Wheaton, J.M.; [et al.]. 2013. Riparian vegetation communities change rapidly following passive restoration at a northern Utah stream. Ecological Engineering. 58: 371–377. https://doi.org/10.1016/j.ecoleng.2013.07.042.

Hough-Snee, N.; Roper, B.B.; Wheaton, J.M.; [et al.]. 2015. Riparian vegetation communities of the American Pacific Northwest are tied to multi-scale environmental filters. River Research and Applications. 31(9): 1151-1165. https://doi.org/10.1002/rra.2815.

Howery, L.D. 2015. A brief history of how the Society for Range Management was founded. Rangelands. 37(1): 20–25. https://doi.org/10.1016/j.rala.2014.12.007.

Hulse, J.W. 2012. The Silver State: Nevada's heritage reinterpreted. Third edition. Reno, NV: University of Nevada Press. 392 p.

Hulse, J.W. 2017. A Great Basin mosaic: The cultures of rural Nevada. Reno, NV: University of Nevada Press. 175 p.

Humboldt-Toiyabe National Forest [HTNF]. 2008. Benefits to people: At a glance report. 4 p.

Humboldt-Toiyabe National Forest [HTNF]. 2011. Humboldt-Toiyabe National Forest climate change vulnerability report. 17 p.

Hunt, L.; Fair, J.; Dyste, J.; [et al.]. 2015. Restoring Walker meadows: Assessment and prioritization. A report by American Rivers to the National Fish and Wildlife Foundation. 30 p. http://climate.calcommons.org/sites/default/files/Walker%20Assessment%20Final.pdf. [Accessed 28 June 2024].

Hunt, L.; Fair, J.; Odland, M. 2018. Meadow restoration increases baseflow and groundwater storage in the Sierra Nevada Mountains of California. Journal of the American Water Resources Association. 54(5): 1127-1136. https://doi.org/10.1111/1752-1688.12675.

Huntington, J.M. 2010. Conceptual understanding and groundwater quality of the basin-fill aquifers in Eagle and Carson Valleys, Nevada. In: Thiros, S.A.; Bexfield, L.M.; Anning, D.W.; [et al.], eds. Conceptual understanding and groundwater quality of selected basin-fill aquifers in the Southwestern United States. Professional Paper 1781. Reston, VA: U.S. Department of the Interior, Geological Survey: 49-69. https://pubs.usgs.gov/pp/1781/pdf/pp1781_section4.pdf. [Accessed 28 June 2024].

Hurlburt, V. 1935. The Taylor Grazing Act. The Journal of Land & Public Utility Economics. 11(2): 203–206. https://doi.org/10.2307/3158670.

Huxman, T.E.; Wilcox, B.P.; Breshears, D.D.; [et al.]. 2005. Ecohydrological implications of woody plant encroachment. Ecology. 86(2): 308-319. https://doi.org/10.1890/03-0583.

Ice, G.G.; Neary, D.G.; Adams, P.W. 2004. Effects of wildfire on soils and watershed processes. Journal of Forestry. 102(6): 16–20. https://doi.org/10.1093/jof/102.6.16.

Inbar, M.; Tamir, M.; Wittenberg, L. 1998. Runoff and erosion processes after a forest fire in Mount Carmel, a Mediterranean area. Geomorphology. 24(1): 17–33. https://doi.org/10.1016/S0169-555X(97)00098-6.

Isaak, D.J.; Wenger, S.J.; Peterson, E.E.; [et al.]. 2017. The NorWeST summer stream temperature model and scenarios for the Western U.S.: A crowd-sourced database and new geospatial tools foster a user community and predict broad climate warming of rivers and streams. Water Resources Research. 53: 9181-9205. https://doi.org/10.1002/2017WR020969.

Jefferson, A.; Grant, G.; Rose, T. 2006. Influence of volcanic history on groundwater patterns on the west slope of the Oregon High Cascades. Water Resources Research. 42(12): W12411. https://doi.org/10.1029/2005WR004812.

Jelinek, L.J. 1999. “Property of every kind”: Ranching and farming during the Gold-Rush era. California History. 77(4): 233–249. https://doi.org/10.2307/25462516.

Jewett, D.G.; Lord, M.L.; Miller, J.R.; [et al.]. 2004. Geomorphic and hydrologic controls on surface and subsurface flow regimes in riparian meadow ecosystems. In: Chambers, J.C.; Miller, J.R., eds. Great Basin riparian ecosystems: Ecology, management, and restoration. Washington, D.C.: Island Press: 124-161.

Johansen, M.P.; Hakonson, T.E.; Breshears, D.D. 2001. Post-fire runoff and erosion from rainfall simulation: Contrasting forests with shrublands and grasslands. Hydrological Processes. 15(15): 2953–2965. https://doi.org/10.1002/hyp.384.

Johnson, G.L.; Weller, D.E. 1994. The status of the bull trout in Nevada. Final Report to the US Fish and Wildlife Service. Reno, NV: Nevada Division of Wildlife. 14 p.

Johnson, R.R.; Carothers, S.W.; Finch, D.M.; [et al.]. 2018. Riparian research and management: Past, present, future: Volume 1. Gen. Tech. Rep. RMRS-GTR-377. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 226 p. https://doi.org/10.2737/RMRS-GTR-377.

Johnston, C.A. 1991. Sediment and nutrient retention by freshwater wetlands: Effects on surface water quality. Critical Reviews in Environmental Control. 21(5–6): 491–565. https://doi.org/10.1080/10643389109388425.

Jones, J.A.; Swanson, F.J.; Wemple, B.C.; [et al.]. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology. 14(1): 76–85. https://doi.org/10.1046/j.1523-1739.2000.99083.x.

Junghans, K.; Springer, A.E.; Stevens, L.E.; [et al.]. 2016. Springs ecosystem distribution and density for improving stewardship. Freshwater Science. 35(4): 1330-1339. https://doi.org/10.1086/689182.

Junk, W.J.; Bayley, P.B.; Sparks, R.E. 1989. The flood pulse concept in river-floodplain systems. In: Dodge, Douglas P. Proceedings of the International Large River Symposium (LARS); Honey Harbour, Ontario, Canada; September 14-21, 1986. Canadian Special Publication of Fisheries and Aquatic Sciences. 106: 110-127. https://publications.gc.ca/site/eng/9.816457/publication.html. [Accessed 28 June 2024].

Kattelmann, R. 2012. East Walker River watershed assessment. Bishop, CA: Eastern Sierra Land Trust. 177 p. http://inyo-monowater.org/wp-content/uploads/2011/09/E-Walker-Assessment-FINAL.pdf. [Accessed 28 June 2024].

Kattelmann, R.; Embury, M. 1996. Riparian areas and wetlands. In: Sierra Nevada ecosystem project: Final report to Congress, vol. III, assessments and scientific basis for management options. Davis, CA: University of California, Centers for Water and Wildland Resources.

Kendy, E.; Bredehoeft, J.D. 2006. Transient effects of groundwater pumping and surface-water-irrigation returns on streamflow. Water Resources Research. 42(8): W08415. https://doi.org/10.1029/2005WR004792.

Kidd, K.R.; Aust, W.M.; Copenheaver C.A. 2014. Recreational stream crossing effects on sediment delivery and macroinvertebrates in Southwestern Virginia, USA. Environmental Management. 54: 505-516. https://doi.org/10.1007/s00267-014-0328-5.

Kleindl, W.J.; Rains, M.C.; Marshall, L.A.; [et al.]. 2015. Fire and flood expand the floodplain shifting habitat mosaic concept. Freshwater Science. 34(4): 1366-1382. https://doi.org/10.1086/684016.

Kløve, B.; Ala-Aho, P.; Bertrand, G.; [et al.]. 2011. Groundwater dependent ecosystems. Part I: Hydroecological status and trends. Environmental Science & Policy. 14(7): 770-781. https://doi.org/10.1016/j.envsci.2011.04.002.

Kløve, B.; Ala-Aho, P.; Bertrand, G.; [et al.]. 2014. Climate change impacts on groundwater and dependent ecosystems. Journal of Hydrology. 518(B): 250-266. https://doi.org/10.1016/j.jhydrol.2013.06.037.

Knapp, R.A.; Matthews, K.R.; Preisler, H.K.; [et al.]. 2003. Developing probabilistic models to predict amphibian site occupancy in a patchy landscape. Ecological Applications. 13(4): 1069-1082. https://www.jstor.org/stable/4134743.

Kondolf, G.M. 1997. Hungry water: Effects of dams and gravel mining on river channels. Environmental Management. 21(4): 533–551. https://doi.org/10.1007/s002679900048.

Kreamer, D.K.; Stevens, L.E.; Ledbetter, J.D. 2015. Groundwater dependent ecosystems - science, challenges, and policy directions. In: Adelana, S.M., ed. Groundwater: Hydrogeochemistry, environmental impacts and management practices. Hauppauge, NY: Nova Science Publishers, Inc.: 205-230.

Krueper, D.J. 1993. Effects of land use practices on western riparian ecosystems. In: Finch, D.M.; Stangel, P.W., eds. Status and management of neotropical migratory birds: September 21-25, 1992, Estes Park, Colorado. Gen. Tech. Rep. RM-GTR-229. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 331–338. https://research.fs.usda.gov/treesearch/22916.

Krueper, D.J. 1996. Effects of livestock management on Southwestern riparian ecosystems. In: Shaw, D.W.; Finch, D.M. Desired future conditions for Southwestern riparian ecosystems: Bringing interests and concerns together. Gen. Tech. Rep. RM-GTR-272. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 281-301. https://research.fs.usda.gov/treesearch/35732.

Lambert, C.T.; Hall, L.K.; Larsen, R.T.; [et al.]. 2018. Temporal partitioning and the effects of climate change on two ecologically similar desert bats. Journal of Mammalogy. 99(6): 1486–1494. https://doi.org/10.1093/jmammal/gyy113.

LANDFIRE. Existing Vegetation Type layer. Page last modified: No date. U.S. Department of Interior, Geological Survey. http://landfire.cr.usgs.gov/viewer/. [Accessed 2022 September 27].

LaPointe, D.D.; Price, J.G. 2009. Digging deeper into the Comstock. Earth Science Week Field Trip. Nevada Bureau of Mines and Geology Education Series E-48. 14 p. http://epubs.nsla.nv.gov/statepubs/epubs/31428003119340.pdf. [Accessed 28 June 2024].

Larson-Praplan, S. 2014. History of rangeland management in California. Rangelands. 36(5): 11–17. https://doi.org/10.2111/Rangelands-D-14-00020.1.

Lemly, J.M.; Cooper, D.J. 2011. Multiscale factors control community and species distribution in mountain peatlands. Botany. 89(10): 689–713. https://doi.org/10.1139/b11-040.

Leonard, J.M.; Magaña, H.A.; Bangert, R.K.; Neary, D.G.; Montgomery, W.L. 2017. Fire and floods: the recovery of headwater stream systems following high-severity wildfire. Fire Ecology. 13: 62-84. https://doi.org/10.4996/fireecology.130306284.

Liang, C.T.; Stohlgren, T.J. 2011. Habitat suitability of patch types: A case study of the Yosemite toad. Frontiers of Earth Science. 5(2): 217-228. https://doi.org/10.1007/s11707-011-0157-2.

Lines, G.C. 1985. The ground-water system and possible effects of underground coal mining in the trail mountain area, Central Utah. Water-Supply Paper 2259. Alexandria, VA: U.S. Department of the Interior, Geological Survey. 38 p. https://doi.org/10.3133/wsp2259.

Loffland, H. 2019. Using birds to inform meadow restoration at Hope Valley West Meadow. Point Reyes Station, CA: The Institute for Bird Populations. 24 p. https://www.birdpop.org/docs/pubs/Loffland_2019_Using_Birds_to_Inform_Meadow_Restoration_at_Hope_Valley_West.pdf. [Accessed 28 June 2024].

Loomis, D.; Champion, S.; Gassaway, L.; [et al.]. 2007. East Carson River strategy. Carson Ranger District, Humboldt-Toiyabe National Forest, Alpine County, California and Douglas County, Nevada. Carson City, NV: U.S. Department of Agriculture, Forest Service. 43 p.

Lopes, T.J.; Allander, K.K. 2009. Water budgets of the Walker River Basin and Walker Lake, California and Nevada. Scientific Investigations Report 2009-5157. Reston, VA: U.S. Department of the Interior, Geological Survey. 44 p. https://doi.org/10.3133/sir20095157.

Lowry, M.M. 1993. Groundwater elevations and temperature adjacent to a beaver pond in central Oregon. Corvallis, OR: Oregon State University. Thesis. 134 p. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/tt44pq90d. [Accessed 28 June 2024].

Lytle, D.A.; Merritt, D.M. 2004. Hydrologic regimes and riparian forests: A structured population model for cottonwood. Ecological Society of America. 85(9): 2493-2503. https://doi.org/10.1890/04-0282.

Macfarlane, W.W.; Gilbert, J.T.; Jensen, M.L.; [et al.]. 2017. Riparian vegetation as an indicator of riparian condition: Detecting departures from historic condition across the North American West. Journal of Environmental Management. 202(2): 447–460. https://doi.org/10.1016/j.jenvman.2016.10.054.

Madsen, D.B. 2002. Great Basin peoples and late Quaternary aquatic history. In: Hershler, R.; Madsen, D.B.; Currey, D.R., eds. Great Basin aquatic systems history. Washington, D.C.: Smithsonian Institution Press: 387-405.

Magargal, K.E.; Parker, A.K.; Vernon, K.B.; [et al.]. 2017. The ecology of population dispersal: Modeling alternative basin-plateau foraging strategies to explain the Numic expansion. American Journal of Human Biology. 29(4): e23000. https://doi.org/10.1002/ajhb.23000.

Magee, T.K.; Kentula, M.E. 2005. Response of wetland plant species to hydrologic conditions. Wetlands Ecology and Management. 13: 163–181. https://doi.org/10.1007/s11273-004-6258-x.

Magilligan, F.J.; Nislow, K.H. 2005. Changes in hydrologic regime by dams. Geomorphology. 71(1–2): 61–78. https://doi.org/10.1016/j.geomorph.2004.08.017.

Makley, M.S. 2018. The small shall be strong: A history of Lake Tahoe's Washoe Indians. Amherst, MA: University of Massachusetts Press. 248 p.

Malesky, D.M.; Bentz, B.J.; Brown, G.R.; [et al.]. 2018. Effects of climate change on ecological disturbances. In: Halofsky, J.E.; Peterson, D.L.; Ho, J.J.; [et al.], eds. Climate change vulnerability and adaptation in the Intermountain Region part 2. Gen. Tech. Rep. RMRS-GTR-375. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 199-263. https://research.fs.usda.gov/treesearch/56118.

Manning, M.E.; Padgett, W.G. 1995. Riparian community type classification for Humboldt and Toiyabe National Forests, Nevada and eastern California. R4-Ecol-95-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 306 p.

Marshall, K.N.; Hobbs, N.T.; Cooper, D.J. 2013. Stream hydrology limits recovery of riparian ecosystems after wolf reintroduction. Proceedings of the Royal Society B. 280 (1756): 20122977. https://doi.org/10.1098/rspb.2012.2977.

Maurer, D.K.; Lopes, T.J.; Medina, R.L.; [et al.]. 2004. Hydrogeology and hydrologic landscape regions of Nevada. Scientific Investigations Report 2004–5131. Carson City, NV: U.S. Department of the Interior, Geological Survey. 41 p. https://doi.org/10.3133/sir20045131.

McBride, T. 2002. Exploration and early settlement in Nevada. Carson City, NV: Nevada State Historic Preservation Office. 42 p. https://shpo.nv.gov/uploads/documents/McBride_-_Exploration_and_Early_Settlement_in_NV,_2002,_NVSHPO.pdf. [Accessed 28 June 2024].

McGwire, K.C. 2019. Optimized stratification for mapping riparian vegetation in arid and semiarid environments. Remote Sensing. 11(14): 1638. https://doi.org/10.3390/rs11141638.

McKelvey, K.S.; Kallstrom, C.; Ledbetter, J.; Sada, D.W.; Pilgrim, K.L.; Schwartz M.K. 2020. An inventory of springsnails (*Pyrgulopsis* spp.) in and adjacent to the Spring Mountains, Nevada. Western North American Naturalist. 80: 183-193. https://scholarsarchive.byu.edu/wnan/vol80/iss2/6. [Accessed 28 June 2024].

McNeil, M.E.; Frederick, J.; Whalen, B. 1997. Jarbidge River watershed analysis. Jarbidge Ranger District, Humboldt-Toiyabe National Forest. U.S. Department of Agriculture, Forest Service. 52 p.

Medin, D.E.; Clary, W.P. 1990. Bird populations in and adjacent to a beaver pond ecosystem in Idaho. Research Paper INT-432. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 6 p.

Medin, D.E.; Clary, W.P. 1991. Small mammals of a beaver pond ecosystem and adjacent riparian habitat in Idaho. Research Paper INT-445. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 10 p.

Menlove, J.; Shaw, J.D.; Witt, C.; [et al.]. 2016. Nevada's forest resources, 2004-2013. Resour. Bull. RMRS-RB-22. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 167 p. https://doi.org/10.2737/RMRS-RB-22.

Mesner, N.; Geiger, J. 2005. Dissolved Oxygen. Logan, UT: Utah State University. 3 p. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=2249&context=extension_curall. [Accessed 28 June 2024].

Miller, J.; Germanoski, D.; Waltman, K.; [et al.]. 2001. Influence of late Holocene hillslope processes and landforms on modern channel dynamics in upland watersheds of central Nevada. Geomorphology. 38(3-4): 373-391. https://doi.org/10.1016/S0169-555X(00)00106-9.

Miller, R.F.; Chambers, J.C.; Pyke, D.A.; [et al.]. 2013. A review of fire effects on vegetation and soils in the Great Basin region: Response and ecological site characteristics. Gen. Tech. Rep. RMRS-GTR-308. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 126 p. https://doi.org/10.2737/RMRS-GTR-308.

Mills, J.P.; Huntoon, P. 1989. Foreland structure and karstic groundwater circulation in the eastern Gros Ventre Range, Wyoming. WWRC-89-02. Research Project Technical Completion Report G-1600, Project Number 02. Laramie, WY: University of Wyoming; U.S. Department of the Interior, Geological Survey. 101 p.

Minshall, G.W.; Jensen, S.E.; Platts, W.S. 1989. The ecology of stream and riparian habitats of the Great Basin region: A community profile. Biological Report 85(7.24). Washington, D.C.: U.S. Department of the Interior, Fish and Wildlife Service. 142 p.

Mitchell, J.E. 2000. Rangeland resource trends in the United States: A technical document supporting the 2000 USDA Forest Service RPA Assessment. Gen. Tech. Rep. RMRS-GTR-68. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 84 p. https://doi.org/10.2737/RMRS-GTR-68.

Montgomery, D.R.; Collins, B.D.; Buffington, J.M.; [et al.]. 2003. Geomorphic effects of wood in rivers. In: Gregory, S.V.; Boyer, K.L.; Gurnell, A.M., eds. The ecology and management of wood in world rivers. Bethesda, MD: American Fisheries Society: 21-47. https://doi.org/10.47886/9781888569568.ch2.

Moore, K.M.S.; Gregory, S.V. 1988. Response of young-of-the-year cutthroat trout to manipulation of habitat structure in a small stream. Transactions of the American Fisheries Society. 117: 162-170. https://doi.org/10.1577/1548-8659(1988)117<0162:ROYOTY>2.3.CO;2

Morris, T.H.; Stubben, M.A. 1994. Geologic contrasts of the Great Basin and Colorado Plateau. In: Harper, K.T.; St. Clair L.L.; Thorne, K.H.; [et al.], eds. 1994. Natural history of the Colorado Plateau and Great Basin. Niwot, CO: University Press of Colorado: 9-26.

Morton, M.L.; Pereyra, M.E. 2010. Habitat use by Yosemite toads: Life history traits and implications for conservation. Herpetological Conservation and Biology. 5(3): 388-394. https://www.herpconbio.org/Volume_5/Issue_3/Morton_Pereyra_2010.pdf. [Accessed 28 June 2024].

Mosley, L.M. 2015. Drought impacts on the water quality of freshwater systems; review and integration. Earth-Science Reviews. 140: 203–214. https://doi.org/10.1016/j.earscirev.2014.11.010.

Murray, B.R.; Hose, G.C.; Eamus D.; [et al.]. 2006. Valuation of groundwater-dependent ecosystems: A functional methodology incorporating ecosystem services. Australian Journal of Botany. 54(2): 221–229. https://doi.org/10.1071/BT05018.

Naiman, R.J.; Johnston, C.A.; Kelley, J.C. 1988. Alteration of North American streams by beaver: The structure and dynamics of streams are changing as beaver recolonize their historic habitat. BioScience. 38(11): 753–762. https://doi.org/10.2307/1310784.

Native Land Digital. Page last modified: No date. World Press. https://native-land.ca/. [Accessed 2022 September 27].

Natural Resources Conservation Service, USDA. 2016. Grazing management and soil health. MT 02/16. 12 p. https://www.nrcs.usda.gov/sites/default/files/2022-09/Grazing%20Management_SoilHealth_0.pdf. [Accessed 28 June 2024].

NatureServe. 2018. International ecological classification standard: Terrestrial ecological classifications. NatureServe Central Databases. Arlington, VA. 685 p.

NatureServe. 2020. NatureServe Network Biodiversity Location Data accessed through NatureServe Explorer [web application]. NatureServe, Arlington, Virginia. Available https://explorer.natureserve.org/. [Accessed: 1 June 2020].

Naumburg, E.; Mata-Gonzalez, R.; Hunter, R.G.; [et al.]. 2005. Phreatophytic vegetation and groundwater fluctuations: A review of current research and application of ecosystem response modeling with an emphasis on Great Basin vegetation. Environmental Management. 35(6): 726–740. https://doi.org/10.1007/s00267-004-0194-7.

Navarro, M.C.; Pérez-Sirvent, C.; Martínez-Sánchez, M.J.; [et al.]. 2008. Abandoned mine sites as a source of contamination by heavy metals: A case study in a semi-arid zone. Journal of Geochemical Exploration. 96(2-3): 183-193. https://doi.org/10.1016/j.gexplo.2007.04.011.

Neary, D.G.; Gottfried, G.J.; Ffolliott, P.F. 2003. Post-wildfire watershed flood responses. Second International Wildland Fire Ecology and Fire Management Congress; 2003 November 16-20; Orlando, FL. 8 p. https://ams.confex.com/ams/pdfpapers/65982.pdf. [Accessed 28 June 2024].

Nevada Department of Transportation. 2017. Stormwater quality manuals; construction site best management practices (BMPs) manual. Carson City, NV: Nevada Department of Transportation. 255 p. https://www.dot.nv.gov/home/showpublisheddocument/9417/636475468364870000. [Accessed 28 June 2024].

Nevada Rangeland Management and Grazing. Page last modified: No date. Washington, D.C.: Department of the Interior. https://www.blm.gov/programs/natural-resources/rangeland-and-grazing/rangeland-health/nevada. [Accessed 2022 September 27].

Newcombe, C.P.; Macdonald, D.D. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management. 11(1): 72-82. https://doi.org/10.1577/1548-8675(1991)011<0072:EOSSOA>2.3.CO;2.

Ngole-Jeme, V.M.; Fantke, P. 2017. Ecological and human health risks associated with abandoned gold mine tailings contaminated soil. PLoS ONE. 12(2): e0172517. https://doi.org/10.1371/journal.pone.0172517.

Olechnowski, B.F.M.; Debinski, D.M. 2008. Response of songbirds to riparian willow habitat structure in the Greater Yellowstone ecosystem. The Wilson Journal of Ornithology. 120(4): 830-839. https://doi.org/10.1676/07-132.1.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers. 77(1): 118–125. https://doi.org/10.1111/j.1467-8306.1987.tb00149.x.

Ostoja, S.M.; Brooks, M.L.; Chambers, J.C.; Pendleton, B.K. 2013. Species of conservation concern and environmental stressors: Local, regional, and global effects [Chapter 6] (Executive Summary). In: Chambers, J.C.; Brooks, M.L.; Pendleton, B.K.; Raish, C.B., eds. The Southern Nevada Agency Partnership Science and Research Synthesis: Science to support land management in Southern Nevada – Executive Summary. Gen. Tech. Rep. RMRS-GTR-304. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. P. 35-39. https://research.fs.usda.gov/treesearch/44314.

Overton, C.K.; Chandler, G.L.; Pisano, J.A. 1994. Northern/Intermountain Regions' fish habitat inventory: Grazed, rested, and ungrazed reference stream reaches, Silver King Creek, California. Gen. Tech. Rep. INT-GTR-311. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 27 p. https://doi.org/10.2737/INT-GTR-311.

Padgett, W.G.; Youngblood, A.P.; Winward, A.H. 1989. Riparian community type classification of Utah and southeastern Idaho. R4-Ecol-89-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 191 p.

Parks, forests, and public property. Title 36. Chapter 2: Forest Service, Department of Agriculture. Planning. Part 219, (2012).

Parsons, D.J.; DeBenedetti, S.H. 1979. Impact of fire suppression on a mixed-conifer forest. Forest Ecology and Management. 2: 21–33. https://doi.org/10.1016/0378-1127(79)90034-3.

Patterson, L.; Cooper, D.J. 2007. The use of hydrologic and ecological indicators for the restoration of drainage ditches and water diversions in a mountain fen, Cascade Range, California. Wetlands. 27(2): 290-304. https://doi.org/10.1672/0277-5212(2007)27[290:TUOHAE]2.0.CO;2.

Pendleton, B.K.; Chambers, J.C.; Brooks, M.L.; Ostoja, S.M. 2013. Ecosystem stressors in southern Nevada [Chapter 2] (Executive Summary). In: Chambers, J.C.; Brooks, M.L.; Pendleton, B.K.; Raish, C.B. eds. The Southern Nevada Agency partnership Science and Research Synthesis: Science to support land management in Southern Nevada – Executive Summary. Gen. Tech. Rep. RMRS-GTR-304. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. P. 9-13. https://research.fs.usda.gov/treesearch/44310.

Pickering, C.M.; Hill, W.; Newsome, D.; [et al.]. 2010. Comparing hiking, mountain biking and horse riding impacts on vegetation and soils in Australia and the United States of America. Journal of Environmental Management. 91(3): 551–562. https://doi.org/10.1016/j.jenvman.2009.09.025.

Planert, M.; Williams, J.S. 1995. Ground water atlas of the United States. Hydrologic Investigations Atlas 730-B. Reston, VA: U.S. Department of the Interior, Geological Survey. 30 p. https://doi.org/10.3133/ha730B.

Platts, W.S.; Nelson, R.L. 1989. Characteristics of riparian plant communities and streambanks with respect to grazing in northeastern Utah. In: Gresswell, R.E.; Barton, B.A.; Kershner, J.L., eds. Practical approaches to riparian resource management. An educational workshop. 1989 May 8-11. Billings, MT: U.S. Bureau of Land Management: 73-81.

Plume, R.W. 1996. Hydrogeologic framework of the Great Basin region of Nevada, Utah, and adjacent states. Professional Paper 1409-B. Washington, D.C.: U.S. Department of the Interior, Geological Survey. 78 p. https://doi.org/10.3133/pp1409B.

Plume, R.W. 2005. Changes in ground-water levels in the Carlin Trend area, north-central Nevada, 1989-2003. Scientific Investigations Report 2005-5075. Carson City, NV: U.S. Department of the Interior, Geological Survey. 21 p. https://doi.org/10.3133/sir20055075.

Poff, N.L.; Allan, J.D.; Bain, M.B.; [et al.]. 1997. The natural flow regime. BioScience. 47(11): 769-784. https://doi.org/10.2307/1313099.

Pollock, M.M.; Beechie, T.J.; Wheaton, J.M.; [et al.]. 2014. Using beaver dams to restore incised stream ecosystems. BioScience. 64(4): 279-290. https://doi.org/10.1093/biosci/biu036.

Poole, G.C.; Berman, C.H. 2001. An ecological perspective on in-stream temperature: Natural heat dynamics and mechanisms of human-caused thermal degradation. Environmental Management. 27(6): 787–802. https://doi.org/10.1007/s002670010188.

Potyondy, J.P.; Geier, T.W. 2011. Watershed condition classification technical guide. FS-978. Washington, D.C.: United States Department of Agriculture, Forest Service. 49 p. https://www.fs.usda.gov/biology/resources/pubs/watershed/maps/watershed_classification_guide2011FS978.pdf. [Accessed 28 June 2024].

Powers, P.D.; Helstab, M.; Niezgoda, S.L. 2019. A process-based approach to restoring depositional river valleys to Stage 0, an anastomosing channel network. River Research and Applications. 35(1): 3-13. https://doi.org/10.1002/rra.3378.

Price, J.G. 2011. Overview. In: The Nevada mineral industry 2010. Nevada Bureau of Mines and Geology Special Publication MI-2010. Reno, NV: University of Nevada: 3-19.

Rashin, E.B.; Clishe, C.J.; Loch, A.T.; [et al.]. 2007. Effectiveness of timber harvest practices for controlling sediment related water quality impacts. Journal of the American Water Resources Association. 42(5): 1307–1327. https://doi.org/10.1111/j.1752-1688.2006.tb05303.x.

Reed, C.C.; Merrill, A.G.; Drew, W.M.; [et al.]. 2020. Montane meadows: A soil carbon sink or source? Ecosystems. 24: 1125-1141. https://doi.org/10.1007/s10021-020-00572-x.

Reid, L.M.; Dunne, T. 1984. Sediment production from forest road surfaces. Water Resources Research. 20(11): 1753–1761. https://doi.org/10.1029/WR020i011p01753.

Rhoades, C.C.; Chow, A.T.; Covino, T.P.; Fegel, T.S.; Pierson, D.N.; Rhea A.E. 2019. The legacy of a severe wildfire on stream nitrogen and carbon in headwater catchments. Ecosystems. 22: 643-657. https://doi.org/10.1007/s10021-018-0293-6.

Richards, C.; Bacon, K.L. 1994. Influence of fine sediment on macroinvertebrate colonization of surface and hyporheic stream substrates. The Great Basin Naturalist. 54(2): 106-113. https://scholarsarchive.byu.edu/gbn/vol54/iss2/2. [Accessed 28 June 2024].

Richardson, D.M.; Holmes, P.M.; Esler, K.J.; [et al.]. 2007. Riparian vegetation: Degradation, alien plant invasions, and restoration prospects. Diversity and Distributions. 13(1): 126-139. https://doi.org/10.1111/j.1366-9516.2006.00314.x.

Rickart, E.A.; Bienek, K.G.; Rowe, R.J. 2013. Impact of livestock grazing on plant and small mammal communities in the Ruby Mountains, northeastern Nevada. Western North American Naturalist. 73(4): 505-515. https://doi.org/10.3398/064.073.0403.

Riley, K.L.; Williams, A.P.; Urbanski, S.P.; Calkin, D.E.; Short, K.C.; O'Connor, C.D. 2019. Will landscape fire increase in the future? A systems approach to climate, fire, fuel, and human drivers. Current Pollution Reports. 5: 9-24. https://doi.org/10.1007/s40726-019-0103-6.

Rind, D.; Goldberg, R.; Hansen, J.; [et al.]. 1990. Potential evapotranspiration and the likelihood of future drought. Journal of Geophysical Research: Atmospheres. 95(D7): 9983–10004. https://doi.org/10.1029/JD095iD07p09983.

Robinson, M.; Donovan, M.P.; Schwaner, T.D. 1998. Western toad, *Bufo boreas*, in southern Utah: Notes on a single population along the East Fork of the Sevier River. The Great Basin Naturalist. 58(1): 87-89. https://scholarsarchive.byu.edu/gbn/vol58/iss1/10. [Accessed 28 June 2024].

Roche, L.M.; Allen-Diaz, B.; Eastburn, D.J.; [et al.]. 2012. Cattle grazing and Yosemite toad (*Bufo canorus* Camp) breeding habitat in Sierra Nevada meadows. Rangeland Ecology & Management. 65(1): 56-65. https://doi.org/10.2111/REM-D-11-00092.1.

Rogers, D.S.; Belk, M.C.; González, M.W.; [et al.]. 2006. Patterns of habitat use by bats along a riparian corridor in northern Utah. The Southwestern Naturalist. 51(1): 52-58. https://scholarsarchive.byu.edu/facpub/5456. [Accessed 28 June 2024].

Rood, S.B.; Gourley, C.R.; Ammon, E.M.; [et al.]. 2003. Flows for floodplain forests: A successful riparian restoration. BioScience. 53(7): 647-656. https://doi.org/10.1641/0006-3568(2003)053[0647:FFFFAS]2.0.CO;2.

Rust, A.J.; Saxe, S.; McCray, J.; Rhoades, C.C.; Hogue, T.S. 2019. Evaluating the factors responsible for post-fire water quality response in forests of the Western USA. International Journal of Wildland Fire. 28: 769-784. https://doi.org/10.1071/WF18191.

Ryan, S. Dwire. K. 2012. Wildfire impacts on stream sedimentation: Re-visiting the Boulder Creek Burn in Little Granite Creek, Wyoming, USA. In: Stone, M.; Collins, A.; Thoms, Martin, eds. Wildfire and Water Quality: Processes, Impacts and Challenges (Proceedings of a conference held in Banff, Canada, 1114 June 2012). IAHS Publ. 354. International Association of Hydrological Sciences. P. 75-80. https://iahs.info/uploads/dms/16024.13-75-80-354-06-Ryan_-Dwire_Comments.pdf. [Accessed 28 June 2024].

Saab, V.A.; Vierling, K.T. 2001. Reproductive success of Lewis's woodpecker in burned pine and cottonwood riparian forests. The Condor. 103(3): 491-501. https://doi.org/10.1093/condor/103.3.491.

Sada, D.W.; Fleishman, E.; Murphy, D.D. 2005. Associations among spring-dependent aquatic assemblages and environmental and land use gradients in a Mojave Desert mountain range. Diversity and Distributions. 11(1): 91-99. https://doi.org/10.1111/j.1366-9516.2005.00131.x.

Sada, D.W.; Pohlmann, K.F. 2006. U.S. National Park Service Mojave inventory and monitoring network spring survey protocols: Level I and level II. Reno, NV: Desert Research Institute. 95 p.

Sada, D.W.; Williams, J.E.; Silvey, J.C.; [et al.]. 2001. A guide to managing, restoring, and conserving springs in the Western United States. Technical Reference 1737-17. Denver, CO: U.S. Department of Interior, Bureau of Land Management. 70 p. https://digitalcommons.usu.edu/govdocs/252.

Safeeq, M.; Hunsaker, C.T. 2016. Characterizing runoff and water yield for headwater catchments in the southern Sierra Nevada. Journal of the American Water Resources Association. 52(6): 1327-1346. https://doi.org/10.1111/1752-1688.12457.

Saglam, I.K.; Prince, D.J.; Meek, M.; [et al.]. 2017. Genomic analysis reveals genetic distinctiveness of the Paiute cutthroat trout *Oncorhynchus clarkii seleniris*. Transactions of the American Fisheries Society. 146(6): 1291-1302. https://doi.org/10.1080/00028487.2017.1356373.

Salo, J.A.; Theobald, D.M. 2016. A multi-scale, hierarchical model to map riparian zones. River Research and Applications. 32(8): 1709-1720. https://doi.org/10.1002/rra.3019.

Sánchez, E.; Colmenarejo, M.F.; Vicente, J.; [et al.]. 2007. Use of the water quality index and dissolved oxygen deficit as simple indicators of watersheds pollution. Ecological Indicators. 7(2): 315–328. https://doi.org/10.1016/j.ecolind.2006.02.005.

Sanchez-Garcia, C.; Santin, C.; Neris, J.; Sigmund, G.; Otero, X.L.; Manley, J.; Gonzalex-Rodriguez, G.; Belcher, C.M.; Cerda, A.; Marcotte, A.L.; Murphy, S.F.; Rhoades, C.C.; Sheridan, G.; Strydom, T.; Robichaud, P.R.; Doerr. S.H. 2023. Chemical characteristics of wildfire as across the globe and their environmental and socio-economic implications. Environment International. 178: 108065. https://doi.org/10.1016/j.envint.2023.108065.

Schimelpfenig, D.W.; Cooper, D.J.; Chimner, R.A. 2014. Effectiveness of ditch blockage for restoring hydrologic and soil processes in mountain peatlands. Restoration Ecology. 22(2): 257-265. https://doi.org/10.1111/rec.12053.

Schoennagel, T.; Veblen, T.T.; Romme, W.H. 2004. The interaction of fire, fuels, and climate across Rocky Mountain forests. BioScience. 54(7): 661-676. https://doi.org/10.1641/0006-3568(2004)054[0661:TIOFFA]2.0.CO;2.

Shafroth, P.B.; Stromberg, J.C.; Patten, D.T. 2000. Woody riparian vegetation response to different alluvial water table regimes. Western North American Naturalist. 60(1): 66-76. https://scholarsarchive.byu.edu/wnan/vol60/iss1/6. [Accessed 28 June 2024].

Shakesby, R.A.; Doerr, S.H. 2006. Wildfire as a hydrological and geomorphological agent. Earth-Science Reviews. 74(3–4): 269–307. https://doi.org/10.1016/j.earscirev.2005.10.006.

Sikes, K.; Cooper, D.; Weis, S.; [et al.]. 2013. Fen conservation and vegetation assessment in the National Forests of the Sierra Nevada and adjacent mountains, California. Vallejo, CA: U.S. Department of Agriculture, Forest Service. 314 p. https://www.cnps.org/wp-content/uploads/2019/01/veg-fen-sierra-nev-2013.pdf. [Accessed 28 June 2024].

Singer, F.J.; Mark, L.C.; Cates, R.C. 1994. Ungulate herbivory of willows on Yellowstone's northern winter range. Journal of Range Management. 47: 435-443. https://doi.org/10.2307/4002993.

Smith, D.M.; Finch, D.M. 2014. Use of native and nonnative nest plants by riparian-nesting birds along two streams in New Mexico. River Research and Applications. 30(9): 1134-1145. https://doi.org/10.1002/rra.2713.

Smith, D.M.; Finch, D.M. 2017. Climate change and wildfire effects in aridland riparian ecosystems: An examination of current and future conditions. Gen. Tech. Rep. RMRS-GTR-364. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 65 p. https://doi.org/10.2737/RMRS-GTR-364.

Smith, D.M.; Finch, D.M.; Gunning, C.; [et al.]. 2009. Post-wildfire recovery of riparian vegetation during a period of water scarcity in the Southwestern USA. Fire Ecology. 5(1): 38-55. https://doi.org/10.4996/fireecology.0501038.

Smith, G.; Lemly, J. 2019. Fen mapping for the Humboldt-Toiyabe National Forest. Fort Collins, CO: Colorado Natural Heritage Program, Colorado State University. 39 p.

Smith, S.D.; Devitt, D.A.; Sala, A.; [et al.]. 1998. Water relations of riparian plants from warm desert regions. Wetlands. 18(4): 687-696. https://doi.org/10.1007/BF03161683.

Smith, V.H.; Tilman, G.D.; Nekola, J.C. 1999. Eutrophication: Impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environmental Pollution. 100(1-3): 179–196. https://doi.org/10.1016/S0269-7491(99)00091-3.

Solem, S.J.; Pendleton, B.K.; Giffen, C.; Coles-Ritchie, M.; Ledbetter, J.; McKelvey, K.S.; Berg, J.; Menlove, J.; Woodlief, C.K.; Boehnke, L.A. 2013. Final Program Report for 2010-2012: Monitoring and evaluation for conserving biological resources of the Spring Mountains National Recreation Area. El Paso, TX: Management and Engineering Technologies International, Inc.; Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Grassland, Desert, and Shrubland Program. 184 p. https://research.fs.usda.gov/treesearch/44827. [Accessed 28 June 2024].

Sophocleous, M. 2002. Interactions between groundwater and surface water: The state of the science. Hydrogeology Journal. 10(1): 52–67. https://doi.org/10.1007/s10040-002-0204-x.

Spence, A.; Poortinga, W.; Pidgeon, N. 2012. The psychological distance of climate change. Risk Analysis. 32(6): 957-972. https://doi.org/10.1111/risa.13683.

Spencer, C.N.; Gabel, K.O.; Hauer, F.R. 2003. Wildfire effects on stream food webs and nutrient dynamics in Glacier National Park, USA. Forest Ecology and Management. 178(1–2): 141–153. https://doi.org/10.1016/S0378-1127(03)00058-6.

Spoon, J.; Arnold, R. 2009. Nuwuvi participatory consultation Draft Environmental Impact Statement (DEIS) Middle Kyle Complex, Spring Mountains National Recreation Area, Humboldt-Toiyabe National Forest, Nevada. Portland, OR: The Mountain Institute and Portland State University. 45 p.

Spoon, J.; Arnold, R.; Lefler, B.J.; [et al.]. 2015. Nuwuvi (Southern Paiute), shifting fire regimes, and the Carpenter One Fire in the Spring Mountains National Recreation Area, Nevada. Journal of Ethnobiology. 35(1): 85-110. https://doi.org/10.2993/0278-0771-35.1.85.

Springer, A.E.; Stevens, L.E. 2009. Spheres of discharge of springs. Hydrogeology Journal. 17(1): 83-94. https://doi.org/10.1007/s10040-008-0341-y.

Springs Stewardship Institute. Page last modified: No date. Flagstaff, AZ: Springs Stewardship Institute. https://springstewardshipinstitute.org/springs-dependent-species-2. [Accessed 2022 September 27].

Springsnail Conservation Team. 2017. Conservation agreement for springsnails in Nevada and Utah. 28 p.

Stanford, J.A.; Lorang, M.S.; Hauer, F.R. 2005. The shifting habitat mosaic of river ecosystems. SIL Proceedings, 1922-2010. 29(1): 123–136. https://doi.org/10.1080/03680770.2005.11901979.

Stanford, J.A.; Ward, J.V. 1988. The hyporheic habitat of river ecosystems. Nature. 335: 64–66. https://doi.org/10.1038/335064a0.

Stanford, J.A.; Ward, J.V. 1993. An ecosystem perspective of alluvial rivers: Connectivity and the hyporheic corridor. Journal of the North American Benthological Society. 12(1): 48-60. https://doi.org/10.2307/1467685.

Stevens, L.E.; Meretsky, V.J., eds. 2008. Aridland springs in North America. Tucson, AZ: University of Arizona Press. 430 p.

Stewart, G. 1936. History of range use. In: Wallace, H.A.; Silcox, F.A., eds. The Western Range. Washington, D.C.: U.S. Government Printing Office: 119–133.

Stromberg, J.C. 2001. Influence of stream flow regime and temperature on growth rate of the riparian tree, *Platanus wrightii*, in Arizona. Freshwater Biology. 46(2): 227–239. https://doi.org/10.1046/j.1365-2427.2001.00651.x.

Stromberg, J.C.; Merritt, D.M. 2016. Riparian plant guilds of ephemeral, intermittent and perennial rivers. Freshwater Biology. 61(8): 1259-1275. https://doi.org/10.1111/fwb.12686.

The Forest Reserve Act of 1891. Pub. L. 51-561. 26 Stat. 1095, (March 3, 1891).

The Homestead Act of 1862. Pub. L. 37-64. 12 Stat. 392, (May 20, 1862).

The Taylor Grazing Act of 1934. Pub. L. 73-482. 48 Stat. 1269, (June 28, 1934).

Thurow, T.L. 1991. Hydrology and erosion. In: Heitschmidt, R.K.; Stuth, J.W., eds. Grazing management: An ecological perspective. Portland, OR: Timber Press: 141-160.

Tribal Connections. Page last modified: No date. Washington, D.C.: U.S. Department of Agriculture, Forest Service. https://www.arcgis.com/apps/webappviewer/index.html?id=fe311f69cb1d43558227d73bc34f3a32. [Accessed 2022 September 27].

Trombulak, S.C.; Frissell, C.A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology. 14(1): 18–30. https://doi.org/10.1046/j.1523-1739.2000.99084.x.

Trowbridge, W.; Chambers, J.C.; Germanoski, D.; [et al.]. 2011. Characterization of meadow ecosystems based on watershed and valley segment/reach scale characteristics. In: Chambers, J. C.; Miller, J.R., eds. Geomorphology, hydrology, and ecology of Great Basin meadow complexes - implications for management and restoration. Gen. Tech. Rep. RMRS-GTR-258. Fort Collins, CO: U.S. Department of Agriculture, Forest Service: 95-112. https://research.fs.usda.gov/treesearch/38976. [Accessed 28 June 2024].

Tye, S.P.; Geluso, K. 2019. Day roosts of *Myotis* (Mammalia: Chiroptera) in an arid riparian corridor in southwestern New Mexico. Western North American Naturalist. 79(4): 515-522. https://scholarsarchive.byu.edu/wnan/vol79/iss4/5.

U.S. Forest Service [USFS]. 2007. Technical guide to managing ground water resources. FS-881. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 295 p. https://www.fs.usda.gov/biology/resources/pubs/watershed/groundwater/ground_water_technical_guide_fs-881_march2007.pdf. [Accessed 28 June 2024].

U.S. Forest Service [USFS]. 2012a. Groundwater-dependent ecosystems: Level I inventory field guide. Gen. Tech. Rep. GTR-WO-86a. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 201 p. https://www.fs.usda.gov/sites/default/files/gde-level-I-fg-final-june2022-rev2.pdf. [Accessed 28 June 2024].

U.S. Forest Service [USFS]. 2012b. Groundwater-dependent ecosystems: Level II inventory field guide. Gen. Tech. Rep. GTR-WO-86b. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 131 p. https://www.fs.usda.gov/geology/GDE_Level_II_FG_final_March2012_rev1_s.pdf. [Accessed 28 June 2024].

U.S. Forest Service [USFS]. 2015. Forest Service Manual 2880.5. Definitions - Geological resources, hazards, and services. In: USDA Forest Service [USFS]. Forest Service Manual (FSM) 2800 - Minerals and Geology. Chapter 2880: Geological resources, hazards, and services. Washington, D.C.: U.S. Department of Agriculture, Forest Service: National Headquarters, Washington Office.

U.S. Forest Service [USFS]. 2016. Resource planning guide, caves and karst resources prepared by minerals and geology management office of geological resources, hazards, and surface management. Washington, D.C.: U.S. Department of Agriculture, Forest Service.

U.S. Fish and Wildlife Service [FWS]. 2004. Revised recovery plan for the Paiute cutthroat trout (*Oncorhynchus clarki seleniris*). Portland, OR: U.S. Department of the Interior, Fish and Wildlife Service. 105 p. https://www.govinfo.gov/content/pkg/GOVPUB-I49-PURL-LPS61640/pdf/GOVPUB-I49-PURL-LPS61640.pdf. [Accessed 28 June 2024].

U.S. Fish and Wildlife Service [FWS]. 2015. Recovery plan for the coterminous United States population of bull trout (*Salvelinus confluentus*). Portland, OR: U.S. Department of the Interior, Fish and Wildlife Service. 198 p. https://ecos.fws.gov/docs/recovery_plan/Final_Bull_Trout_Recovery_Plan_092915-corrected.pdf. [Accessed 28 June 2024].

Unmack, P.J.; Minckley, W.L. 2008. The demise of desert springs. In: Stevens, L.E.; Meretsky, V.J., eds. Aridland springs in North America: Ecology and conservation. Tucson, AZ: University of Arizona Press: 11-34.

Van de Water, K.; North, M. 2010. Fire history of coniferous riparian forests in the Sierra Nevada. Forest Ecology and Management. 260(3): 384-395. https://doi.org/10.1016/j.foreco.2010.04.032.

Van de Water, K.; North, M. 2011. Stand structure, fuel loads, and fire behavior in riparian and upland forests, Sierra Nevada Mountains, USA; A comparison of current and reconstructed conditions. Forest Ecology and Management. 262(2): 215-228. https://doi.org/10.1016/j.foreco.2011.03.026.

Vander Laan, J.J. 2012. Environmental assessment of streams: Linking land use, instream stressors, and biological indices to infer likely causes of ecological impairment. Logan, UT: Utah State University. Thesis. 101 p. https://doi.org/10.26076/c855-8874.

Vannote, R.L.; Minshall, G.W.; Cummins, K.W.; [et al.]. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences. 37: 130-137. https://doi.org/10.1139/f80-017.

Varness, K.J.; Pacha, R.E.; Lapen, R.F. 1978. Effects of dispersed recreational activities on the microbiological quality of forest surface water. Applied and Environmental Microbiology. 36(1): 95-104. https://doi.org/10.1128/aem.36.1.95-104.1978.

Viers, J.H.; Purdy, S.E.; Peek, R.A.; [et al.]. 2013. Montane meadows in the Sierra Nevada: Changing hydroclimatic conditions and concepts for vulnerability assessment. Center for Watershed Sciences Technical Report CWS-2013-01. Davis, CA: University of California. 63 p. http://climate.calcommons.org/sites/default/files/CWSMeadowsVulnerabilityWhitePaper_2013-1-1_FinalReport_0.pdf. [Accessed 28 June 2024].

Wallace, H.A.; Silcox, F.A. 1936. The western range. Washington, D.C.: U.S. Government Printing Office. 620 p.

Ward, J.V.; Tockner, K.; Schiemer, F. 1999. Biodiversity of floodplain river ecosystems: Ecotones and connectivity. Regulated Rivers: Research and Management. 15(1-3): 125-139. https://doi.org/10.1002/(SICI)1099-1646(199901/06)15:1/3<125::AID-RRR523>3.0.CO;2-E.

Waring, G.L. 2011. A natural history of the Intermountain West: Its ecological and evolutionary story. Salt Lake City, Utah: University of Utah Press. 240 p.

Weber, N.; Bouwes, N.; Pollock, M.M.; [et al.]. 2017. Alteration of stream temperature by natural and artificial beaver dams. PLoS ONE. 12(5): e0176313. https://doi.org/10.1371/journal.pone.0176313.

Weiss, J.L.; Castro, C.L.; Overpeck, J.T. 2009. Distinguishing pronounced droughts in the Southwestern United States: Seasonality and effects of warmer temperatures. Journal of Climate. 22(22): 5918–5932. https://doi.org/10.1175/2009JCLI2905.1.

Weixelman, D.A.; Hill, B.; Cooper, D.J.; [et al.]. 2011. A field key to meadow hydrogeomorphic types for the Sierra Nevada and southern Cascade Ranges in California. Gen. Tech. Rep. R5-TP-034. Vallejo, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region. 34 p.

Weixelman, D.A.; Zamudio, D.C.; Zamudio, K.A. 1996. Central Nevada riparian field guide. Sparks, NV: U.S. Department of Agriculture, Forest Service, Intermountain Region. 270 p.

Weixelman, D.A.; Zamudio, D.C.; Zamudio, K.A. 1999. Eastern Sierra Nevada riparian field guide. U.S. Department of Agriculture, Forest Service. 121 p.

Weixelman, D.A.; Zamudio, D.C.; Zamudio, K.A.; [et al.]. 1997. Classifying ecological types and evaluating site degradation. Journal of Range Management. 50(3): 315-321. https://doi.org/10.2307/4003735.

Welch, A.H.; Bright, D.J.; Knochenmus, L.A., eds. 2007. Water resources of the basin and range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah. Scientific Investigations Report 2007–5261. Reston, VA: U.S. Department of the Interior, Geological Survey. 96 p. https://pubs.usgs.gov/sir/2007/5261/. [Accessed 28 June 2024].

Westbrook, C.J.; Cooper, D.J.; Baker, B.W. 2006. Beaver dams and overbank floods influence groundwater-surface water interactions of a Rocky Mountain riparian area. Water Resources Research. 42(6): W06404. https://doi.org/10.1029/2005WR004560.

Westbrook, C.J.; Cooper, D.J.; Baker, B.W. 2011. Beaver assisted river valley formation. River Research and Applications. 27(2): 247-256. https://doi.org/10.1002/rra.1359.

Whiting, P.J.; Moog, D.B. 2001. The geometric, sedimentologic and hydrologic attributes of spring-dominated channels in volcanic areas. Geomorphology. 39(3): 131–149. https://doi.org/10.1016/S0169-555X(00)00103-3.

Whiting, P.J.; Stamm, J. 1995. The hydrology and form of spring-dominated channels. Geomorphology. 12(3): 233-240. https://doi.org/10.1016/0169-555X(95)00006-Q.

Wilding, T.K.; Sanderson, J.S.; Merritt, D.M.; [et al.]. 2014. Riparian responses to reduced flood flows: Comparing and contrasting narrowleaf and broadleaf cottonwoods. Hydrological Sciences Journal. 59(3-4): 605-617. https://doi.org/10.1080/02626667.2014.880786.

Wildlife Action Plan Team [WAPT]. 2012. Nevada Wildlife Action Plan. Reno, NV: Nevada Department of Wildlife. 91 p. https://www.ndow.org/blog/nevada-wildlife-action-plan/#. [Accessed 28 June 2024].

Winograd, I.J.; Riggs, A.C.; Coplen, T.B. 1998. The relative contributions of summer and cool-season precipitation to groundwater recharge, Spring Mountains, Nevada, USA. Hydrogeology Journal. 6: 77-93. https://doi.org/10.1007/s100400050135.

Winship, G.P., ed. 1904. The journey of Coronado, 1540–1542. New York City, NY: A.S. Barnes & Company. 286 p.

Winter, T.C.; Harvey, J.W.; Franke, O.L.; [et al.]. 1998. Ground water and surface water a single resource. Circular 1139. Denver, CO: U.S. Department of the Interior, Geological Survey. 88 p. https://doi.org/10.3133/cir1139.

Winward, A.H. 2000. Monitoring the vegetation resources in riparian areas. Gen. Tech. Rep. RMRS-GTR-47. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49 p. https://doi.org/10.2737/RMRS-GTR-47.

Wohl, E. 2021. Legacy effects of loss of beavers in the continental United States. Environmental Research Letters. 16(2): 025010. https://doi.org/10.1088/1748-9326/abd34e.

Wohl, E.; Barros, A.; Brunsell, N.; [et al.]. 2012. The hydrology of the humid tropics. Nature Climate Change. 2: 655-662. https://doi.org/10.1038/nclimate1556.

Wohl, E.; Lininger, K.B.; Scott, D.N. 2018. River beads as a conceptual framework for building carbon storage and resilience to extreme climate events into river management. Biogeochemistry. 141: 365-383. https://doi.org/10.1007/s10533-017-0397-7.

Wolf, E.C.; Cooper, D.J. 2015. Fens of the Sierra Nevada, California, USA: Patterns of distribution and vegetation. Mires and Peat. 15: 1-22. http://www.mires-and-peat.net/pages/volumes/map15/map1508.php. [Accessed 28 June 2024].

Wolf, E.C.; Cooper, D.J.; Hobbs, N.T. 2007. Hydrologic regime and herbivory stabilize an alternative state in Yellowstone National Park. Ecological Applications. 17(6): 1572-1587. https://doi.org/10.1890/06-2042.1.

Wondzell, S.M.; Diabat, M.; Haggerty, R. 2019. What matters most: Are future stream temperatures more sensitive to changing air temperatures, discharge, or riparian vegetation? Journal of the American Water Resources Association. 55(1): 116-132. https://doi.org/10.1111/1752-1688.12707.

Wood, P.J.; Armitage, P.D. 1997. Biological effects of fine sediment in the lotic environment. Environmental Management. 21: 203–217. https://doi.org/10.1007/s002679900019.

Wood, S.H.; Wurts, C.; Lane, T.; [et al.]. 1985. The Borah Peak, Idaho earthquake of October 28, 1983-hydrologic effects. Earthquake Spectra. 2(1): 127-150. https://doi.org/10.1193/1.1585305.

Yarnell, S.M.; Peek, R.A.; Keung, N.; [et al.]. 2019. A lentic breeder in lotic waters: Sierra Nevada yellow-legged frog (*Rana sierrae*) habitat suitability in northern Sierra Nevada streams. Copeia. 107(4): 676-693. https://doi.org/10.1643/CH-19-213.

Young, J.A. 1994. Changes in plant communities in the Great Basin induced by domestic livestock grazing. In: Harper, K.T.; St. Clair, L.L.; Thorne, K.H.; [et al.], eds. Natural history of the Colorado Plateau and Great Basin. Denver, CO: University Press of Colorado: 113-124.

Youngblood, A.P.; Padgett, W.G.; Winward, A.H. 1985. Riparian community type classification of Eastern Idaho - Western Wyoming. R4-Ecol-85-01. U.S. Department of Agriculture, Forest Service, Intermountain Region. 78 p.

Zeier, C.; Picciani, J.; Waters, D.; [et al.]. 2004. Upper Carson River watershed stream corridor condition assessment. South Lake Tahoe, CA: Alpine Watershed Group. 188 p.

APPENDIX A. Data Used to Assess Riparian and Groundwater-dependent Ecosystems of the Humboldt-Toiyabe National Forest

Table A.1—Sources and description of datasets used to assess riparian and groundwater-dependent ecosystems of the Humboldt-Toiyabe National Forest.

Data	Source(s)	Explanation
Perennial stream miles	National Hydrography Dataset	Total length of stream segments with year-round surface flows
Intermittent stream miles	National Hydrography Dataset	Total length of stream segments with seasonal surface flows and accessible groundwater
Hydrogeology	USGS State Geological Maps Compilation	Bedrock and unconsolidated deposits classified for evaluation of groundwater dynamics.
US Forest Service existing vegetation shapefile (FS VEG)	Humboldt-Toiyabe National Forest Dataset	Existing vegetation classified by vegetation type
Map of Riparian Vegetation in Nevada (MARVN) shapefile	Ken McGwire, Desert Research Institute	Potential extent of riparian areas, identified using normalized difference vegetation index (NDVI)
LF Remap existing vegetation type raster	LANDFIRE	Existing vegetation classified by vegetation type
Spring density	Spring Stewardship Institute	Number of springs per acre, as mapped by the SSI
Acres of potential fens	Colorado Natural History Program	Amount of area covered by wetlands that are potentially fens
Historical Lahontan cutthroat trout miles	Humboldt-Toiyabe National Forest Dataset	Miles of streams inhabited by Lahontan cutthroat trout prior to Euro-American influences
Current Lahontan cutthroat trout miles	Humboldt-Toiyabe National Forest Dataset	Miles of streams currently inhabited by Lahontan cutthroat trout
Historical Paiute cutthroat trout miles	Humboldt-Toiyabe National Forest Dataset	Miles of streams inhabited by Paiute cutthroat trout prior to Euro-American influences
Current Paiute cutthroat trout miles	Humboldt-Toiyabe National Forest Dataset	Miles of streams currently inhabited by Paiute cutthroat trout
Current bull trout miles	Humboldt-Toiyabe National Forest Dataset	Miles of streams currently inhabited by bull trout
Greater sage-grouse priority areas for conservation	US Forest Service National Dataset	Areas identified for conservation of greater sage-grouse populations
Greater sage-grouse summer brood habitat	Humboldt-Toiyabe National Forest Dataset	Areas identified as important cover and forage sites for sage-grouse hens and their broods

Table A.1 continued.

Data	Source(s)	Explanation
Greater sage-grouse riparian foraging habitat	Humboldt-Toiyabe National Forest Dataset	Area of willow-, nonwillow shrub-, and herbaceous-dominated riparian zones within summer brood habitats
Road density	US Forest Service Terrestrial Condition Assessment	Road miles per acre of geographic unit
% of roads unimproved	US Forest Service Terrestrial Condition Assessment	Percentage of roads that are unpaved and non-graveled
Trail density	US Forest Service National Dataset	Recreation trail miles per acre
Floodplain road density	US Forest Service Terrestrial Condition Assessment, 50 Year Floodplain Map	Road miles per 50-year floodplain acre
Floodplain trail density	US Forest Service National Dataset, 50-year Floodplain Map	Trail miles per 50-year floodplain acre
Floodplain recreation Sites	US Forest Service National Dataset, 50 Year Floodplain Map	Number of recreation sites per 50-year floodplain acre
Diversion density	State of Nevada US Forest Service Water Rights and Uses Database	Number of water diversion points per acre
Dams per stream mile	State of Nevada US Forest Service Water Rights and Uses Database	Number of diversion or retention dams per acre
% unit RMU	US Forest Service National Dataset	Percentage of the area overlapping range management units (grazing leases)
% unit RMU active	US Forest Service National Dataset	Percentage of the area overlapping actively grazed range management units
% unit harvested	US Forest Service National Dataset	Percentage of the area with timber harvest
% harvests clearcut	US Forest Service National Dataset	Percentage of the area with timber harvest using clearcut methods
% high severity burn	US Forest Service Terrestrial Condition Assessment	Percentage of the area burned by high severity wildfires between 1984 and 2014
Winter temperature deviation	US Forest Service Terrestrial Condition Assessment	Percent change in winter temperature
Winter precipitation deviation	US Forest Service Terrestrial Condition Assessment	Percent change in winter precipitation

Table A.1 continued.

Data	Source(s)	Explanation
Floodplain high/very high WHP	US Forest Service Terrestrial Condition Assessment	Percentage of 50-year floodplain with high or very high wildfire hazard potential
Moderate/high wildfire severity	US Forest Service Terrestrial Condition Assessment	Percentage of 50-year floodplain experiencing moderate to high severity wildfire between 1984 and 2014
Conversion to conifer	Riparian Condition Assessment Toolbox	Mean proportion of confiner encroachment occurring along stream reaches
Conversion to grass/shrub	Riparian Condition Assessment Toolbox	Mean proportion of upland vegetation encroachment occurring along stream reaches
Water quantity score	US Forest Service Watershed Condition Classification	Indicator of change in magnitude, duration and timing in relation to natural hydrograph
Riparian/wetland vegetation condition	US Forest Service Watershed Condition Classification	Indicator of function of native vegetation at streams and water bodies
Conversion to development/ agriculture	Riparian Condition Assessment Toolbox	Percentage of stream reaches where vegetation has converted from riparian to developed or agriculture cover
Stream temperature	US Forest Service NorWeST Stream Temperature Database	Average annual stream temperature
WCC impaired waters	US Forest Service watershed Condition Classification	Percentage of water bodies listed as impaired by the state
WCC water quality Problems	US Forest Service watershed Condition Classification	Indicator water quality issues above natural or background levels
% of unit impaired	State of Nevada	Percentage of water bodies listed as impaired by the state
Channel shape and function	US Forest Service watershed Condition Classification	Indicator that width-depth ratio is within expected range
% of stream with no change	Riparian Condition Assessment Toolbox	% of stream segment with no change from riparian vegetation
% of confined stream impacted	Riparian Condition Assessment Toolbox	% of confined segment with conversion of riparian vegetation and replacement by developed land
% of unconfined streams very poor to moderate	Riparian Condition Assessment Toolbox	% of confined segment with conversion of riparian vegetation and floodplain development
Conversion to invasive vegetation	Riparian Condition Assessment Toolbox	Mean proportion of conversion to invasive species occurring along stream reaches
Stream confinement	Riparian Condition Assessment Toolbox	Percentage of stream reaches classified as confined by the RCA procedure

APPENDIX B. Plant Communities and Fish and Wildlife Associated with Riparian and Groundwater-dependent Ecosystems of the Humboldt-Toiyabe National Forest

Table B.1—Riparian communities documented in vegetation plots measured by Manning and Padgett (1995), Weixelman et al. (1996, 1997), and the ongoing HTNF monitoring program (Weixelman et al. 1997). NS rank is based on Nature Serve conservation rankings of similar vegetation associations. G1 = critically imperiled, G2 = imperiled, G3 = vulnerable, G4 = apparently secure, G5 = secure , NA = no similar association, NR = no ranking.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Coniferous tree	Conifer/*Betula occidentalis* (conifer/water birch)	G3	10	6,690-8,520	Benches	Inceptisols, Cryoborolls, Haploxerolls, Other Xerolls, Other Mollisols	Eastern Mountains
	Conifer/*Carex scopulorum* (conifer/ mountain sedge)	NA	7	6,600-8,800	Meadows, Springs, Streambanks	Cryaquolls, Cryoborolls	Sierra Nevada
	Conifer/*Cornus sericea* (conifer/redosier dogwood)	G2-G4	2	7,080-8,240	Benches, Floodplains, Terraces, Toe Slopes	Entisols, Inceptisols, Mollisols	Eastern Mountains, Sierra Nevada
	Conifer/mesic forb	NA	7	7,610-9,280	Benches, Springs	Cryoborolls	Eastern Mountains
	Conifer/mesic graminoid	NA	15	6,480-8,440	Drainageways, Floodplains, Terraces	Cryofluvents, Cryaquents, Cryorthents, Cryochrepts, Cryoborolls, Cryaquolls, Endoaquolls	Sierra Nevada
	Conifer/*Poa pratensis* (conifer/Kentucky bluegrass)	NR	3	5,820-7,880	Terraces, Meadows	Mollisols	Sierra Nevada
	Conifer/*Rosa woodsii* (conifer/Wood's rose)	NR	3	7,240-7,550	Springs	No Data	SMNRA
	Conifer/*Salix* (conifer/willow)	NA	10	6,460-9,080	Drainageways, Floodplains	Udifluvents, Cryaquents, Cryaquepts, Cryoborolls, Cryaquolls	Sierra Nevada
	Conifer/tall forb	NA	3	8,320-8,820	Terraces	Inceptisols, Mollisols	Eastern Mountains, Sierra Nevada
Tall deciduous tree	*Populus/Betula occidentalis* (cottonwood/water birch)	G3	7	6,390-7,400	Floodplains, Streambanks, Terraces	Haploborolls, Haploxerolls	Central Mountains, Eastern Mountains
	Populus/Cornus sericea (cottonwood/redosier dogwood)	G3-G4	6	6,240-7,280	Bars, Benches, Floodplains, Shallow ponds, Terraces	Entisols, Haplocryolls, Inceptisols, Mollisols	Eastern Mountains, Ruby Mountains

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Tall deciduous tree	*Populus*/*Rhus trilobata* (cottonwood/skunkbush sumac)	G3	5	6,390-6,600	Floodplains Terraces	Haploxerolls	Eastern Mountains
	Populus/*Rosa woodsii* (cottonwood/wood's rose)	G2	11	6,320-7,550	Terraces	Cryofluvents, Haploborolls, Haploxerolls	Central Mountains, Eastern Mountains, Ruby Mountains, SMNRA,
	Populus/*Salix* (cottonwood/willow)	NA	5	5,030-7,360	Benches, Terraces	Xerofluvents, Other Fluvents	Central Mountains, Eastern Mountains, Northern Mountains, Sierra Nevada
	Populus/stream bar (cottonwood/stream bar)	NA	5	5,160-6,640	Bars, Floodplains	Xerofluvents, Other Fluvents, Dystrochrepts, Haploborolls	Central Mountains, Eastern Mountains, Sierra Nevada
	Populus angustifolia (narrowleaf cottonwood)	NA	6	5,732-7,440	Channel bottoms, Terraces, Toe Slopes	Cryofluvents, Cryoborolls, Haplocryolls	Central Mountains, Ruby Mountains
	Populus angustifolia/mesic graminoid (narrowleaf cottonwood/mesic graminoid)	NA	2	6,464	Drainageways, Terraces	Haplocryolls	Eastern Mountains
	Populus angustifolia/ *Populus tremuloides* (narrowleaf cottonwood/quaking aspen)	NA	1	6,564	Floodplains	Cryaquents	Ruby Mountains
	Populus angustifolia/shrub (narrowleaf cottonwood/shrub)	NA	2	7,050-7,317	Inset Fans, Terraces	Haplocryolls	Eastern Mountains, Ruby Mountains
	Populus balsamifera (black cottonwood)	G3	12	5,180-7,420	Drainageways, Floodplains, Gravel Bars, Terraces, Toe slopes	Cryofluvents, Cryoborolls, Cryoborolls, Haplodolls, Cryaquolls, Cryoborolls	Central Mountains, Northern Mountains

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Tall deciduous tree	*Populus balsamifera/Alnus incana* (black cottonwood/gray alder)	G3	1	6,320	Drainageways	Haplocryolls	Northern Mountains
	Populus balsamifera/ Juniperus scopulorum (black cottonwood/ Rocky Mountain juniper)	NA	2	5,650-6,075	Terraces	Cryofluvents, Oxyaquic Hapludolls	Northern Mountains
	Populus balsamifera/ Populus tremuloides (black cottonwood/quaking aspen)	NA	3	5,440-6,920	Drainageways, Floodplains	Cryofluvents, Haplocryolls	Northern Mountains
	Populus tremuloides (quaking aspen)	NA	63	6,081-9,850	Bajadas, Benches, Drainageways, Floodplains, Gravel Bars, Hill Faults, Hill Slopes, Springs, Terraces, Toeslopes, Valley Floors	Cryofluvents, Cryorthents, Cryaquents, Cryochrepts, Cryoborolls, Cryaquolls, Endoaquolls	Central Mountains, Eastern Mountains, Northern Mountains, Ruby Mountains, Sierra Nevada
	Populus tremuloides/Artemisia tridentata/Salix (quaking aspen/big sagebrush/ willow)	NA	1	7,580	No Data	No Data	Central Mountains
	Populus tremuloides/Betula occidentalis (quaking aspen/water birch)	G3	6	6,560-7,960	Benches, Streambanks, Terraces	Haploxerolls, Hapludolls	Eastern Mountains
	Populus tremuloides/Bromus carinatus (quaking aspen/California brome)	G5	4	6,120-7,320	Terraces	Cryoborolls, Haploborolls, Haploxerolls	Central Mountains, Sierra Nevada
	Populus tremuloides/Cornus sericea (quaking aspen /redosier dogwood)	G4	6	6,290-7,480	Terraces, Benches, Floodplains, Streambanks, Springs	Xerofluvents, Haploxerolls	Eastern Mountains, Ruby Mountains

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Tall deciduous tree	*Populus tremuloides*/dry graminoid (quaking aspen/dry graminoid)	NA	1	6,923	Mountain Slopes	No Data	Sierra Nevada
	Populus tremuloides/ *Elymus glaucus* (quaking aspen/blue wildrye)	G3	5	7,520-8,520	Floodplains, Terraces	Cryaquolls, Cryoborolls	Sierra Nevada
	Populus tremuloides/mesic graminoid (quaking aspen/mesic graminoid)	NA	2	7,740-8,479	Drainageways, Hillslopes	Haplocryolls	Central Mountains, Ruby Mountains
	Populus tremuloides/*Osmorhiza berteroi* (quaking aspen/ sweetcicely)	NA	8	6,720-8,700	Drainageways, Floodplains	Cryofluvents, Cryoborolls	East Sierra, Sierra Nevada
	Populus tremuloides/*Poa pratensis* (quaking aspen/Kentucky bluegrass)	NR	2	7,450-7,970	Benches, Floodplains, Springs, Terraces,	Entisols, Mollisols	Central Mountains, Eastern Mountains
	Populus tremuloides/ *Poa pratensis*/ *Agrostis stolonifera* (quaking aspen/creeping bentgrass)	NA	1	6,640	Terraces	Eutrocryepts	Northern Mountains
	Populus tremuloides/*Rosa woodsii* (quaking aspen/Woods' rose)	NR	9	6,560-8,120	Terraces	Haploborolls, Haploxerolls	Central Mountains, Eastern Mountains, Northern Mountains, Ruby Mountains
	Populus tremuloides/*Salix* (quaking aspen/willow)	NA	4	7,200-8,490	Benches	Dystrochrepts, Cryaquolls, Haploborolls	Central Mountains, Eastern Mountains,
	Populus tremuloides/ *Salix amygdaloides* (quaking aspen/ peachleaf willow)	NA	1	6,574	Terraces	No Data	Northern Mountains

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Tall deciduous tree	*Populus tremuloides*/ *Salix boothii* (quaking aspen/Booth's willow)	NR	2	6,385-6,493	Gravel Bars	No Data	Sierra Nevada
	Populus tremuloides/*Salix* (quaking aspen/willow)	NA	1	6,640	Floodplains	Haplocryolls	Ruby Mountains
	Populus tremuloides/shrub (quaking aspen/shrub)	NA	20	6,320-9,138	Drainageways, Floodplains, Inset Fans, Springs, Terraces	Argicryolls, Cryaquolls, Haplocryolls, Haploxerolls, Cryofibrists	Eastern Mountains, Northern Mountains, Ruby Mountains
	Populus tremuloides/wet graminoid (quaking aspen/wet graminoid)	NA	1	7,740	Gravel Bars	Haplocryolls	Ruby Mountains
Low deciduous tree	*Alnus incana*/bench (gray alder/bench)	NR	7	5,940-7,760	Benches	Cryofluvents, Udifluvents, Other Fluvents	Northern Mountains, Sierra Nevada
	Alnus incana/*Cornus sericea* (gray alder/redosier dogwood)	G3	2	5,800-7,840	Streambanks	Entisols, Mollisols	Northern Mountains, Sierra Nevada
	Alnus incana/mesic forb (gray alder/mesic forb)	G3	10	6,200-8,400	Floodplains, Springs, Streambanks, Terraces	Udifluvents, Xerorthents, Cryochrepts, Cryaquolls, Cryoborolls, Haploxerolls	Northern Mountains, Sierra Nevada
	Alnus incana/mesic graminoid (gray alder/mesic graminoid)	G3	5	5,650-7,200	Bars, Benches, Floodplains, Streambanks	Udifluvents, Haplaquolls, other Aquolls	Northern Mountains
	Alnus incana/*Salix lutea*/*Salix boothii* (gray alder/yellow willow/Booth's willow)	NA	1	5,873	Terraces	No Data	Northern Mountains
	Alnus incana/*Salix lutea*/*Salix lucida* (gray alder/yellow willow/shining willow)	G3	1	6,261	Terraces	No Data	Northern Mountains
	Betula occidentalis (water birch)	G3	4	6,890-7,513	Springs, Terraces	Calcicryolls, Cryaquolls, Haplocryolls	Eastern Mountains
	Betula occidentalis/bench (water birch/bench)	G3	7	6,400-6,800	Benches, Terraces	Haploborolls, Haploxerolls, Hapludolls	Central Mountains, Eastern Mountains
	Betula occidentalis/*Cornus sericea* (water birch/redosier dogwood)	G3	9	6,240-8,320	Benches, Floodplains, Streambanks, Terraces	Ustifluvents, Haploborolls, Haploxerolls, Hapludolls	Central Mountains, Eastern Mountains

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Low deciduous tree	*Betula occidentalis*/*Equisetum arvense* (water birch/field horsetail)	NA	4	6,400-7,520	Benches, Springs	Udifluvents, Dystrochrepts, Haploborolls	Central Mountains, Eastern Mountains
	Betula occidentalis/mesic graminoid (water birch/mesic graminoid)	G3	24	6,400-8,160	Benches, Gravel Bars, Floodplains, Terraces, Toe Slopes, Springs	Cryorthents, Cryochrepts, Humaquepts, Cryoborolls, Cryaquolls, Haploborolls, Haplocryolls, Haploxerolls, Borohemists, Borosaprists	Central Mountains, Eastern Mountains
	Betula occidentalis/mesic forb (water birch/mesic forb)	NA	7	6,560-8,300	Springs, Streambanks, Terraces	Haploborolls, Haploxerolls, Borohemists	Central Mountains, Eastern Mountains, SMNRA
	Betula occidentalis/*Poa pratensis* (water birch/Kentucky bluegrass)	NA	6	6,460-7,700	Springs, Streambanks, Terraces	Dystrochrepts, Haplaquolls, Haploborolls, Haploxerolls	Central Mountains, Eastern Mountains
Nonwillow shrub	*Artemisia arbuscula* (little sagebrush)	G4	2	6,288-7,100	Fan Piedmonts	Haplargids	Central Mountains, Northern Mountains
	Artemisia cana/*Artemisia arbuscula* (silver sagebrush/little sagebrush)	NA	1	6,459	No Data	No Data	Sierra Nevada
	Artemisia cana/dry graminoid (silver sagebrush/dry graminoid)	NA	11	7,839-8,700	Glacial Cirques, Meadows, Terraces	Argixerolls, Cryoborolls, Haplocryolls, Haploxerolls, Haplustolls	Central Mountains, Eastern Mountains, Northern Mountains, Ruby Mountains, Sierra Nevada
	Artemisia cana/mesic graminoid (silver sagebrush/mesic graminoid)	G1-G4	38	5,680-9,889	Drainageways, Glacial Cirques, Gravel Bars, Floodplains, Meadows, Springs, Terraces, Toe Slopes	Cryofluvents, Cryorthents, Endoaquents, Cryochrepts, Cryumbrepts, Haplocryoalfs, Argicryolls, Cryaquolls, Cryoborolls, Haploborolls, Haplocryolls, Haploxerolls, Palecryolls	Central Mountains, East Sierra, Eastern Mountains, Northern Mountains, Sierra Nevada
	Artemisia nova (black sagebrush)	G4	1	5,872	Benches	No Data	Eastern Mountains

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Nonwillow shrub	*Artemisia tridentata*/*Carex douglasii*/*dry draminoid* (big sagebrush/Douglas' sedge/dry graminoid)	NA	1	5,906	Terraces	No Data	Northern Mountains
	Artemisia tridentata/*Leymus cinereus* (big sagebrush/basin wildrye)	NA	20	6,200-8,320	Drainageways, Floodplains, Inset Fans, Mountain Slopes, Springs, Terraces, Toe Slopes	Cryoborolls, Haplocryolls Haploxerolls, Haplustolls	Central Mountains, Northern Mountains
	Artemisia tridentata/ riparian (big sagebrush/riparian)	NA	1	7,489	No Data	No Data	Central Mountains
	Artemisia tridentata/*Rosa woodsii* (big sagebrush/Woods' rose)	NA	4	6,480-6,790	Terraces	Argixerolls, Other Mollisols	Eastern Mountains
	Cornus sericea (redosier dogwood)	G4	15	5,040-8,240	Bars, Benches, Floodplains, Streambanks, Toe Slopes	Cryofluvents, Xerofluvents, Cryoborolls, Haploxerolls	Eastern Mountains, Central Mountains, Northern Mountains, Ruby Mountains, Sierra Nevada
	Cornus sericea/*Salix* (redosier dogwood/willow)	NA	15	5,560-8,840	Benches, Terraces	Udifluvents, Dystrochrepts, Other Inseptisolls, Haploborolls, Haploxerolls	Central Mountains, Northern Mountains, Sierra Nevada
	Dasiphora fruticosa/*Ligusticum grayi* (shrubby cinquefoil/Gray's licorice-root)	NA	3	8,500-8,800	Terraces, Toe slopes	Cryoborolls	Ruby Mountains
	Ericameria nauseosa/*Artemisia tridentata*/*Leymus cinereus* (rubber rabbitbrush/big sagebrush/basin wildrye)	G5	1	7,659	Valley bottoms	No Data	Central Mountains
	Mesic/riparian shrub	NA	5	6,500-7,935	Drainageways, Springs, Streambanks	No Data	Central Mountains, Eastern Mountains, Ruby Mountains
	Prunus virginiana/*Rosa woodsii* (chokecherry/Wood's rose)	NA	4	6,590-8,000	Terraces	Xerofluvents, Haploxerolls, Other Xerolls	Eastern Mountains

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Nonwillow shrub	*Rosa woodsii* (Woods' rose)	G5	15	5,160-8,160	Floodplains, Springs, Terraces	Cryofluvents, Xerofluvents, Xerochrepts, Haploxerolls, Other Xerolls	Central Mountains, Eastern Mountains, Northern Mountains, Sierra Nevada, SMNRA
Low willow	Low *Salix*/mesic forb	NA	5	8,050-10,360	Meadows, Springs, Terraces,	Cryaquolls, Cryoborolls	Northern Mountains, Ruby Mountains, Sierra Nevada
	Salix eastwoodiae (mountain willow)	G2	11	8,340-10,300	Drainageways, Floodplains	Cryaquents, Cryofluvents, Cryaquepts, Haplargids, Cryoborolls, Cryaquolls	Sierra Nevada
	Salix eastwoodiae/Carex scopulorum (mountain willow/mountain sedge)	NA	18	8,180-9,600	Benches, Springs, Toes Slopes	Cryaquepts, Cryaquolls, Cryoborolls, Borofibrists	Ruby Mountains, Sierra Nevada
	Salix orestera/tall forb (Sierra willow/tall forb)	NR	6	8,800-9,500	Terraces, Toe Slopes	Cryoborolls	Ruby Mountains, Sierra Nevada
	Salix planifolia/Carex scopulorum (diamondleaf willow/ mountain sedge)	G4	4	9,440-10,560	Floodplains, Springs	Cryaquolls, Borofibrists	Sierra Nevada
	Salix wolfii/Carex scopulorum (Wolf's willow/mountain sedge)	NA	6	8,560-9,680	Meadows, Springs	Cryaquepts, Cryaquolls, Borohemists	Ruby Mountains
Tall willow	Cold willow/mesic forb	NA	13	6,501	Gravel Bars, Floodplains, Terraces	Cryaquolls, Cryoborolls, Cryaquolls	Central Mountains
	Cold willow/mesic graminoid	NA	47	5,800-9,200	Drainageways, Floodplains, Gravel Bars, Terraces	Cryaquents, Cryofluvents, Cryorthents, Cryaquept, Cryochrepts, Cryaquolls, Cryoborolls	Central Mountains, East Sierra, Sierra Nevada
	Salix (willow)	NA	5	7,016-7,718	Drainageways, Floodplains, Springs	Cryaquents	Northern Mountains
	Salix/*Carex utriculata* (willow/Northwest Territory sedge)	NA	5	6,800-8,000	Benches, Meadows, Springs	Haplaquolls, Haploxerolls, Borohemists	Central Mountains, Northern Mountains, Sierra Nevada
	Salix/*Equisetum arvense* (willow/field horsetail)	NA	7	4,900-7,980	Benches, Terraces	Cryaquolls, Cryoborolls, Haplaquolls, Haploborolls	Central Mountains, Sierra Nevada

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Tall willow	*Salix*/mesic forb (willow/mesic forb)	NA	15	6,180-8,840	Drainageways, Floodplains, Gravel Bars, Terraces	Cryofluvent, Cryaquoll, Cryoborolls, Haploborolls, Haplocryoll	Eastern Mountains, Northern Mountains, Ruby Mountains, Sierra Nevada
	Salix/mesic graminoid (willow/mesic graminoid)	NA	28	4,020-9,320	Benches, Drainageway, Floodplain, Gravel Bars, Springs, Terraces	Cryaquents, Cryofluvents, Cryorthents, Aquepts, Argicryolls, Cryaquolls, 8Cryaquolls, Endoaquolls, Haplaquolls, Haplocryolls, Haploxerolls, Haplustolls	All units
	Salix/*Poa pratensis* (willow/Kentucky bluegrass)	NA	9	5,820-8,000	Terraces	Cryoborolls, Haploborolls, Haploxerolls	Central Mountains, Eastern Mountains, Northern Mountains, Sierra Nevada
	Salix/*Rosa woodsii* (willow/Woods' rose)	NA	6	4,720-8,000	Terraces	Hapludolls, Haploxerolls	Eastern Mountains, Northern Mountains
	Salix/tall forb (willow/tall forb)	NA	5	6,800-8,400	Terraces	Udifluvents, Agriborolls, Cryoborolls, Haploxerolls	Central Mountains, Northern Mountains
	Salix boothii (Booth's willow)	NR	3	7,422-7,520	Gravel Bars, Floodplains, Terraces	Cryaquepts, Cryaquolls, Endoaquolls	Central Mountains
	Salix boothii/mesic graminoid (Booth's willow/mesic graminoid)	G3	3	6,000-7,120	Floodplains, Terraces	Cryaquolls, Haplocryolls	Ruby Mountains, Northern Mountains
	Salix drummondiana (Drummond's willow)	NA	5	7,360-9,760	Benches, Shallow Ponds, Springs, Terraces	Cryofluvents, Cryochrepts, Cryaquolls, Cryoborolls	Central Mountains, Northern Mountains, Sierra Nevada
	Salix exigua/bench (narrowleaf willow/bench)	G5	8	4,920-8,000	Bars, Benches, Shallow Ponds, Streambanks	Udifluvents, Xerofluvents, Haplaquolls, Haploxerolls	Central Mountains, Eastern Mountains, Northern Mountains, Sierra Nevada
	Salix exigua/mesic forb (narrowleaf willow/mesic forb)	G2	5	6,130-8,060	Benches, Gravel Bars, Meadows, Streambanks, Terraces	Fluvaquents, Haplumbrepts, Haploborolls, Haploxerolls	Central Mountains, Eastern Mountains, Northern Mountains

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Tall willow	*Salix exigua*/mesic graminoid (narrowleaf willow/mesic graminoid)	G5	6	5,930-7,628	Floodplains, Gravel Bars, Terraces	Cryofluvents, Fluvaquents, Cryaquolls, Haplocryolls	Eastern Mountains, Northern Mountains, Ruby Mountains
	Salix exigua/*Rosa woodsii* (narrowleaf willow/Woods' rose)	NA	20	5,630-7,920	Benches, Terraces	Xerofluvents, Argixerolls, Haploborolls, Haploxerolls, Hapludolls	Central Mountains, East Sierra, Eastern Mountains, Northern Mountains
	Salix geyeriana (Geyer willow)	NR	1	9,430	Floodplains	Cryaquolls	Central Mountains
	Salix geyeriana/*Carex nebrascensis* (Geyer willow/Nebraska sedge)	NA	1	9,260	Floodplains	Cryaquolls	Central Mountains
	Salix geyeriana/*Carex utriculata* (Geyer willow/Northwest Territory sedge)	G5	4	6,500-8,450	Benches, Floodplains, Meadows, Shallow Ponds, Springs, Streambanks, Terraces	Cryaquolls, Haplaquolls, Borohemists, Borosaprists	Northern Mountains, Sierra Nevada
	Salix geyeriana/mesic graminoid (Geyer willow/mesic graminoid)	G3	14	5,960-9,560	Benches, Floodplains, Gravel Bars, Meadows, Springs, Terraces	Cryofluvents, Cryaquepts, Haplaquepts, Cryaquolls, Cryoborolls, Endoaquolls, Haplaquolls, Haploborolls, Hapludolls, Borofibrists	Central Mountains, East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada
	Salix geyeriana/*Salix boothii* (Geyer willow/Booth's willow)	NR	2	7,420-7,424	Drainageways, Floodplains	Cryofluvents	Northern Mountains
	Salix lasiolepis/bench (arroyo willow/bench)	G3	9	5,540-7,090	Benches, Streambanks	Udifluvents, Xerofluvents, Other Fluvents, Haplumbrepts, Haploxerolls	Eastern Mountains, Northern Mountains, SMNRA
	Salix lasiolepis/mesic graminoid (arroyo willow/mesic graminoid)	NA	3	5,901-6,190	Terraces	Calciorthids	SMNRA
	Salix lasiolepis/*Rosa woodsii* (arroyo willow/Woods' rose)	G3	10	5,440-8,160	Benches, Springs	Fluvents, Haploxerolls, Other Xerols	Eastern Mountains, Northern Mountains, SMNRA

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Tall willow	*Salix lemmonii*/Bench (Lemmon's willow/bench)	NR	10	6,160-9,360	Benches	Xerofluvents, Cryoborolls, Haplaquolls, Haploborolls, Haploxerolls	Northern Mountains, Sierra Nevada
	Salix lemmonii/Carex scopulorum (Lemmon's willow/mountain sedge)	NA	4	8,400-9,300	Meadows, Springs, Streambanks	Cryaquepts, Cryaquolls	Sierra Nevada
	Salix lemmonii/mesic forb (Lemmon's willow/mesic forb)	G3	11	7,860-9,300	Benches, Floodplains, Springs	Cryaquolls, Cryoborolls	Sierra Nevada
	Salix lemmonii/mesic graminoid (Lemmon's willow/mesic graminoid)	NR	5	5,800-8,720	Benches, Drainageways, Springs	Cryoborolls, Haploxerolls	East Sierra, Northern Mountains, Sierra Nevada
	Salix lemmonii/seep (Lemmon's willow/seep)	NA	3	8,000-8,400	Meadows, Springs, Toe Slopes	Mollisols	Sierra Nevada
	Salix lemmonii/tall forb (Lemmon's willow/tall forb)	G3	12	7,400-10,200	Benches, Meadows	Cryumbrepts, Cryoborolls, Haploxerolls	Northern Mountains, Sierra Nevada
	Salix lucida/bench (shining willow/bench)	G3	5	5,060-7,520	Bars, Benches, Floodplains, Streambanks, Terraces	Cryofluvents, Xerofluvents, Cryaquolls	Northern Mountains, Ruby Mountains
	Salix lucida/mesic forb (shining willow/ mesic forb)	NA	4	6,520-7,680	Benches	Haploborolls	Central Mountains, Northern Mountains
	Salix lucida/mesic graminoid (shining willow/ mesic graminoid)	NA	1	6,350	Gravel Bars	Cryaquents	Ruby Mountains
	Salix lucida/Salix boothii/Poa pratensis (shining willow/Booth's willow/ Kentucky bluegrass)	NA	1	6,720	Terraces	Cryofluvents	Northern Mountains
	Salix lucida/wet graminoid (shining willow/ wet graminoid)	NA	1	7,360	Drainageways	Cryofluvents	Northern Mountains
	Salix lutea/bench (yellow willow/bench)	NA	8	8,160	Benches, Springs, Streambanks, Terraces	Cryofluvents, Xerofluvents, Dystrochrepts, Cryoborolls, Haploborolls, Haploxerolls	Central Mountains, East Sierra, Northern Mountains

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Tall willow	*Salix lutea*/dry graminoid (yellow willow/dry graminoid)	NA	1	6,140	Terraces	Cryaquolls	Northern Mountains
	Salix lutea/mesic graminoid (yellow willow/mesic graminoid)	NR	16	5,400-8,531	Benches, Drainageways, Meadows, Springs	Dystrochrepts, Cryaquolls, Cryoborolls, Haplaquolls, Haploborolls	Central Mountains, East Sierra, Eastern Mountains, Northern Mountains, Sierra Nevada
	Salix lutea/*Poa pratensis* (yellow willow/Kentucky bluegrass)	NA	5	5,800-7,640	Terraces	Ustifluvents, Haplaquolls, Haploborolls, Haploxerolls	Eastern Mountains, Northern Mountains, Sierra Nevada
	Salix lutea/*Rosa woodsii* (yellow willow/Woods' rose)	G3	18	5,080-7,970	Terraces	Xerofluvents, Haplumbrepts, Argixerolls, Haploborolls, Haploxerolls	Central Mountains, East Sierra, Eastern Mountains, Northern Mountains, Ruby Mountains
	Salix lutea/*Salix boothii* (yellow willow/Booth's willow)	NA	1	6,530	Terraces	Cryaquolls	Northern Mountains
	Salix scouleriana/annual forb (Scouler's willow/ annual forb)	NA	1	8,482	Terraces	No Data	Ruby Mountains
	Warm willow/*Leymus cinereus* (warm willow/basin wildrye)	NA	1	6,968	Drainageways, Springs	No Data	Central Mountains
	Warm willow/forb	NA	6	5,890-7,845	Floodplains	Cryofluvents, Cryaquents, Haploborolls	East Sierra, Sierra Nevada
	Warm willow/floodplain	NA	4	6,120-6,720	Floodplains, Terraces	Udifluvents, Cryochrepts, Cryaquolls	East Sierra, Sierra Nevada
	Warm willow/gravel bar	NA	9	5,690-7,920	Gravel Bars	Cryaquents, Cryorthents, Endoaquents, Fluvaquents, Udifluvents, Ustorthents	East Sierra, Sierra Nevada
	Warm willow/mesic forb	NA	17	6,250-7,980	Floodplains, Gravel Bars, Toe Slopes, Mountain Slopes, Terraces	Cryofluvents, Cryaquents, Cryochrepts, Cryaquolls, Cryoborolls	Central Mountains

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Tall willow	Warm willow/mesic graminoid	NA	19	6,200-8,400	Gravel Bars, Floodplains	Cryofluvents, Cryorthents, Cryaquents, Udifluvents, Cryaquepts, Ustochrepts, Cryaquolls, Cryoborolls, Borofibrists	Central Mountains
Herbaceous	*Agrostis stolonifera* (creeping bentgrass)	NR	8	6,400-8,480	Bars, Benches, Meadows, Springs	Haplaquolls, Haploborolls, Borosaprists	Central Mountains, Eastern Mountains, Northern Mountains, Sierra Nevada
	Alkaline dry graminoid	NA	2	6,166-6,385	No Data	No Data	Central Mountains
	Alkaline mesic graminoid	NA	1	6,400	Drainageways	No Data	Central Mountains
	Alkaline wet graminoid	NA	1	6,328	No Data	No Data	Central Mountains
	Bromus tectorum-dry graminoid (cheatgrass-dry graminoid	NR	1	5,963	Terraces	No Data	SMNRA
	Carex aquatilis (water sedge)	G5	28	6,500-10,200	Benches, Drainageways, Floodplains, Meadows, Shallow Ponds, Springs, Streambanks, Terraces	Cryaquents, Cryochrepts, Cryaquepts, Cryaquolls, Cryoborolls, Hapludolls, Borofibrists, Borohemists, Cryofibrist	Central Mountains, Northern Mountains, Ruby Mountains, Sierra Nevada
	Carex aquatilis-wet graminoid (water sedge-wet graminoid)	NA	1	8,435	Springs	No Data	Northern Mountains
	Carex douglasii (Douglas' sedge)	G4	7	6,800-8,080	Meadows	Haploborolls, Haploxerolls	Central Mountains, East Sierra, Eastern Mountains
	Carex lasiocarpa (woollyfruit sedge)	G4	1	7,760	Floodplains	Cryaquolls	Central Mountains
	Carex microptera (smallwing sedge)	G4	4	7,131-9,040	Benches, Meadows, Springs, Terraces	Entisols, Inceptisols, Mollisols	East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Herbaceous	*Carex nebrascensis* (Nebraska sedge)	G4	83	5,800-9,290	Basins, Benches, Drainageways, Floodplains, Gravel Bars, Meadows, Springs, Streambanks, Toe Slopes, Terraces	Cryofluvents, Udifluvents, Cryorthents, Cryaquents, Aquepts, Cryaquepts, Dystroquepts, Humaquepts, Haplaquepts, Cryoboralfs, Argiaquolls, Cryoborolls, Cryaquolls, Haplaquolls, Haploborolls, Haploxerolls, Borofibrists	All units
	Carex nebrascensis-Carex praegracilis (Nebraska sedge-clustered field sedge)	NA	1	7,963	Springs	No Data	Sierra Nevada
	Carex nebrascensis-Deschampsia cespitosa (Nebraska sedge-tufted hairgrass)	NA	12	6,520-9,154	Drainageways, Floodplains, Springs	Cryaquolls, Haplocryolls	Central Mountains, Eastern Mountains, Northern Mountains, Ruby Mountains
	Carex nebrascensis-Juncus arcticus (Nebraska sedge-arctic rush)	NA	1	7,825	Alpine Fellfields	No Data	Sierra Nevada
	Carex nebrascensis/Poa pratensis (Nebraska sedge/Kentucky bluegrass)	NA	1	6,118	Streambanks	No Data	Ruby Mountains
	Carex pellita (woolly sedge)	G3	4	5,880-8,120	Basins, Floodplains, Meadows, Springs, Terraces	Cryaquolls, Haplaquolls	Central Mountains, Northern Mountains, Sierra Nevada
	Carex scopulorum (mountain sedge)	G5	35	6,830-10,160	Alpine, Benches, Drainageways, Fens, Floodplains, Glacial Hill Slopes, Meadows, Springs, Streambanks, Terraces, Toe slopes	Cryorthents, Cryaquepts, Cryochrepts, Cryumbrepts, Cryaquolls, Cryoborolls, Borofibrist, Borohemists, Other Histosols	Central Mountains, East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada
	Carex scopulorum/Deschampsia cespitosa (mountain sedge/tufted hairgrass)	NA	2	8,912-9,900	Glacial Cirque, Trough Drainageway	No Data	Ruby Mountains, Sierra Nevada

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Herbaceous	*Carex simulata* (analogue sedge)	G4	20	5,900-9,300	Benches, Fens Floodplains, Meadows, Springs, Terraces	Cryaquepts, Cryaquolls, Haplaquolls, Haploborolls, Borofibrists, Borohemists	Central Mountains, East Sierra, Eastern Mountains, Northern Mountains, Sierra Nevada
	Carex utriculata (Northwest Territory sedge)	G3-G5	34	5,800-8,600	Basins, Benches, Drainageways, Fens, Floodplains, Meadows, Shallow Ponds, Streambanks, Springs, Terraces	Cryaquepts, Cryaquolls, Cryoborolls, Epiaquolls, Haplaquolls, Borohemists, Medihemists	Central Mountains, East Sierra, Northern Mountains, Sierra Nevada
	Danthonia spp. (oatgrass)	G1-G2	15	5,963-8,790	Drainageways, Floodplains, Inset Fans, Springs, Terraces	Cryorthents, Cryaqualfs, Haplocryalfs, Argicryoll, Cryaquolls, Haplocryolls, Haplustolls, Palecryolls	Northern Mountains, Ruby Mountains
	Deschampsia cespitosa (tufted hairgrass)	G4	31	6,460-10,900	Basins, Drainageways Floodplains, Gravel Bars, Gravel Meander Belts, Meadows, Mountain Basins, Shallow Ponds, Springs, Terraces, Toe Slopes	Cryofluvents, Ustifluvents, Cryaquepts, Cryaquolls, Cryoborolls, Haplaquolls, Haploborolls	Central Mountains, Northern Mountains, Sierra Nevada
	Deschampsia cespitosa-Carex nebrascensis (tufted hairgrass-Nebraska sedge)	NA	5	6,500-8,640	Basins, Floodplains, Meadows, Shallow Ponds, Springs	Cryaquolls, Haplaquolls, Haploborolls	Central Mountains, Eastern, Mountains, Northern Mountains, Sierra Nevada
	Distichlis spicata (saltgrass)	G5	1	6,952	Benches	No Data	Central Mountains
	Dodecatheon jeffreyi (Sierra shootingstar)	NA	5	8,140-8,900	Springs	Inceptisols	SMNRA
	Dry alkaline graminoid	NA	1	7,184	Drainageways	No Data	Central Mountains

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Herbaceous	Dry graminoid	NA	82	5,065-10,580	Calciforous Flats, Drainageways, Fan Moraines, Floodplains, Glacial Cirques, Gravel Bars, Meadows, Springs, Terraces, Toe Slopes, Valley Floors	Cryorthents, Cryaquepts, Cryochrepts, Ustochrepts, Cryoboralfs, Argicryoll, Argiaquolls, Cryaquoll, Cryoboroll, Haploboroll, Haplocryoll, Haploxeroll, Hapludoll, Haplustoll, Palecryoll, Palexeroll	All units
	Eleocharis palustris (common spikerush)	G5	4	8,100-9,680	Benches, Meadows, Shallow Ponds, Springs, Streambanks	Cryaquepts, Hapludolls, Borohemists	East Sierra, Northern Mountains, Sierra Nevada
	Eleocharis quinqueflora (fewflower spikerush)	G4	8	5,760-8,700	Fens, Meadows, Shallow ponds, Springs, Streambanks	Cryaquolls, Borofibrists, Borosaprists	Northern Mountains, Ruby Mountains, Sierra Nevada
	High wet forb	NA	1	8,375	Floodplains	Cryaquolls	Ruby Mountains
	High wet graminoid	NA	37	7,568-10,931	Drainageways, Fens, Floodplains, Glacial Cirques, Mountain Lake Shores, Spring, Stream Terraces	Cryaquents, Cryofluvents, Cryaquept, Cryochrepts, Dystrocryepts, Cryaqualfs, Argicryolls, Cryaquolls, Cryoborolls, , Haplocryolls, Cryofibrists	Eastern Mountains Northern Mountains, Ruby Mountains, Sierra Nevada
	Hordeum brachyantherum (meadow barley)	G2	9	5,820-8,800	Benches, Meadows	Argixerolls, Cryoborolls, Haplaquolls, Haploborolls, Hapludolls	Central Mountains, Northern Mountains, Sierra Nevada
	Iris missouriensis/dry graminoid (Rocky Mountain iris/ dry graminoid)	NA	16	5,760-8,520	Meadows	Xerofluvents, Argixerolls, Cryoborolls, Haploborolls, Haploxerolls, Hapludolls	Central Mountains, East Sierra, Eastern Mountains, Sierra Nevada
	Juncus arcticus (arctic rush)	G5	20	5,800-9,400	Basins, Benches, Floodplains, Meadows, Springs, Terraces,	Cryaquepts, Cryumbrepts, Cryaquolls, Argixerolls, Cryoborolls, Haplaquolls, Haploborolls, Haploxerolls	Central Mountains, East Sierra, Eastern Mountains, Northern Mountains, Sierra Nevada

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Herbaceous	*Juncus arcticus*/*Distichlis spicata* (arctic rush/saltgrass)	NA	1	6,499	Springs	No Data	Central Mountains
	Leymus cinereus (basin wildrye)	G1-G2	27	5,285-9,159	Drainageways, Floodplains, Gravel Bars, Slot Canyons, Springs, Terraces, Toeslope	Haplanthrepts, Haplustepts, Argicryolls, Cryoborolls, Durustolls, Haplocryolls, Haplustolls	East Sierra, Eastern Mountains, Northern Mountains, Ruby Mountains, SMNRA
	Leymus cinereus-dry graminoid (basin wildrye-dry graminoid)	NA	2	5,716	Springs, Terraces	No Data	Northern Mountains, SMNRA
	Leymus cinereus-riparian shrub (basin wildrye-riparian shrub)	NA	1	7,277	Springs	No Data	Central Mountains
	Lupinus polyphyllus-Senecio triangularis (bigleaf lupine- arrowleaf ragwort)	NA	4	8,800-9,280	Springs, Streambanks, Toe Slopes,	Cryaquolls, Cryoborolls	Sierra Nevada
	Mertensia ciliata (tall fringed bluebells)	G3	2	8,950-9,370	Benches, Floodplains, Streambanks, Toe Slopes	Entisols, Mollisols	Eastern Mountains
	Mesic forb	NA	1	10,174	Glacial Cirques	No Data	Sierra Nevada
	Mesic graminoid	NA	192	4,910-11,210	Alluvial Fans, Drainageways, Floodplains, Glacial Cirques, Inset Fan, Meadows, Springs, Terraces, Toe Slopes, Valley bottoms	Cryaquents, Cryofluvents, Cryaquepts, Cryochrepts, Cryoboralfs, Haplocryalfs, Agriaquolls, Argicryolls, Argixerolls, Calcicryolls, Cryaquolls, Cryoborolls, Endoaquolls, Haploborolls, Haplocryolls, Haploxerolls, Haplustolls, Palecryolls, Sphagnofibrists	All units
	Mesic-dry graminoid	NA	1	7,131	Drainageways	No Data	Eastern Mountains
	Poa cusickii (Cusick's bluegrass)	G2	16	6,520-9,600	Drainageways, Floodplains, Springs, Terraces, Toe Slopes	Cryaquents, Cryaquolls, Cryoborolls, Haploborolls	East Sierra, Sierra Nevada

Table B.1 continued.

Dominance group	Riparian community	NS rank	# of plots	Elevation range	Geomorphic features	Soil taxa	Known geographic units
Herbaceous	*Poa pratensis* (Kentucky bluegrass)	NR	8	6,640-8,120	Benches, Meadows, Terraces,	Haploborolls, Haploxerolls	Central Mountains, Eastern Mountains, Northern Mountains, Sierra Nevada
	Poa secunda (Sandberg bluegrass)	G4	9	5,814-7500	Meadows, Springs, Terraces	Argiaquolls, Argixerolls, Haploborolls, Haploxerolls	Eastern Mountains, Northern Mountains, Sierra Nevada
	Saline dry graminoid	NA	1	6,529	Drainageways, Springs	No Data	Eastern Mountains
	Subalpine grass/forb	NA	1	8,446	Subalpine Meadows	No Data	Sierra Nevada
	Tall forb	NA	2	8,338-9,140	Valley Floors	Cryaquents	Central Mountains
	Veratrum californicum (California false hellebore)	G3	15	7,440-10,200	Benches, Floodplains, Meadows, Springs, Toe slopes	Cryaquepts, Cryumbrepts, Agriborolls, Cryaquolls, Cryoborolls, Haploborolls	Central Mountains, Northern Mountains, Ruby Mountains, Sierra Nevada
	Wet graminoid	NA	105	5,180-10,697	Alluvial Fans, Drainageways, Fens, Floodplains, Glacial Cirques, Springs, Terraces, Valley Floors	Cryaquents, Cryofluvents, Cryorthents, Oxyaquents, Cryaquepts, Cryochrepts, Argiaquolls, Argicryolls, Cryaquolls, Cryoborolls, Endoaquolls, Epiaquolls, Haplocryolls, Haploxerolls, Haplustolls	Central Mountains, East Sierra, Eastern Mountains, Northern Mountains, Ruby Mountains, Sierra Nevada
	Wet graminoid/*Carex aquatilis* (wet graminoid/water sedge)	NA	1	6,042	Springs	No Data	Central Mountains
	Wet meadow	NA	4	5,939-7,181	Drainageways, Springs	No Data	Eastern Mountains, Northern Mountains
Unclassified Vegetation	Woody stream	NA	2	6,800-7,250	Bars, Floodplains	Haplocryolls	Northern Mountains

Table B.2—Fish and wildlife species associated with riparian and groundwater-dependent ecosystems within HUC8s overlapping geographic units of the HTNF. Several species are federally listed as threatened or endangered. Unlisted species are classified as Species of Greatest Conservation need by the states of Idaho or Nevada. Information about status, habitat, and threats was obtained from NatureServe (https://explorer.natureserve.org/).

Group	Species	Federal status	Habitat	Threats	Units
Amphibians	Arizona toad (*Anaxyrus microscaphus*)	Unlisted	Streams and irrigation ditches bordered by willows and cottonwoods	Degradation of riparian corridors from dams and diversions; hybridization with Woodhouse's toad	Eastern Mountains, SMNRA
	Columbia spotted frog (*Rana luteiventris*)	Unlisted	Vegetated margins of streams, lakes, ponds, springs, and marshes	Aridification; predation by nonnative species	Central Mountains, Eastern Mountains, Northern Mountains, Ruby Mountains
	Great Plains toad (*Anaxyrus cognatus*)	Unlisted	Valley bottoms with low-stature vegetation; pools, ponds, and lakes	Loss and degradation of habitat from development, intensive agriculture, and pollution	Central Mountains, Eastern Mountains, SMNRA
	Northern leopard frog (*Lithobates pipiens*)	Unlisted	Springs, slow streams, marshes, bogs, ponds, canals, flood plains, reservoirs, and lakes; permanent water with rooted aquatic vegetation; wet meadows and fields in summer	Loss of lowland wetland habitat; competition and predation by nonnative species	Eastern Mountains, East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada, SMNRA
	Sierra Nevada yellow-legged frog (*Rana sierrae*)	Endangered	Slow-moving meadow streams and mountain lakes	Predation by nonnative species; disease; degradation of habitat following wildfire	Sierra Nevada
	Western toad (*Anaxyrus boreas*)	Unlisted	Aquatic features including springs, ponds, lakes, and reservoirs; adjacent riparian habitat for burrowing and foraging	Disease and parasites; increased exposure to UV radiation; predation by native and nonnative species	Central Mountains, Eastern Mountains, Northern Mountains, Ruby Mountains, Sierra Nevada
	Woodhouse's toad (*Anaxyrus woodhousii*)	Unlisted	Areas with low-stature vegetation and deep, friable soils; breeding sites in wetlands, pools, ponds, lakes, and floodplains	Local, unspecified threats	Eastern Mountains, Northern Mountains, SMNRA
	Yosemite toad (*Anaxyrus canorus*)	Threatened	Streamside meadows; forest edges; ponds, lakes, and slow-moving streams	Degradation of riparian habitat from livestock grazing; disease; drought and other climate impacts	Sierra Nevada
Birds	American avocet (*Recurvirostra americana*)	Unlisted	Lowland marshes, mudflats, ponds, alkaline lakes, and estuaries	Local, unspecified threats	All units

Table B.2 continued.

Group	Species	Federal status	Habitat	Threats	Units
Birds	American bittern (*Botaurus lentiginosus*)	Unlisted	Large marshes with cattails, sedges, or bulrushes and patches of open water and aquatic-bed vegetation	Loss of wetland habitat from drainage, filling, pollution, siltation, and conversion to agriculture	All units
	American white pelican (*Pelecanus erythrorhynchos*)	Unlisted	Rivers, lakes, reservoirs, and open marshes for foraging; islands and peninsulas for nesting and roosting	Human disturbance to nesting colonies; drought; pollution	All units
	Bald eagle (*Haliaeetus leucocephalus*)	Unlisted	Large trees for nests and roosts; rivers, lakes, reservoirs, or other bodies of water for foraging	Loss and degradation of nesting habitat to timber harvest and pollution; loss of food sources; human disturbance	All units
	Bank swallow (*Riparia riparia*)	Unlisted	Steep streambanks used for digging nest burrows	Loss of streambank nesting habitat from alteration of natural stream dynamics	All units
	Bell's vireo (*Vireo bellii*)	Unlisted	Dense shrubland, often near water	Loss and degradation of riparian nesting habitat from flood control, water diversions, urban development, and agriculture; cowbird parasitism	Eastern Mountains, SMNRA
	Black swift (*Cypseloides niger*)	Unlisted	Nesting sites near waterfalls and on wet streamside cliffs	Stream flow reduction that renders nesting sites unsuitable	East Sierra, Sierra Nevada
	Black tern (*Chlidonias niger*)	Unlisted	Wetlands and associated streams, lakes, and reservoirs	Loss and degradation of wetland habitat from invasive plants, water diversions, pollution, and drought	Central Mountains, Eastern Mountains, East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada
	Bobolink (*Dolichonyx oryzivorus*)	Unlisted	Meadows, prairies, and wetlands with tall herbaceous vegetation	Conversion of habitat to low-stature crops, early and frequent haying	Eastern Mountains, Northern Mountains, Ruby Mountains
	California spotted owl (*Strix occidentalis occidentalis*)	Unlisted	Dense, multi-storied coniferous forest with large trees	Loss and degradation of habitat from logging and high-severity wildfire; competition from barred owls	Sierra Nevada
	California gull (*Larus californicus*)	Unlisted	Wetlands, lakes, and agricultural areas	Local, unspecified threats	All units
	Caspian tern (*Hydroprogne caspia*)	Unlisted	Lakes, wetlands, and rivers with gravelly beaches	Loss of nesting habitat to disturbance and development	All units
	Canvasback (*Aythya valisineria*)	Unlisted	Marshes, ponds, lakes, and rivers	Loss of habitat from draining and conversion to agriculture	All units

Table B.2 continued.

Group	Species	Federal status	Habitat	Threats	Units
Birds	Clark's grebe (*Aechmophorus clarkii*)	Unlisted	Lakes and wetlands with emergent vegetation; large rivers	Loss of habitat to disturbance and pollution	All units
	Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*)	Unlisted	Riparian areas with deciduous shrubs for feeding, roosting, and escape cover	Degradation of habitat from grazing; forest encroachment on grasslands and shrublands	Northern Mountains
	Common loon (*Gavia immer*)	Unlisted	Lakes and wetlands	Loss and degradation of aquatic habitat from draining, shoreline development, and pollution	All units
	Ferruginous hawk (*Buteo regalis*)	Unlisted	Tall trees or willows along streams for nesting near open areas	Alteration of grassland foraging habitat by agriculture and invasive plants	All units
	Franklin's gull (*Leucophaeus pipixcan*)	Unlisted	Wetlands, lakes, and agricultural areas	Local, unspecified threats	Eastern Mountains, East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada
	Gilded flicker (*Colaptes chrysoides*)	Unlisted	Cactus stands; riparian areas with cottonwoods or other large trees	Small geographic range in U.S.	SMNRA
	Great Basin willow flycatcher (*Empidonax traillii adastus*)	Unlisted	Brushy areas with willows and other shrubs along streams and in wetlands	Loss and degradation of habitat from livestock grazing, dams, and diversions	All units
	Greater sage-grouse (*Centrocercus urophasianus*)	Unlisted	Sagebrush steppe; riparian and wet meadow areas with tall grass, succulent forbs, and insects in the summer	Fragmentation of sagebrush habitat; degradation of habitat by invasive plants, fire, water developments, and grazing	Central Mountains, Eastern Mountains, East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada
	Least bittern (*Ixobrychus exilis*)	Unlisted	Wetlands with tall emergent vegetation	Loss and degradation of habitat from drainage and pollution	Eastern Mountains, SMNRA
	Lewis's woodpecker (*Melanerpes lewis*)	Unlisted	Open forest and woodland habitats, including riparian and post-fire conifer	Loss of large nesting snags following fire suppression and conversion of riparian ecosystems	All units
	Long-billed curlew (*Numenius americanus*)	Unlisted	Dry or moist meadows near water	Conversion of meadow habitats by development or agriculture; pollution	All units

Table B.2 continued.

Group	Species	Federal status	Habitat	Threats	Units
Birds	Long-billed dowitcher (*Limnodromus scolopaceus*)	Unlisted	Ponds, shallow lakes, and wetlands	Loss and degradation of habitat from draining, pollution, and climate change	All units
	Mountain quail (*Oreortyx pictus*)	Unlisted	Areas with tall dense shrubs near water	Loss, degradation, and fragmentation of riparian habitat from woody plant removal and livestock grazing	Central Mountains, East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada
	Northern goshawk (*Accipiter gentilis*)	Unlisted	Dense, multi-storied coniferous or deciduous forest	Timber harvest or other disturbances that reduce stand density and canopy cover	All units
	Northern pintail (*Anas acuta*)	Unlisted	Prairies, wetlands, ponds, and shallow lakes	Loss of prairie nesting habitat	All units
	Olive-sided flycatcher (*Contopus cooperi*)	Unlisted	Forests and woodlands with coniferous trees and large snags; wetlands and burned areas near forest edges	Fire suppression and logging	All units
	Peregrine falcon (*Falco peregrinus*)	Unlisted	Areas where prey concentrate, including marshes, lakeshores and river mouths	Loss of wetland foraging habitat; pollution from pesticides	All units
	Redhead (*Aythya americana*)	Unlisted	Lakes and large wetlands	Drainage of wetland habitats	All units
	Red-necked phalarope (*Phalaropus lobatus*)	Unlisted	Lakes, ponds, and wetlands	Local, unspecified threats	East Sierra, Sierra Nevada
	Ring-billed gull (*Larus delawarensis*)	Unlisted	Wetlands, lakes, and agricultural areas	Local, unspecified threats	All units
	Rufous hummingbird (*Selasphorus rufus*)	Unlisted	Coniferous forests and riparian shrublands	Loss of nesting habitat and nectar-producing shrubs	All units
	Sandhill crane (*Antigone canadensis*)	Unlisted	Areas with shallow water, such as marshes, fens, or wet meadows	Loss and degradation of wetland habitats	All units
	Scott's oriole (*Icterus parisorum*)	Unlisted	Woodlands; yucca and palm stands	Local, unspecified threats	Central Mountains, Eastern Mountains, East Sierra, Ruby Mountains, SMNRA
	Short-eared owl (*Asio flammeus*)	Unlisted	Meadows, wetlands, and other open areas	Conversion of meadows and wetland to agriculture, development, or other vegetation types	All units

Table B.2 continued.

Group	Species	Federal status	Habitat	Threats	Units
Birds	Sierra Nevada willow flycatcher (*Empidonax traillii brewsteri*)	Unlisted	Brushy areas with willows and other shrubs along streams and in wetlands	Loss and degradation of habitat from livestock grazing, dams, and diversions	Sierra Nevada
	Southwestern willow flycatcher (*Empidonax traillii extimus*)	Endangered	Dense, woody riparian vegetation near water or saturated soil	Loss and degradation of riparian nesting habitat from water diversion, groundwater pumping, grazing, and other changes to southwestern streams; fragmentation of populations	Eastern Mountains, SMNRA
	Snowy plover (*Charadrius nivosus*)	Unlisted	Dry mud and sand flats; sandy beaches along streams and lakes	Colonization of open areas by invasive plants; pollution; impoundment of nesting habitat	Central Mountains, Eastern Mountains, East Sierra, Northern Mountains, Sierra Nevada, SMNRA
	Tricolored blackbird (*Agelaius tricolor*)	Unlisted	Emergent wetlands	Loss and fragmentation of habitat from water diversion and conversion to agriculture	East Sierra, Sierra Nevada
	Trumpeter swan (*Cygnus buccinator*)	Unlisted	Ponds and lakes with emergent vegetation	Loss of nesting and winter habitat to development and disturbance	Central Mountains, Eastern Mountains, East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada
	Western grebe (*Aechmophorus occidentalis*)	Unlisted	Lakes and wetlands with emergent vegetation; large rivers	Loss of habitat to disturbance and pollution	All units
	Western sandpiper (*Calidris mauri*)	Unlisted	Shores of lakes and ponds	Local, unspecified threats	All units
	Western yellow-billed cuckoo (*Coccyzus americanus occidentalis*)	Threatened	Deciduous riparian woodland with dense stands of cottonwood, willow, and other woody plants	Loss and degradation of riparian habitat from stream modification, grazing, and invasive plants; fragmentation of populations	Eastern Mountains
	White-faced ibis (*Plegadis chihi*)	Unlisted	Wetlands, ponds, and streams	Reduction in water levels; pollution	All units
	Wilson's phalarope (*Phalaropus tricolor*)	Unlisted	Ponds, shallow lakes, and wetlands	Loss and degradation of wetlands and basin lakes	All units

Table B.2 continued.

Group	Species	Federal status	Habitat	Threats	Units
Birds	Virginia's warbler (*Leiothlypis virginiae*)	Unlisted	Shrublands and woodlands	Local, unspecified threats	All units
	Yuma Ridgway's rail (*Rallus obsoletus yumanensis*)	Endangered	Freshwater marshes containing dense stands of wetland vegetation	Loss and degradation of riparian and wetland habitats from modification of streams for water storage and delivery	SMNRA
Fishes	Ash Meadows pupfish (*Cyprinodon nevadensis mionectes*)	Endangered	Spring pools and channels	Loss of habitat from diversions and groundwater pumping; predation from nonnative species	SMNRA
	Ash Meadows speckled dace (*Rhinichthys osculus nevadensis*)	Endangered	Spring pools and channels	Loss and degradation of habitat from diversions and groundwater pumping	SMNRA
	Big Smoky Valley specked dace (*Rhinichthys osculus lariversi*)	Unlisted	Springs, spring-fed streams, and intermittent streams	Degradation of habitat from livestock grazing, stream diversion, and groundwater pumping; competition and predation by nonnative species	Central Mountains
	Bonytail (*Gila elegans*)	Endangered	Mainstem rivers with deep, swift water, flowing pools, and eddies just outside the main current; flooded bottomland nursery habitat	Loss and fragmentation of habitat from streamflow regulation; competition with and predation by nonnative fishes	SMNRA
	Bull trout (*Salvelinus confluentus*)	Threatened	Riffles and deep pools in cold, clear streams with a variety of cover types and connectivity between summer and winter habitats	Hybridization and competition with brook trout, competition with other nonnative salmonids; reduction of water quality from siltation and stream warming	Northern Mountains
	Clover Valley speckled dace (*Rhinichthys osculus oligoporus*)	Endangered	Springs and spring-fed streams	Alteration of springs and streams for irrigation; predation by nonnative species	Ruby Mountains
	Colorado pikeminnow (*Ptychocheilus lucius*)	Endangered	Medium to large rivers with deep turbid strongly flowing water, eddies, runs, and flooded bottoms or backwaters	Loss of channel and floodplain habitat; changes in flow and water temperature; blockage of migration routes by dams and reservoirs	SMNRA

Table B.2 continued.

Group	Species	Federal status	Habitat	Threats	Units
Fishes	Cui-ui (*Chasmistes cujus*)	Endangered	Shallow portions of Pyramid Lake; spawning sites at gravel bars in shallow, fast-moving reaches of the Truckee River	Loss and degradation of spawning habitat in the Truckee River from water diversions, siltation, and pollution	Sierra Nevada
	Devil's Hole pupfish (*Cyprinodon diabolis*)	Endangered	A deep limestone pool with algae-covered ledges	Restricted to a single pool; vulnerable to pollution and reduction in water level	SMNRA
	Diamond valley speckled dace (*Rhinichthys osculus* ssp. 10)	Unlisted	Springs and spring-fed streams	Local, unspecified threats	Central Mountains
	Flannelmouth sucker (*Catostomus latipinnis*)	Unlisted	Rocky pools, runs, riffles, and backwaters of medium to large streams	Competition and predation by nonnative species; loss of connectivity; changes in stream characteristics	SMNRA
	Hiko White River springfish (*Crenichthys baileyi grandis*)	Endangered	Springs and spring-fed streams	Loss and degradation of habitat from irrigation alterations and grazing; competition and predation from nonnative species	Eastern Mountains
	Humpback chub (*Gila cypha*)	Threatened	Deep, turbulent currents, pools, shaded areas, riffles, and eddies in large rivers	Loss, fragmentation, and degradation of habitat by dams; competition and predation by nonnative fishes	SMNRA
	Independence Valley speckled dace (*Rhinichthys osculus lethoporus*)	Endangered	Springs; spring-fed streams and wetlands	Small, isolated population vulnerable to groundwater pumping, pollution, wildfire, and nonnative species	Ruby Mountains
	Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*)	Threatened	Basin lakes; mountain lakes; small and large streams with gravel spawning substrate, pools, and vegetated banks	Loss of access to spawning grounds from dams and diversions; degradation of spawning habitat from grazing, roads, mining, timber harvest, and wildfire; degradation of lake habitat from pollution and stream diversions; competition and predation from nonnative species	Central Mountains, Eastern Mountains, East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada
	Monitor valley speckled dace (*Rhinichthys osculus* ssp. 5)	Unlisted	Freshwater streams	Restricted habitat vulnerable to groundwater pumping, pollution, wildfire, and nonnative species	Central Mountains

Table B.2 continued.

Group	Species	Federal status	Habitat	Threats	Units
Fishes	Moorman White River springfish (*Crenichthys baileyi thermophilus*)	Unlisted	Freshwater streams	Restricted habitat vulnerable to groundwater pumping, pollution, wildfire, and nonnative species	Eastern Mountains
	Mountain whitefish (*Prosopium williamsoni*)	Unlisted	Mountain lakes; streams with riffles and large pools	Local, unspecified threats	East Sierra, Sierra Nevada
	Northern leatherside chub (*Lepidomeda copei*)	Unlisted	Pools and backwaters with complex stream velocities; small to medium rivers with overhanging vegetation; beaver ponds	Degradation of habitat from water diversions, dams, and siltation; predation by nonnative species	Northern Mountains
	Oasis Valley speckled dace (*Rhinichthys osculus* ssp. 6)	Unlisted	Freshwater streams	Local, unspecified threats	SMNRA
	Pahranagut roundtail chub (*Gila robusta jordani*)	Endangered	Thermal springs and spring-fed streams	Loss of habitat from diversions and groundwater pumping; alteration of stream channels for irrigation; predation from nonnative species	Eastern Mountains
	Pahranagat speckled dace (*Rhinichthys osculus velifer*)	Unlisted	Springs and spring-fed streams	Competition and predation from nonnative species; loss and degradation of habitat from stream diversion, groundwater pumping, and drought	Eastern Mountains
	Pahranagat spinedace (*Lepidomeda altivelis*)	Unlisted	Springs and spring-fed streams	Competition and predation from nonnative species; possibly extinct	Eastern Mountains
	Pahrump poolfish (*Empetrichthys latos*)	Endangered	Shallow warm-water springs and spring-fed streams	Loss of aquatic habitat from groundwater pumping; competition and predation by nonnative species	Eastern Mountains, SMNRA
	Paiute cutthroat trout (*Oncorhynchus clarkii seleniris*)	Threatened	Meadow streams with pools, overhanging banks, riparian vegetation, and clean gravel for spawning	Competition and predation from nonnative species; degradation of habitat from grazing and wildfire	Sierra Nevada
	Preston White River springfish (*Crenichthys baileyi albivallis*)	Unlisted	Freshwater streams	Restricted habitat vulnerable to groundwater pumping, pollution, wildfire, and nonnative species	Eastern Mountains

Table B.2 continued.

Group	Species	Federal status	Habitat	Threats	Units
Fishes	Railroad valley springfish (*Crenichthys nevadae*)	Threatened	Springs and spring-fed streams	Loss of aquatic habitat from stream diversion and groundwater pumping; degradation of habitat from grazing; competition and predation by nonnative species	Central Mountains, Eastern Mountains
	Razorback sucker (*Xyrauchen texanus*)	Endangered	Deep runs, eddies, backwaters, and flooded off-channel environments; streams without barriers to long-distance movements	Loss and degradation of habitat from dams; loss of connectivity; predation by nonnative fishes	SMNRA
	Relict dace (*Relictus solitarius*)	Unlisted	Lakes, springs, spring-fed streams, and wetlands	Loss and degradation of habitat from grazing and diversions; predation by nonnative species	Eastern Mountains, Ruby Mountains
	Warm Springs Amargosa pupfish (*Cyprinodon nevadensis pectoralis*)	Endangered	Thermal springs	Groundwater pumping; predation by nonnative species	SMNRA
	White River desert sucker (*Catostomus clarkii intermedius*)	Unlisted	Freshwater streams	Restricted habitat vulnerable to groundwater pumping, pollution, wildfire, and nonnative species	Eastern Mountains
	White River speckled dace (*Rhinichthys osculus* ssp.7)	Unlisted	Freshwater streams and springs	Local, unspecified threats	Eastern Mountains
	White River spinedace (*Lepidomeda albivallis*)	Endangered	Springs and spring-fed streams with aquatic and riparian vegetation	Loss and degradation of habitat from stream diversion and groundwater pumping; competition and predation by nonnative species	Eastern Mountains
	White River springfish (*Crenichthys baileyi*)	Unlisted	Thermal springs and spring-fed streams	Competition and predation from nonnative species; loss and degradation of habitat from stream diversion, groundwater pumping, and grazing	Eastern Mountains
Mammals	Allen's big-eared bat (*Idionycteris phyllotis*)	Unlisted	Wooded canyons; riparian woodlands and shrublands near streams or ponds	Disturbance or loss of roosts and nursery sites in caves or large pine snags	SMNRA

Table B.2 continued.

Group	Species	Federal status	Habitat	Threats	Units
Mammals	Brazilian free-tailed bat (*Tadarida brasiliensis*)	Unlisted	Shrublands, woodlands, and forests	Disturbance of roosts, loss of food supply from pollution and drought	Central Mountains, Eastern Mountains, East Sierra, Ruby Mountains, Sierra Nevada, SMNRA
	California leaf-nosed bat (*Macrotus californicus*)	Unlisted	Lowland desert scrub and rocky canyons	Disturbance or loss of roosts; loss of riparian habitat to development; pollution	SMNRA
	Dusky shrew (*Sorex monticola*)	Unlisted	Wet meadows and fens surrounded by coniferous forest	Local, unspecified threats	Central Mountains, Eastern Mountains, East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada
	Fisher (*Pekania pennanti*)	Unlisted	Coniferous, deciduous, and mixed forests	Overtrapping; timber harvest	East Sierra, Sierra Nevada
	Fringed myotis (*Myotis thysanodes*)	Unlisted	Forests, woodlands, grasslands, and riparian areas; roost sites in cliffs, caves, and large pine snags	Disturbance of roost sites; degradation of aquatic and riparian habitats	All units
	Hoary bat (*Lasiurus cinereus*)	Unlisted	Forests and woodlands with foraging spaces over open water	Loss of forest habitat; pollution, wind turbine collisions	All units
	Inyo shrew (*Sorex tenellus*)	Unlisted	River bottoms and canyons with logs, sagebrush scrub, and coniferous trees	Local, unspecified threats	Central Mountains, Eastern Mountains, East Sierra, Sierra Nevada
	Little brown myotis (*Myotis lucifugus*)	Unlisted	Roosting sites in caves and large trees; foraging sites in woodlands near open water	Disease; wind turbine collisions; loss of forest habitat; pollution	All units
	Long-eared myotis (Myotis evotis)	Unlisted	Forests, shrublands and meadows; streams and other waterbodies	Disturbance to roost sites; loss of large roost trees	All Units
	Sierra Nevada mountain beaver (*Aplodontia rufa californica*)	Unlisted	Springs in canyon and ravines; streamside woodlands	Loss or degradation of habitat from stream diversions and invasive plants	Sierra Nevada
	North American river otter (*Lontra canadensis*)	Unlisted	Streams, lakes, ponds, swamps, or marshes with roots, logs, overhangs, abandoned beaver lodges, dense thickets, or burrows of other animals	Unregulated fur-trapping; degradation of aquatic and riparian habitats	East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada

Table B.2 continued.

Group	Species	Federal status	Habitat	Threats	Units
Mammals	Northern flying squirrel (*Glaucomys sabrinus*)	Unlisted	Coniferous and mixed forests near streams and wetlands	Local, unspecified threats	East Sierra, Sierra Nevada
	Pacific marten (*Martes caurina*)	Unlisted	Coniferous forest with large trees, snags, stumps, and down wood	Fur-trapping and timber harvest	East Sierra, Sierra Nevada
	Pahranagat Valley vole (*Microtus montanus fucosus*)	Unlisted	Wet meadows near streams and lakes	Local, unspecified threats	Eastern Mountains
	Preble's shrew (*Sorex preblei*)	Unlisted	Shrub and grass associations including willow stands and marshes	Local, unspecified threats	Northern Mountains, Ruby Mountains
	Silver-haired bat (*Lasionycteris noctivagans*)	Unlisted	Coniferous forest near lakes, ponds, and streams	Wind turbine collisions; timber harvest; pollution	All units
	Spotted bat (*Euderma maculatum*)	Unlisted	Canyon bottoms and riparian corridors with open areas for foraging	Loss and degradation of foraging habitat from grazing, timber harvest, and pesticides; inundation of cliff roosts behind dams	All units
	Pahranagat Valley vole (*Microtus montanus fucosus*)	Unlisted	Wet meadows near streams and lakes	Local, unspecified threats	Eastern Mountains
	Townsend's big-eared bat (*Corynorhinus townsendii*)	Unlisted	Mesic habitats characterized by coniferous and deciduous forests	Disturbance or destruction of roost sites; pesticides	All units
	Western jumping mouse (*Zapus princeps*)	Unlisted	Meadows, marshes, and herbaceous riparian areas	Local, unspecified threats	Central Mountains, Eastern Mountains, East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada
	Western red bat (*Lasiurus blossevillii*)	Unlisted	Lowland riparian forests with oaks, cottonwoods, or other deciduous trees	Loss and degradation riparian habitat from water diversions, dams, and agricultural conversion; pesticides	Central Mountains, Eastern Mountains, East Sierra, Sierra Nevada, SMNRA
	Western small-footed myotis (*Myotis ciliolabrum*)	Unlisted	Forests, shrublands, and woodlands, often near streams	Loss and degradation of woodland and shrubland foraging habitat from grazing and stream alteration	All units

Table B.2 continued.

Group	Species	Federal status	Habitat	Threats	Units
Mammals	Western water shrew (*Sorex navigator*)	Unlisted	Streams and ponds lined with dense overhanging riparian vegetation	Stream diversions and water pollution	Central Mountains, Eastern Mountains, East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada
Reptiles	Arizona mountain kingsnake (*Lampropeltis pyromelana*)	Unlisted	Woody vegetation types near streams and springs; rocky canyons	Local, unspecified threats	Eastern Mountains, Ruby Mountains
	California kingsnake (*Lampropeltis californiae*)	Unlisted	Forests, riparian woodlands, shrublands, and wetlands	Conversion of habitat to agriculture and development	Central Mountains, Eastern Mountains, East Sierra, Ruby Mountains, Sierra Nevada, SMNRA
	Desert spiny lizard (*Sceloporus magister*)	Unlisted	Shrublands and woodlands	Local, unspecified threats	All units
	Gila monster (*Heloderma suspectum*)	Unlisted	Canyon bottoms and arroyos	Conversion of habitat to agriculture and development; dispersal barriers such as roads	Central Mountains, Eastern Mountains, East Sierra, Ruby Mountains, Sierra Nevada, SMNRA
	Long-nosed snake (*Rhinocheilus lecontei*)	Unlisted	Woodlands, shrublands, and grasslands	Loss of habitat to agricultural and urban development	Central Mountains, Eastern Mountains, East Sierra, Northern Mountains, Sierra Nevada
	North American racer (*Coluber constrictor*)	Unlisted	A variety of vegetation types in riparian corridors	Conversion of habitat to agriculture	All units
	Norther rubber boa (*Charina bottae*)	Unlisted	Woodlands, shrublands, and canyons with down wood and litter	Local, unspecified threats	Central Mountains, Eastern Mountains, East Sierra, Northern Mountains, Ruby Mountains, Sierra Nevada
	Northwestern pond turtle (*Actinemys marmorata*)	Unlisted	Lakes, ponds, and streams with adjacent open areas for nest sites	Loss and degradation of wetland and riparian habitats; predation and competition from nonnative species	Sierra Nevada
	Ring-necked snake (*Diadophis punctatus*)	Unlisted	Streamside areas and other seasonally wet habitats	Local, unspecified threats	Eastern Mountains, Northern Mountains, SMNRA

Table B.2 continued.

Group	Species	Federal status	Habitat	Threats	Units
Reptiles	Sierra alligator lizard (*Elgaria coerulea palmeri*)	Unlisted	Forest and woodland edges; areas near streams	Local, unspecified threats	East Sierra, Sierra Nevada
	Smith's black-headed snake (*Tantilla hobartsmithi*)	Unlisted	Shrublands and woodlands	Local, unspecified threats	Eastern Mountains, SMNRA
	Western threadsnake (*Rena humilis*)	Unlisted	Deserts, grasslands, shrublands, canyon, and areas near streams and springs	Local, unspecified threats	Eastern Mountains, SMNRA

References

Manning, M.E.; Padgett, W.G. 1995. Riparian community type classification for Humboldt and Toiyabe National Forests, Nevada and eastern California. R4-Ecol-95-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 306 p.

Weixelman, D.A.; Zamudio, D.C.; Zamudio, K.A. 1996. Central Nevada riparian field guide. Sparks, NV: U.S. Department of Agriculture, Forest Service, Intermountain Region. 270 p.

Weixelman, D.A.; Zamudio, D.C.; Zamudio, K.A.; [et al.]. 1997. Classifying ecological types and evaluating site degradation. Journal of Range Management. 50(3): 315-321.

APPENDIX C. Distribution of Riparian and Groundwater-Dependent Ecosystems in Geographic Units of the Humboldt-Toiyabe National Forest

Methods

We mapped the distribution and extent of riparian ecosystems using several sources of spatial data. Existing vegetation shapefiles (FS VEG) were constructed using three datasets: one developed by the USFS for the East Sierra and Sierra Nevada units, one developed for the Spring Mountains National Recreation area (SMNRA), and one developed for the remaining units. These maps were generated by applying automated classification techniques to remotely sensed imagery to identify vegetation types (Nelson et al. 2015). The Map of Riparian Vegetation in Nevada (MARVN) shapefile was generated by the Desert Research Institute. This map shows potential riparian areas, identified using normalized difference vegetation index (NDVI) to distinguish riparian vegetation from adjacent upland vegetation (McGwire 2019). The LANDFIRE LF Remap Existing Vegetation Type (EVT) raster was created using predictive landscape models based on field-referenced data, satellite imagery, and biophysical gradient layers using classification and regression trees (LANDFIRE). We also obtained shapefiles displaying the distribution of meadows in the Central Mountains geographic unit (Trowbridge et al. 2011) and the East Sierra and Sierra Nevada geographic units Nevada (Viers et al. 2013).

We used several sources of data to map the distribution of GDEs in each geographic unit. We created a shapefile of spring locations using data we received from the Spring Stewardship Institute. To map fens, we obtained a shapefile of potential fens generated by the Colorado Natural History Program (CNHP). Using National Wetland Inventory Data and aerial imagery, CNHP staff located wetlands that are potential fens and classified them as likely fens, possible fens, or low confidence fens based on the number of fen-like characteristics they observed (Smith and Lemly 2019). We obtained shapefiles representing hydrogeology of California and Nevada (Horton et al. 2017) to map geological drivers of GDEs. To standardize geological descriptions, we reclassified geologic units following the methods of Maurer et al. (2004).

Below are descriptions of riparian and GDE distribution for geographic units and areas within the units.

Unit Summaries

Central Mountains

This geographic unit consists of four areas that we summarized separately.

Monitor-Hot Creek area

The Monitor-Hot Creek area consists of the Monitor Range, a portion of the Hot Creek Range, and the Little Fish Lake Valley separating the two. Both ranges contain large amounts of extrusive igneous rocks, with clastic, carbonate, and metamorphic rocks, primarily quartzite, present as well (fig. C.1). extrusive igneous rocks are mostly

volcanic breccia or tuff (89 percent). All portions of this unit are connected with Basin and Range basin-fill aquifers. The western portion of the unit is also part of a Basin and Range carbonate-rock aquifer system.

Vegetation classification indicates that riparian ecosystems cover 0.4 percent (LANDFIRE) to 0.8 percent (FS VEG) of this area. Based on MARVN results, riparian ecosystems cover 1.1 percent. In addition to these mapping programs, Trowbridge et al. (2011) mapped 97.3 meadow acres in this area. Large amounts of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, were mapped in the Little Fish Lake Valley, Hunts Canyon, and several streams in the Monitor Range (fig. C.2).

There are 452 springs mapped by SSI in this area (0.0005/acre). Springs are clustered at heavily faulted portions of the Hot Creek Range and in tuffaceous deposits of the Monitor Range. Trowbridge et al. (2011) mapped 109 springs in riparian meadows. The CNHP identified 0.041 percent of the area as potential fens, with 198.4 acres of low confidence fens, 149.9 acres of possible fens, and 10.9 acres of likely fens. Most of these wetlands are in the Monitor Range and Little Fish Lake Valley. There are potential valley bottom fens in Little Fish Lake Valley and along several streams including Butler Creek, Hunts Creek, Tulle Creek, and Wadsworth Creek.

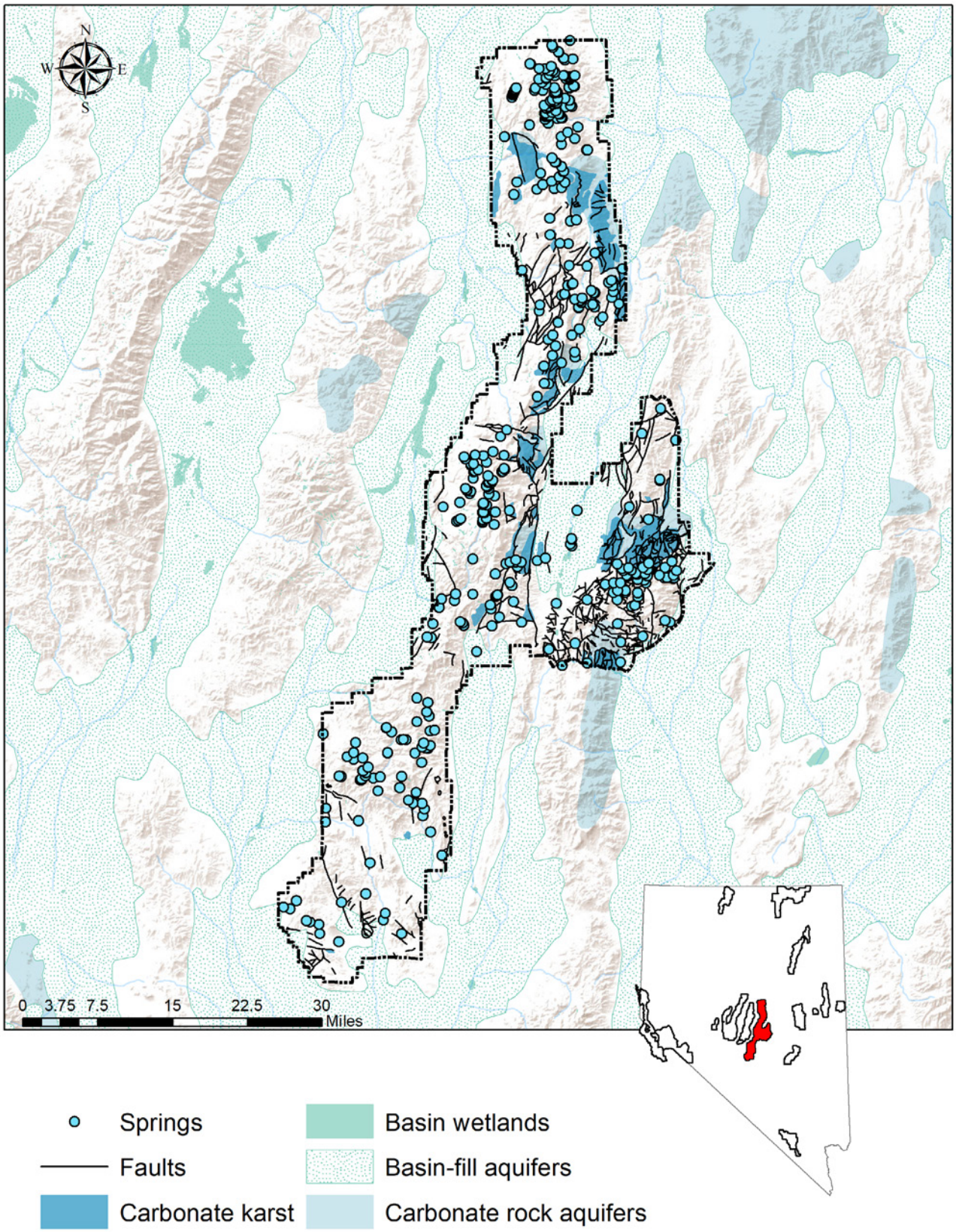


Figure C.1—Distribution of aquifers, faults, karst, and springs in the Monitor-Hot Creek area of the Central Mountains geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

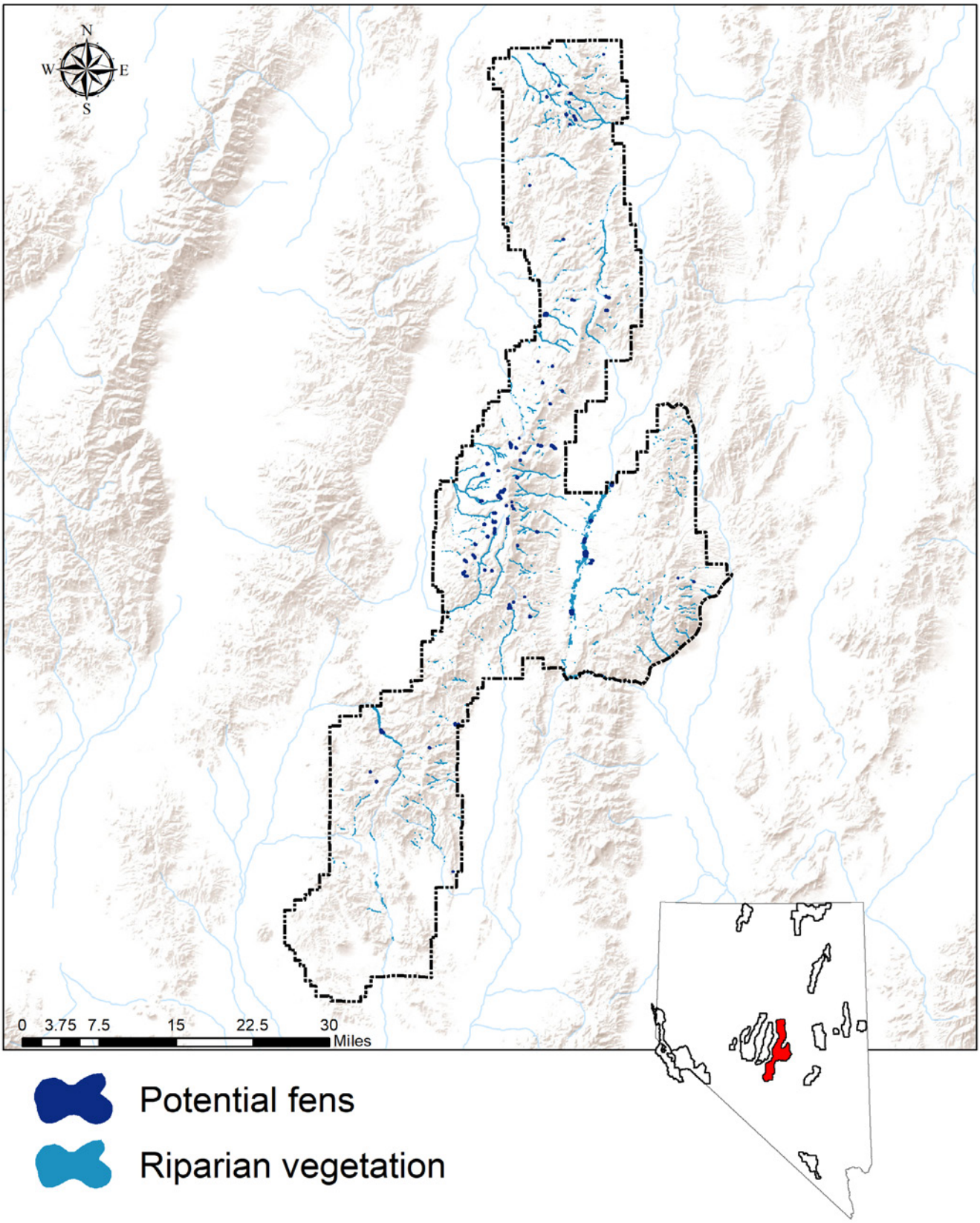


Figure C.2—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the Monitor-Hot Creek area of the Central Mountains geographic unit of the Humboldt-Toiyabe National Forest.

Paradise area

This area consists of the Paradise Range, which is largely composed of carbonate sedimentary rocks and extrusive igneous rocks. Clastic rocks and intrusive granitic rocks are present as well (fig. C.3). Extrusive igneous rocks are mostly volcanic breccia or tuff (82 percent) and andesite (16 percent). Portions of this unit are connected with Basin and Range basin-fill aquifers.

Vegetation classification indicates that riparian ecosystems cover 0.04 percent (FS VEG) to 0.1 percent (LANDFIRE) of this area. Based on MARVN results, riparian ecosystems cover 0.3 percent of the area. Large amounts of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, are in Lebeau Park and Cottonwood Canyon (fig. C.4).

There are 39 mapped springs (0.0006/acre), which are scattered throughout the unit. The largest cluster is in volcanic deposits. The CNHP identified 0.001 percent of the area as potential fens, with 0.6 acres of low confidence fens, 0 acres of possible fens, and 0 acres of likely fens. The low confidence fens are associated with springs in carbonate and volcanic rocks in the northern portion. There are potential valley bottom fens in Lebeau Park.

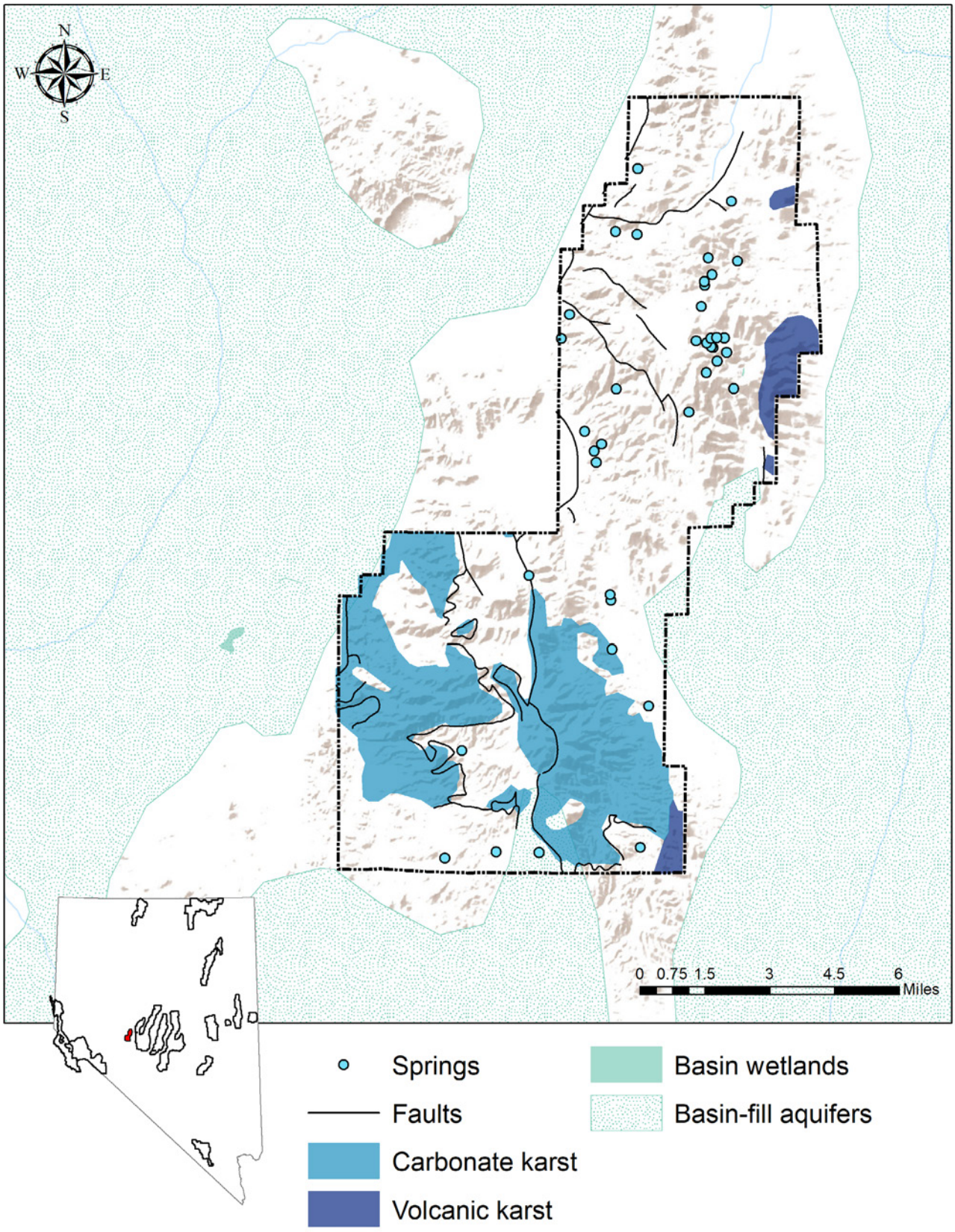


Figure C.3—Distribution of aquifers, faults, karst, and springs in the Paradise area of the Central Mountains geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

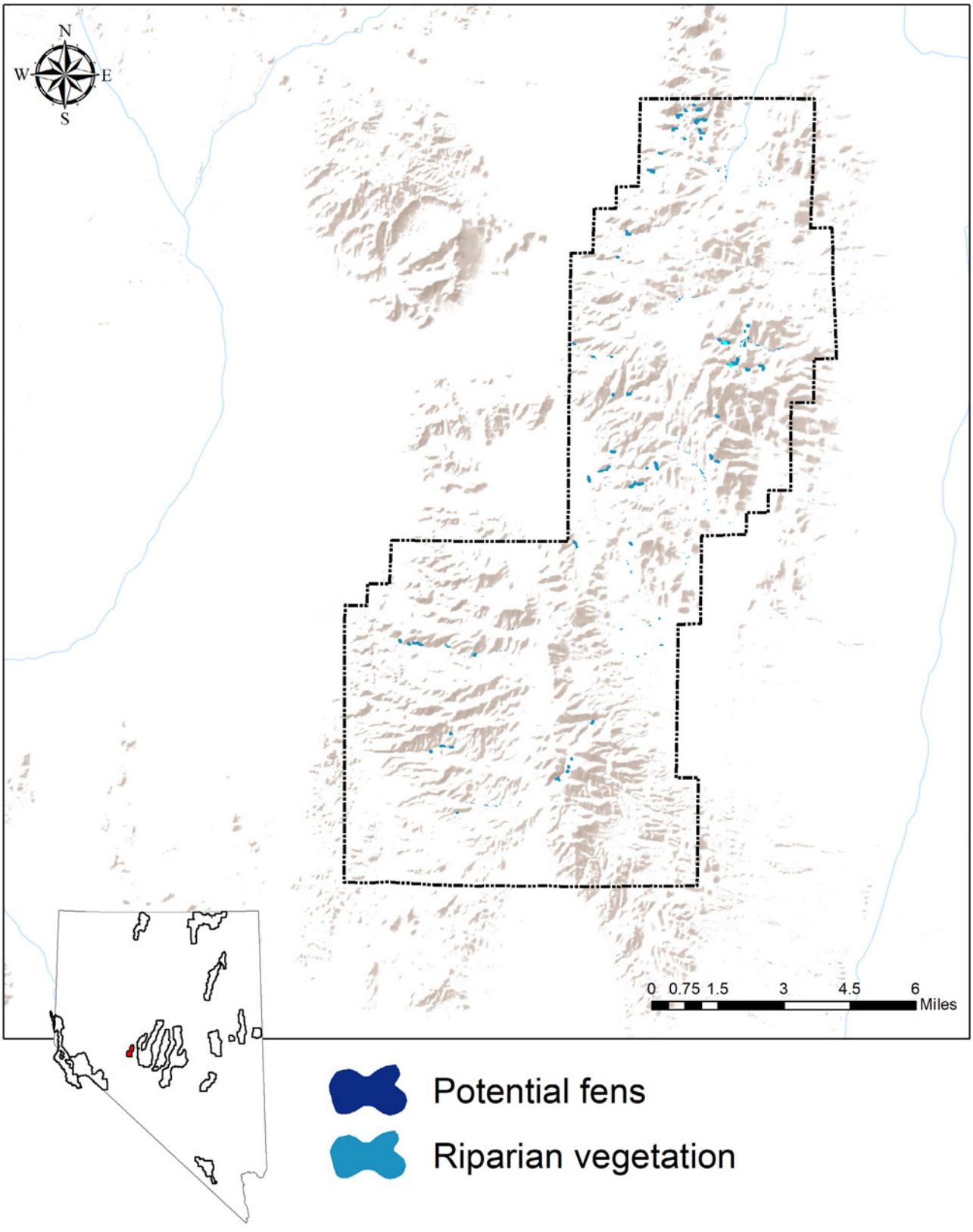


Figure C.4—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the Paradise area of the Central Mountains geographic unit of the Humboldt-Toiyabe National Forest.

Toiyabe-Shoshone area

Features include the Toiyabe Range, the Shoshone Mountains, Indian Valley, and Dry Canyon. The Shoshone Mountains and the southern end of the Toiyabe Range are largely composed of extrusive igneous rocks. The northern portion of the Toiyabe Range contains carbonate sedimentary, clastic sedimentary, intrusive granitic, metamorphic, and extrusive igneous rocks (fig. C.5). Extrusive igneous rocks are mostly breccia or tuff (91 percent). All portions of this unit are connected with Basin and Range basin-fill aquifers.

Vegetation classification indicates that riparian ecosystems cover 0.8 percent (LANDFIRE EVT) to 1.5 percent (FS VEG) of this area. Based on MARVN results, riparian ecosystems cover 1.9 percent of the area. Trowbridge et al. (2011) mapped 227.9 meadow acres in the area. Large amounts of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, are in Indian Valley and along the Reese River and its tributaries, Barney Meadows Creek, and Bade Creek in Grass Valley (fig. C.6).

There are 692 springs (0.0009/acre) mapped by SSI. These springs are distributed throughout the area, with the largest clusters in volcanic deposits in the southern portion. Trowbridge et al. (2011) mapped 100 springs in riparian meadows. The CNHP identified 0.013 percent of the area as potential fens, with 80.5 acres of low confidence fens, 18.3 acres of possible fens, and 0 acres of likely fens. Most of these wetlands are associated with volcanic deposits of the Toiyabe Range. There are potential valley bottom fens in Johnson Canyon and along several streams including Cloverdale Creek, Indian Creek, Kingston Creek, and Marysville Creek.

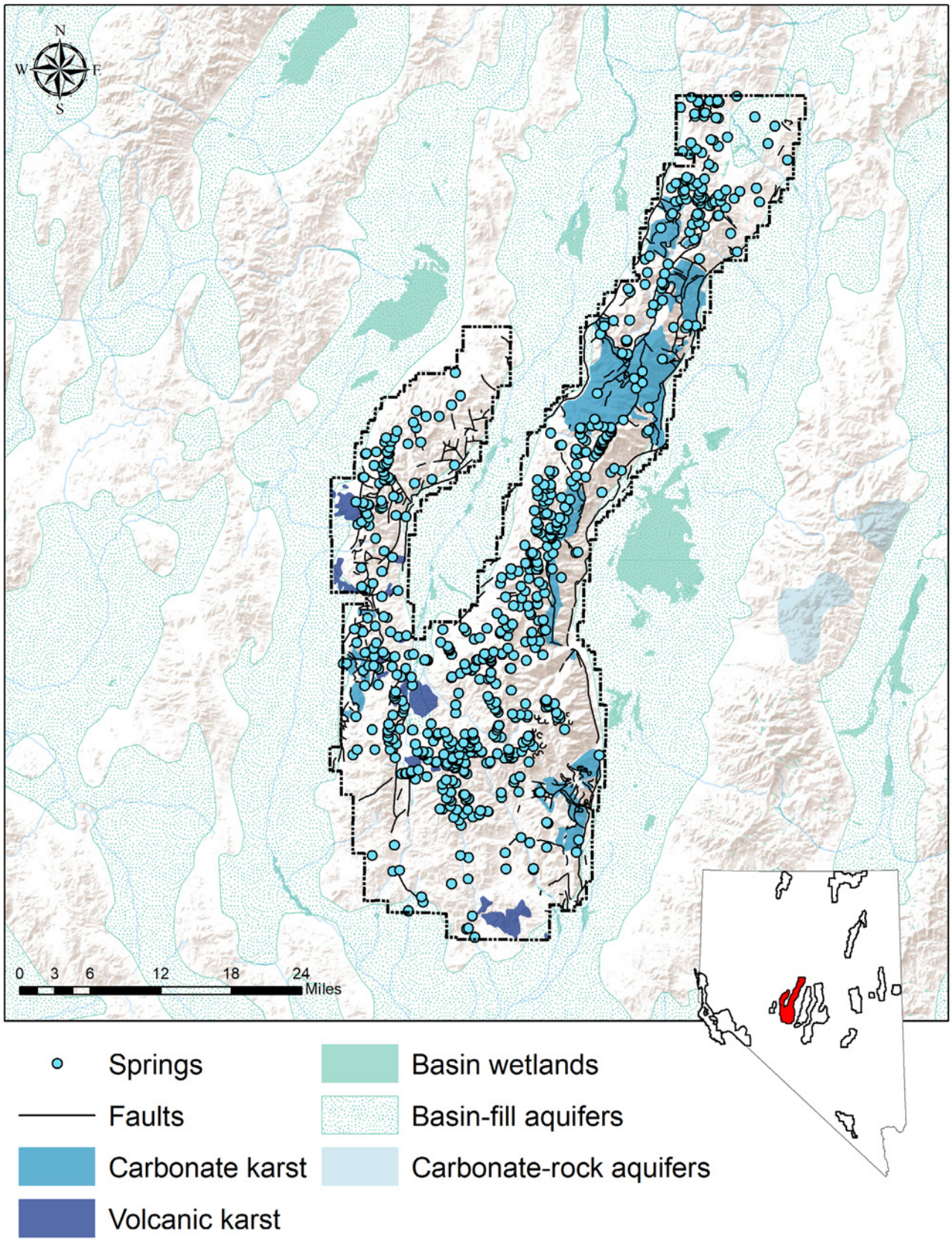


Figure C.5—Distribution of aquifers, faults, karst, and springs in the Toiyabe-Shoshone area of the Central Mountains geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

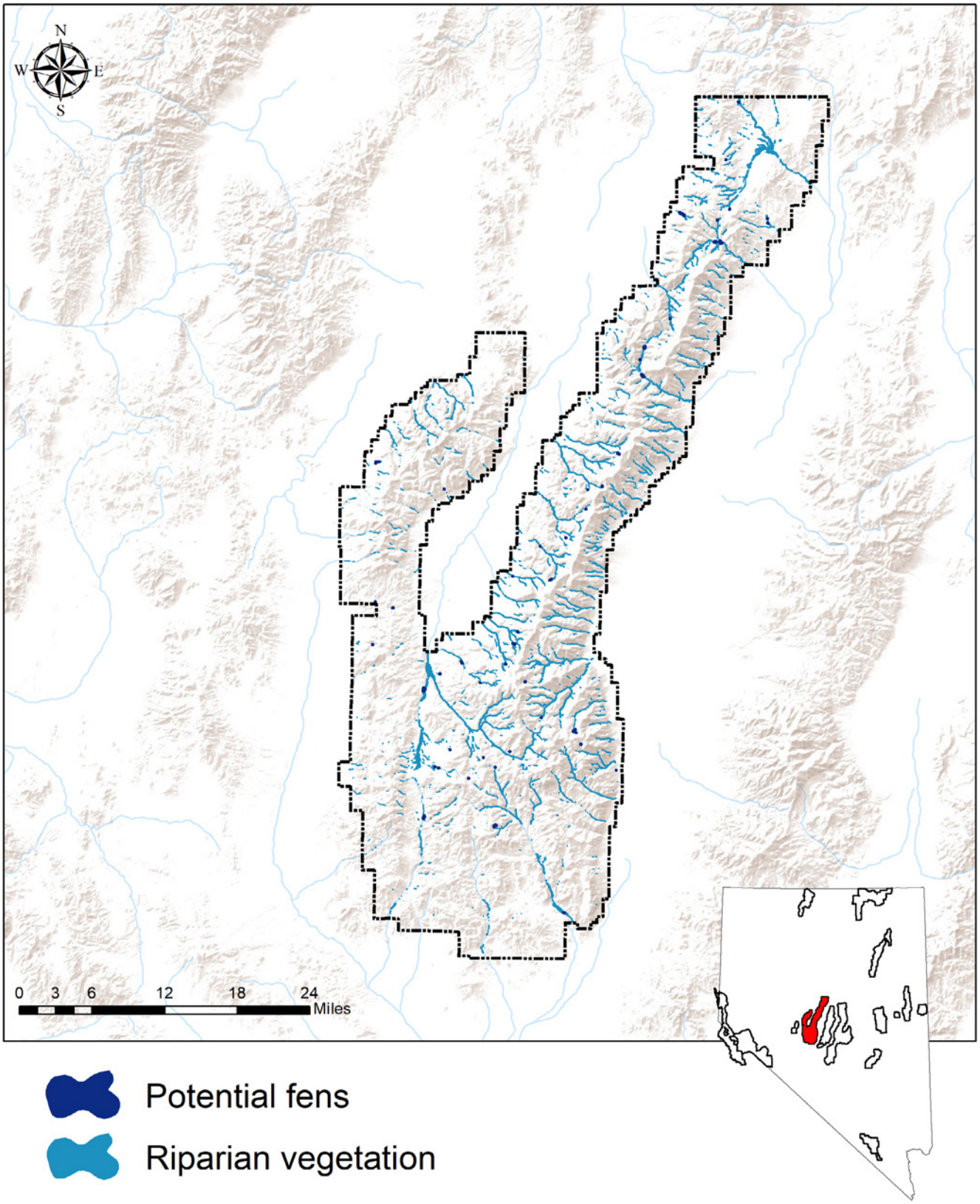


Figure C.6—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the Toiyabe-Shoshone area of the Central Mountains geographic unit of the Humboldt-Toiyabe National Forest.

Toquima area

This area consists of the Toquima range, composed mostly of extrusive igneous rocks, with granitic, metamorphic, carbonate, and clastic rocks present as well (fig. C.7). Extrusive igneous rocks are mostly breccia or tuff (97 percent). This unit is connected with Basin and Range basin-fill aquifers.

Vegetation classification indicates that riparian ecosystems cover 0.3 percent (LANDFIRE) to 0.6 percent (FS VEG) of this area. Based on MARVN results, riparian ecosystems cover 1.1 percent of the area. Trowbridge et al. (2011) mapped 81.4 meadow acres in the area. Large amounts of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, are along Stoneberger Creek and several streams draining the southern end of the Toquima Range (fig. C.8).

There are 269 mapped springs (0.0006/acre), which are distributed throughout the area. The largest cluster is in volcanic deposits near the southern end of the range. Trowbridge et al. (2011) mapped 79 springs in riparian meadows.

The CNHP identified 0.010 percent of the area as potential fens, with 36.1 acres of low confidence fens, 5.9 acres of possible fens, and 3.3 acres of likely fens. These wetlands occur in a variety of geological types, with most in volcanic deposits. There are potential valley bottom fens along several streams including Anderson Creek, Barker Creek, Corcoran Creek, Meadow Creek, Moores Creek, and Stoneberger Creek.

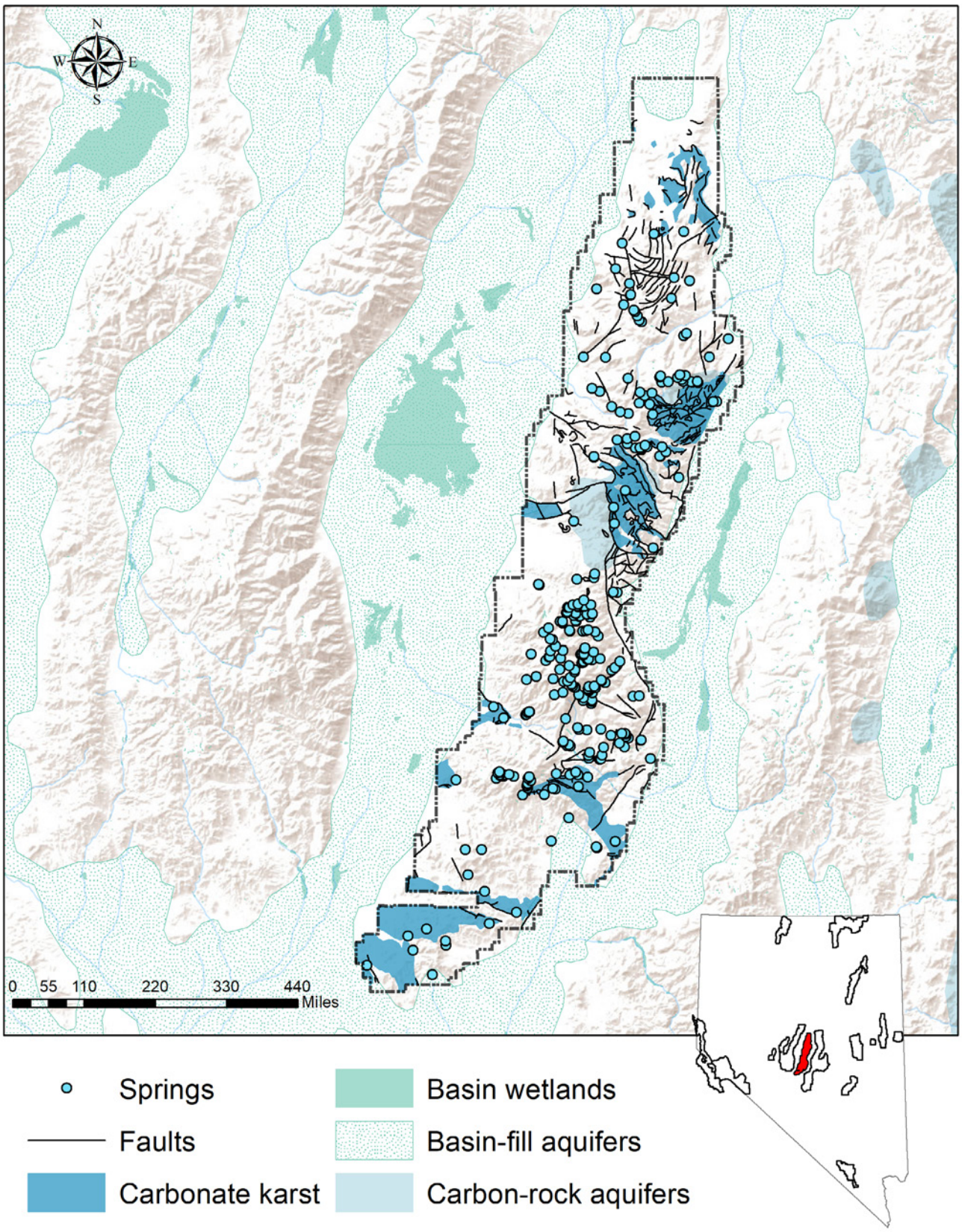


Figure C.7—Distribution of aquifers, faults, karst, and springs in the Toquima area of the Central Mountains geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

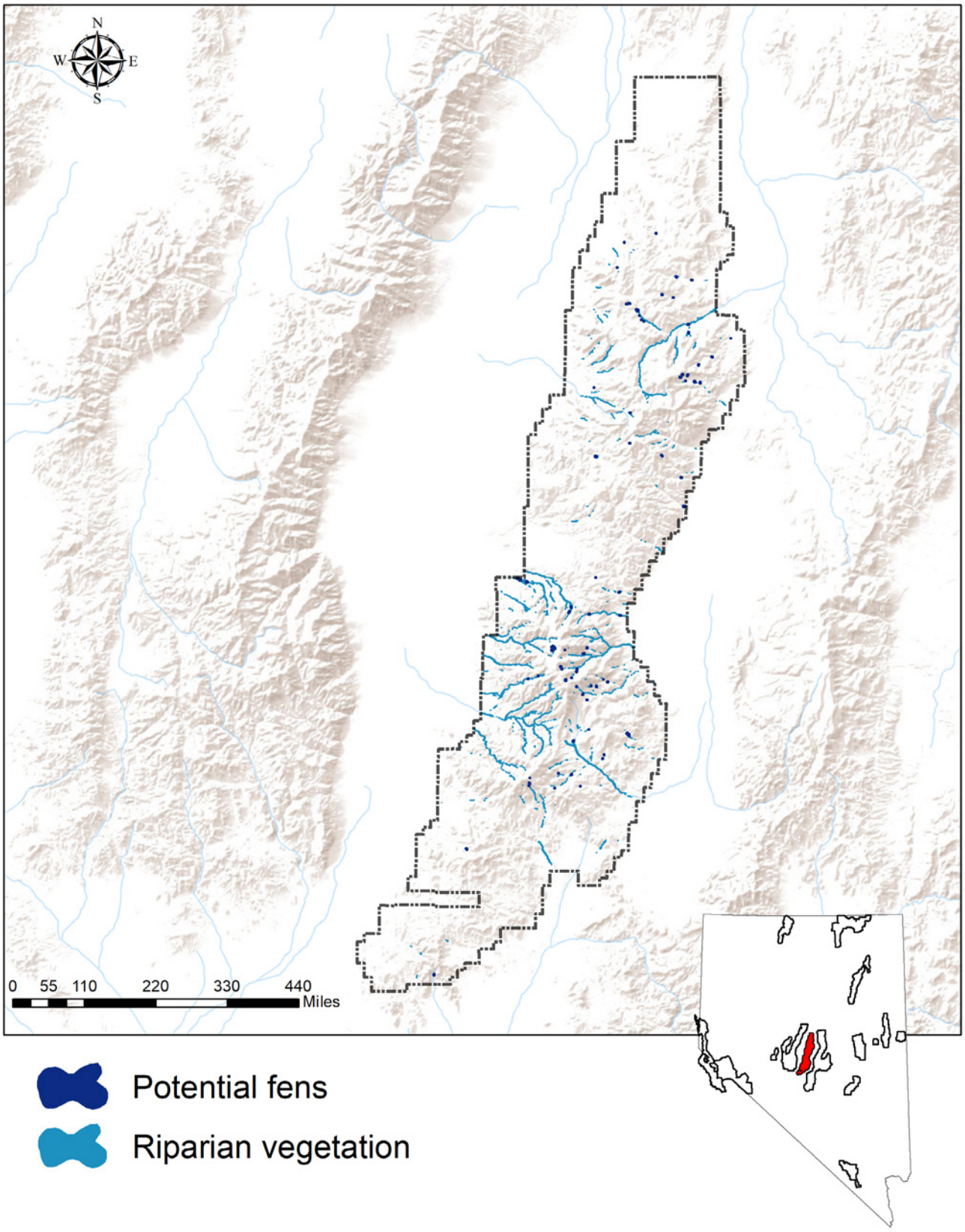


Figure C.8—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the Toquima area of the Central Mountains geographic unit of the Humboldt-Toiyabe National Forest.

East Sierra

Features in this geographic unit include the East Walker River in Antelope Valley, the East Walker River, Desert Creek, Rough Creek, the Sweetwater Mountains, Pine Grove Hills, and the southern end of the Wassuk Range. The mountain ranges are primarily composed of extrusive and intrusive igneous rocks (fig. C.9). Extrusive igneous rocks are mostly andesitic (68 percent) with basaltic (19 percent), rhyolitic (6 percent), and breccia/tuffaceous rocks (5 percent) present as well. This unit is connected with Basin and Range basin-fill aquifers.

Vegetation classification indicates that riparian ecosystems cover 0.6 percent (FS VEG) to 0.8 percent (LANDFIRE) of this geographic unit. Based on MARVN results, riparian ecosystems cover 1 percent of the portion in Nevada. The Sierra Nevada Meadows Project (Viers et al. 2013) mapped 41.2 meadow acres in the unit (fig. C.10).

Areas with large amounts of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, include the East Walker River, West Walker River, Upper Desert Creek, Rough Creek, and Dalzell Canyon.

There are 148 springs (0.0002/acre) mapped by the SSI. Springs are scattered across the unit, with clusters associated with the Wassuck Range in eastern portion and with faults in the western portion. The CNHP identified 0.027 percent of the unit as potential fens, with 184.0 acres of low confidence fens, 45.8 acres of possible fens, and 3.9 acres of likely fens. Most of these wetlands are in the Sweetwater Range, with others in the Pine Grove Hills. There are potential valley bottom fens along streams including Fryingpan Creek, Murphy Creek, and Rough Creek.

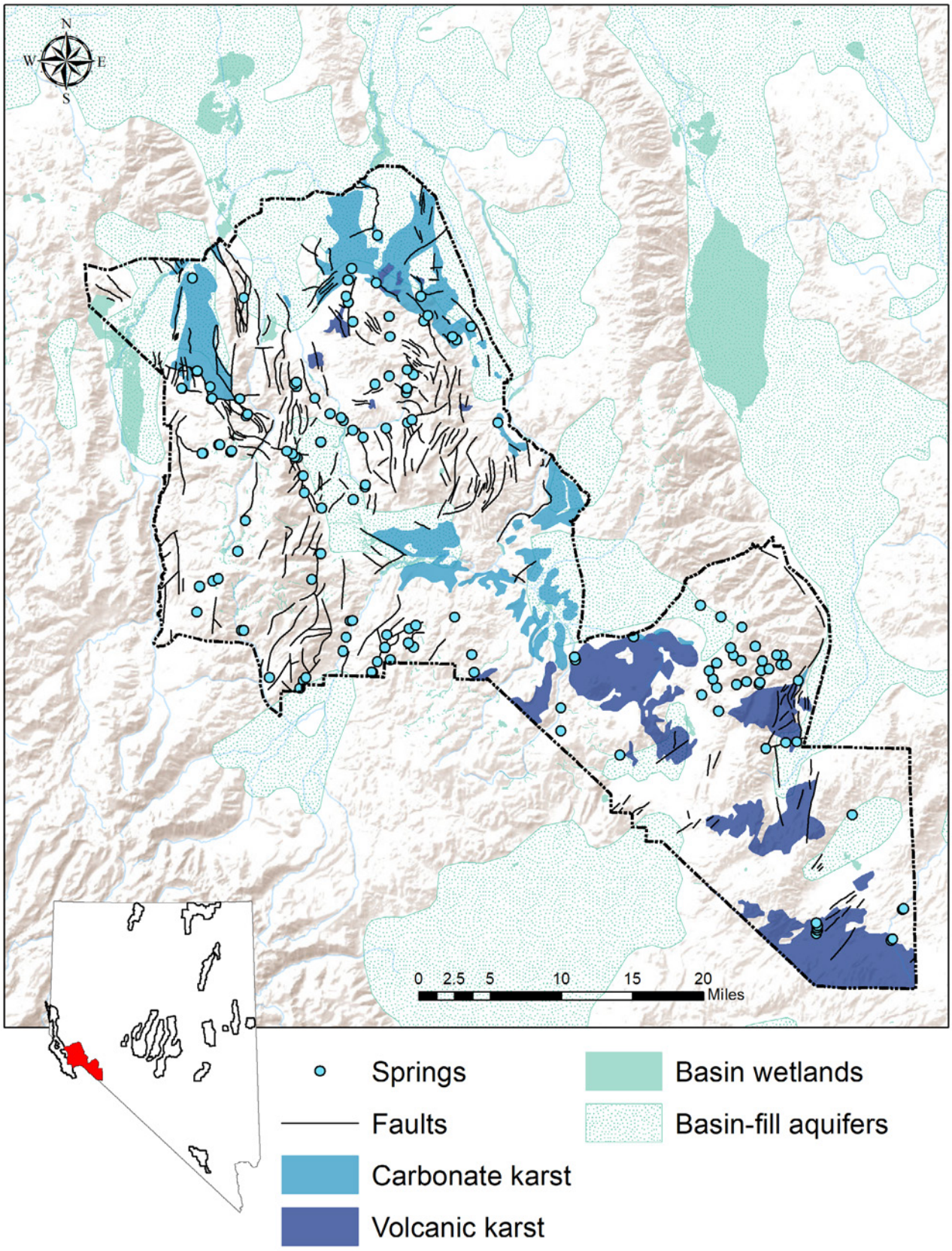


Figure C.9—Distribution of aquifers, faults, karst, and springs in the East Sierra geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

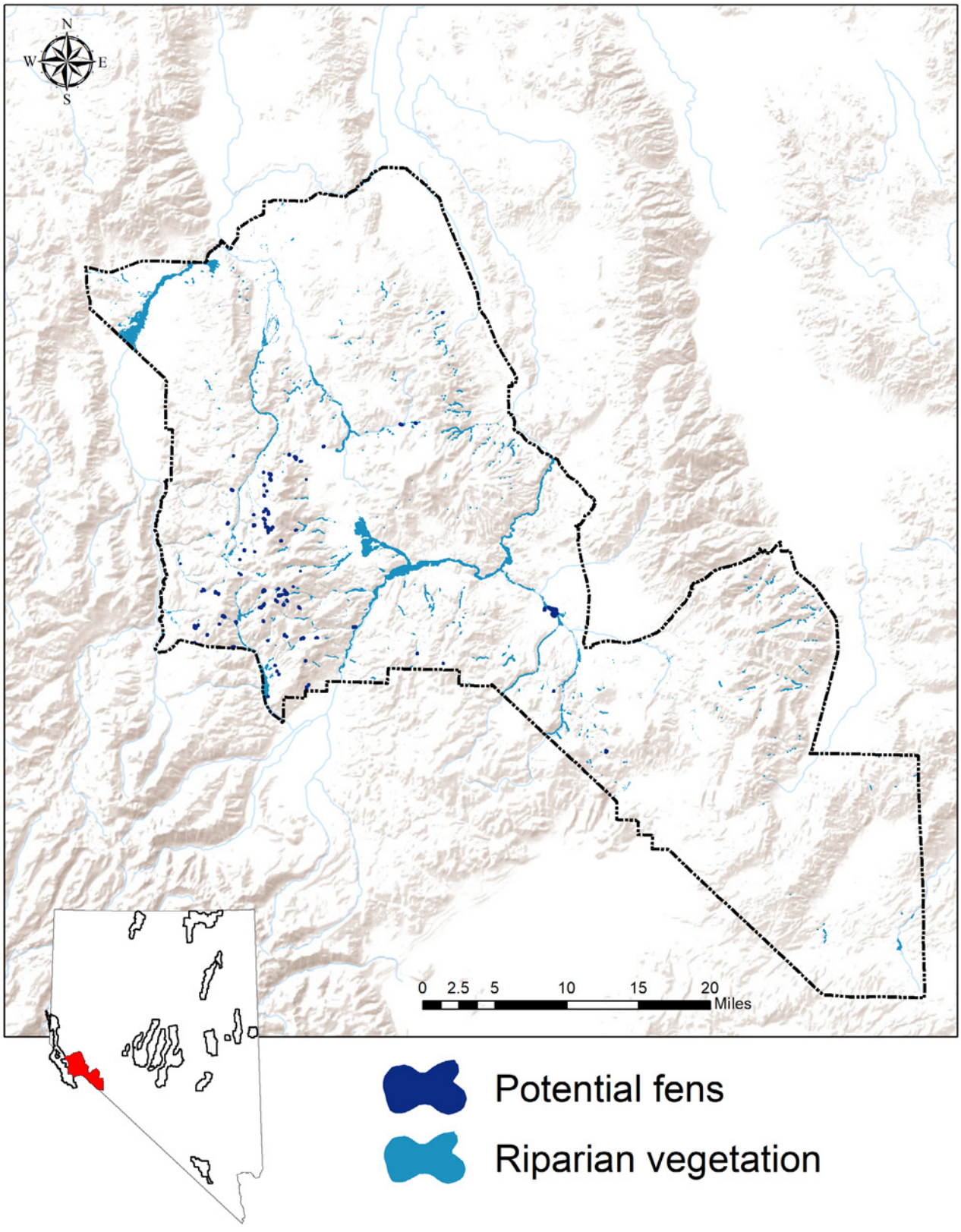


Figure C.10—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the East Sierra geographic unit of the Humboldt-Toiyabe National Forest.

Eastern Mountains

This geographic unit consists of five areas that we summarized separately.

Quinn-Grant area

Features include the Grant Range, the Horse Spring Hills, the Quinn Canyon Range, and Quinn Canyon. The Quinn Canyon Range is mostly composed of extrusive igneous rocks. The Grant Range is mostly carbonate rocks. Clastic sedimentary, intrusive granitic, and metamorphic rocks, primarily quartzite, are present as well (fig. C.11). Extrusive igneous rocks are mostly volcanic breccia or tuff (83 percent) and rhyolitic (16 percent). This unit is part of a Basin and Range carbonate-rock aquifer system that is connected with Basin and Range basin-fill aquifers.

Vegetation classification indicates that riparian ecosystems cover 0.2 percent (LANDFIRE) to 0.5 percent (FS VEG) of this area. Based on MARVN results, riparian ecosystems cover 0.8 percent of the area. Large amounts of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, include Troy Creek and several creeks draining northwest and southeast from the Quinn Canyon Range (fig. C.12).

There are 80 springs (0.0004/acre) mapped by the SSI. Springs are concentrated in the southern and northern ends of this area, with the largest clusters in volcanic deposits and faulted carbonate bedrock.

The CNHP identified 0.008 percent of the area as potential fens, with 8.3 acres of low confidence fens, 10.2 acres of possible fens, and 0 acres of likely fens. These wetlands are scattered across the area, in a variety of geological types. There are potential valley bottom fens in Big Spring Wash and Quinn Canyon and along several streams including Bruno Creek Little Meadows Creek.

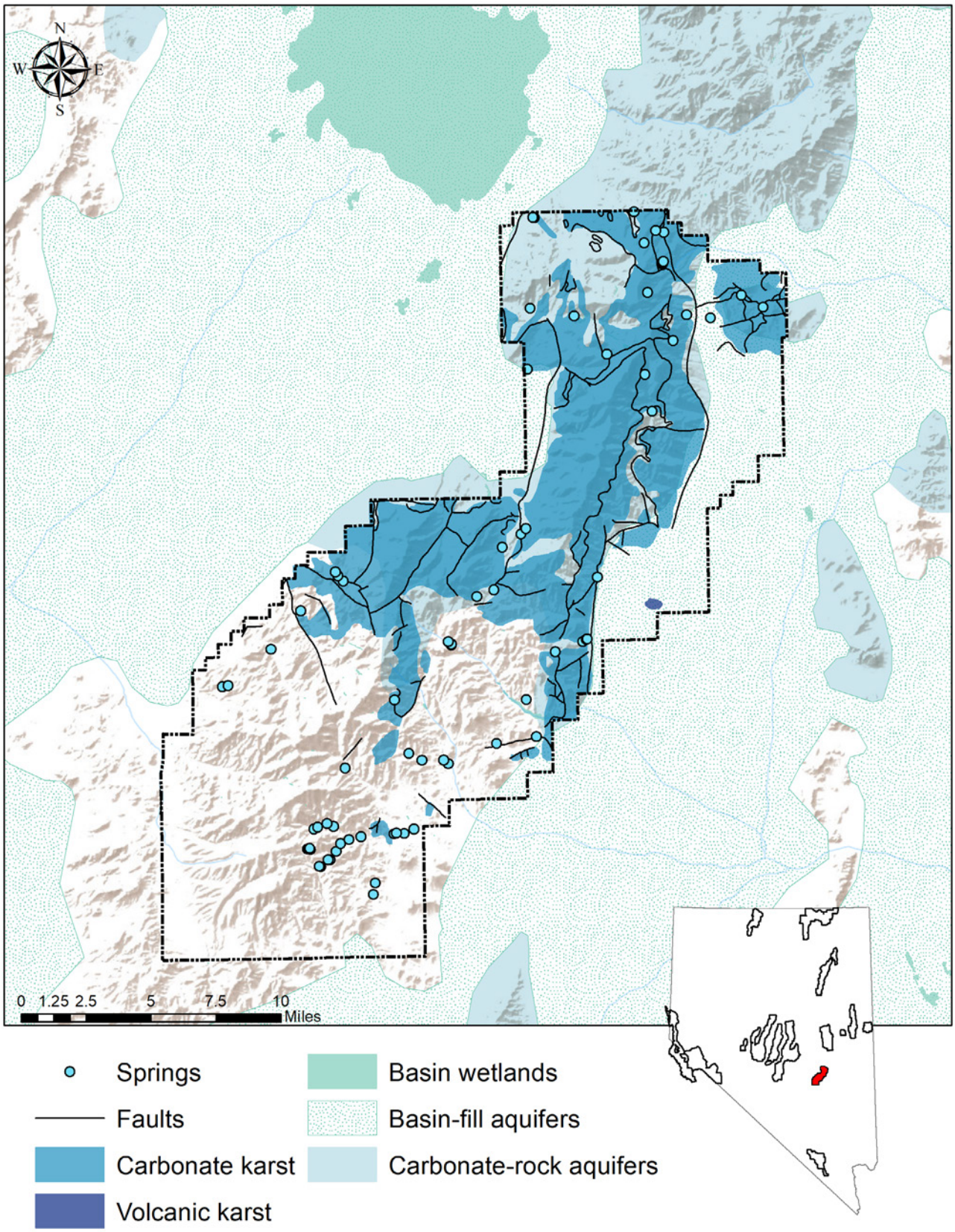


Figure C.11—Distribution of aquifers, faults, karst, and springs in the Quinn-Grant area of the Eastern Mountains geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

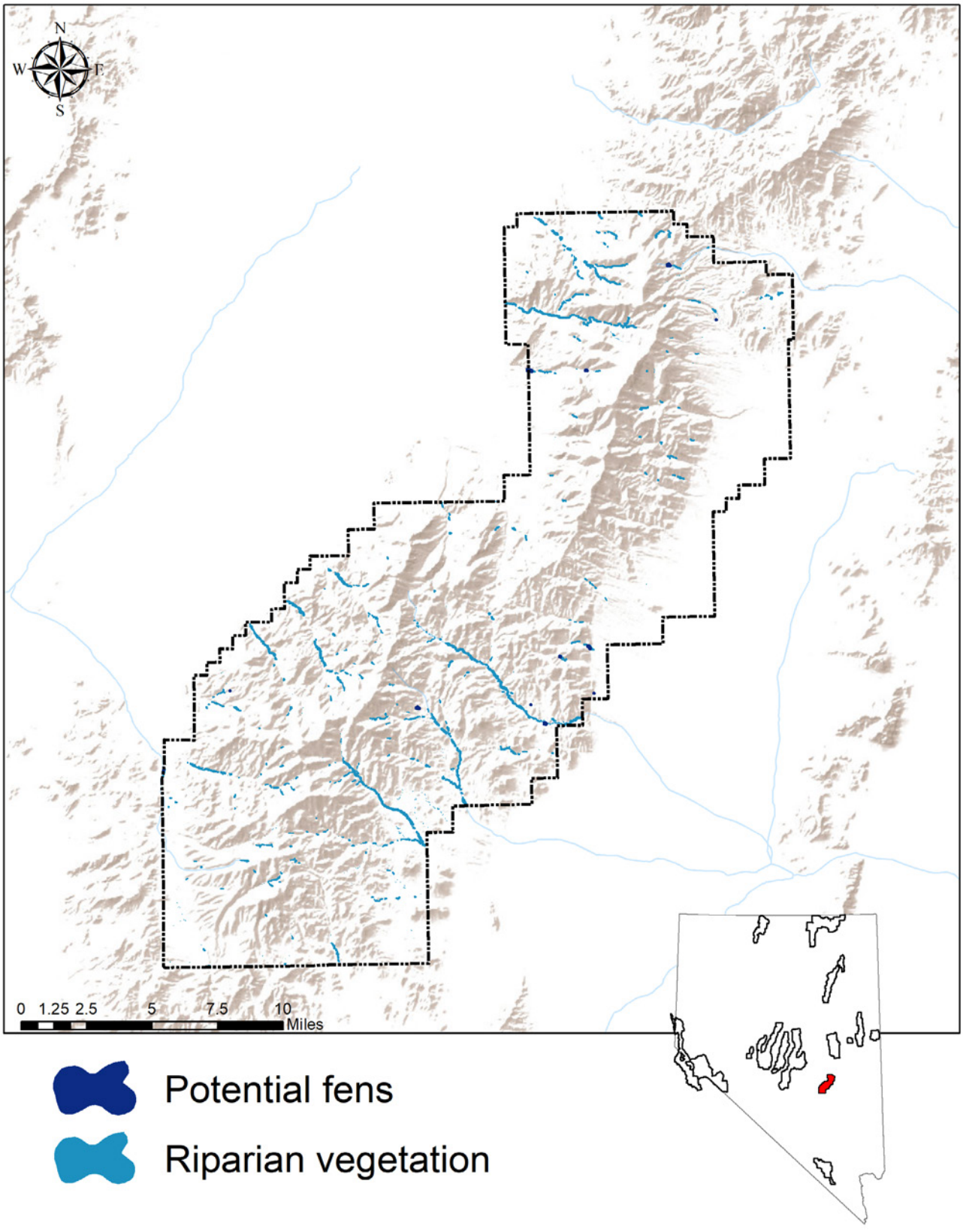


Figure C.12—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the Quinn-Grant area of the Eastern Mountains geographic unit of the Humboldt-Toiyabe National Forest.

Schell Creek area

This area includes the Schell Creek Range and a portion of the Duck Creek Range. These ranges are composed of a variety of bedrock types, including carbonate sedimentary rocks, clastic sedimentary rocks, extrusive igneous rocks, and tuffaceous sedimentary rocks (fig. C.13). Extrusive igneous rocks are mostly andesitic (74 percent) and volcanic breccia/tuff (17 percent). Metamorphic rocks are primarily quartzite. Much of this unit is a part of a Basin and Range carbonate-rock aquifer system. This unit is also connected with Basin and Range basin-fill aquifers.

Vegetation classification indicates that riparian ecosystems cover 0.4 percent (LANDFIRE) to 1.2 percent (FS VEG) of this area. Based on MARVN results, riparian ecosystems cover 2.0 percent of the area. Large amounts of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, were mapped along Steptoe Creek, Cleve Creek, North Creek, and numerous creeks draining to the east and west in the Schell Creek Range (fig. C.14).

There are 372 mapped springs (0.0012/acre), which are abundant throughout the unit. A large concentration is in faulted carbonate and extrusive igneous rocks at the northern end. The CNHP identified 0.021 percent of the area as potential fens, with 42.9 acres of low confidence fens, 19.0 acres of possible fens, and 0 acres of likely fens. These wetlands are scattered across the area, in a variety of geological types. There are potential valley bottom fens in Cooper Canyon and Cooper Wash and along streams including Cave Creek and McDonald Creek.

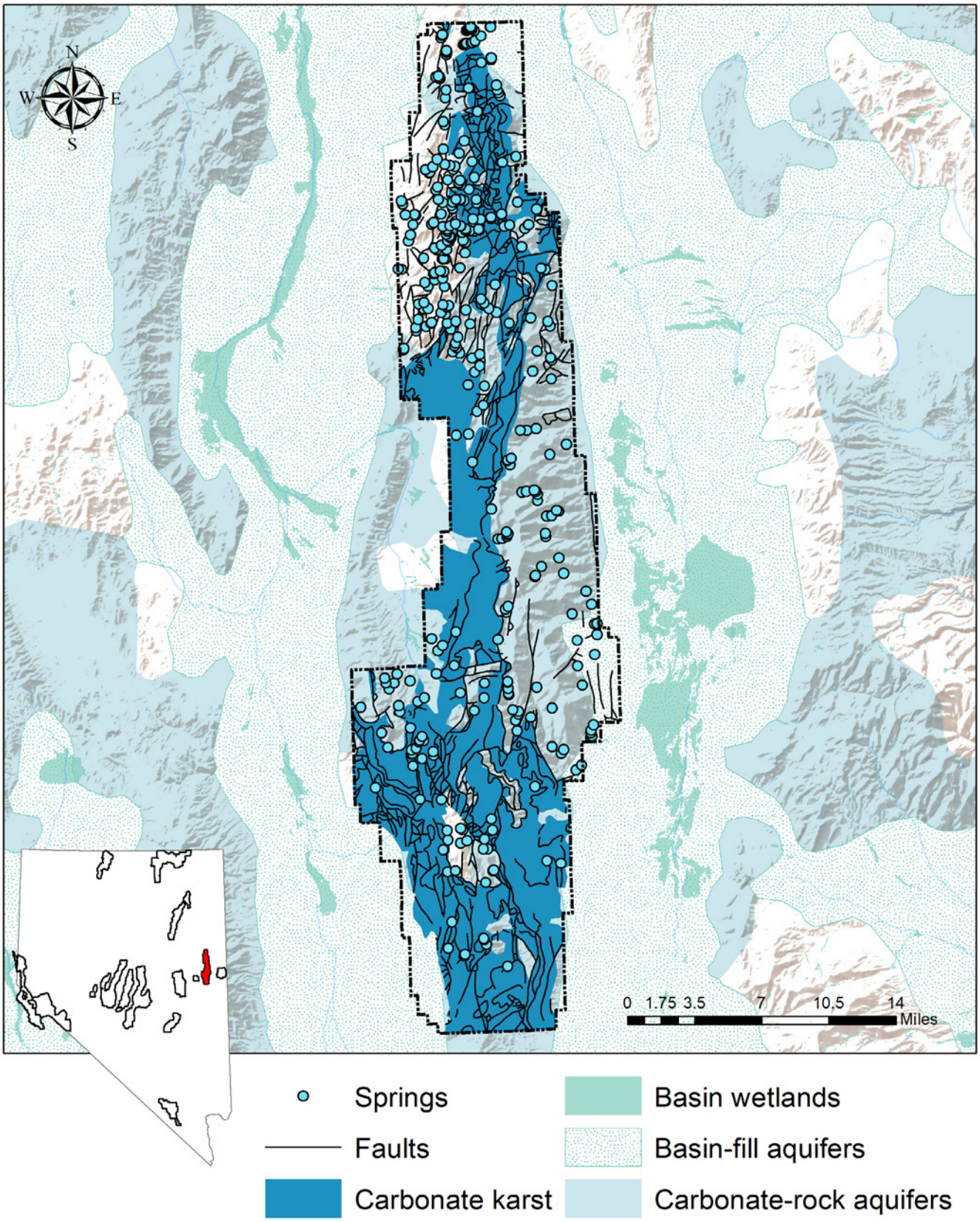


Figure C.13—Distribution of aquifers, faults, karst, and springs in the Schell Creek area of the Eastern Mountains geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

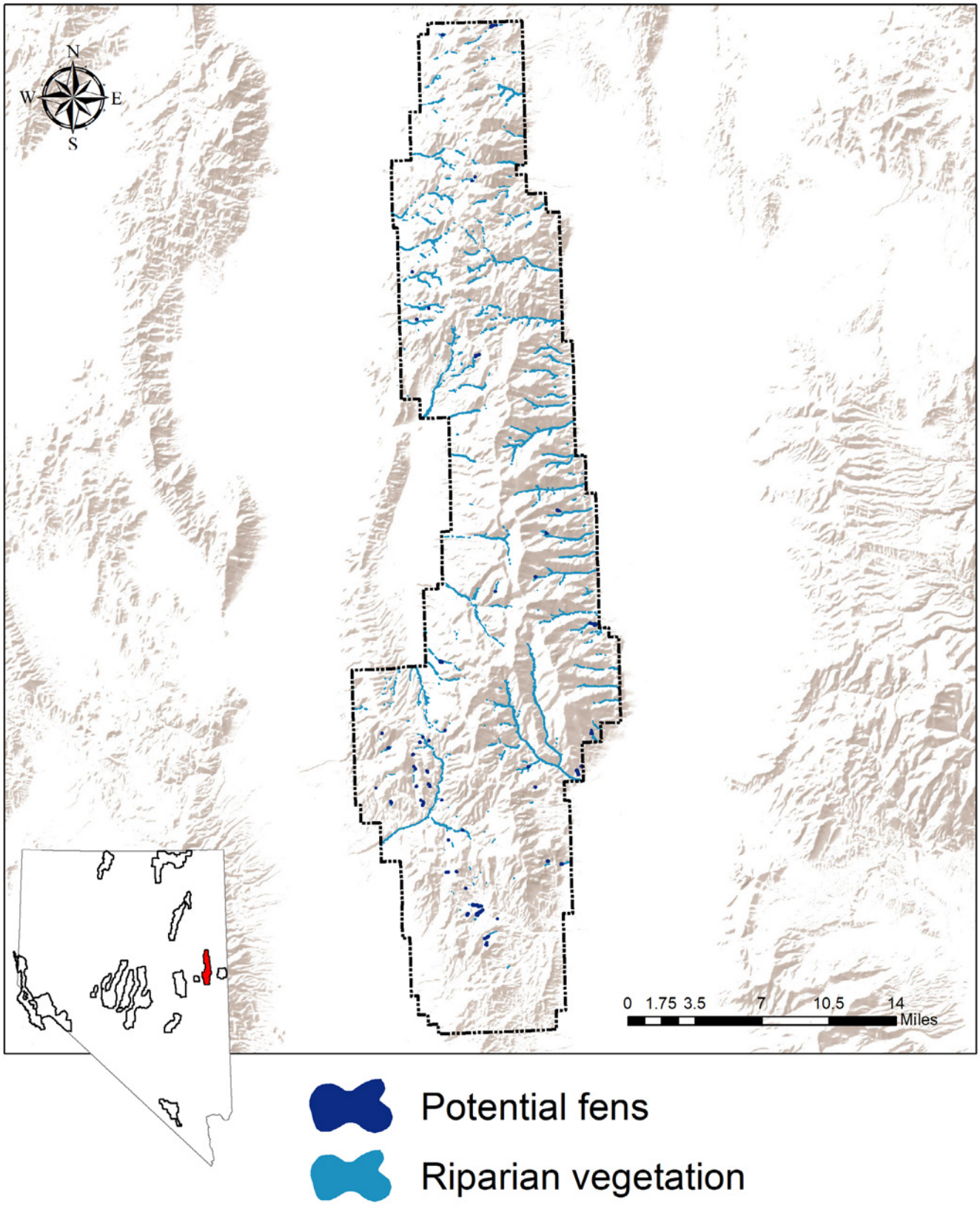


Figure C.14—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the Schell Creek area of the Eastern Mountains geographic unit of the Humboldt-Toiyabe National Forest.

Snake area

This small area includes a portion of the Snake Range. This range is composed of carbonate sedimentary rocks and metamorphic rocks, with granitic rocks, clastic rocks, and tuffaceous sedimentary rocks present as well (fig. C.15). Metamorphic rocks are mostly quartzite. This unit is part of a Basin and Range carbonate-rock aquifer system that is connected with Basin and Range basin-fill aquifers.

Vegetation classification indicates that riparian ecosystems cover 0.3 percent (LANDFIRE) to 1.0 percent (FS VEG) of this area. Based on MARVN results, riparian ecosystems cover 1.7 percent of the area. Large amounts of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, were mapped along Silver Creek, Hendrys Creek, and Smith Creek (fig. C.16).

There are 59 springs (0.0005/acre) mapped by the SSI. Springs are concentrated in faulted carbonate rocks in the western portion of the unit. The CNHP identified 0.035 percent of the area as potential fens, with 35.8 acres of low confidence fens, 5.6 acres of possible fens, and 0 acres of likely fens. These wetlands are scattered across the area, in a variety of geological types. There are potential valley bottom fens along Deadman Creek, Left Fork Silver Creek, Timber Creek, and other streams.

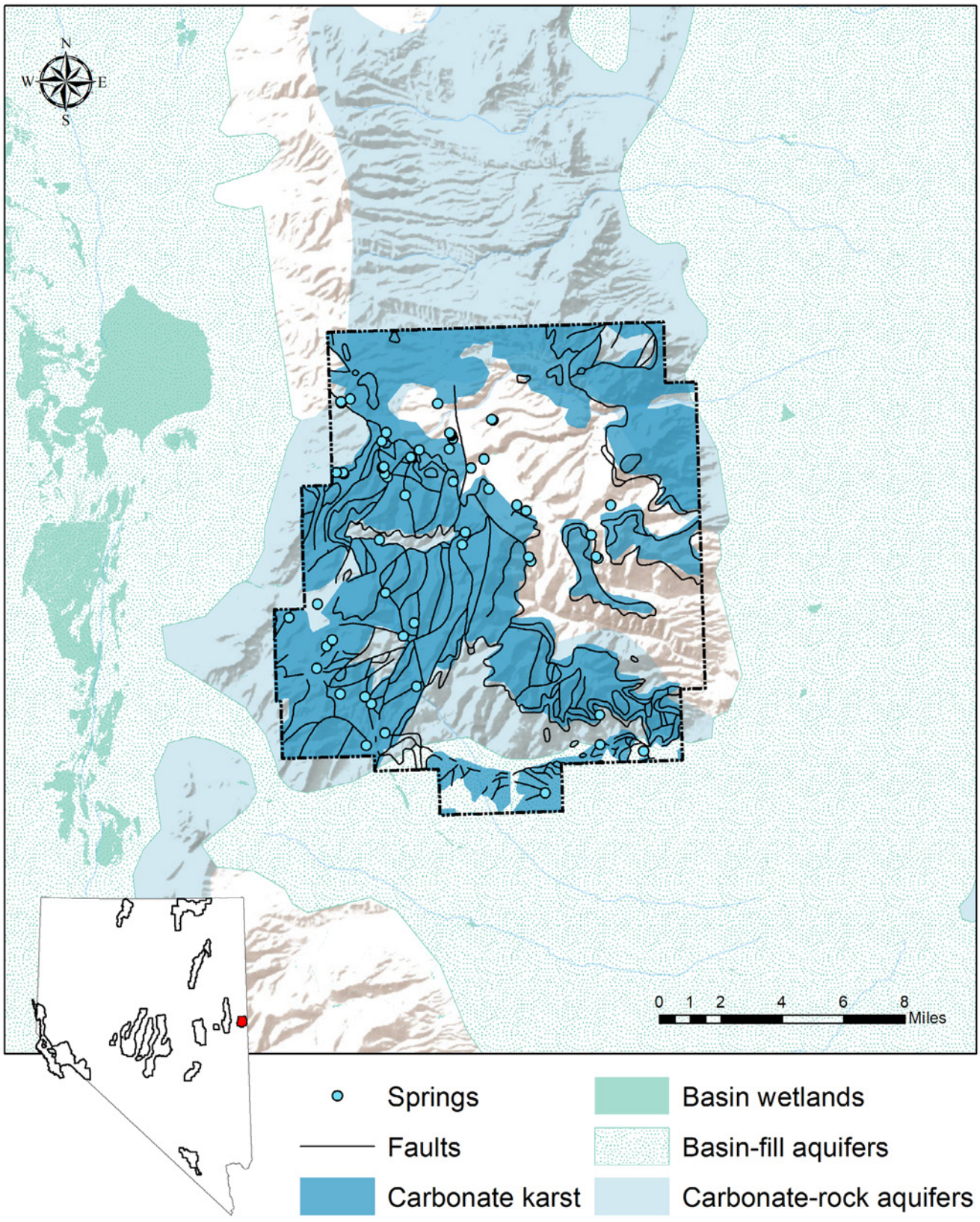


Figure C.15—Distribution of aquifers, faults, karst, and springs in the Snake area of the Eastern Mountains geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

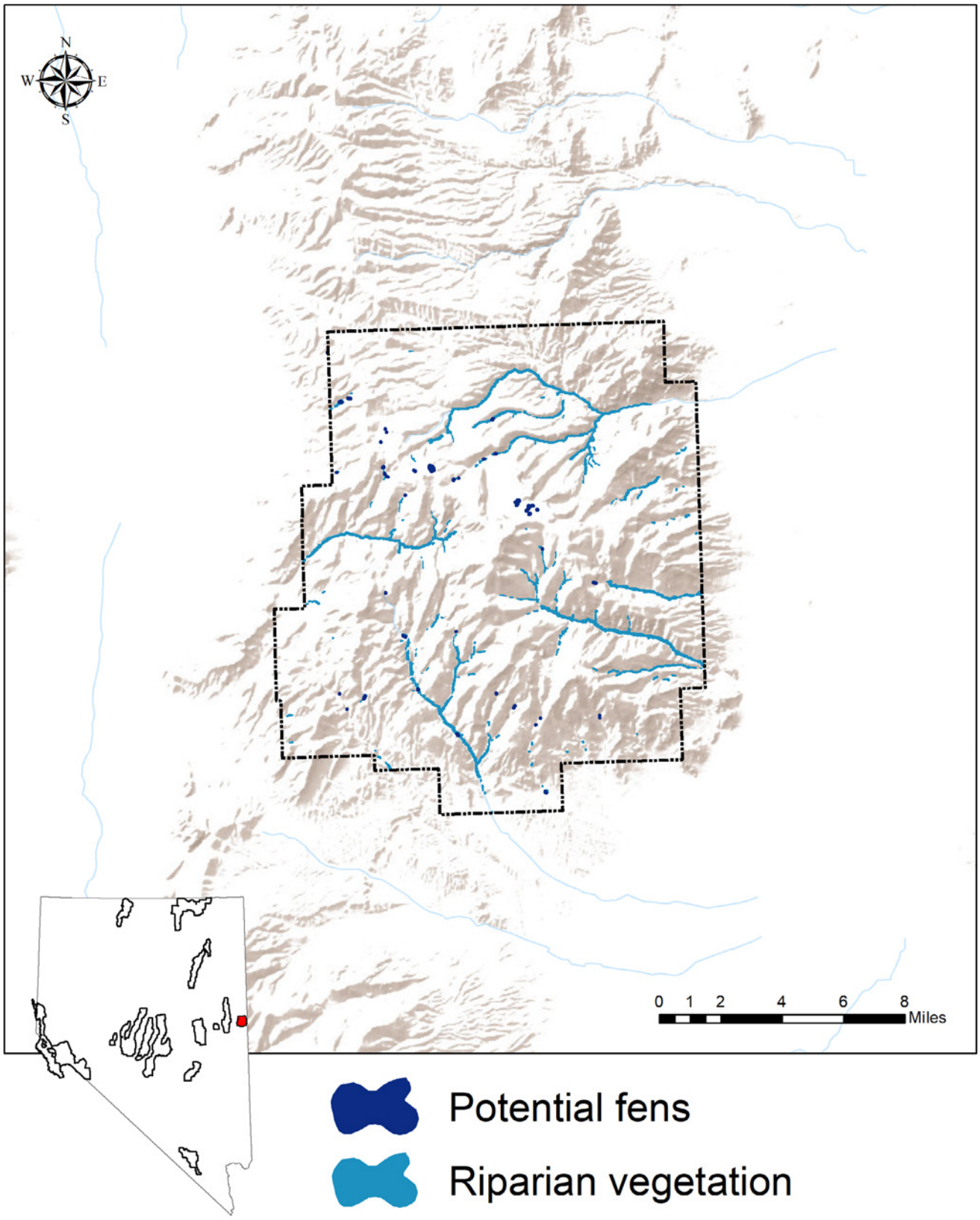


Figure C.16—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the Snake area of the Eastern Mountains geographic unit of the Humboldt-Toiyabe National Forest.

Ward area

This small area includes a portion of the Egan Range. This range is composed of clastic sedimentary rocks, carbonate sedimentary rocks, and extrusive igneous rocks (fig. C.17). Extrusive igneous rocks are mostly volcanic breccia or tuff (93 percent). This unit is part of a Basin and Range carbonate-rock aquifer system that is connected with Basin and Range basin-fill aquifers.

Vegetation classification indicates that riparian ecosystems cover 0.04 percent (LANDFIRE) to 0.3 percent (FS VEG) of this area. Based on MARVN results, riparian ecosystems cover 0.2 percent of the area. Large amounts of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, were mapped in North Fork Sawmill Canyon and along Holt Creek (fig. C.18).

There are 19 mapped springs (0.0005/acre), most of which are associated with faulted sedimentary rocks. The CNHP identified 0.006 percent of the unit as potential fens, with 2.4 acres of low confidence fens, 0.2 acres of possible fens, and 0 acres of likely fens. These wetlands are scattered across the unit, in a variety of geological types. There are potential valley bottom fens along Holt Creek.

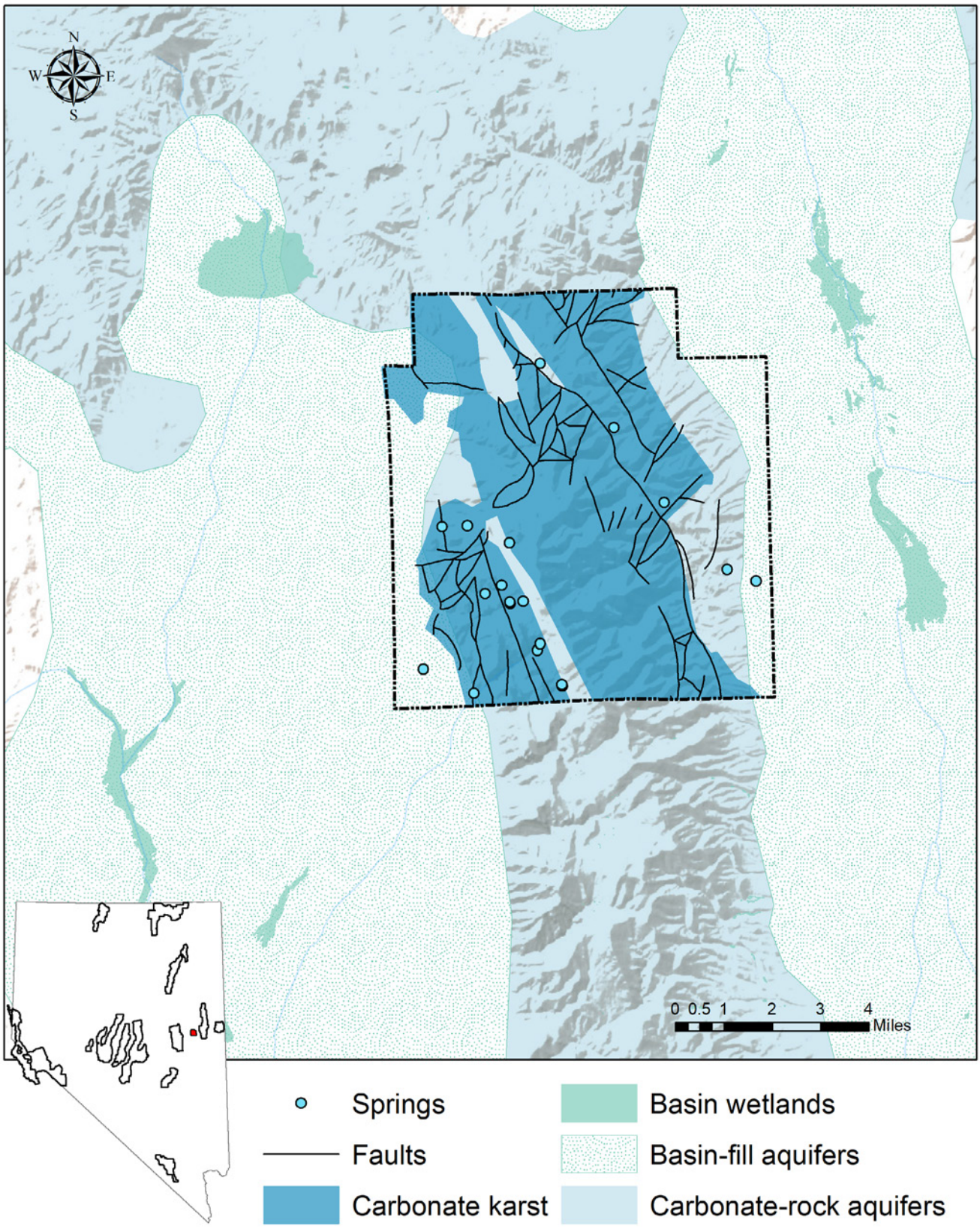


Figure C.17—Distribution of aquifers, faults, karst, and springs in the Ward area of the Eastern Mountains geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

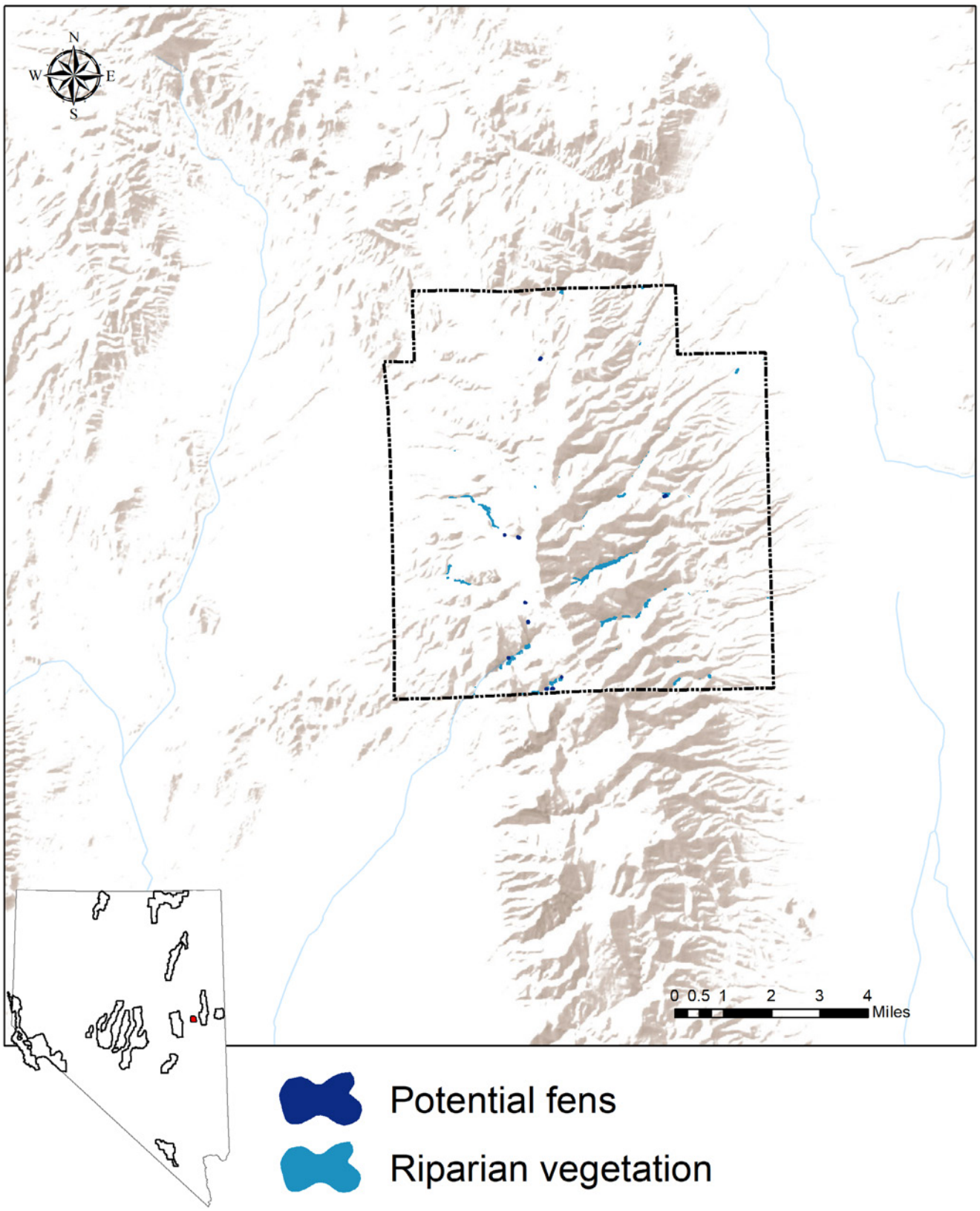


Figure C.18—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the Ward area of the Eastern Mountains geographic unit of the Humboldt-Toiyabe National Forest.

White Pine area

Features include the White Pine Range, the Horse Range, and the White River, of the Lower Colorado Basin. The ranges are composed of carbonate sedimentary rocks, clastic sedimentary rocks, and extrusive igneous rocks, with intrusive granitic rocks and metamorphic rocks, primarily quartzite, present as well (fig. C.19). Extrusive igneous rocks are mostly rhyolite (84 percent) and andesite (10 percent). This unit is part of a Basin and Range carbonate-rock aquifer system that is connected with Basin and Range basin-fill aquifers.

Vegetation classification indicates that riparian ecosystems cover 0.2 percent (FS VEG and LANDFIRE) of this area. Based on MARVN results, riparian ecosystems cover 0.6 percent of the area. Large amounts of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, were mapped along White River, Currant Creek, Ellison Creek, and Cottonwood Creek (fig. C.20).

There are 186 mapped springs (0.0005/acre), which are scattered across the area, with clusters in extrusive igneous rocks and faulted sedimentary rocks. The CNHP identified 0.005 percent of the area as potential fens, with 16.3 acres of low confidence fens, 0 acres of possible fens, and 0 acres of likely fens. These wetlands are scattered in sedimentary rocks and unconsolidated deposits. There are potential valley bottom fens in Lampson Canyon and near Ellison Creek and other streams.

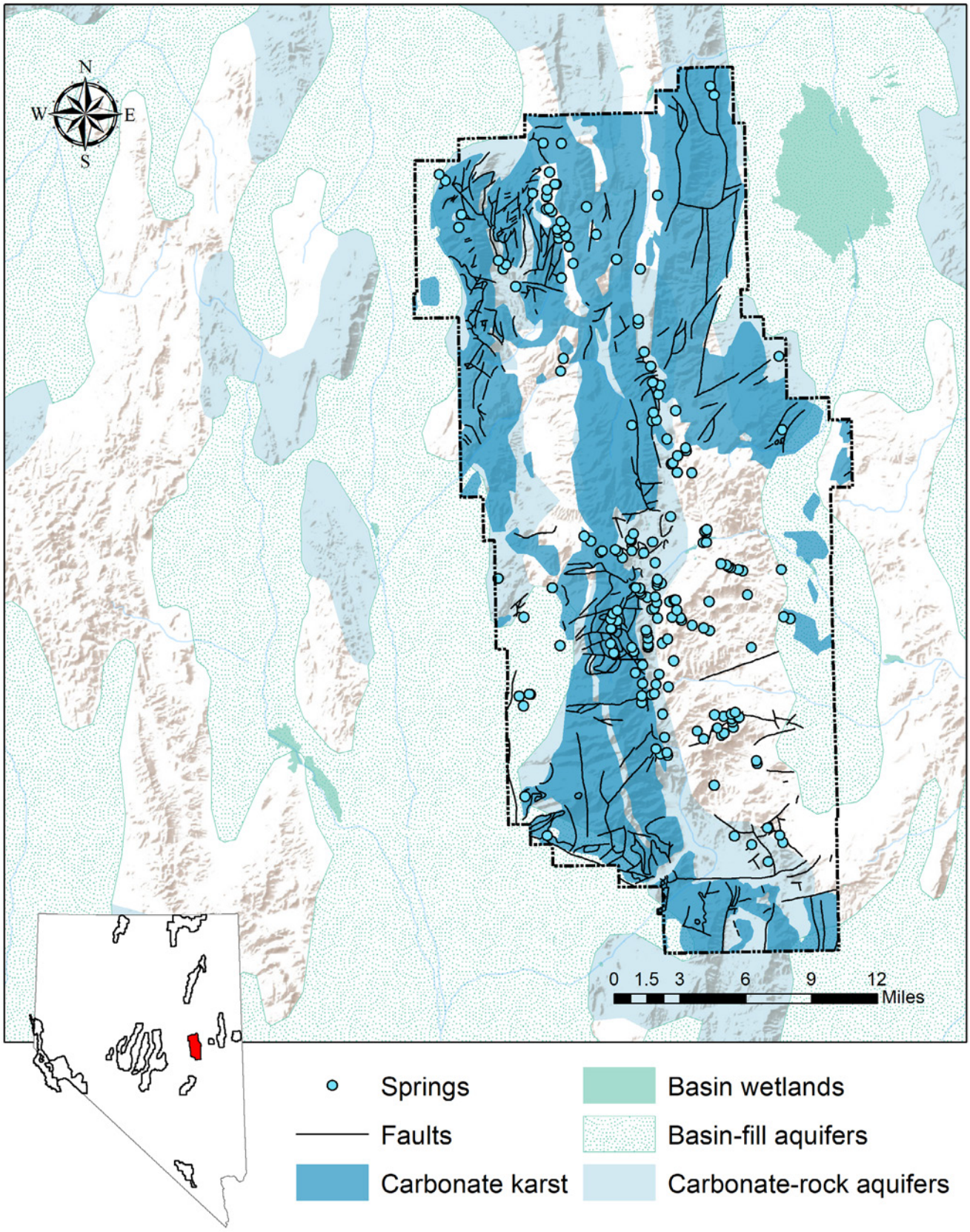


Figure C.19—Distribution of aquifers, faults, karst, and springs in the White Pine area of the Eastern Mountains geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

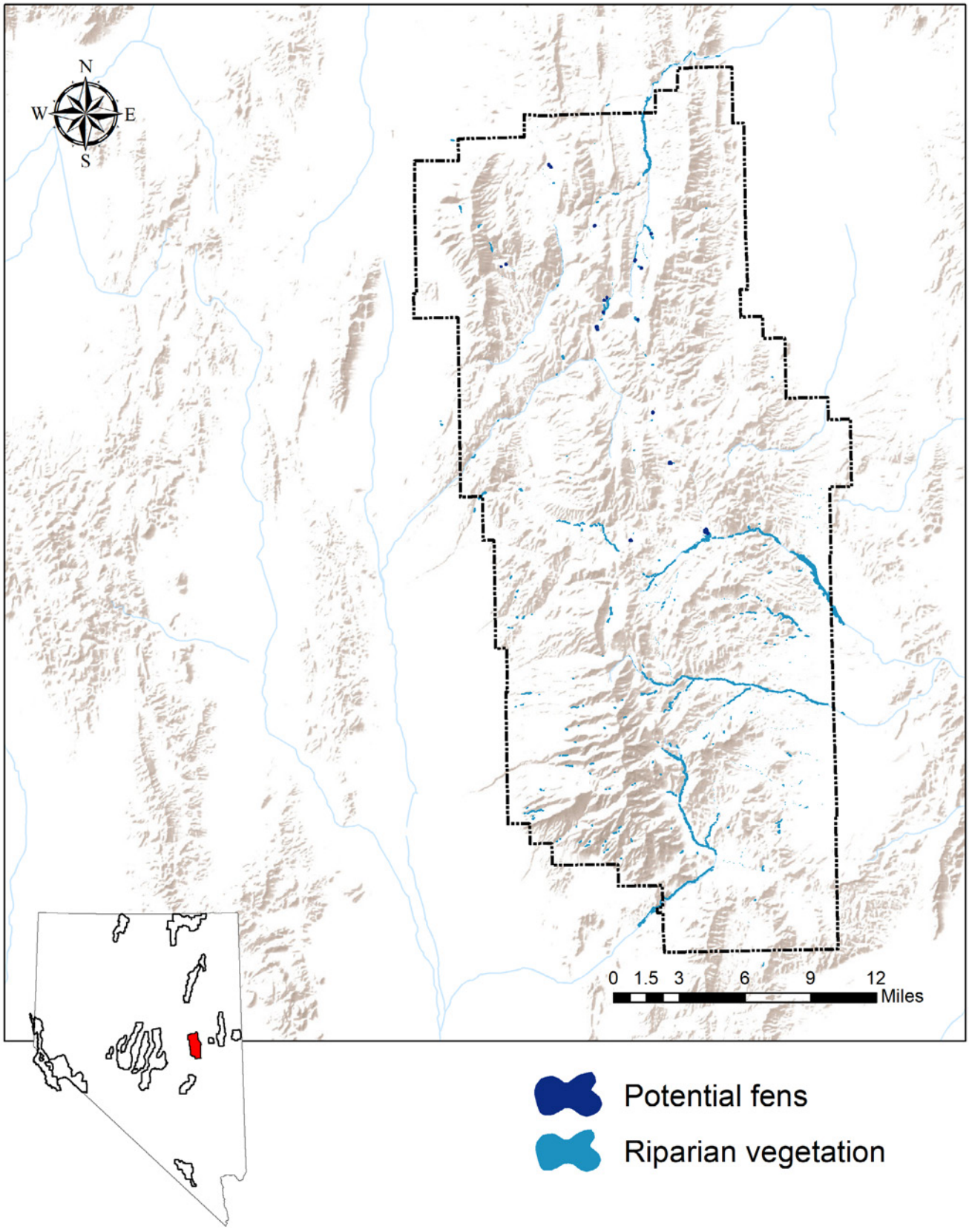


Figure C.20—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the White Pine area of the Eastern Mountains geographic unit of the Humboldt-Toiyabe National Forest.

Northern Mountains

This geographic unit consists of two areas that we summarized separately.

Jarbidge area

This area consists of several mountain ranges, including the Independence Mountains, the Bull Run Mountains, the Mahoganies, the Cooper Mountains, and the Jarbidge Mountains. A variety of bedrock types are present, including extrusive igneous rocks, intrusive granitic rocks, metamorphic rocks, carbonate sedimentary rocks, clastic sedimentary rocks, and tuffaceous sedimentary rocks (fig. C.21). Extrusive igneous rocks are mostly rhyolite (56 percent) and volcanic breccia or tuff (35 percent). Portions of the unit that drain to the north are part of a Pacific Northwest basaltic-rock aquifer system and are connected with Pacific Northwest basin-fill aquifers. Portions draining to the south are connected with Basin and Range basin-fill aquifers.

Vegetation classification indicates that riparian ecosystems cover 2.3 percent (LANDFIRE) to 2.7 percent (FS VEG) of this area. Based on MARVN results, riparian ecosystems cover 3.6 percent of the area. Large amounts of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, were mapped along streams throughout the unit (fig. C.22).

There are 606 mapped springs (0.0008/acre), which are scattered across the unit, with clusters associated with faults in a variety of geological types. The CNHP identified 0.037 percent of the area as potential fens, with 186.8 acres of low confidence fens, 77.9 acres of possible fens, and 15.7 acres of likely fens. These wetlands are scattered across the area, in a variety of geological types. There are potential valley bottom fens along Bear Creek, Echo Creek, Lost Meadow Creek, the Jarbidge River, and many other streams in the unit.

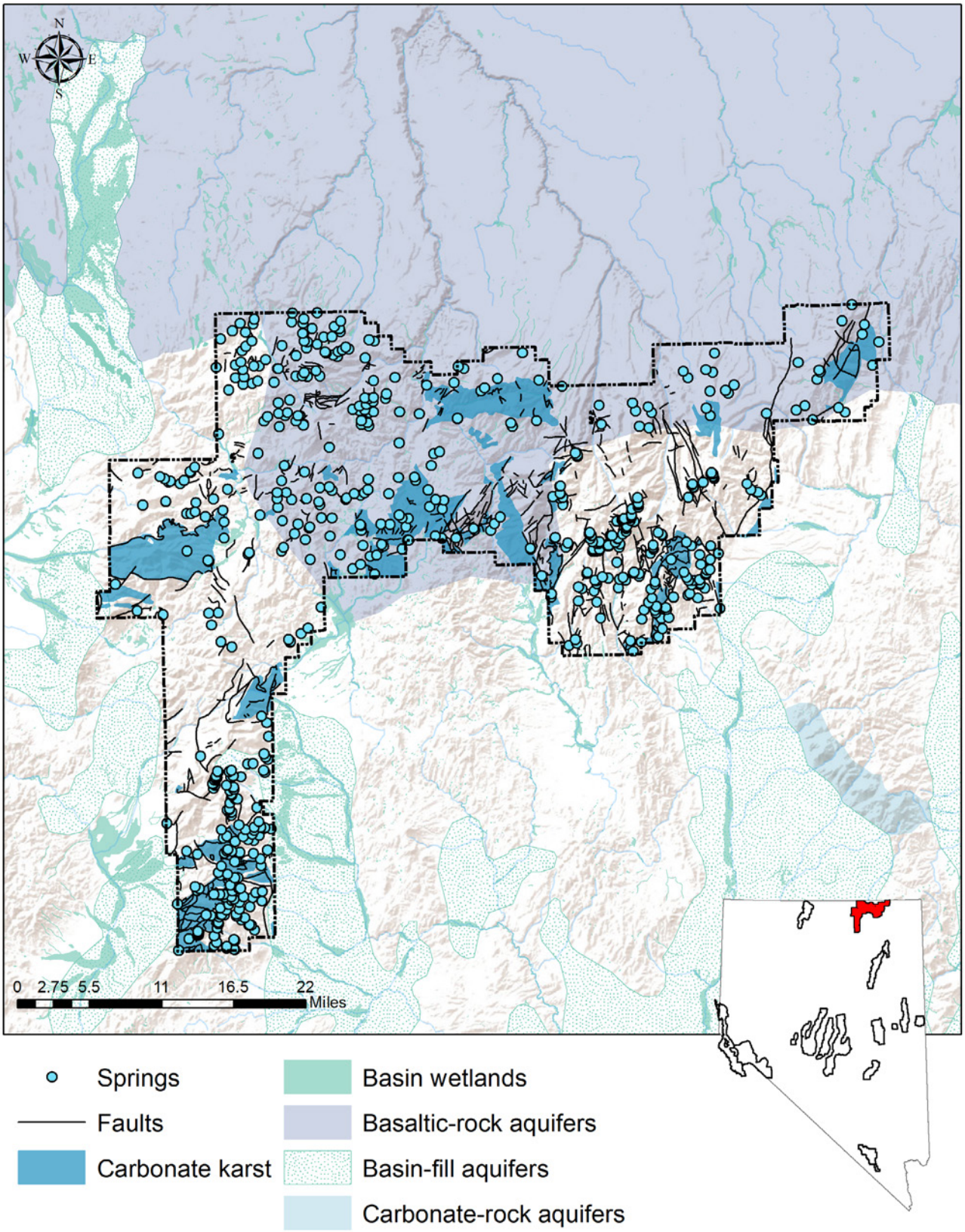


Figure C.21—Distribution of aquifers, faults, karst, and springs in the Jarbidge area of the Northern Mountains geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

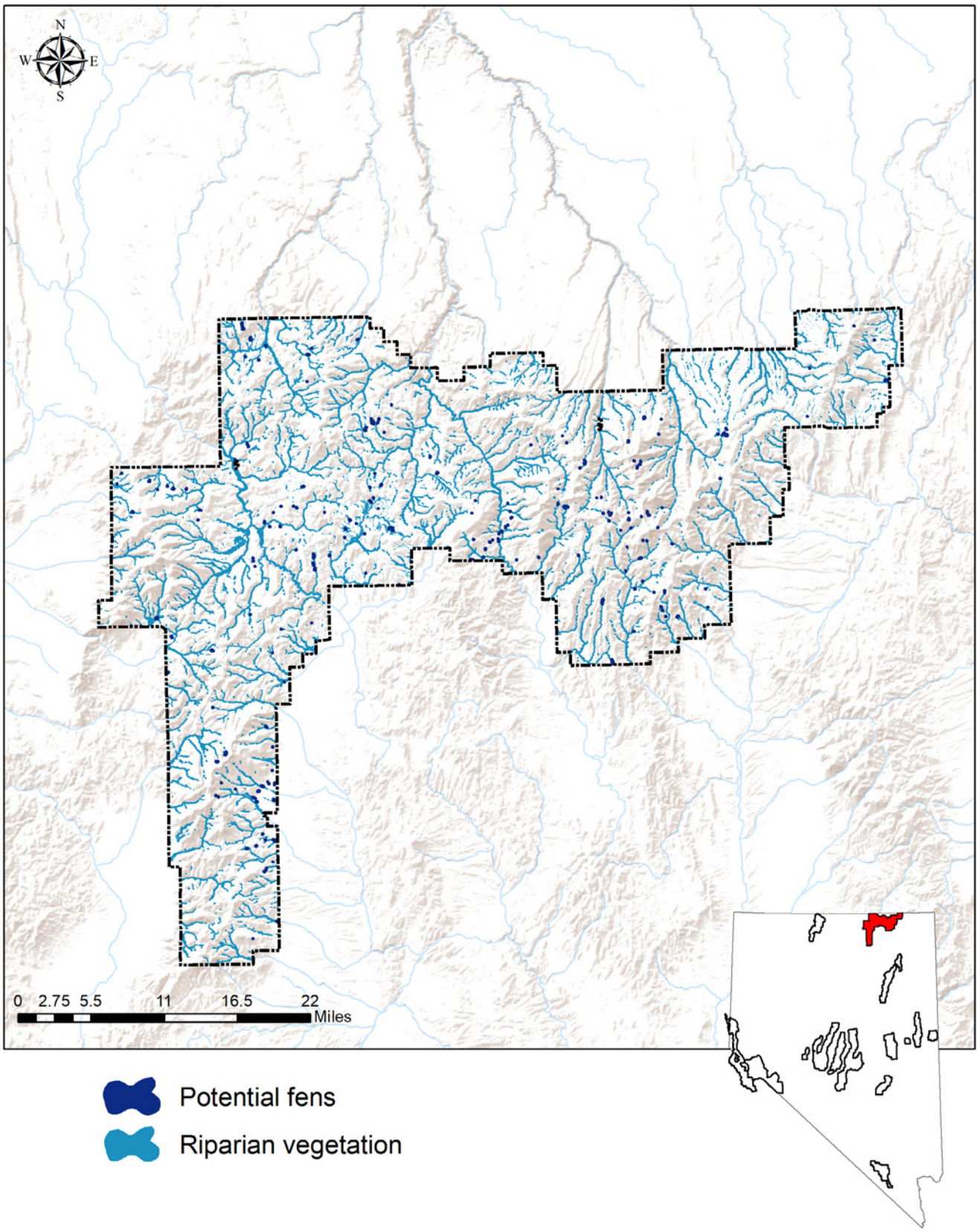


Figure C.22—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the Jarbidge area of the Northern Mountains geographic unit of the Humboldt-Toiyabe National Forest.

Santa Rosa area

Features include the Santa Rosa Range, Odell Mountain, and the Calico Mountains. Extrusive igneous rocks compose a large portion of these ranges, with clastic sedimentary rocks, intrusive granitic rocks, and tuffaceous sedimentary rocks present as well (fig. C.23). Extrusive igneous rocks are mostly rhyolite (58 percent), andesite (28 percent) and volcanic breccia or tuff (14 percent). Much of the unit is connected with Basin and Range basin-fill aquifers. The northeastern portion of the unit is connected to a Pacific Northwest basaltic-rock aquifer system.

Vegetation classification indicates that riparian ecosystems cover 1.1 percent (LANDFIRE) to 1.5 percent (FS VEG) of this area. Based on MARVN results, riparian ecosystems cover 5.1 percent of the area. Large amounts of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, were mapped along the East Fork Quinn River, North Fork Little Humboldt River, and other streams throughout the area (fig. C.24).

There are 540 springs (0.0018 /acre) mapped by the SSI, the highest density of any area or geographic unit. Most springs are associated with extrusive igneous rocks in the northern portion of the area. Springs are also abundant in sedimentary, granitic, and metamorphic bedrock of the southern portion. The CNHP identified 0.069 percent of the area as potential fens, with 171.0 acres of low confidence fens, 36.3 acres of possible fens, and 0 acres of likely fens. Most of these wetlands are associated with the volcanic rocks in the northern portion of the unit. There are potential valley bottom fens along the North Fork Little Humboldt River, South Fork Quinn River, Round Corral Creek, and many other streams in the unit.

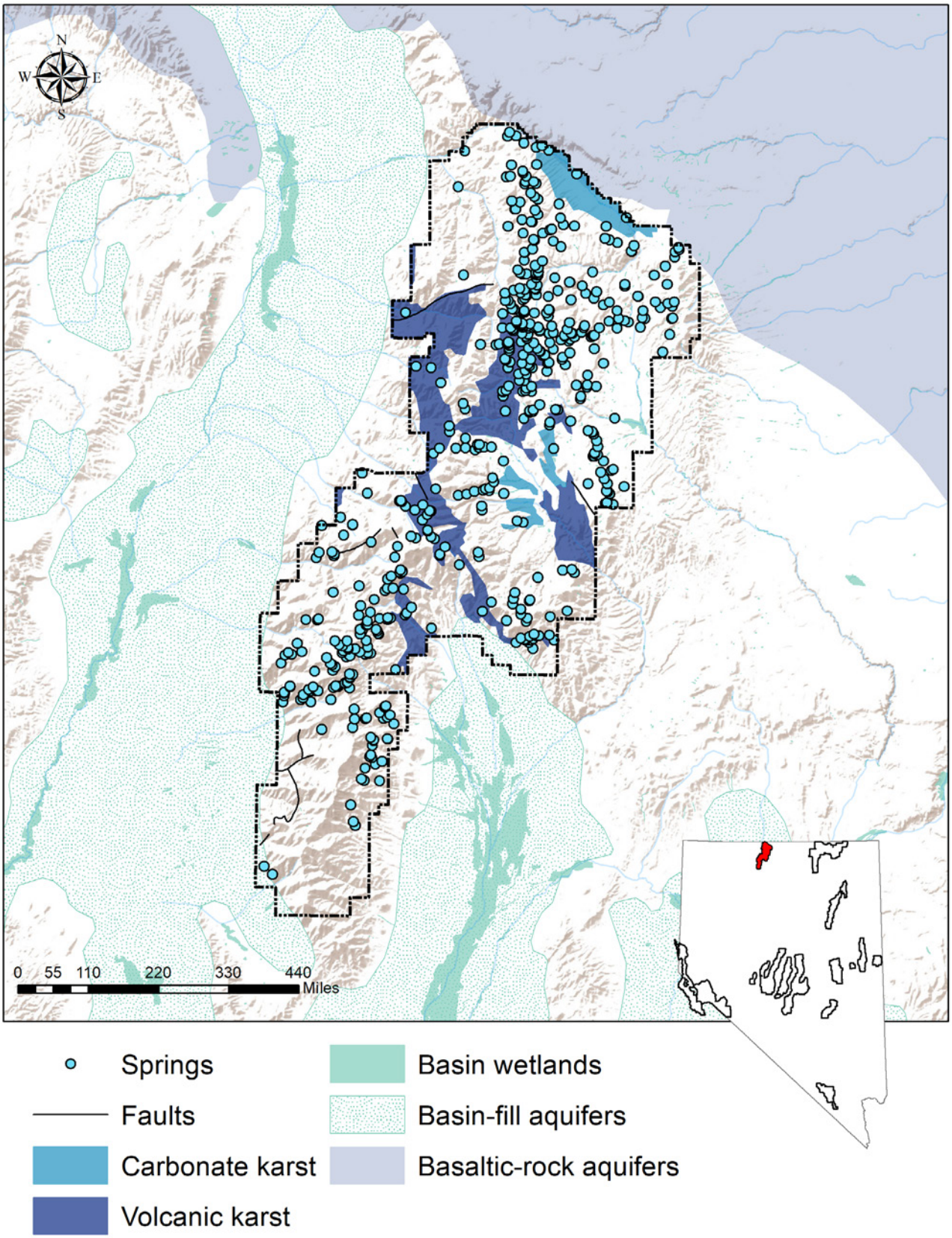


Figure C.23—Distribution of aquifers, faults, karst, and springs in the Santa Rosa area of the Northern Mountains geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

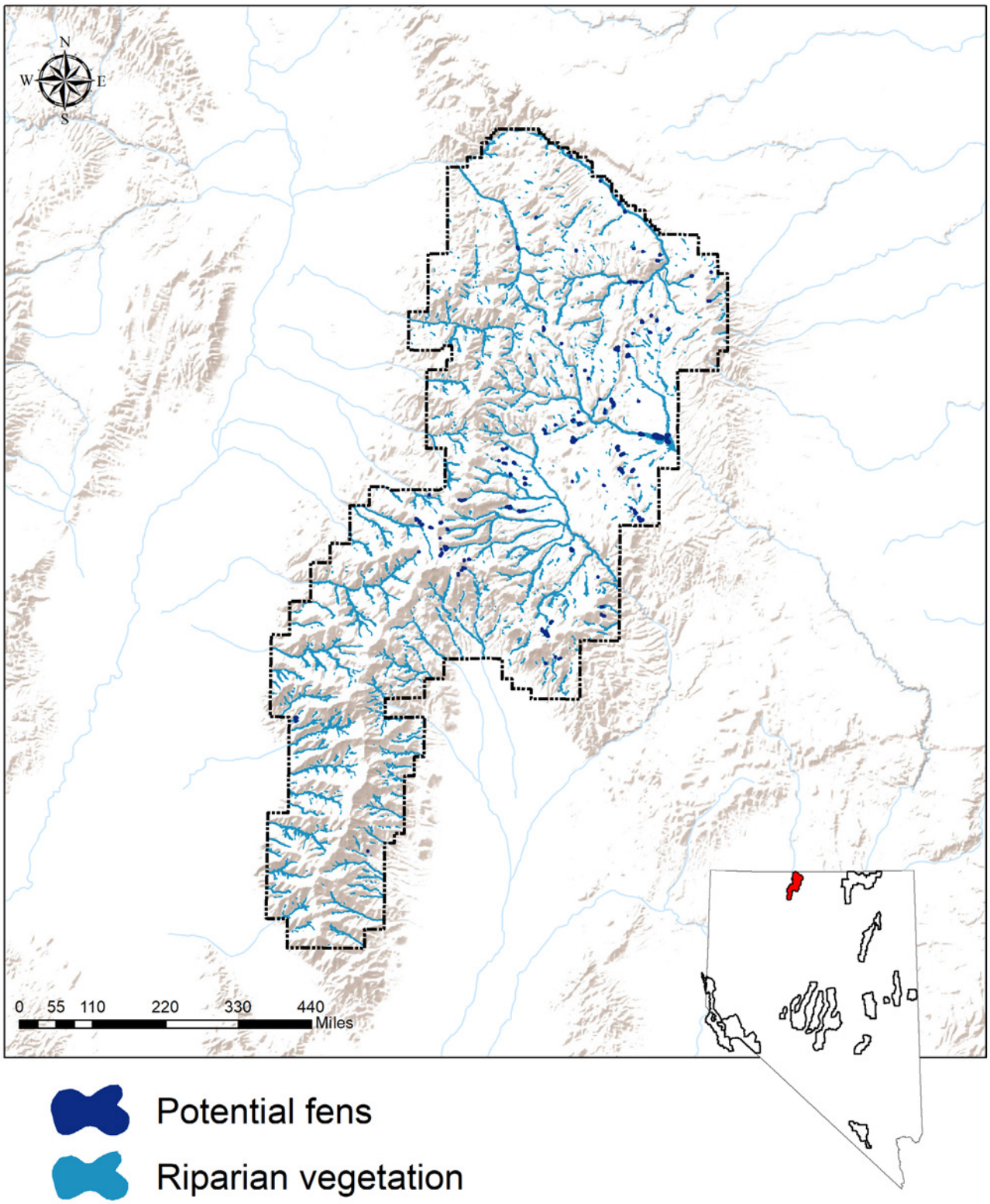


Figure C.24—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the Santa Rosa area of the Northern Mountains geographic unit of the Humboldt-Toiyabe National Forest.

Ruby Mountains

Features include the Ruby Mountains, the East Humboldt Range, and Lamoille Canyon. The Ruby Mountains are largely composed of carbonate sedimentary rocks in the south and metamorphic rocks in the north, with some intrusive granitic rocks, clastic sedimentary rocks, extrusive igneous rocks, and tuffaceous sedimentary rocks present as well (fig. C.25). Extrusive igneous rocks are rhyolite (53 percent) and breccia/tuff (47 percent). Metamorphic rocks include marble and quartzite. All portions of this unit are connected with Basin and Range basin-fill aquifers. The southern portion of the unit is also part of a Basin and Range carbonate-rock aquifer system.

Vegetation classification indicates that riparian ecosystems cover 1.4 percent (LANDFIRE) to 1.9 percent (FS VEG) of this geographic unit. Based on MARVN results, riparian ecosystems cover 2.5 percent of the unit. Areas with large amounts of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, include Lamoille Canyon and numerous streams draining the Ruby Mountains and East Humboldt Range (fig. C.26).

There are 353 mapped springs (0.0008/acre), which are distributed throughout the unit. The largest clusters in are carbonate, granitic, and metamorphic rocks in the western portion. The CNHP identified 0.074 percent of the unit as potential fens, with 155.9 acres of low confidence fens, 102.2 acres of possible fens, and 68.1 acres of likely fens. These wetlands are scattered across the unit, with most in granitic rocks, metamorphic rocks, and unconsolidated deposits. There are potential valley bottom fens along Kleckner Creek, Leach Creek, Robinson Creek, Soldier Creek, Willow Creek, and many other streams in this unit.

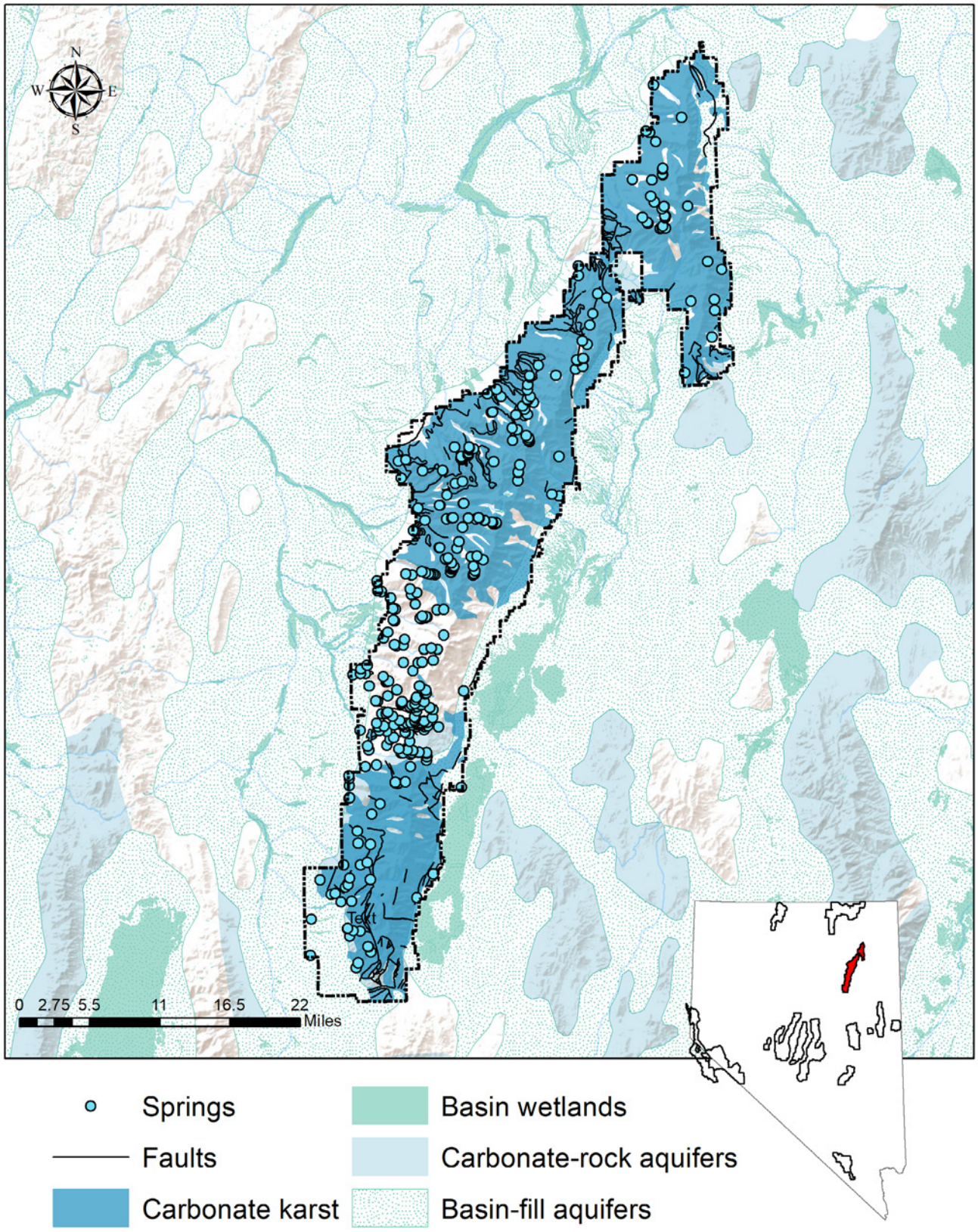


Figure C.25—Distribution of aquifers, faults, karst, and springs in the Ruby Mountains geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

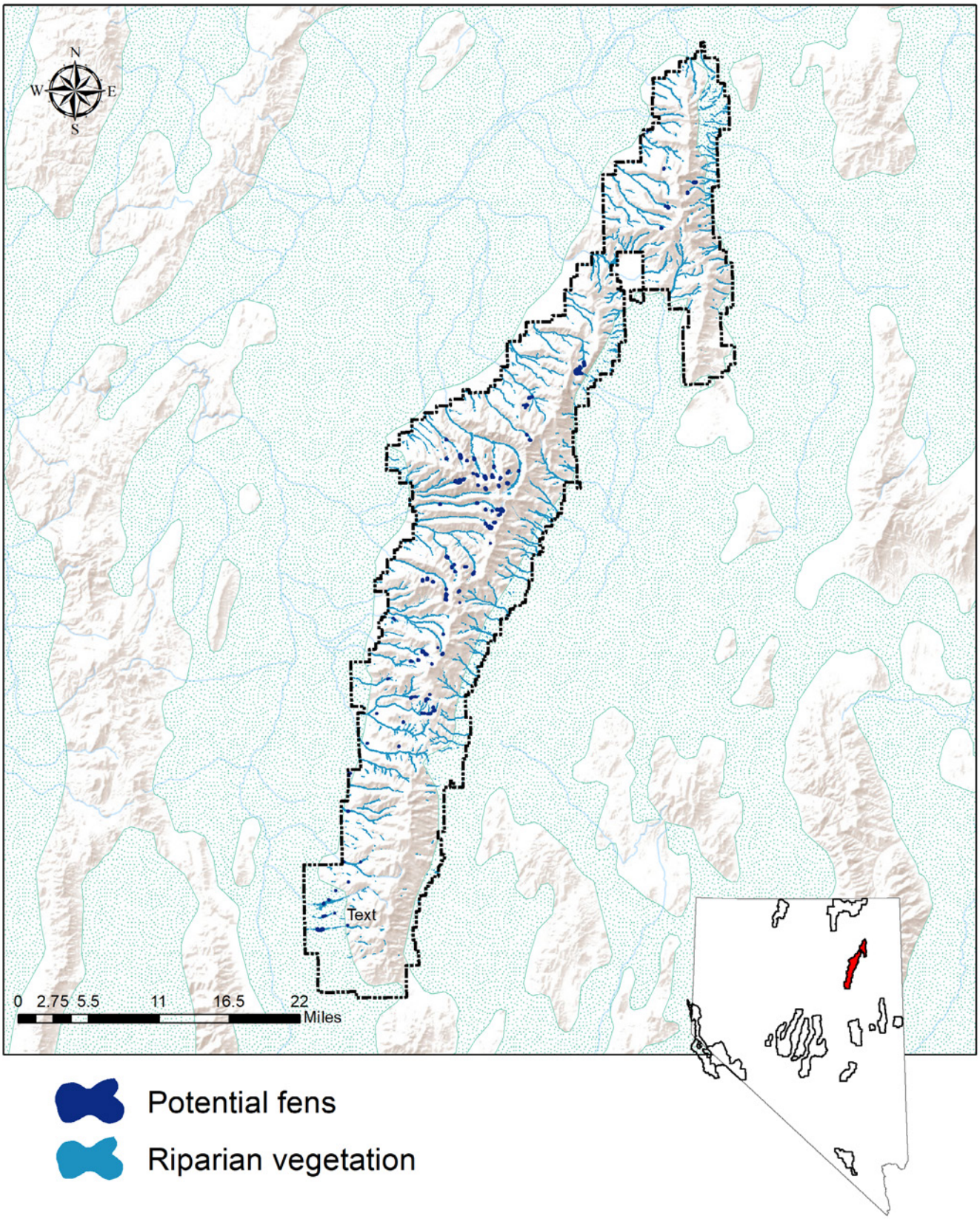


Figure C.26—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the Ruby Mountains geographic unit of the Humboldt-Toiyabe National Forest.

Sierra Nevada

The dominant features of this geographical unit are the Sierra Nevada and Carson Ranges. This unit also contains portions of Reno and Carson City, as well as several smaller towns. The mountain ranges are primarily composed of extrusive igneous and intrusive granitic rocks (fig. C.27). Extrusive igneous rocks are mostly andesitic (89 percent). The Carson and Truckee Rivers are the largest streams in the unit. Several Basin and Range aquifers are connected with the eastern slopes of this unit and are recharged by snowmelt runoff from the Carson Range and Sierra Nevada (Huntington 2010).

Vegetation classification indicates that riparian ecosystems cover 2.5 percent (FS VEG) to 3.7 percent (LANDFIRE) of this geographic unit. Based on MRVN results, riparian ecosystems cover 2.1 percent of the portion in Nevada. The Sierra Nevada Meadows Project (Viers et al. 2013) mapped 7,842.1 meadow acres in the unit (fig. C.28).

Large stands of riparian vegetation, as identified by MARVN, FS VEG, and LANDFIRE, are present throughout the length of this large geographic unit, with many patches in the Sierra Nevada and Carson Ranges and extensive corridors along streams draining to the east.

There are 405 springs (0.0005/acre) mapped by the SSI. These springs are distributed throughout the unit, with the largest clusters in areas of faulted andesitic bedrock. The CNHP identified 0.399 percent of the unit as potential fens, by far the highest coverage of any unit. They mapped 1831.1 acres of low confidence fens, 1162.9 acres of possible fens, and 465.1 acres of likely fens. The acreage of likely fens in this unit is six times the acreage in the Ruby Mountains unit, which has the second-highest acreage in the Forest. Most of these wetlands are in the Sierra Nevada Range in the central and southern portions of the unit, in areas of granitic rocks, andesitic rocks, and other volcanic deposits. There are potential valley bottom fens along the East Fork Carson River, Little Walker River, West Fork Carson River, West Walker River, Buckeye Creek, Cattle Creek, Dunderberg Creek, Green Creek, Robinson Creek, Wolf Creek, and many other streams in this unit.

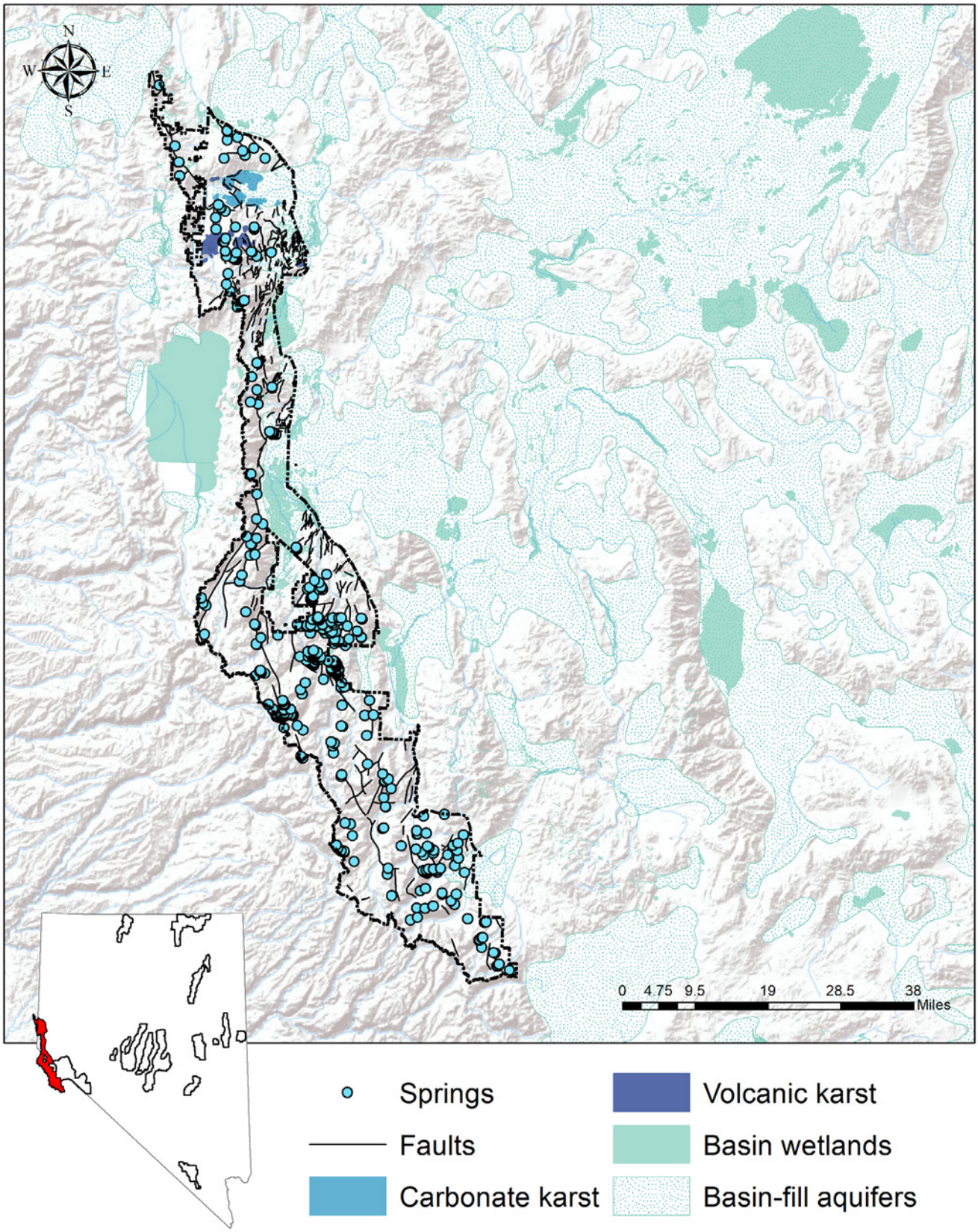


Figure C.27—Distribution of aquifers, faults, karst, and springs in the Sierra Nevada geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

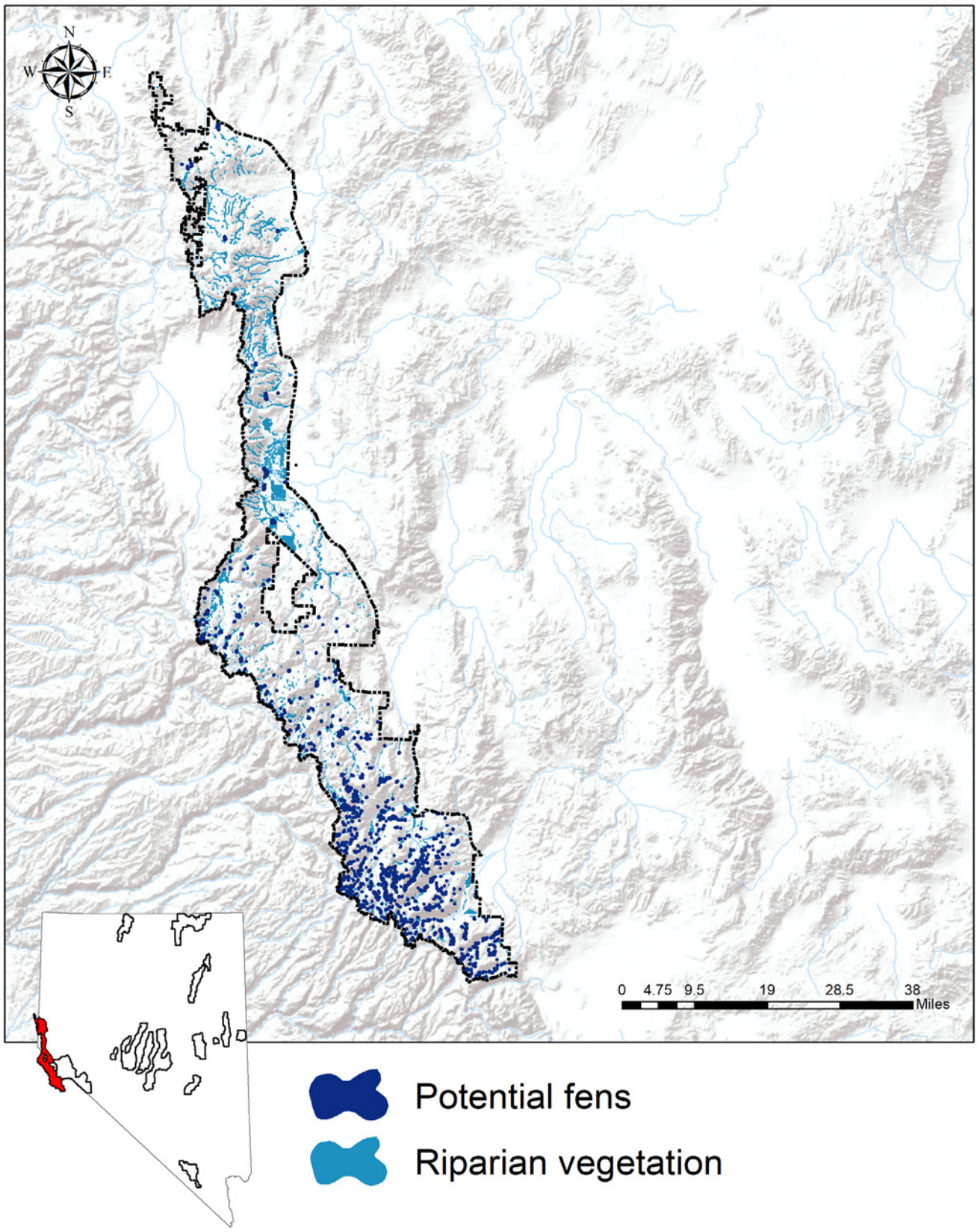


Figure C.28—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the Sierra Nevada geographic unit of the Humboldt-Toiyabe National Forest.

SMNRA

This geographic unit's features include the Spring Mountains, Lee Canyon, Kyle Canyon, and Lovell Canyon. Carbonate sedimentary rocks dominate the unit, with metamorphic rocks, primarily quartzite, and clastic rocks present as well (fig. C.29). This unit is part of a Basin and Range carbonate-rock aquifer system that is connected with Basin and Range basin-fill aquifers.

Vegetation classification indicates that riparian ecosystems cover 0.1 percent (FSVEG) to 0.4 percent (LANDFIRE) of this geographic unit. Based on MARVN results, riparian ecosystems cover 0.1 percent of the unit. Riparian cover is low because permeable bedrock and steep canyons prevent extensive floodplain development (Entrix 2008). Areas with stands of riparian vegetation include reaches of Cold Creek, Deer Creek. Lovell Canyon, and Willow Creek, (fig. C.30). Many of these reaches are fed by large springs.

There are 182 mapped springs (0.0006/acre). The largest clusters are in faulted carbonate rocks. There are 149 known springs addressed in the SMNRA management plan (Coles-Ritchie et al. 2014). Many springs emerge from limestone rock layers or the bases of limestone cliffs. Springs frequently emerge from or flow into avalanche chutes. The CNHP found no potential fens in this unit.

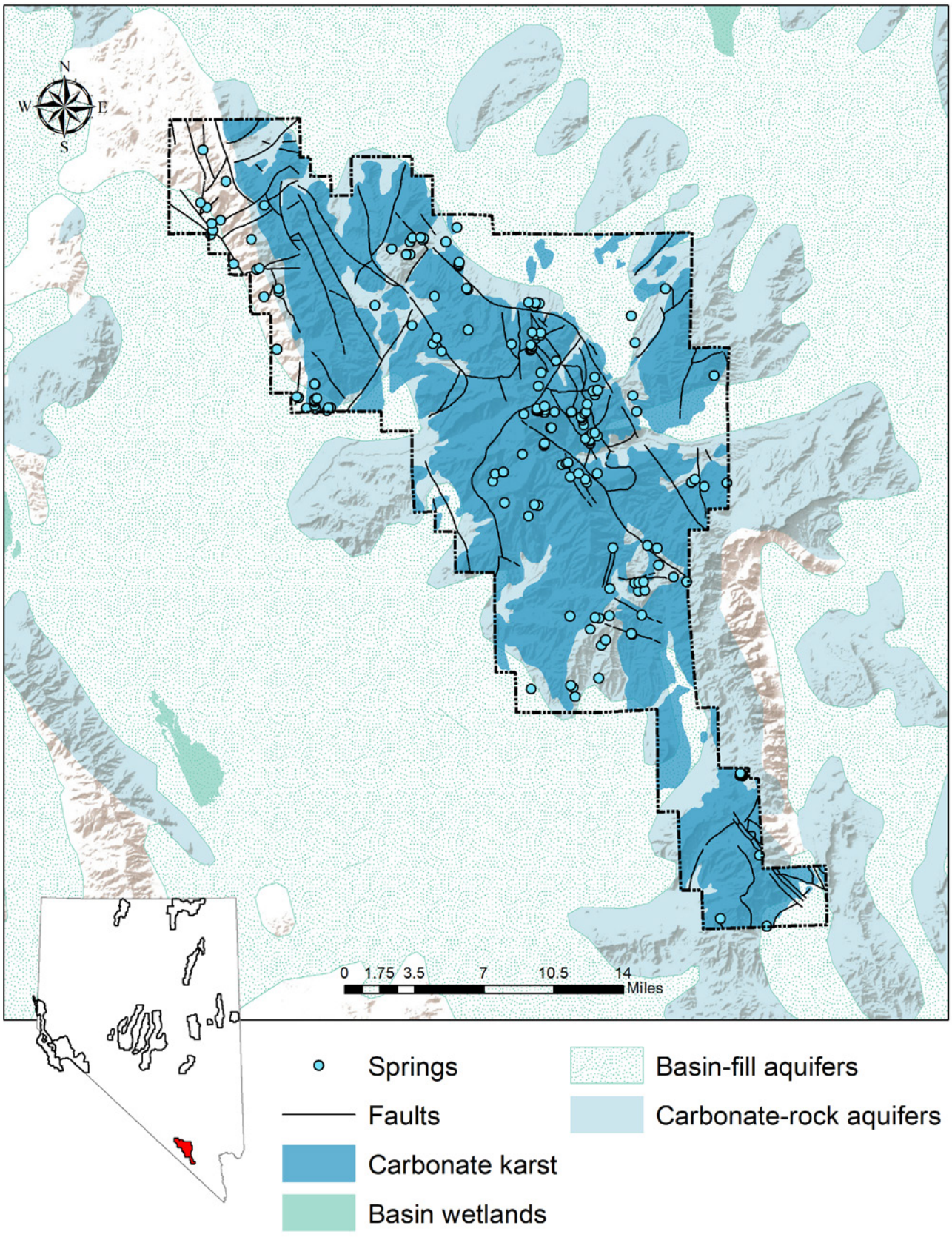


Figure C.29—Distribution of aquifers, faults, karst, and springs in the SMNRA geographic unit of the Humboldt-Toiyabe National Forest. Aquifers and basin wetlands outside of the administrative boundaries are also displayed.

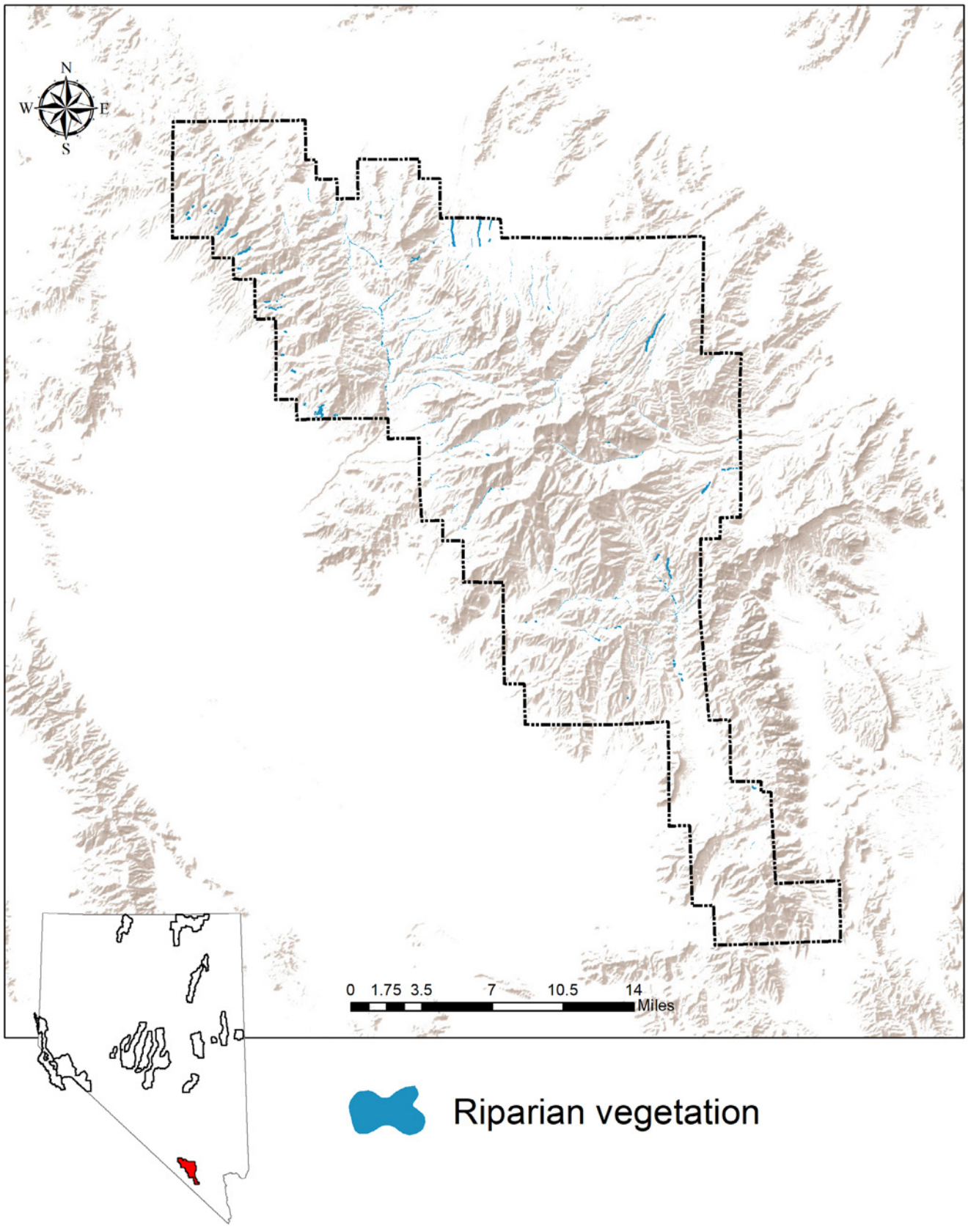


Figure C.30—Distribution of wetlands classified as potential fens and of vegetation classified as riparian in the SMNRA geographic unit of the Humboldt-Toiyabe National Forest.

REFERENCES

Horton, J.D., 2017. The State Geologic Map Compilation (SGMC) geodatabase of the conterminous United States. https://mrdata.usgs.gov/geology/state/USGS_SGMC_Metadata.html [Accessed June 23, 2020].

LANDFIRE Existing Vegetation Type layer. (2019 last update). U.S. Department of Interior, Geological Survey. [Online]. Available: http://landfire.cr.usgs.gov/viewer/ (accessed 2/17/20).

Maurer, D.K.; Lopes, T.J.; Medina, R.L.; Smith, J.L. 2004, Hydrogeology and hydrologic landscape regions of Nevada, U.S. Geological Survey Scientific Investigations Report 2004-5131, 35 p.

McGwire, K. 2019. Optimized Stratification for mapping Riparian Vegetation in Arid and Semiarid Environments, Remote Sensing 11:1638. DOI:10.3390/rs11141638.

Smith, G.; Lemly, J. 2019. Fen Mapping for the Humboldt-Toiyabe National Forest. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado. 39 p.

Trowbridge, W.; Chambers, J.C.; Germanoski, D.; Lord, M.L.; Miller, J.R.; Jewett, D.G. 2011. Characterization of meadow ecosystems based on watershed and valley segment/reach scale characteristics [chapter 7]. In: Chambers, Jeanne C.; Miller, Jerry R., eds. Geomorphology, hydrology, and ecology of Great Basin meadow complexes-implications for management and restoration. Gen. Tech. Rep. RMRS-GTR-258. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 95-112., 258, pp.95-112.

Viers, J.H.; Purdy, S.E.; Peek, R.A.; Fryjoff-Hung, A.; Santos, N.R.; Katz, J.V.E.; Emmons, J.D.; Dolan, D.V.; Yarnell, S.M. 2013. Montane Meadows in the Sierra Nevada: Changing Hydroclimatic Conditions and Concepts for Vulnerability Assessment. Center for Watershed Sciences Technical Report (CWS-2013-01), University of California, Davis. 63 p.

APPENDIX D. Surface Water and Groundwater Fluctuations

Unit Summaries

Central Mountains

There were 7,629 miles of streams within the Central Mountains unit. Of these streams, 10 percent were perennial, and 89 percent were intermittent or ephemeral. Mean daily flows modeled for the time period 1977 to 2006 (Wenger et al. 2010) indicated most streams in the Central Mountains were intermittent with low daily discharge (fig. D.1A). In intermittent streams, bankfull floods tended to occur at flows between one and ten cubic feet per second (cfs) (fig. D.1B). Few intermittent streams experienced flows above 100 cfs even during maximum modeled floods (fig. D.1C). Perennial streams tended to experience bankfull flooding at discharges above 10 cfs (fig. D.1B) and over 2000 miles of perennial streams had maximum flood discharges above 100 cfs (fig. D.1C). Average summer base flows in the Central Mountains tended to be below five cfs in both perennial and intermittent streams (fig. D.1D). A minority of streams in the Central Mountains had snowmelt-dominated, late hydrologic regimes, receiving half of annual flow after April 18 (fig. D.2A). The remaining streams had intermediate, transient hydrologic regimes, meaning half the annual flow in these systems occurred between February 27 and April 18 (fig. D.2A).

The primary stressors to groundwater and surface water fluctuations in the Central Mountains unit were roads, dams and diversions, grazing, tree mortality, and drought. Although the TCA indicated that 99 percent of the Central Mountains was in good or very good condition for road density, local riparian plot data and the WCF suggested roads were a stressor to groundwater and surface water fluctuations. There were 0.0007 road miles per acre, and 94 percent were classified as unimproved. Of the 34 riparian plots monitored in the Central Mountains, roads were indicated as a disturbance at 82 percent. According to the WCF, 85 percent of watersheds in the Central Mountains were functioning, but at risk for road and trail maintenance, meaning best management practices for designed drainage features were applied to 50 to 75 percent of roads, trails, and water crossings in these areas. An additional 5 percent of watersheds were classified as impaired for road and trail maintenance, meaning best management practices were applied to less than 50 percent of road and trail features. The WCF suggested there was a moderate probability that roads had substantially altered the hydrologic regime within 77 percent of Central Mountain watersheds.

There were 0.0003 diversions per acre in the Central Mountains, which was a moderate diversion density compared to other units on the HTNF. There was only one dam located in this unit. The WCF flow characteristics attribute indicated that peak and base flows were likely maintained throughout most of the unit, but that the timing, rate of change, and/or duration of mid-range discharges was altered in 94 percent of Central Mountain watersheds. Additionally, the WCF habitat fragmentation attribute indicated that dewatering had potentially contributed to fragmentation of aquatic habitats, with 80 percent of watersheds classified as functioning-at-risk.

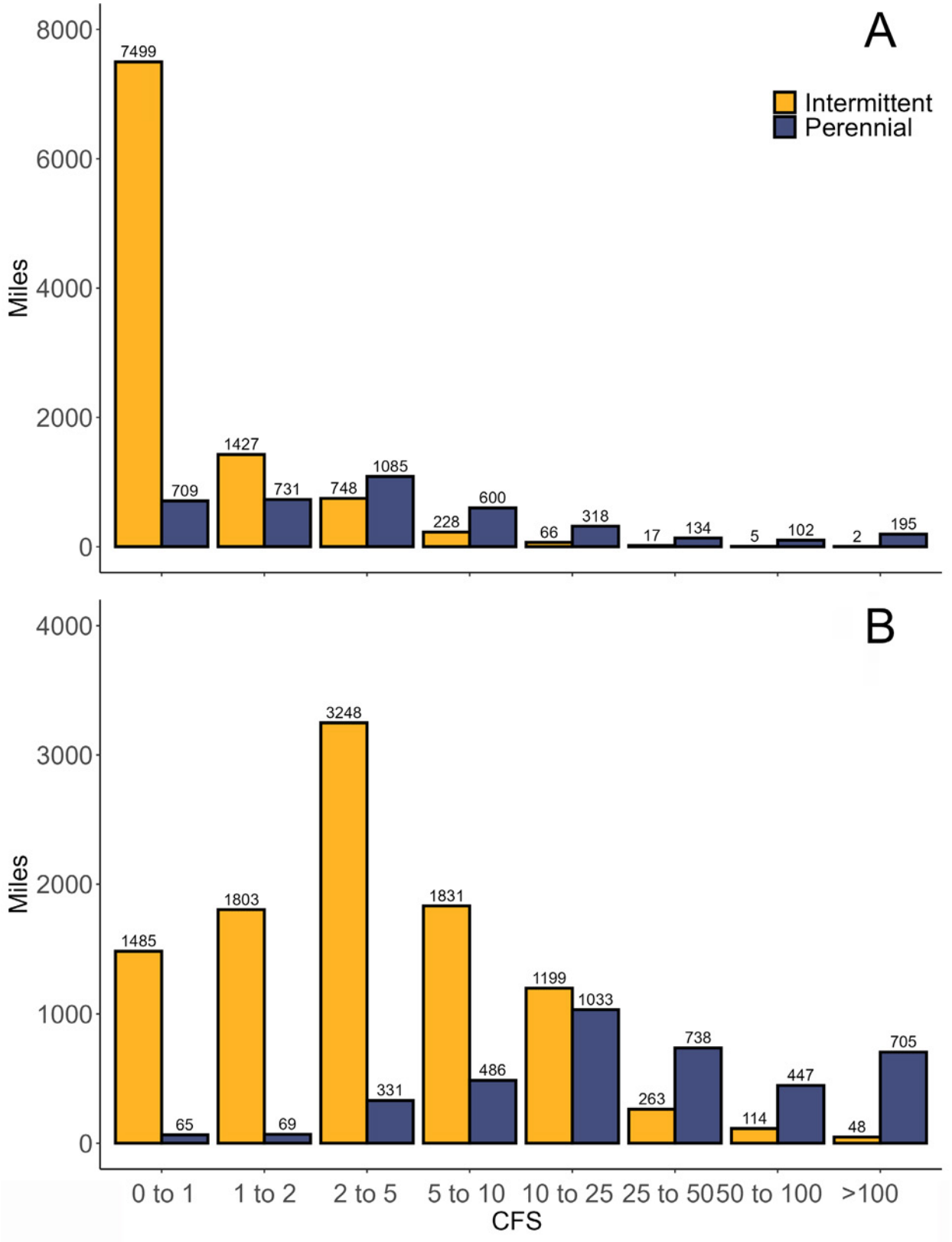


Figure D.1A-B—Modeled flow metrics for intermittent and perennial streams in the Central Mountains, including (A) mean annual flow 1977-2006 and (B) mean 1.5 year flood flow 1977-2006.

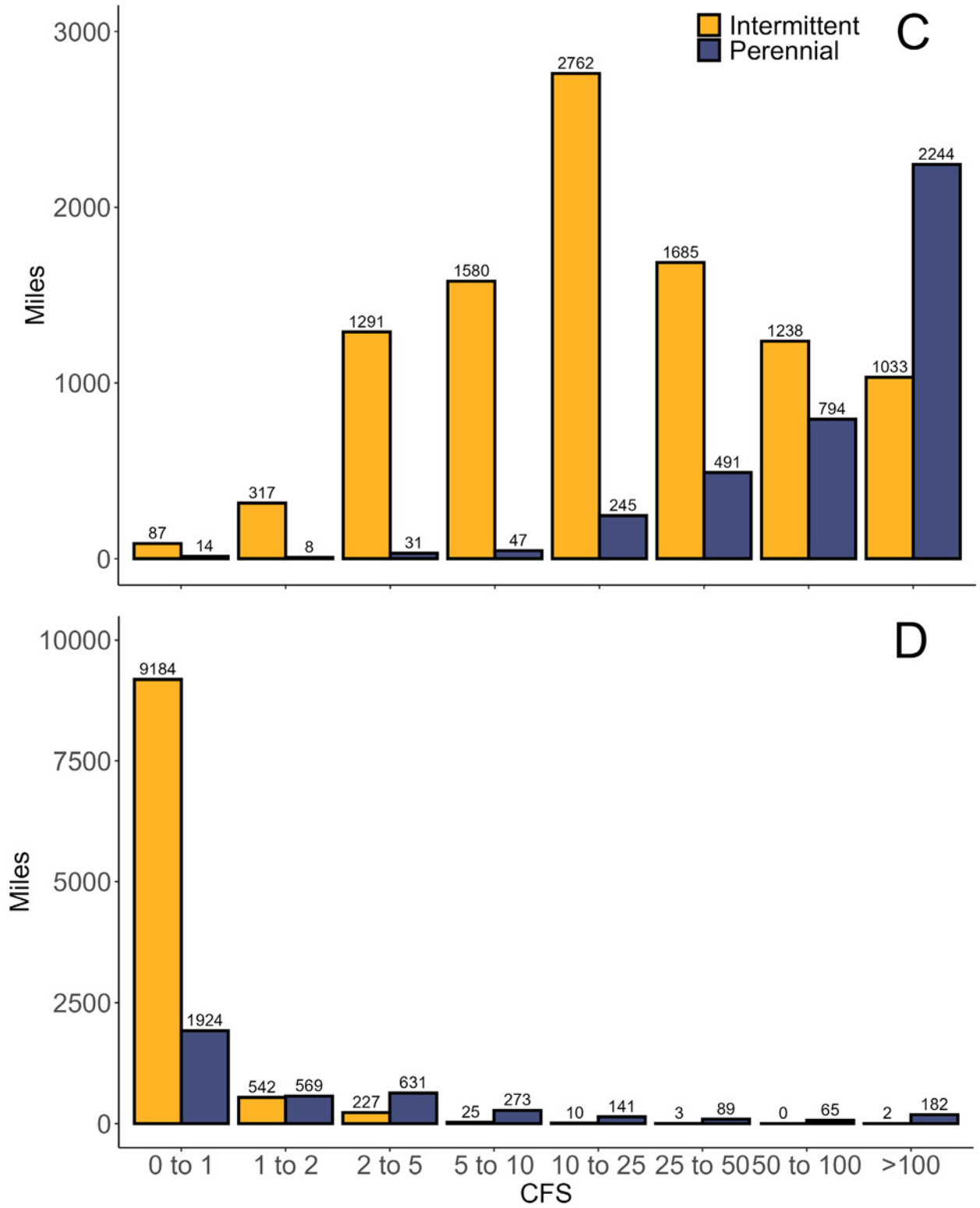


Figure D.1C-D—Modeled flow metrics for intermittent and perennial streams in the Central Mountains, including (C) maximum flood flow 1977-2006 and (D) mean summer base flow 1977-2006.

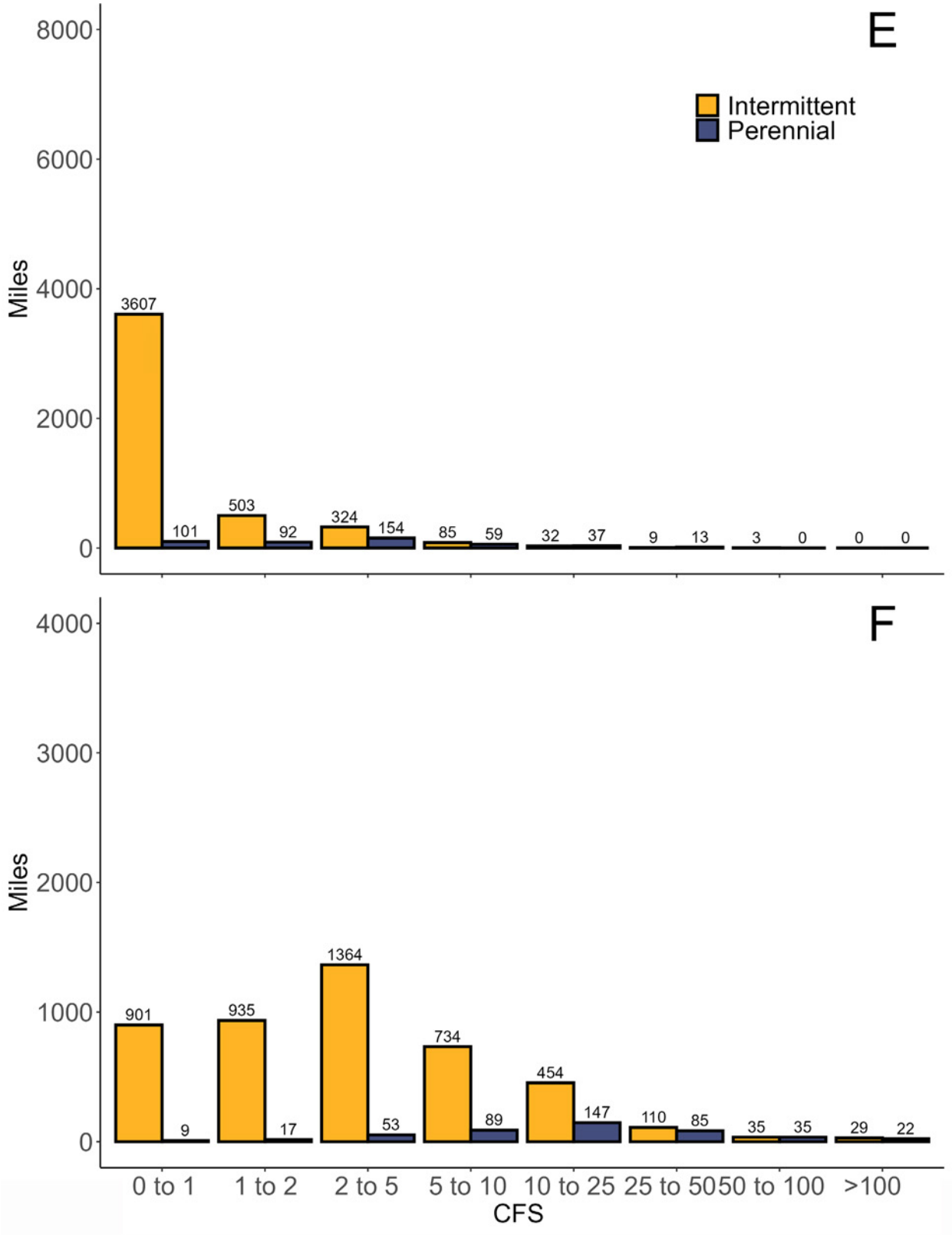


Figure D.1E-F—Modeled flow metrics for intermittent and perennial streams in the Central Mountains, including (E) mean annual flow 2030-2059 and (F) mean 1.5 year flood flow 2030-2059.

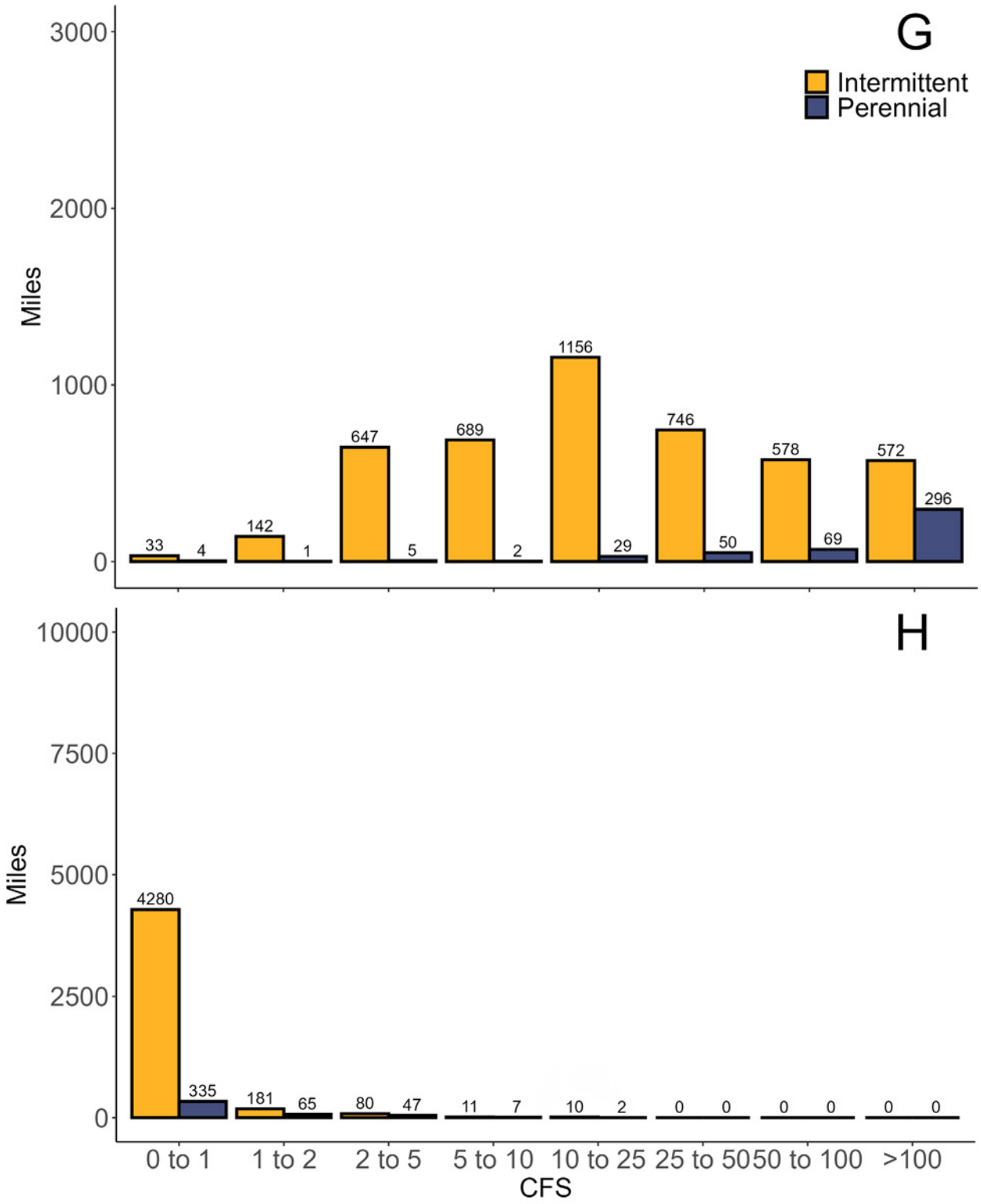


Figure D.1G-H—Modeled flow metrics for intermittent and perennial streams in the Central Mountains, including (G) maximum flood flow 2030-2059 and (H) mean summer base flow 2030-2059.

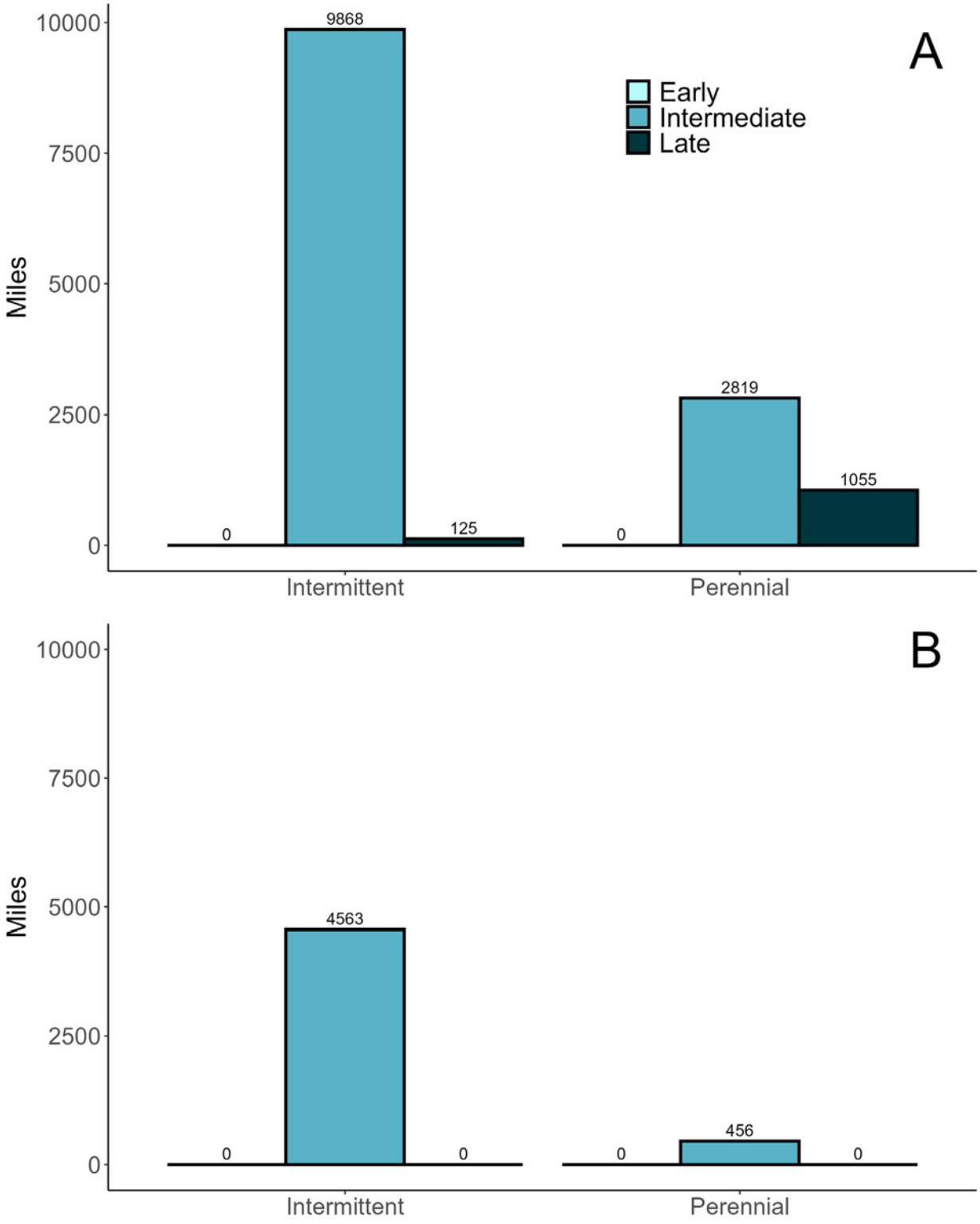


Figure D.2—Miles of intermittent and perennial streams in the Central Mountains unit with modeled intermediate or late hydrologic regimes for the time periods (A) 1977-2006 and (B) 2030-2059.

Ninety-eight percent of the Central Mountains was within a range management unit (RMU) and 69 percent of RMUs were active. Forty-nine percent of the unit was within wild horse and burro territory. Disturbance from grazing and wildlife use

were described at 89 percent of the 34 riparian plots monitored in this unit. The WCF indicated rangeland vegetation was functional, but at risk in 91 percent of watersheds. Rangelands in these watersheds had experienced a reversible loss in their capacity to capture, store, and safely release water from rainfall, runoff, and snowmelt. These areas were vulnerable to irreversible degradation of hydrologic function.

About 5 percent of forested lands in the Central Mountains experienced tree mortality between 2009 and 2013. An additional one percent of forested lands were impacted by tree mortality between 2014 and 2018. The WCF indicated that there was imminent risk of abnormally high tree mortality in most watersheds in the Central Mountains, with 30 percent classified as functioning-at-risk, and 33 percent classified as impaired. The capacity of the forests in these areas to intercept precipitation and regulate snowmelt may be impacted.

According to the TCA, 100 percent of the Central Mountains was in poor or very poor condition for drought, suggesting this unit has experienced long term moisture deficits. Most of the Central Mountains unit is located within Nye County, which according to the U.S. drought monitor experienced seven periods of drought since 2006. Prolonged droughts occurred in Nye County from December 2006 to January 2011, December 2011 to April 2019, and a drought period began in February 2020 and was ongoing at the time of this assessment. Part of the Central Mountains unit is in Lander County, which experienced six periods of drought since 2006. Prolonged drought occurred in Lander County from December 2006 to December 2010, December 2011 to January 2017, January 2018 to March 2019, and a drought period began in February 2020 and was ongoing at the time of this assessment. A small portion of the Central Mountains is in Eureka County, which experienced seven periods of drought since 2006. Prolonged drought occurred in Eureka County from January 2007 to December 2010, December 2011 to January 2017, January 2019 to March 2019, and a period of drought began in February 2020 and was ongoing at the time of this assessment.

Modeled flow metrics for the time period 2030-2059 (Wenger et al. 2010) suggested streams in the Central Mountains may experience substantially altered flow regimes in the coming decades (fig. D.1). Mean daily flows are expected to be reduced and the unit will likely experience an overall loss of perennial and intermittent stream miles (fig. D.1E). Both the magnitude and length of streams that experience flooding may be reduced, with large decreases in miles of perennial streams that experience bankfull or maximum floods (figs. D.1F, D.1G). Summer baseflows will likely be substantially reduced, with no streams expected to maintain flows over 25 cfs between June and September (fig. D.1H). Additionally, all streams are projected to transition to intermediate transient hydrologic regimes, with a loss of all snowmelt-dominated streams (fig. D.2B).

Local riparian plots indicated flooding as a disturbance at six of the 34 plots evaluated in the Central Mountains. This included flooding that occurred in 2011 at Gley Bog, in 2012 at Pete's Spring and Morgan Spring, in 2013 at George's Camp, and 2017 at Windy Canyon 2. Moderate conifer encroachment had occurred along 3.7 percent of streams. Significant conifer encroachment had occurred along 43.6 percent of streams.

Moderate conversion to grasses and shrubs had occurred along 2.1 percent of streams. Significant conversion to grasses and shrubs had occurred along 8.2 percent of streams. The average WCF water quantity score was 2.1, with 94 percent of watersheds within the Central Mountains considered functional-at-risk with moderate departures from natural flow regimes. The remaining 6 percent of watersheds in this unit were classified as having impaired function with significant departures in magnitude, duration, and/or timing of natural flows. Changes in climate were apparent in the Central Mountains unit (table D.1), with increased temperature in all four seasons and shifts in the timing and amount of precipitation. Throughout the unit, winter temperatures have increased by 1.7 to 2.6 °F, with a mean increase of 2.1 °F. On average, winter precipitation in the unit has increased by 0.1 inches; however, some areas experienced reduced precipitation rates of up to 0.3 inches, while other areas within the unit have gained up to 0.3 inches in winter precipitation.

Table D.1—Average seasonal temperature and precipitation deviations for the seven geographic units of the Humboldt-Toiyabe National Forest.

Unit	Temperature Deviation (°F)				Precipitation Deviation (inches)			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Central Mountains	2.09	2.22	2.5	1.75	0.1 (1.9%)	-0.36 (-9.7%)	-0.22 (-9.3%)	0.46 (19.7%)
East Sierra	3.3	3.25	3	2.4	0.1 (2.4%)	0.88 (30.2%)	0.13 (8.6%)	0.25 (12.5%)
Eastern Mountains	1.45	1.65	1.7	1.2	0.1 (1.6%)	-0.26 (-6.7%)	-0.21 (-8.9%)	0.33 (11.8%)
Northern Mountains	1.68	2.1	2.2	1.29	0.35 (8.0%)	0.15 (3.1%)	-0.09 (-5.5%)	0.68 (21.6%)
Ruby Mountains	1.5	1.4	1.4	1.1	0.52 (7.8%)	-0.38 (-5.4%)	-0.07 (-0.1%)	0.98 (22.7%)
Sierra Nevada	3.3	3.3	2.8	2.02	-0.49 (-1.9%)	-0.57 (-2.1%)	0.09 (7.0%)	0.2 (4.9%)
SMNRA	2.9	2.5	2.2	2	-1.19 (-26.5%)	-0.72 (-29.9%)	-0.44 (-17.6%)	-0.34 (-14.9%)

Approximately 58 percent of streams had riparian areas that had converted to upland conifers, grasses, or shrubs, which provided evidence that surface water and groundwater fluctuations in the Central Mountains unit were moderately altered from NRV (table D.2). More than half of Central Mountain watersheds were classified as functional-at-risk for water quantity, providing additional evidence of moderate alteration from NRV. One hundred percent of the unit was in poor or very poor condition for deviation in winter temperature, providing evidence of substantial alteration from NRV. None of the unit was in poor or very poor condition for deviation in winter precipitation, providing no evidence of alteration. Overall, two indicators suggested surface water and groundwater fluctuations were moderately altered from NRV, one indicator suggested substantial alteration, and one indicator suggested no

alteration. We estimated that surface water and groundwater fluctuations in the Central Mountains were likely **moderately altered** from NRV.

Table D.2—Values of surface water and groundwater fluctuation indicators by unit.

Indicators	Central Mountains	East Sierra	Eastern Mountains	Northern Mountains	Ruby Mountains	Sierra Nevada	SMNRA
Percent stream miles converted from riparian to conifer	47.4	47.8	40.0	9.2	12.4	49.7	19.2
Percent stream miles converted from riparian to grass or shrub	10.3	10.4	8.2	66.0	28.8	5.4	17.9
Percent of watersheds with WCC Water Quantity in functioning-at-risk condition	93.9	87.5	85.9	79.3	85.7	78.8	100
Percent of watersheds with WCC Water Quantity in impaired condition	6.1	12.5	14.1	20.7	14.3	21.2	0
Percent of unit rated poor or very poor for winter temperature deviation	100	99.9	33.1	71.8	0.0	99.4	99.8
Percent of unit rated poor or very poor for winter precipitation deviation	0.0	0.0	11.6	0.0	0.0	0.0	0.0

According to the SSI database there were 1,489 springs in the Central Mountains unit. Forty-three surveys conducted between 1991 and 2020 were available at 37 springs in the SSI database. Diversions and grazing were the most common disturbances, highly impacting 7 and 8 percent of springs, respectively. An additional 11 percent of springs were moderately disturbed by cattle. Flooding was indicated as a mild disturbance at 2 percent of springs. The Spring Ecosystem Assessment Protocol (SEAP) was completed at Mud Spring, Sidehill Spring, and Six Mile Spring in 2020. These reports provided the only available data related to condition of water fluctuations at GDEs in the Central Mountains. Mud Spring has been impacted by drought, cattle, and recreation, but aquifer functionality was rated as very good. Sidehill spring had also experienced high levels of disturbance from cattle, but the aquifer functionality remained in good condition. Stressor information was not included in the Six Mile Spring Report, and the aquifer functionality was rated as moderate. There was low risk to aquifer functionality and at least some restoration potential at all three sites. Additional inventory of condition is needed at GDE sites in the Central Mountains. There was **insufficient information** to evaluate water fluctuations at GDEs.

East Sierra

There were 2,938 miles of stream in the East Sierra unit. Of these streams, 8 percent were perennial, and 88 percent were intermittent or ephemeral. Modeled mean daily flow for 1977 to 2006 (Wenger et al. 2010) indicated many streams were intermittent with low daily discharge (fig. D.3A). Bankfull flooding in most intermittent streams tended to occur at flows between one and ten cfs (fig. D.3B), with 138 miles of intermittent streams estimated to have experienced maximum flooding at discharges above 100 cfs (fig. D.3C). Bankfull flooding in perennial streams tended to occur at flows above five cfs (fig. D.3B) and over 200 miles of perennial streams had maximum flood discharges above 100 cfs (fig. D.3C). Average summer base flows in the East Sierra tended to be below five cfs in both perennial and intermittent streams (fig. D.3D). About 45 miles of perennial streams had late, snowmelt-dominated hydrographs (fig. D.4A). The remaining perennial streams and all intermittent streams had intermediate transient hydrographs, typically receiving half their annual flow between February 27 and April 18 (fig. D.4A).

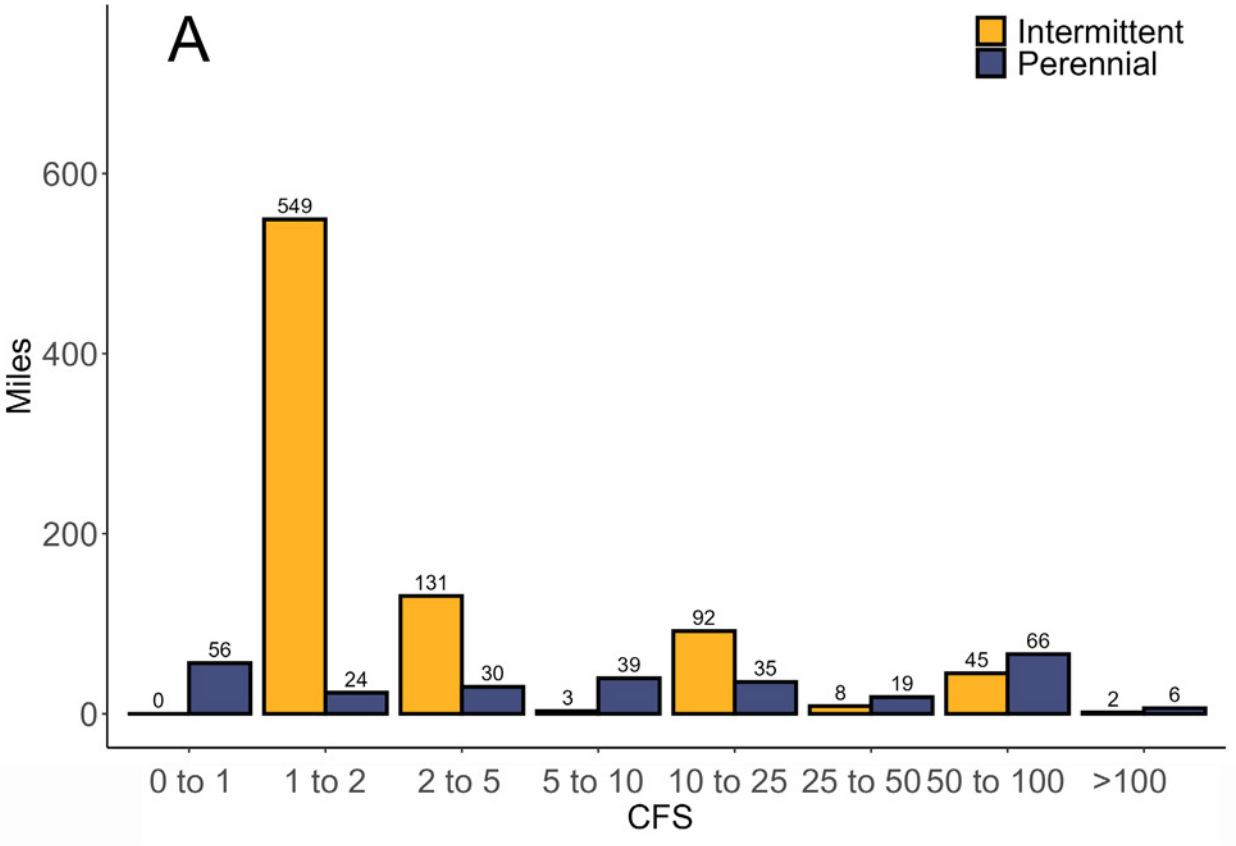


Figure D.3A—Modeled flow metrics for intermittent and perennial streams in the East Sierra, mean annual flow 1977-2006.

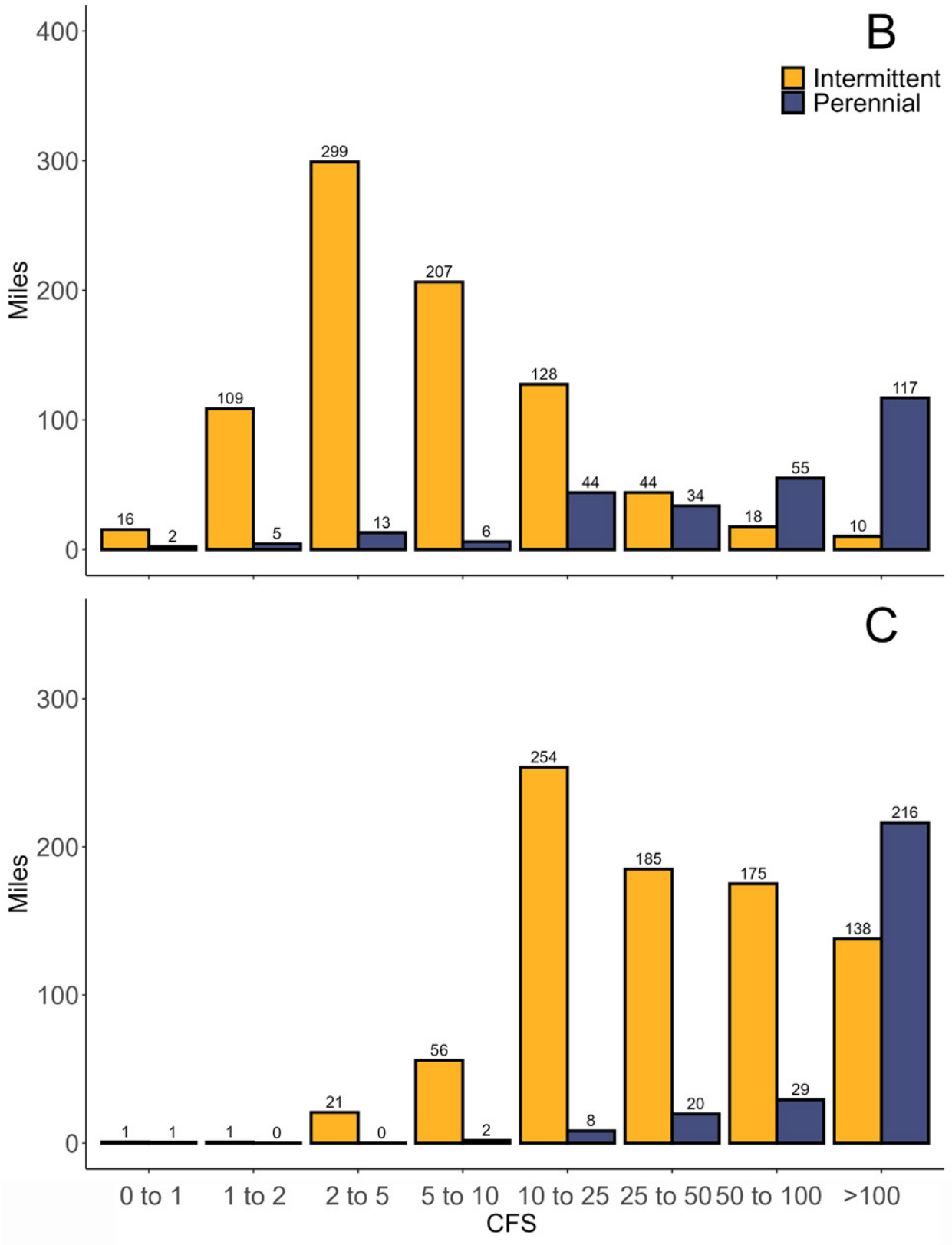


Figure D.3B-C—Modeled flow metrics for intermittent and perennial streams in the East Sierra, including (B) mean 1.5 year flood flow 1977-2006 and (C) maximum flood flow 1977-2006.

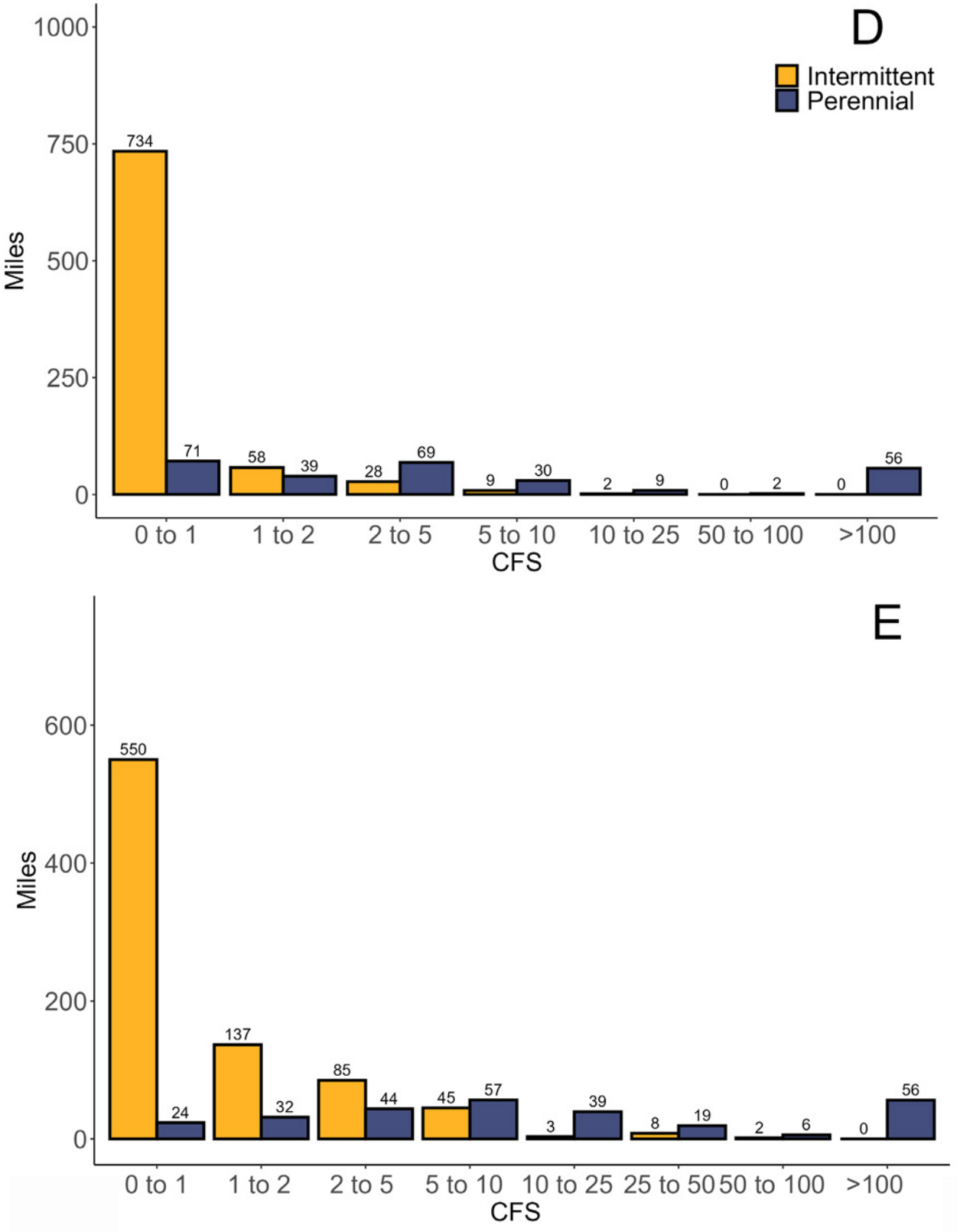


Figure D.3D-E—Modeled flow metrics for intermittent and perennial streams in the East Sierra, including (D) mean summer base flow 1977-2006 and (E) mean annual flow 2030-2059.

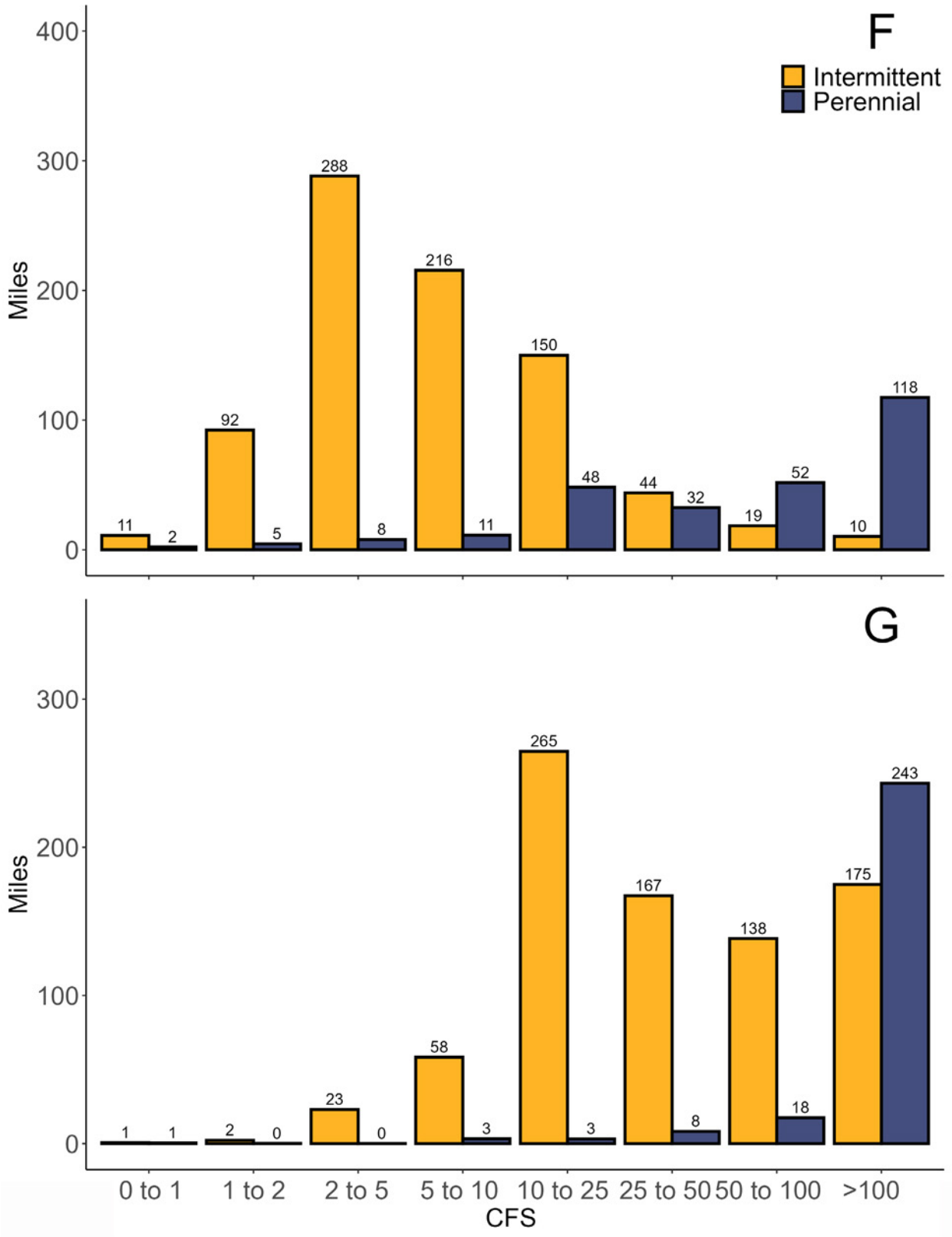


Figure D.3F-G—Modeled flow metrics for intermittent and perennial streams in the East Sierra, (F) mean 1.5 year flood flow 2030-2059 and (G) maximum flood flow 2030-2059.

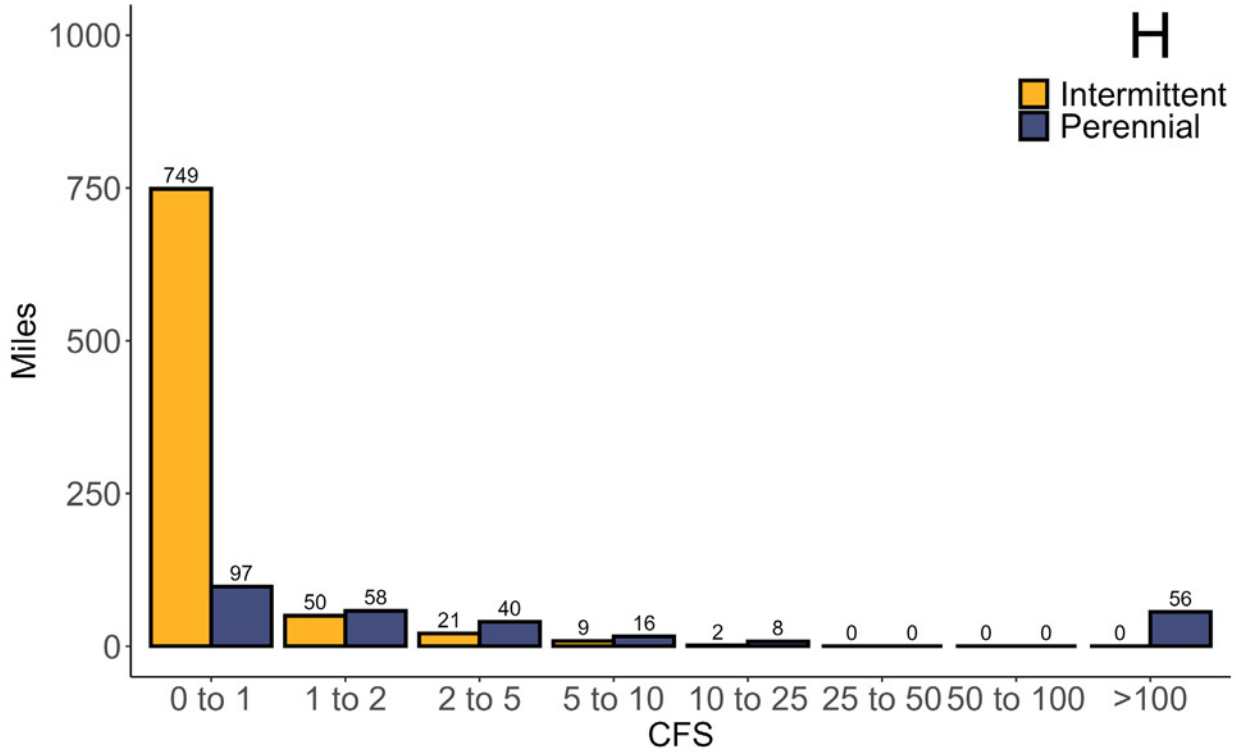


Figure D.3H—Modeled flow metrics for intermittent and perennial streams in the East Sierra, (H) mean summer base flow 2030-2059.

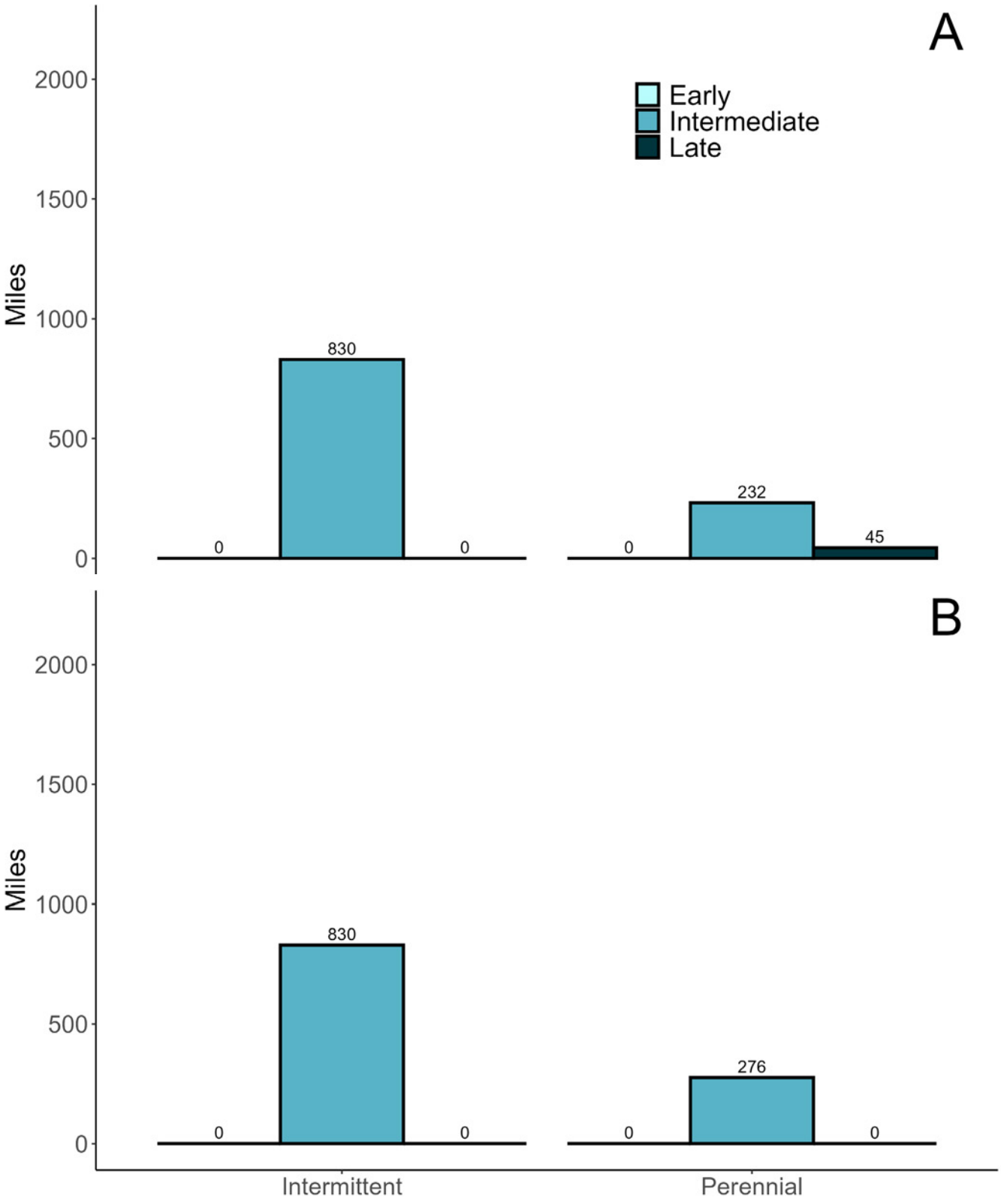


Figure D.4—Miles of intermittent and perennial streams in the East Sierra unit with modeled intermediate or late hydrologic regimes for the time periods (A) 1977-2006 and (B) 2030-2059.

The primary stressors to groundwater and surface water fluctuations in the East Sierra unit were roads, dams and diversions, grazing, and tree mortality. While the TCA indicated that 93 percent of the East Sierra unit was in good or very good condition for road density, the WCF suggested roads were a likely a stressor to groundwater and surface water fluctuations. There were 0.0011 road miles per acre within East Sierra, and 98 percent were classified as unimproved. There were only 3 riparian plots located in East Sierra. One plot indicated road disturbance had occurred at Watergap West. According to the WCF, 85 percent of watersheds in East Sierra were in functioning-at-risk condition for road and trail maintenance, meaning best management practices for designed drainage features were applied to 50 to 75 percent of roads and water crossings in these areas. An additional 10 percent of watersheds were classified as impaired for road and trail maintenance, meaning best management practices were applied to less than 50 percent of road features. The WCF indicated there was high probability that roads had substantially altered the hydrologic regime within 23 percent of watersheds in the East Sierra unit; there was moderate probability of substantially altered hydrologic regimes in an additional 70 percent of East Sierra watersheds.

There were 0.0003 diversions per acre and six dams located within the East Sierra unit. The WCF flow characteristics attribute indicated that peak and base flows were likely maintained throughout most of the unit, but that the timing, rate of change, and/or duration of mid-range discharges was altered, with 88 percent of watersheds classified as functioning-at-risk. Additionally, the WCF habitat fragmentation attribute indicated that dewatering had potentially contributed to fragmentation of aquatic habitats, with 85 percent of watersheds classified as functioning-at-risk.

Eighty-six percent of the unit was within an RMU and 95 percent of RMUs were active. Eighteen percent of the unit was within wild horse and burro territory. Of the three riparian plots sampled in the East Sierra unit, grazing was indicated as a disturbance in one plot (Watergap West) and wildlife use was described as a disturbance at all three. Grazing appeared to have impacted the hydrologic function of rangelands in most of the unit, with 58 percent of watersheds classified by the WCF to have impaired function for rangeland vegetation condition and 43 percent classified as functioning-at-risk. Those with impaired function had lost the capacity to capture, store, and safely release water from rainfall, runoff, and snowmelt. Watersheds classified as functioning-at-risk had suffered a reversible loss of hydrologic function and were vulnerable to irreversible degradation.

Less than 1 percent of the East Sierra unit was impacted by tree mortality between 2009 and 2013; however, impacts spread throughout forested landscapes with 2.5 percent of the unit impacted between 2014 and 2018. The WCF indicated that there was imminent risk of abnormally high tree mortality in most watersheds, with 15 percent classified as functioning-at-risk, and 80 percent classified as impaired. The capacity of forests in these areas to intercept precipitation and regulate snowmelt may be impacted.

Modeled flow metrics for 2030-2059 (Wenger et al. 2010) suggested flow regimes in the East Sierra may be resistant to alterations in the coming decades (fig. D.3). Mean daily discharge in perennial streams was unlikely to change substantially, with a slight

increase in perennial stream miles with more than 100 cfs mean annual flow (fig D.3E). Most intermittent streams were expected to shift from a mean daily discharge of 1 to 2 cfs to a mean daily discharge of 0 to 1 cfs (fig D.3E). Bankfull and maximum modeled flows did not appear to experience major changes (figs. D.3F, D.3G). Additionally, summer baseflows were estimated to remain unchanged (fig D.3H). We do expect a loss of perennial streams with late, snowmelt-dominated hydrographs, with all stream miles predicted to transition to transient, intermediate hydrologic regimes (fig. D.4B).

Local riparian plots indicated flooding as a disturbance at one of the three plots evaluated in the East Sierra: Watergap West in 2011. Moderate conifer encroachment had occurred along 2.5 percent of perennial streams. Significant conifer encroachment had occurred along 45.3 percent of streams. Moderate conversion to grasses and shrubs had occurred along 1.1 percent of streams. Significant conversion to grasses and shrubs had occurred along 9.3 percent of streams. The average WCF water quantity score was 2.1, with 88 percent of watersheds within the East Sierra unit considered functional-at-risk with moderate departures from natural flow regimes. The remaining 13 percent of watersheds were classified as having impaired function and significant departures in magnitude, duration, and/or timing of natural flows. Changes in climate were apparent in the East Sierra unit, with increased temperature in all four seasons and shifts in the timing and amount of precipitation (table D.1). Throughout the unit, winter temperatures had increased by 1.3 to 3.6 °F, with an average increase of 3.3 °F. On average, winter precipitation in the unit has increased by 0.1 inches; however, some areas have received 0.3 inches less precipitation, while other areas within the unit have received up to 0.4 inches more winter precipitation.

Approximately 58 percent of streams had riparian areas that had converted to upland conifers, grasses, or shrubs, which provided evidence that surface water and ground water fluctuations in the East Sierra unit were moderately altered from NRV (table D.2). More than half of East Sierra watersheds were classified as functional-at-risk for water quantity, providing additional evidence of moderate alteration from NRV. Nearly 100 percent of the unit was in poor or very poor condition for deviation in winter temperature, providing evidence of substantial alteration from NRV. None of the unit was in poor or very poor condition for deviation in winter precipitation, providing no evidence of alteration. Overall, two indicators suggested surface water and groundwater fluctuations were moderately altered from NRV, one indicator suggested substantial alteration, and one indicator suggested no alteration. We estimated that surface water and groundwater fluctuations in the East Sierra were likely **moderately altered** from NRV.

According to the SSI database there were 187 springs in the East Sierra unit. Twenty-three spring surveys conducted between 1991 and 2009 were available at 20 springs. Diversions and grazing were the most common disturbances, both highly impacting 6 percent of springs. An additional 4 percent of springs were moderately disturbed by diversions. Flooding was only indicated as a moderate disturbance at one spring, Huntoon Spring in 2001. No reports included information on condition and there was **insufficient information** to evaluate water fluctuations at GDEs in the East Sierra Unit.

Eastern Mountains

There were 3,799 miles of streams within the Eastern Mountains unit. Of these streams, 8 percent were classified as perennial and 91 percent were classified as intermittent or ephemeral. Modeled mean daily flow for 1977 to 2006 (Wenger et al. 2010) indicated nearly all streams in the Eastern Mountains were intermittent with low daily discharge (fig. D.5A). Bankfull floods in intermittent streams tended to occur at flows between one and ten cfs (fig. D.5B), with few intermittent streams experiencing flows above 100 cfs even at maximum modeled floods (fig. D.5C). Perennial streams tended to experience bankfull flooding at flows between five and ten cfs (fig. D.5C). Average summer base flows in the Eastern Mountains tended to be below five cfs in both perennial and intermittent streams (fig. D.5D). All streams within the Eastern Mountain units had intermediate, transient hydrologic regimes, receiving half of annual discharge between February 27 and April 18 (fig. D.6A).

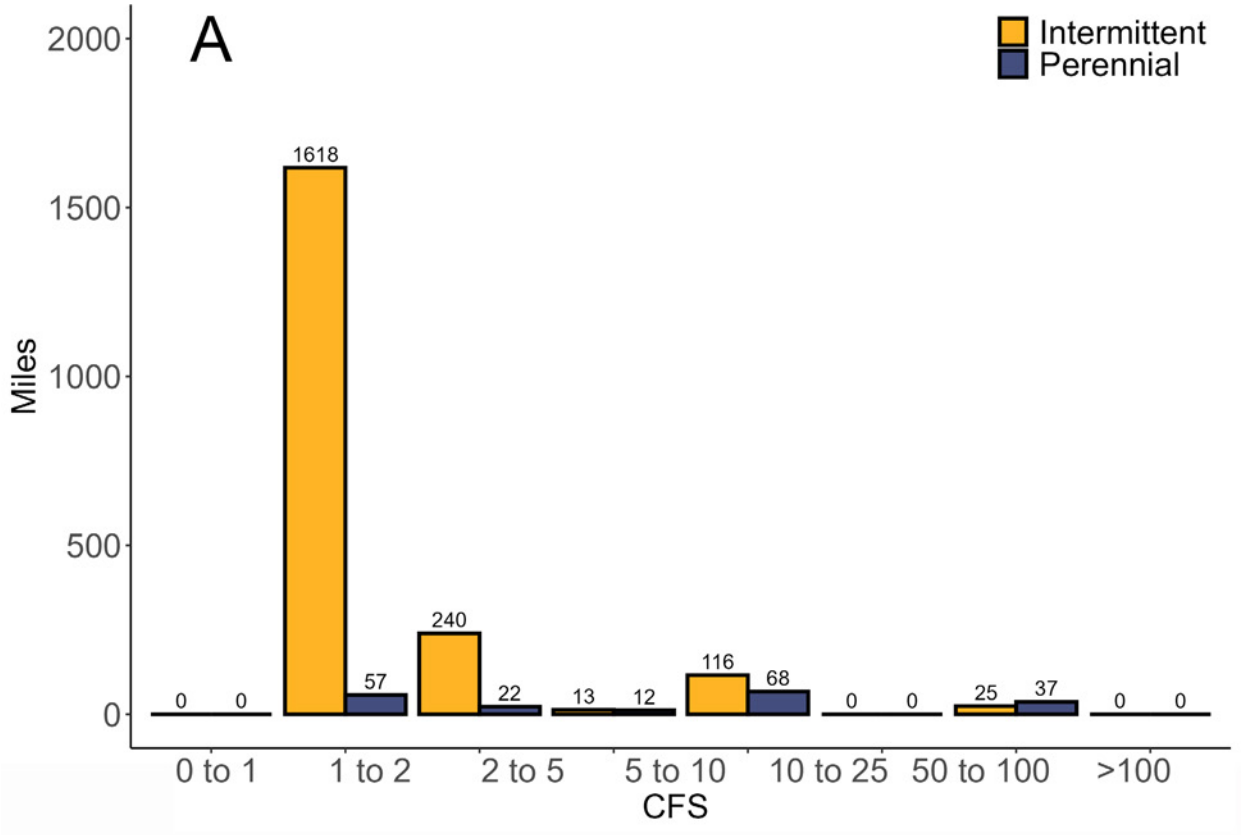


Figure D.5A—Modeled flow metrics for intermittent and perennial streams in the Eastern Mountains, mean annual flow 1977-2006.

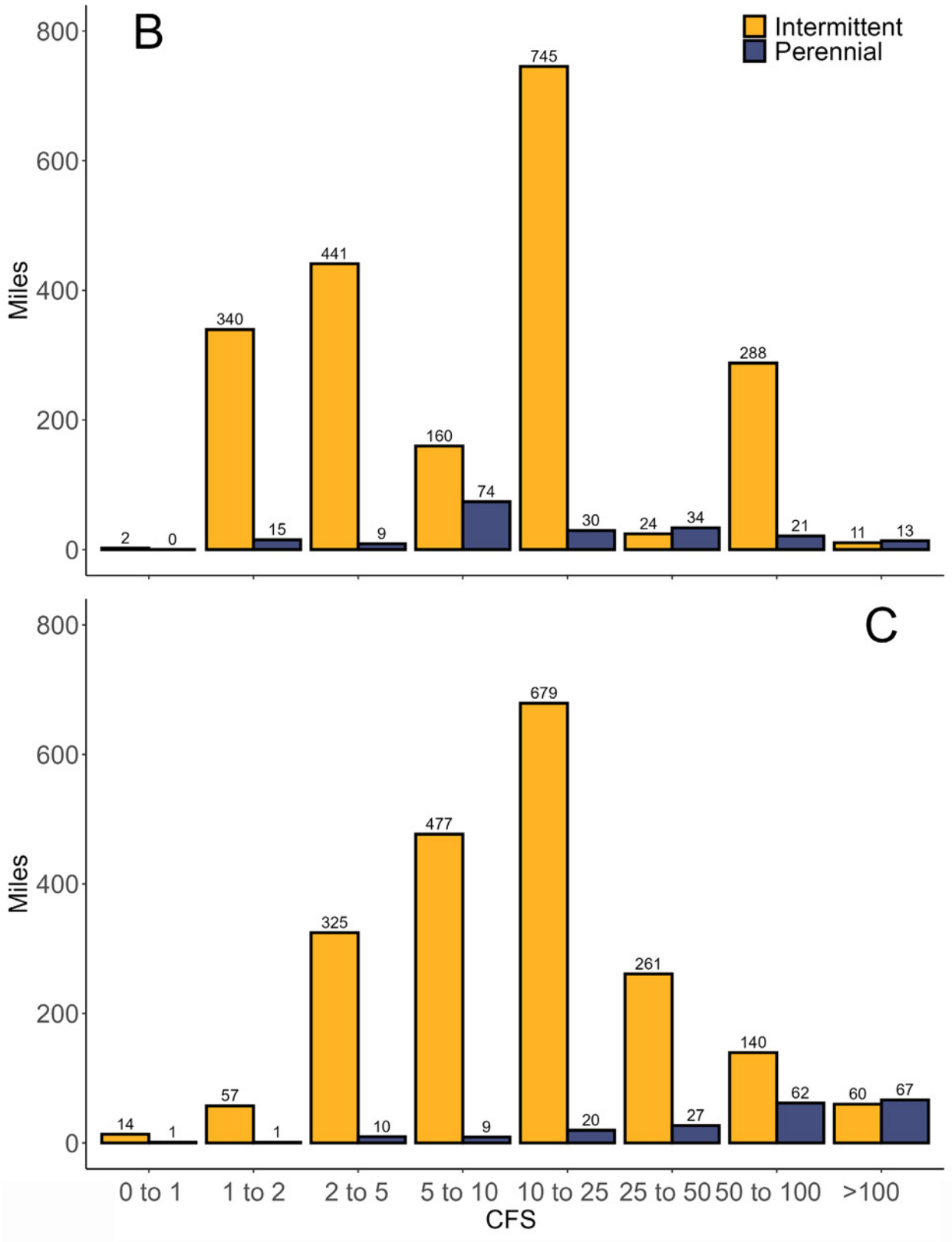


Figure D.5B-C—Modeled flow metrics for intermittent and perennial streams in the Eastern Mountains, including (B) mean 1.5 year flood flow 1977-2006 and (C) maximum flood flow 1977-2006.

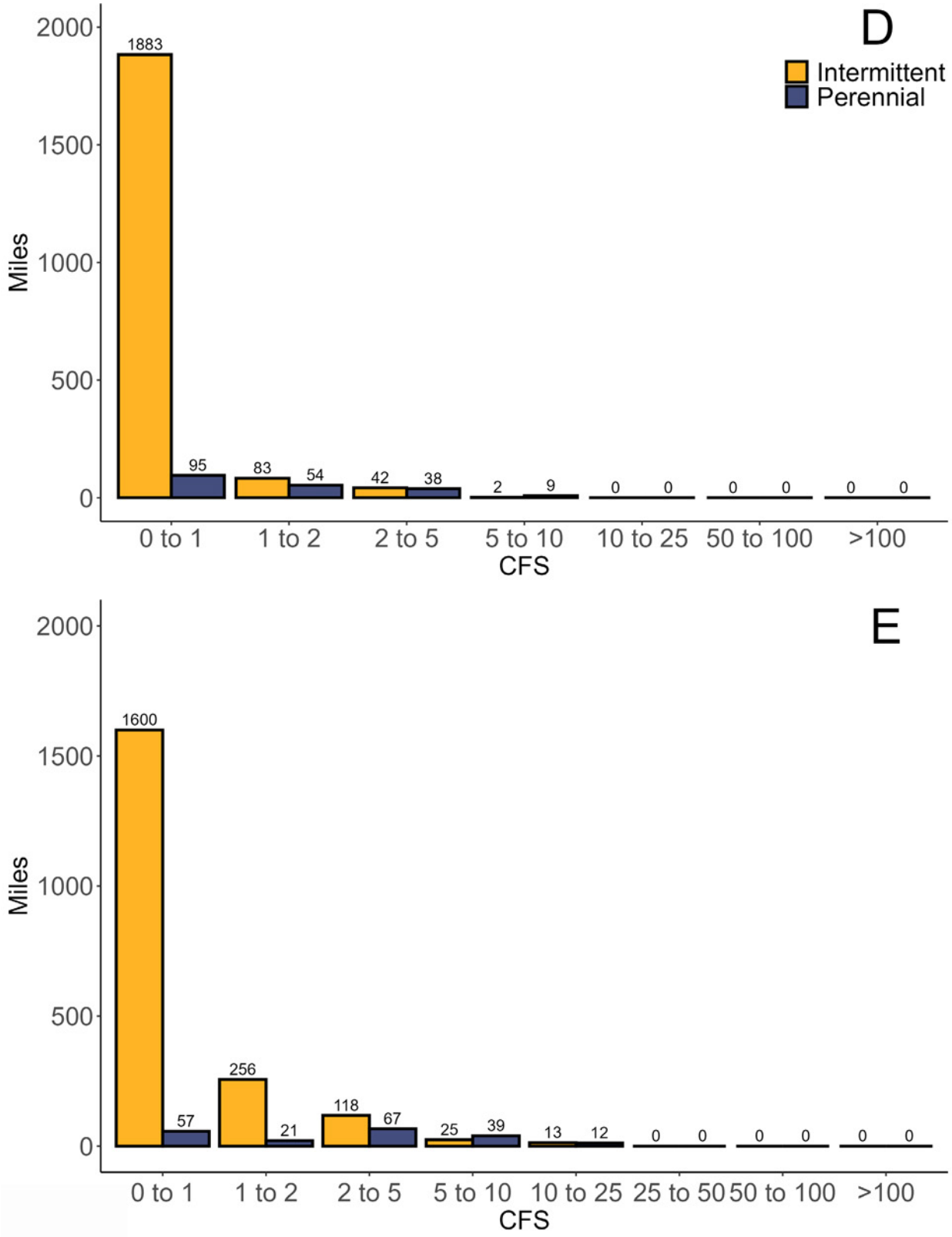


Figure D.5D-E—Modeled flow metrics for intermittent and perennial streams in the Eastern Mountains, including (D) mean summer base flow 1977-2006 and (E) mean annual flow 2030-2059.

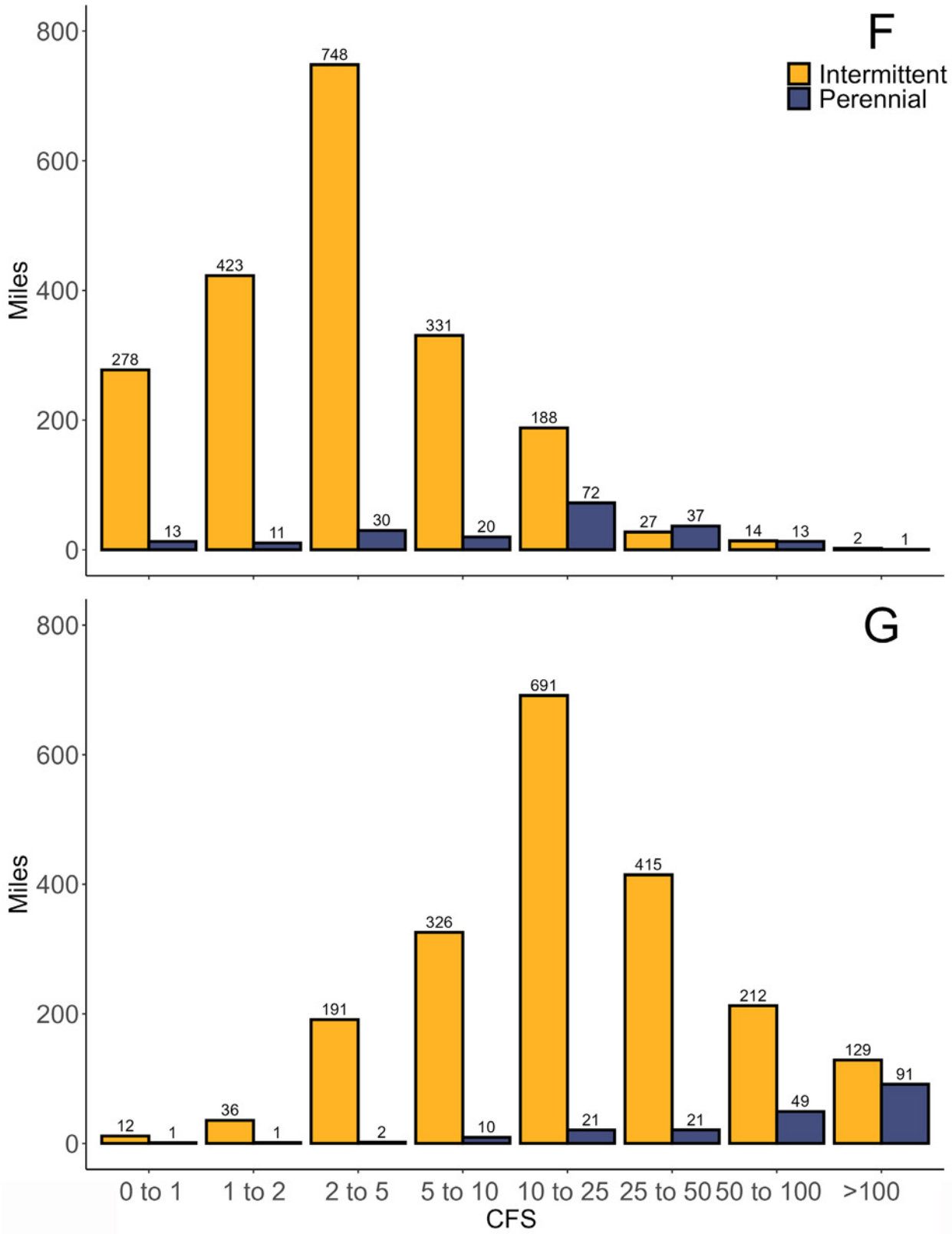


Figure D.5F-G—Modeled flow metrics for intermittent and perennial streams in the Eastern Mountains, including (F) mean 1.5 year flood flow 2030-2059 and (G) maximum flood flow 2030-2059.

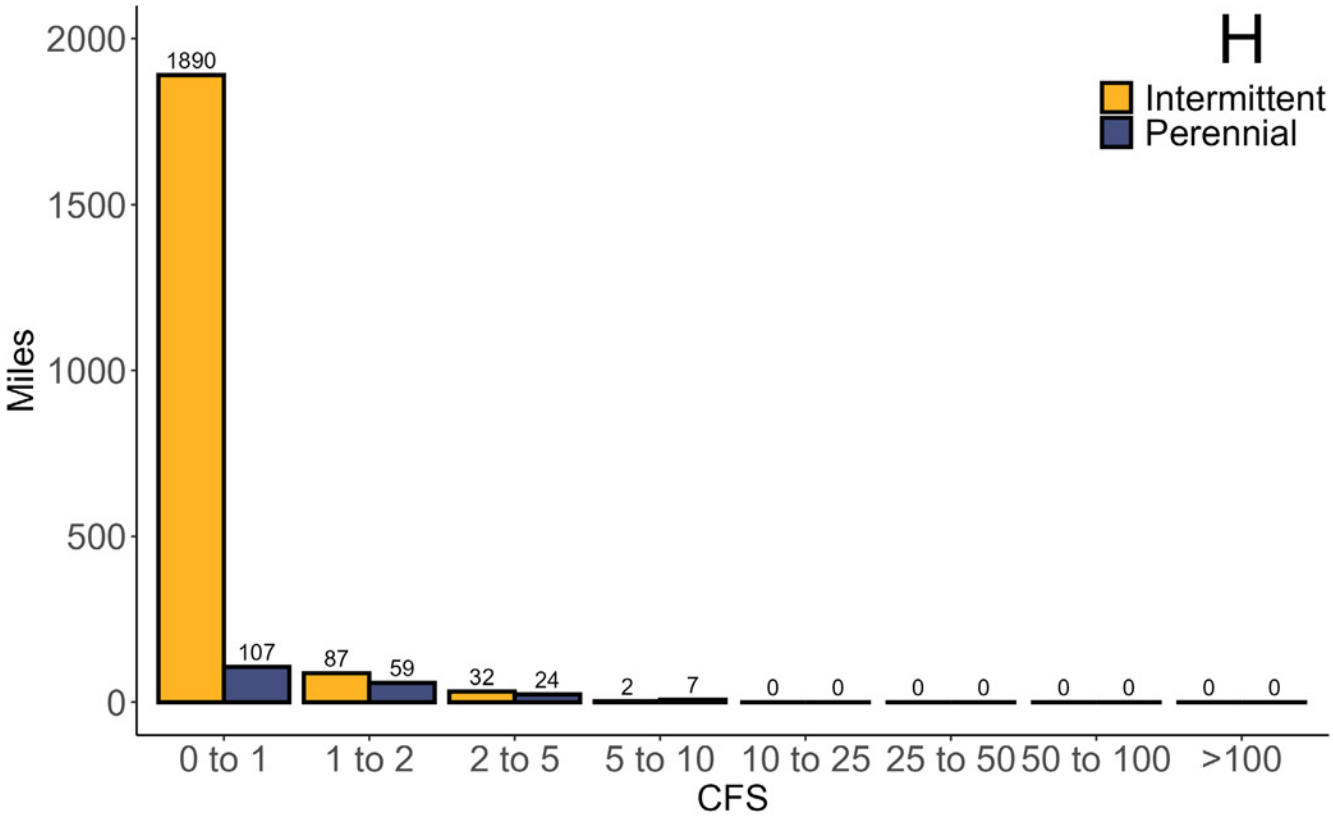


Figure D.5H—Modeled flow metrics for intermittent and perennial streams in the Eastern Mountains, mean summer base flow 2030-2059

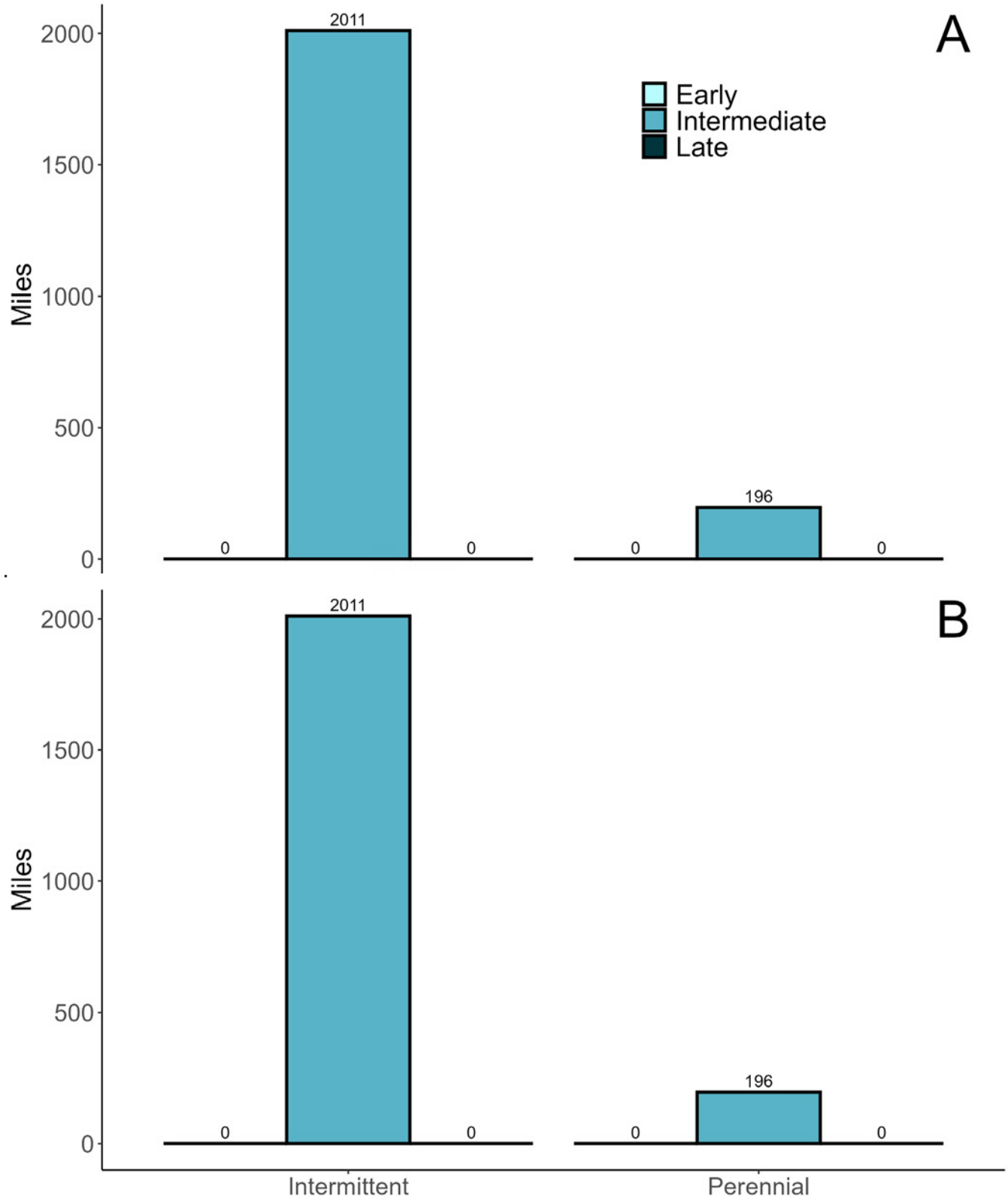


Figure D.6—Miles of intermittent and perennial streams in the Eastern Mountains unit with modeled intermediate or late hydrologic regimes for the time periods (A) 1977-2006 and (B) 2030-2059.

The primary stressors to groundwater and surface water fluctuations in the Eastern Mountains unit were roads, dams and diversions, grazing, and drought. While the TCA indicated that 99 percent of the Eastern Mountains were in good or very good condition for road density, local riparian plot data and the WCF suggested roads were a likely stressor to groundwater and surface water fluctuations in this unit. There were 0.0006 road miles per acre within the unit and 99 percent were classified as unimproved. Of the 49 riparian plots monitored in the Eastern Mountains, roads were a disturbance at 55 percent. According to the WCF, 82 percent of watersheds in the Eastern Mountains were in fair condition for road and trail maintenance, meaning best management practices for designed drainage features were applied to 50 to 75 percent of roads and water crossings in these areas. An additional 6 percent of watersheds were classified as impaired for road and trail maintenance, meaning best management practices were applied to less than 50 percent of road features. The WCF indicated that there was a moderate probability that roads had substantially altered the hydrologic regime within 72 percent of Eastern Mountain watersheds.

There were 0.0002 diversions per acre and two dams in the Eastern Mountains unit. This was the lowest diversion density of units on the HTNF. The WCF flow characteristics attribute indicated that peak and base flows are likely maintained throughout most of the unit, but that the timing, rate of change, and/or duration of mid-range discharges was altered in 86 percent of Eastern Mountain watersheds. Additionally, the WCF habitat fragmentation attribute indicated that dewatering had potentially contributed to fragmentation of aquatic habitats, with 37 percent of watersheds classified as functioning-at-risk and an additional 12 percent of watersheds classified as impaired.

Ninety-eight percent of the Eastern Mountains was within an RMU and 91 percent of those RMUs were active. Twenty-four percent of the unit was within wild horse and burro territory. Of the 49 riparian plots monitored in the Eastern Mountains, grazing and wildlife use were described as disturbances at 90 and 88 percent, respectively. The WCF indicated that rangeland vegetation was impaired in 44 percent of watersheds and functioning-at-risk in 52 percent. Watersheds with impaired rangelands lost the capacity to capture, store, and safely release water from rainfall, runoff, and snowmelt. Functioning-at-risk watersheds have experienced a reversible loss in capacity and are more vulnerable to irreversible degradation.

According to the TCA, 100 percent of the Eastern Mountains was in poor or very poor condition for drought, suggesting this unit experienced long term moisture deficits. Most of the Eastern Mountains unit is in White Pine County, which according to the U.S. drought monitor experienced five periods of drought since 2006. Prolonged drought occurred in White Pine County from January 2007 to December 2010, December 2011 to January 2017, July 2017 to April 2019, and a period of drought began in February 2020 and was ongoing at the time of this assessment. Part of the Eastern Mountains is in Nye County, which experienced seven periods of drought since 2006. Prolonged droughts occurred in Nye County from December 2006 to January 2011, December 2011 to April 2019, and a drought period began in February 2020 and is ongoing at the time of this assessment. A small section of the Eastern Mountains is in Lincoln County,

which experienced six periods of drought since 2006. Prolonged drought occurred in Lincoln County from December 2006 to January 2011, September 2011 to August 2017, November 2017 to April 2019, and a drought began in February 2020 and was ongoing at the time of this assessment.

Modeled flow metrics for 2030 to 2059 (Wenger et al. 2010) suggest hydrologic regimes of intermittent streams may be resistant to alterations due to climate change, while perennial streams may be more vulnerable (fig. D.5). Most intermittent streams are expected to decrease from 1 to 2 cfs mean daily flow to 0 to 1 cfs (fig. D.5E). Typical bankfull floods in intermittent streams will likely decrease to discharges of 2 to 5 cfs (fig. D.5F). There are limited perennial streams in the Eastern Mountains but mean daily flows and bankfull flows are expected to decrease in those that exist (fig. D.5E). Maximum modeled flows and summer baseflows in both perennial and intermittent streams are unlikely to change substantially (figs. D.5G, D.5H). Lastly, there are no expected shifts in hydrologic regimes, with all streams continuing to receive half of annual discharge between February 27 and April 18 (fig. D.6B).

Local riparian plot data indicated flooding as a disturbance at 15 of the 49 monitored plots in the Eastern Mountains. Evidence of flooding was present at Canyon Fork and Oil Springs in 2010, Six Mile Creek in 2012, Copper Creek 1 and Deer Spring in 2013, Little Cherry Creek and Burt Springs in 2014, and at Two Pines, Dandelion, Canyon Bottom, Feral Horses, Cabin Meadow, Bird Creek 3, Hot Plot 1, and Hot Plot in 2018. Moderate conifer encroachment had occurred along 2.4 percent of streams; significant conifer encroachment had occurred along 37.6 percent of streams. Moderate conversion to upland grass and shrub species had occurred along less than 1 percent of streams; significant conversion to upland grass and shrub species occurred along 7.3 percent of streams. The average WCF water quantity score was 2.1, with 86 percent of watersheds within the Eastern Mountains considered functioning-at-risk with moderate departures from natural flow regimes. The remaining 14 percent of watersheds in this unit were classified as impaired with significant departures in magnitude, duration, and/or timing of natural flows. Changes in climate were apparent in the Eastern Mountains (table D.1), with increased temperature in all four seasons and shifts in the timing and amount of precipitation. Throughout the unit, winter temperatures increased by 1.3 to 2.0 °F, with a mean increase of 1.5 °F. On average, winter precipitation in the unit increased by 0.1 inches; however, some areas experienced reduced precipitation rates of up to 0.4 inches, while other areas have gained up to 0.2 inches of winter precipitation.

Approximately 48 percent of streams had riparian areas that had converted to upland conifers, grasses, or shrubs, which provided evidence that surface water and ground water fluctuations in the Eastern Mountains were moderately altered from NRV (table D.2). More than half of Eastern Mountain watersheds were classified as functional-at-risk for water quantity, providing additional evidence of moderate alteration. About one third of the unit was in poor or very poor condition for deviation in winter temperature (table D.2), which provided evidence of moderate alteration. Approximately 12 percent of the unit was in poor or very poor condition for deviation in winter precipitation, which provided no evidence of alteration. Overall, three indicators suggested surface water and groundwater fluctuations were moderately altered from NRV, and one

indicator suggested no alteration. We estimated that surface water and groundwater fluctuations in the Eastern Mountains were likely **moderately altered** from NRV.

According to the SSI database there were 807 springs in the Eastern Mountains unit. Sixty surveys conducted between 1991 and 2020 were available at 57 springs. Multiple protocols had been applied to assess the condition of the springs. Diversions and grazing by wild animals and livestock were commonly noted disturbances at most sites. Several sites had water permanently diverted or had regulated water flow by an impoundment or a dam. SEAP had been applied at 8 sites, with all reports indicating at least moderate impacts to aquifer functionality. Aquifer functionality was rated as poor or very poor with no restoration potential at Indian Garden, Trail, and Red Rock. Additional inventory of condition is needed at GDE sites in the Eastern Mountains. There was **insufficient information** to evaluate water fluctuations at GDEs.

Northern Mountains

There were 4,234 miles of stream within the Northern Mountains unit. Of these streams, 28 percent were perennial, 70 percent were intermittent or ephemeral. Modeled mean daily flow for 1977 to 2006 (Wenger et al. 2010) indicated most intermittent streams had daily discharges between 0 and 1 cfs (fig. D.7A). More perennial streams existed in the Northern Mountains compared to other units, but these tended to be small streams with mean daily discharges of less than 10 cfs (fig. D.7A). Bankfull floods tended to occur in intermittent streams at flows between 1 and 25 cfs (fig. D.7B) and in perennial streams at flows above 5 cfs (fig. D.7B). Maximum modeled floods in intermittent streams were generally greater than 10 cfs and most perennial streams experienced maximum flows above 100 cfs (fig. D.7C). Summer baseflows in most perennial and intermittent streams tended to be less than 1 cfs (fig. D.7D). Most intermittent and perennial streams had transient intermediate hydrographs and received half their annual flow between February 27 and April 18 (fig. D.8A); however, about 56 miles of intermittent streams and 370 miles perennial streams received half their annual flow after April 18, suggesting the presence of some snowmelt-dominated systems in the Northern Mountains unit.

The primary stressors to groundwater and surface water fluctuations in the Northern Mountains unit were roads, dams and diversions, grazing, tree mortality, fire, and drought. The Northern Mountains had the second highest road density of geographic units considered in this assessment. While the TCA indicated that 100 percent of the unit was in good or very good condition for road density, local riparian plot data and the WCF suggested roads may have impacted groundwater and surface water fluctuations. There were 0.0011 road miles per acre within the unit, and 94 percent were classified as unimproved. Of the 32 riparian plots sampled in the Northern Mountains, 72% described disturbance from roads. According to the WCF, 62 percent of watersheds in the Northern Mountains were in fair condition for road and trail maintenance, meaning best management practices for designed drainage features were applied to 50 to 75 percent of roads and water crossings in these areas. An additional 29 percent of watersheds were classified as impaired for road and trail maintenance, meaning best management practices were applied to less than 50 percent of road features. The WCF indicated that there was high probability that roads had substantially altered the

hydrologic regime within 34 percent of watersheds and a moderate probability that roads had substantially altered the hydrologic regime within an additional 53 percent of Northern Mountain watersheds.

There were 0.0011 diversions per acre in the Northern Mountains and two dams located within the unit. The WCF flow characteristics attribute indicated that peak and base flows were likely maintained throughout most of the unit, but that the timing, rate of change, and/or duration of mid-range discharges was altered, with 79 percent of watersheds classified as functioning-at-risk. Additionally, the WCF habitat fragmentation attribute indicated that dewatering had potentially contributed to fragmentation of aquatic habitats, with 74 percent of watersheds classified as functioning-at-risk.

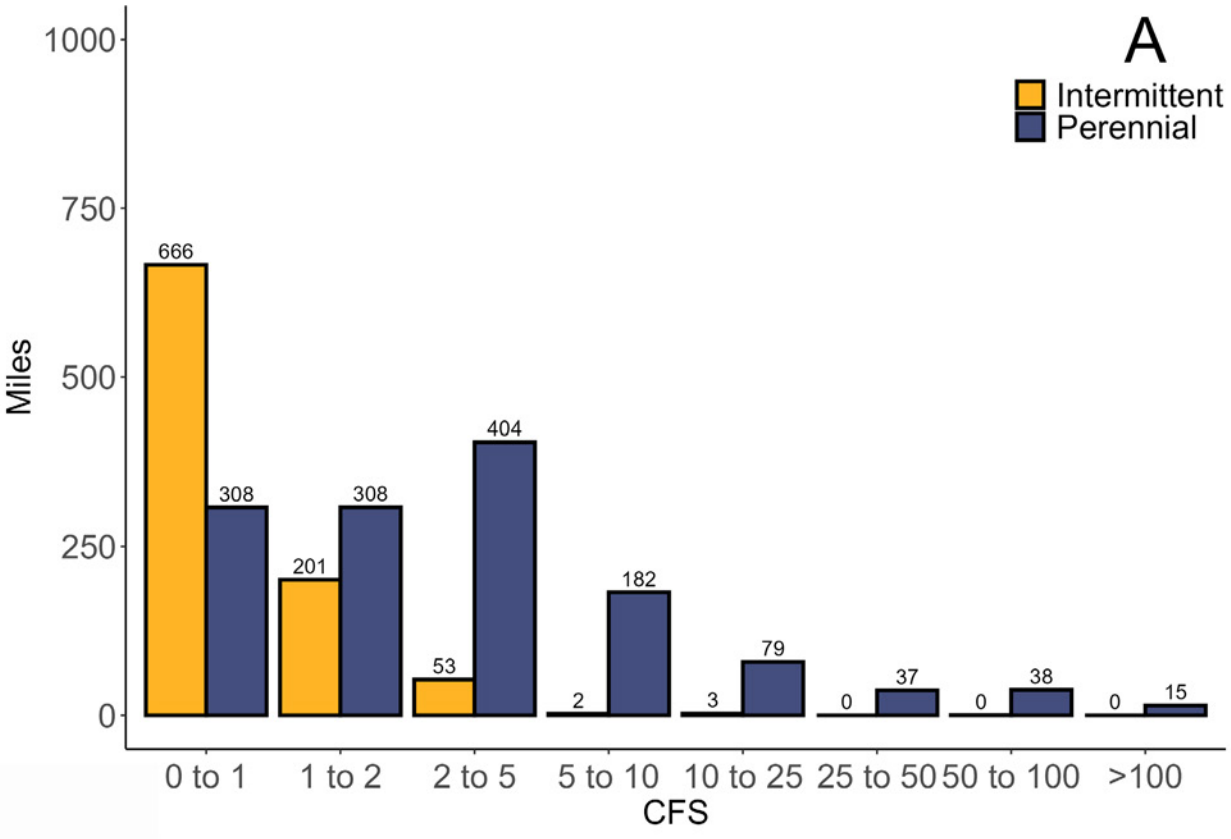


Figure D.7A—Modeled flow metrics for intermittent and perennial streams in the Northern Mountains, mean annual flow 1977-2006.

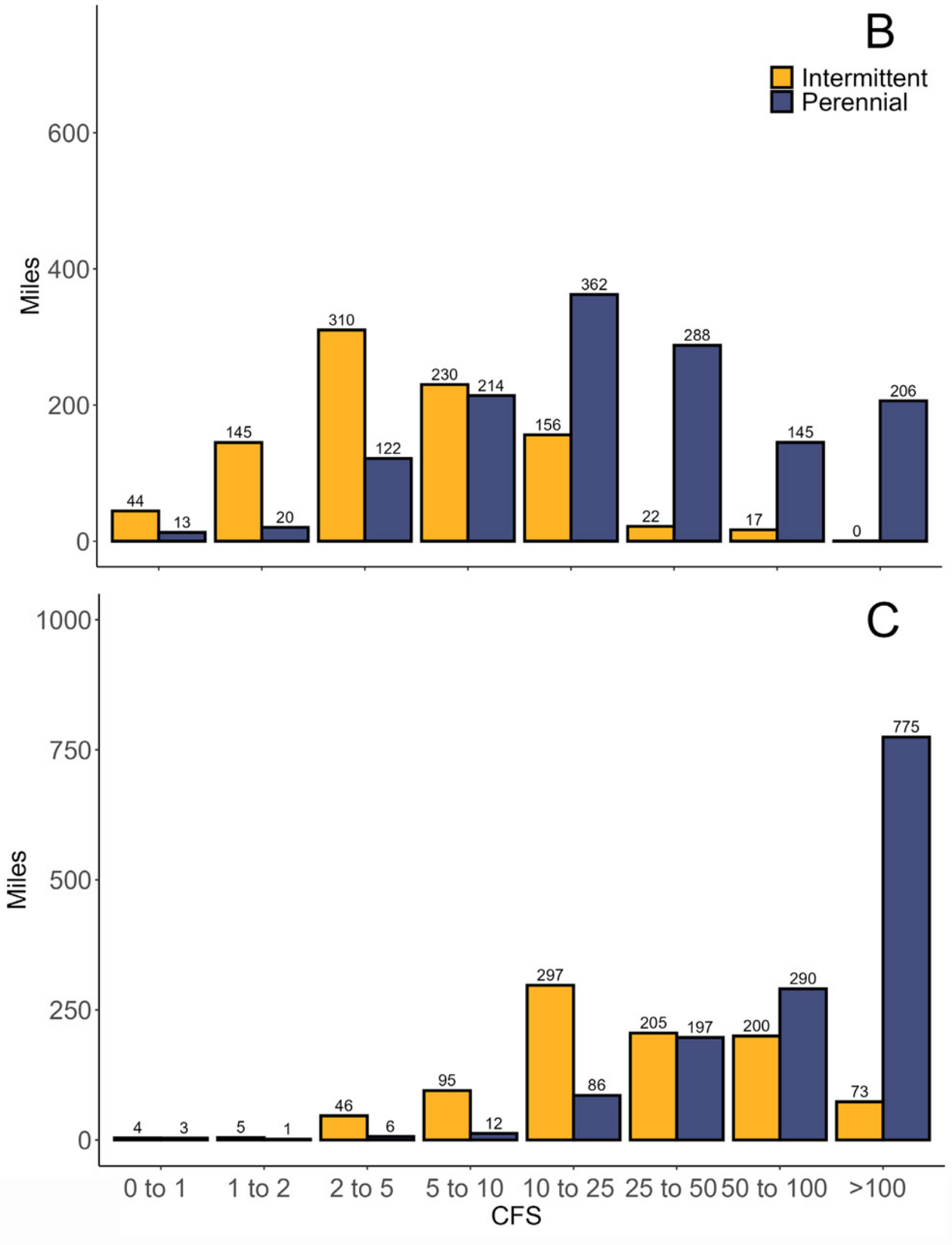


Figure D.7B-C—Modeled flow metrics for intermittent and perennial streams in the Northern Mountains, including (B) mean 1.5 year flood flow 1977-2006 and (C) maximum flood flow 1977-2006.

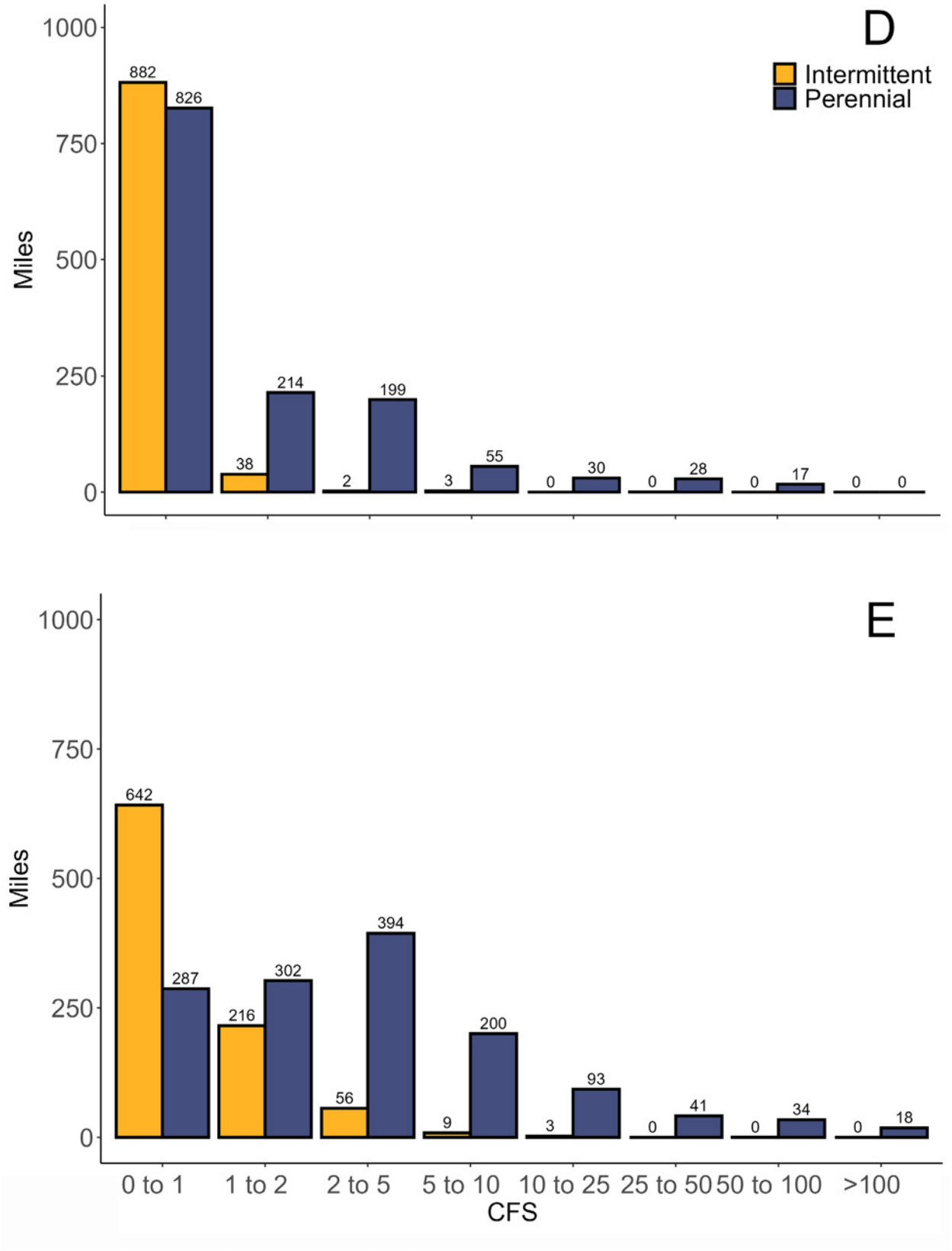


Figure D.7D-E—Modeled flow metrics for intermittent and perennial streams in the Northern Mountains, including (D) mean summer base flow 1977-2006 and (E) mean annual flow 2030-2059.

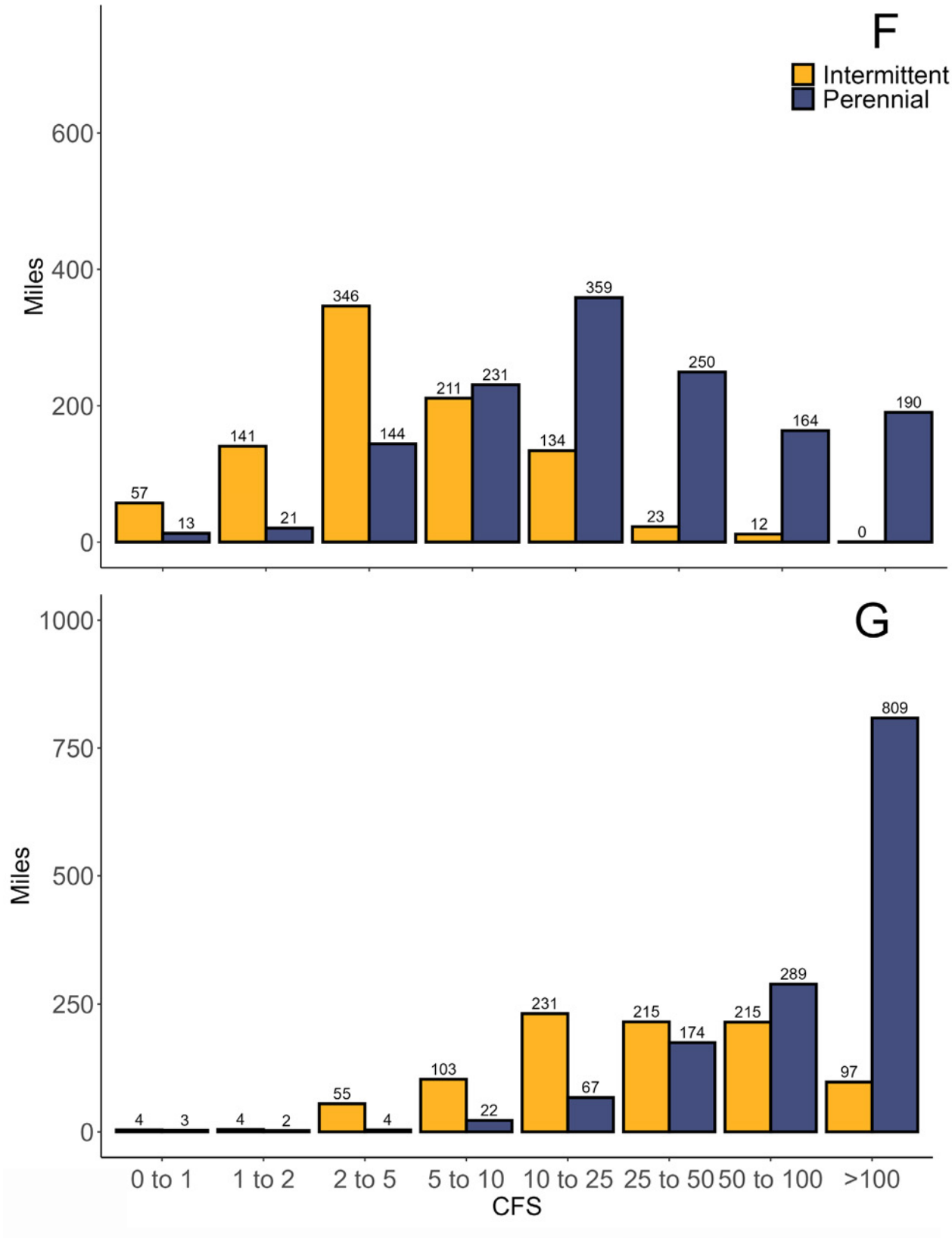


Figure D.7F-G—Modeled flow metrics for intermittent and perennial streams in the Northern Mountains, including (F) mean 1.5 year flood flow 2030-2059 and (G) maximum flood flow 2030-2059.

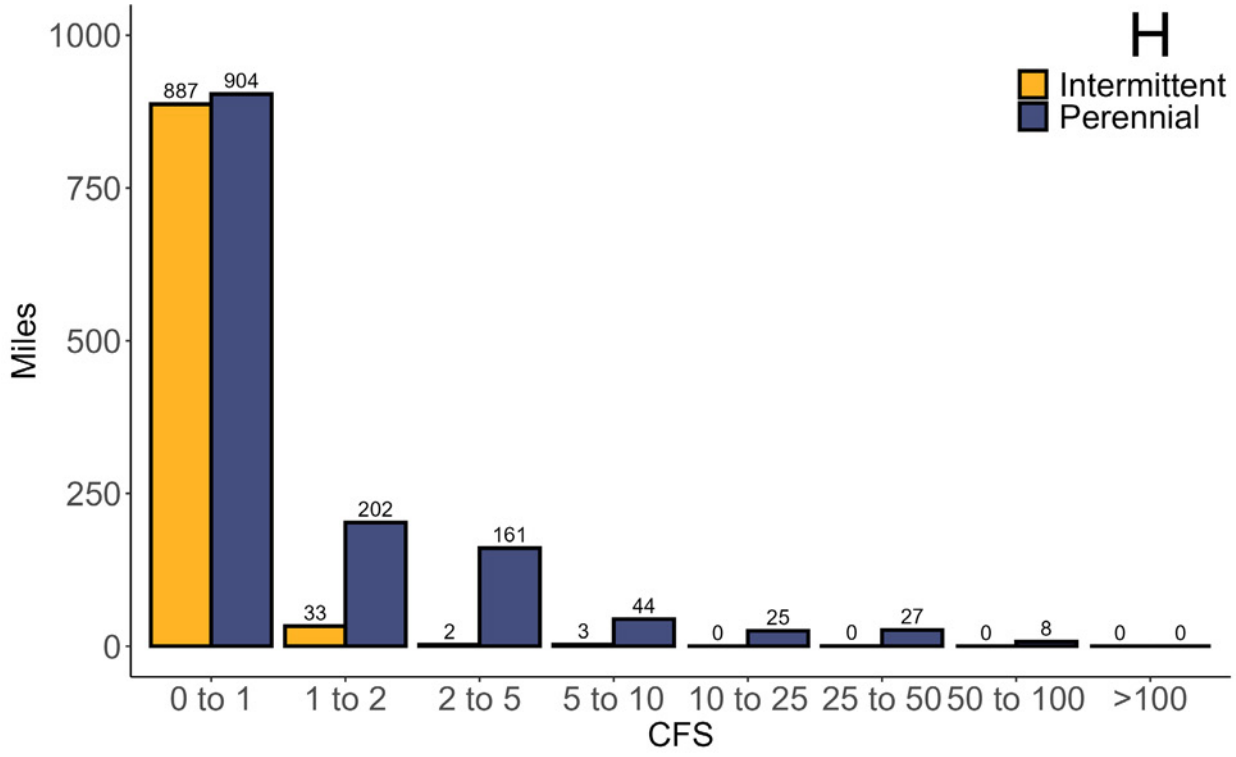


Figure D.7H—Modeled flow metrics for intermittent and perennial streams in the Northern Mountains, mean summer base flow 2030-2059.

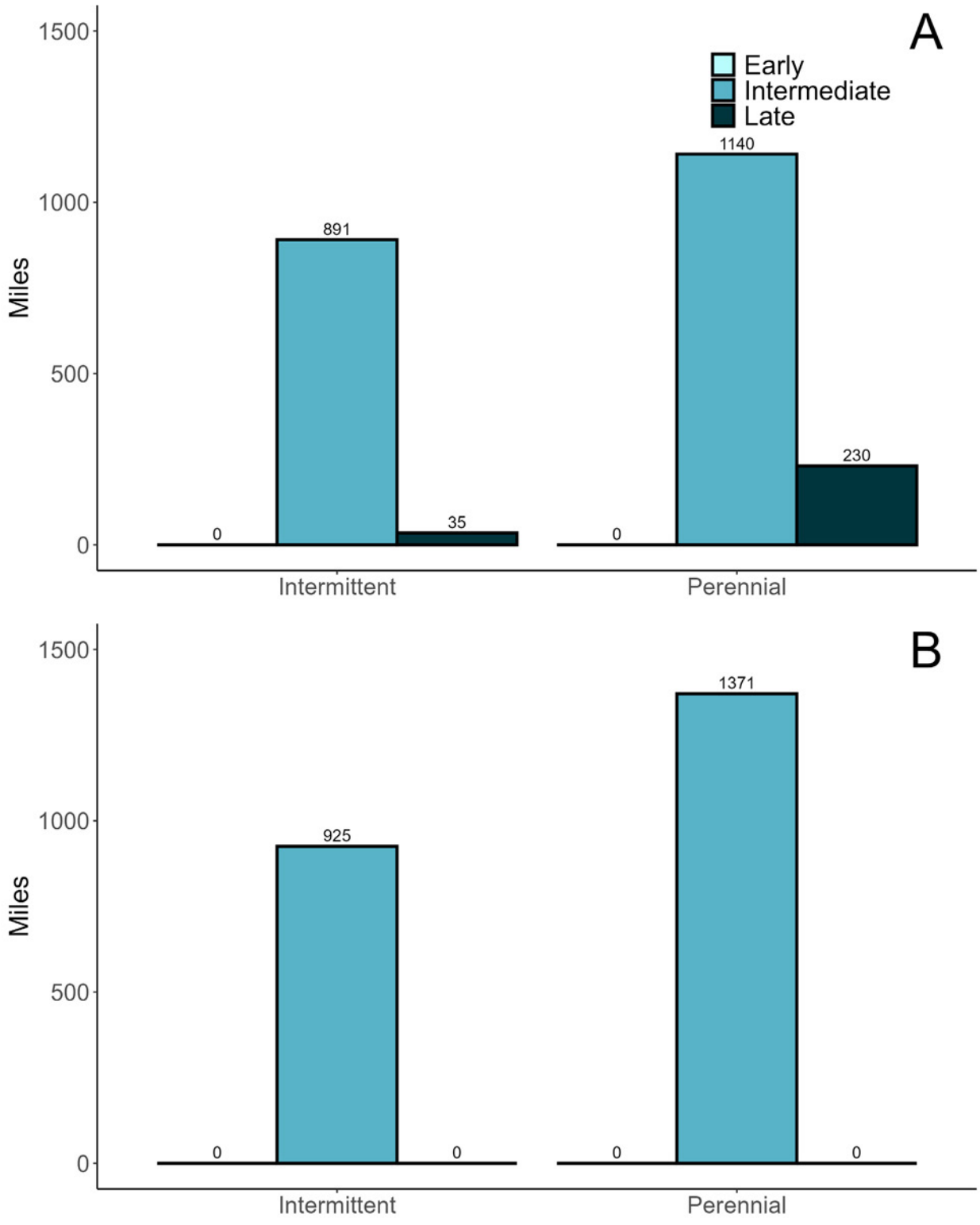


Figure D.8—Miles of intermittent and perennial streams in the Northern Mountains unit with modeled intermediate or late hydrologic regimes for the time periods (A) 1977-2006 and (B) 2030-2059.

About 3 percent of forested lands in the Northern Mountains experienced tree mortality between 2009 and 2013. Less than one percent of forested lands were impacted by tree mortality between 2014 and 2018. The WCF indicated there was imminent risk of

abnormally high tree mortality in most watersheds in the Northern Mountains, with 73 percent classified as functioning-at-risk. The capacity of the forests in these areas to intercept precipitation and regulate snowmelt may be impacted.

About 1.5 percent of the Northern Mountains had burned at mixed severity, which is more than any other unit in the study area. According to the TCA, 23 percent of the Northern Mountains unit was classified poor or very poor condition for uncharacteristic fire severity. No information was recorded for the WCF wildfire effects attribute.

According to the TCA, 28 percent of the Northern Mountains was in poor or very poor condition for drought, suggesting more than one quarter of the unit experienced long term moisture deficits. Most of the Northern Mountains unit is in Elko County, which according to the U.S. drought monitor experienced seven periods of drought since 2006. Prolonged droughts occurred in Elko County from January 2007 to November 2010, December 2011 to January 2017, December 2017 to April 2019, and a period of drought began in March 2020 and was ongoing at the time of this assessment. Part of the Northern Mountains unit is in Humboldt County, which experienced five periods of drought since 2006. Prolonged droughts occurred in Humboldt County from January 2007 to December 2010, November 2011 to January 2017, January 2018 to April 2019, and a drought began in November 2019 and was ongoing at the time of this assessment. A small section of the Northern Mountains is in White Pine County, which experienced five periods of drought since 2006. Prolonged drought occurred in White Pine County from January 2007 to December 2010, December 2011 to January 2017, July 2017 to April 2019, and a period of drought began in February 2020 and was ongoing at the time of this assessment.

Modeled flow metrics for the time period 2030-2059 (Wenger et al. 2010) suggested flow regimes in the Northern Mountains may be resistant to alterations in coming decades (fig. D.7). Little change was expected for mean annual flow, bankfull flows, maximum floods, or summer base flows in intermittent or perennial streams (figs. D.7E-D.7H); however, all late runoff streams are expected to transition to intermediate flow regimes by mid century (fig. D.8B).

Local riparian plots indicated flooding as a disturbance at nine of the 32 plots evaluated in the Northern Mountains. This included flooding that occurred in 2013 at Deer Creek, in 2015 at Rocky Riparian and Falls Meadow, in 2016 at Rebel Creek, and in 2018 at Jenkins Peak and Little Reservoir South. Moderate conifer encroachment occurred along 3.4 percent of streams; significant conifer encroachment occurred along 5.9 percent of streams. Moderate conversion of riparian cover to upland grasses and shrubs occurred along 16.2 percent of streams; significant conversion of riparian cover to upland grasses and shrubs occurred along 49.7 percent of streams. The average WCF water quantity score was 2.2, with 79 percent of watersheds within the Northern Mountains unit considered functional-at-risk with moderate departures from natural flow regimes. The remaining 21 percent of watersheds in this unit were classified as having impaired function and significant departures in magnitude, duration, and/or timing of natural flows. Changes in climate were apparent in the Northern Mountains unit, with increased temperature in all four seasons and shifts in the timing and amount

of precipitation (table D.1). Throughout the unit, winter temperatures have increased by 1.1 to 1.9 °F, with an average increase of 1.7 °F. Winter precipitation throughout the unit has increased between 0.28 and 0.63 inches, with an average increase of 0.35 inches.

Approximately 75 percent of streams had riparian areas that had converted to upland conifers, grasses, or shrubs, which provided evidence that surface water and groundwater fluctuations in the Northern Mountains unit were substantially altered from NRV (table D.2). More than half of Northern Mountain watersheds were classified as functional-at-risk for water quantity, providing evidence of moderate alteration. Nearly three quarters of the unit was in poor or very poor condition for deviation of winter temperature (table D.2), providing evidence of substantial alteration. None of the unit was in poor or very poor condition for deviation in winter precipitation, providing no evidence of alteration. Overall, two indicators suggested surface water and groundwater fluctuations were substantially altered from NRV, one indicator suggested moderate alteration, and one indicator suggested no alteration. We estimated that surface water and groundwater fluctuations in the Northern Mountains were likely **substantially altered** from NRV.

According to the SSI database there were 1,304 springs in the Northern Mountains. 103 spring surveys conducted between 1991 and 2020 were available at 101 springs. Ten reports included information on disturbance. One site was highly disturbed by drought in 2013. Two sites were moderately disturbed by diversions. Horse and burro use had impacted two sites. Eight springs were moderately disturbed, and one was highly disturbed by cattle. Two sites were moderately disturbed, and one site was highly disturbed by recreation. Flooding was not indicated as a disturbance at any of the springs with reported disturbance data. SEAP protocols were implemented at six springs (Mud Circle Cienega, Mantid View, Alder, Libellula Warm, Wilderness Boundary, and Wildflower) in 2018 and at one spring (Veratrum Actual) in 2020. These reports provided the only available data related to condition of water fluctuations at GDEs in the Northern Mountains. Aquifer functionality was rated as good with significant restoration potential at six springs. At Mud Circle Cienega, aquifer functionality was rated as moderate with some restoration potential. The risk to all seven evaluated sites was low, meaning it was likely that aquifer functionality would remain unchanged. Additional inventory of condition is needed at GDE sites in the Northern Mountains. There was **insufficient information** to evaluate water fluctuations at GDEs.

Ruby Mountains

There were 1,158 miles of stream within the Ruby Mountains unit. Of these streams, 45 percent were perennial, and 53 percent were intermittent or ephemeral. Modeled flows for 1977 to 2006 (Wenger et al. 2010) indicated the majority of stream miles in the Ruby Mountains unit were intermittent with low daily discharges (fig. D.9A). Perennial streams were generally small with daily flows less than 5 cfs (fig. D.9A). Bankfull floods in intermittent streams tended to occur at flows between two and ten cfs (fig. D.9B). Most perennial streams experienced bankfull flooding at discharges of 10 to 50 cfs (fig. D.9B). The maximum modeled floods in most intermittent streams occurred at flows of 10 to 50 cfs (fig. D.9C), and most perennial streams experienced maximum flows above 50 cfs (fig. D.9C). Baseflows were generally small, with most perennial and intermittent

streams averaging between 0 and 1 cfs per day during the summer months (fig. D.9D). The Ruby Mountains had more late, snowmelt-dominated systems than other units (fig. D.10A). Most intermittent and perennial streams, however, had transient, intermediate hydrographs and received half of their annual flow between February 27 and April 18.

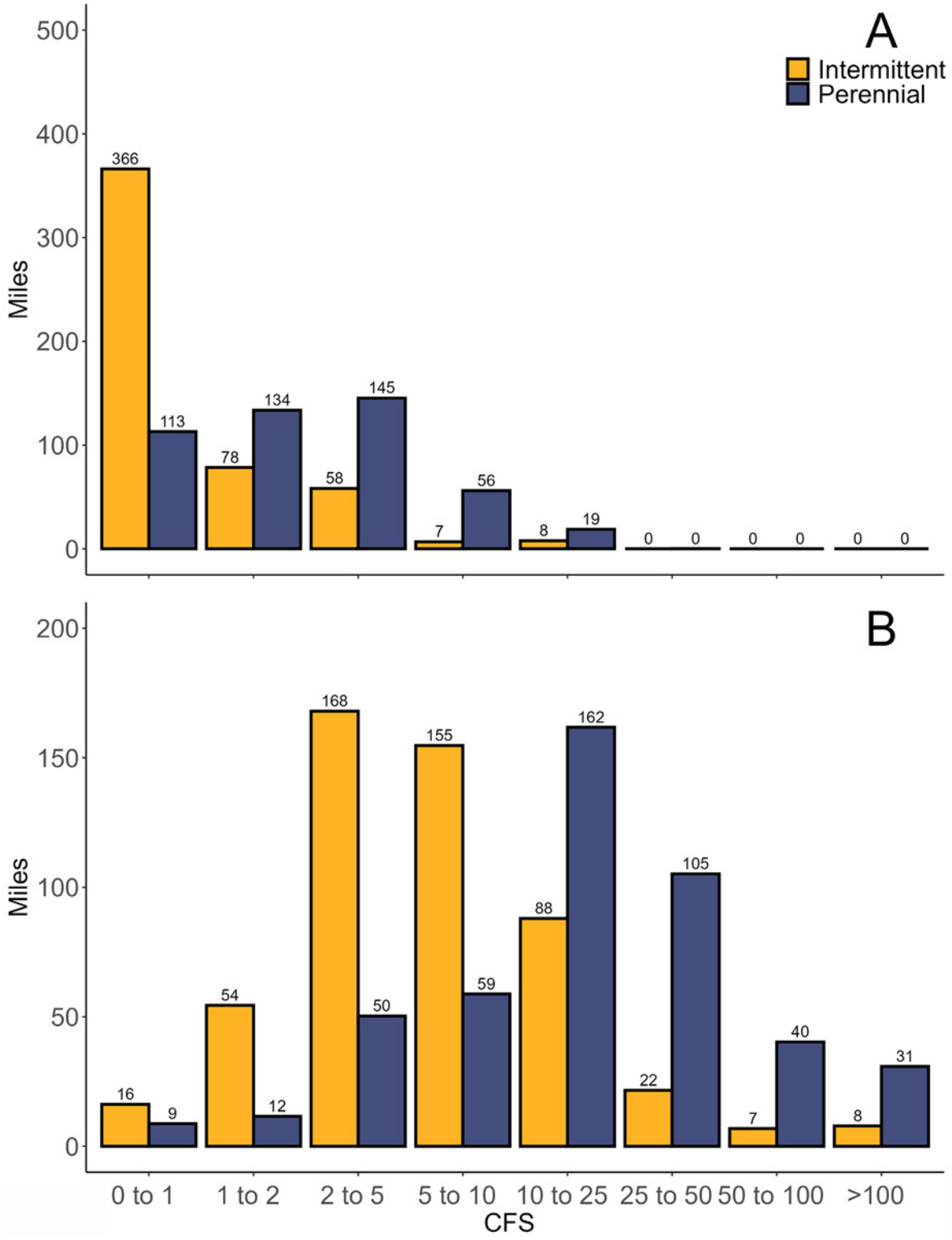


Figure D.9A-B—Modeled flow metrics for intermittent and perennial streams in the Ruby Mountains, including (A) mean annual flow 1977-2006 and (B) mean 1.5 year flood flow 1977-2006.

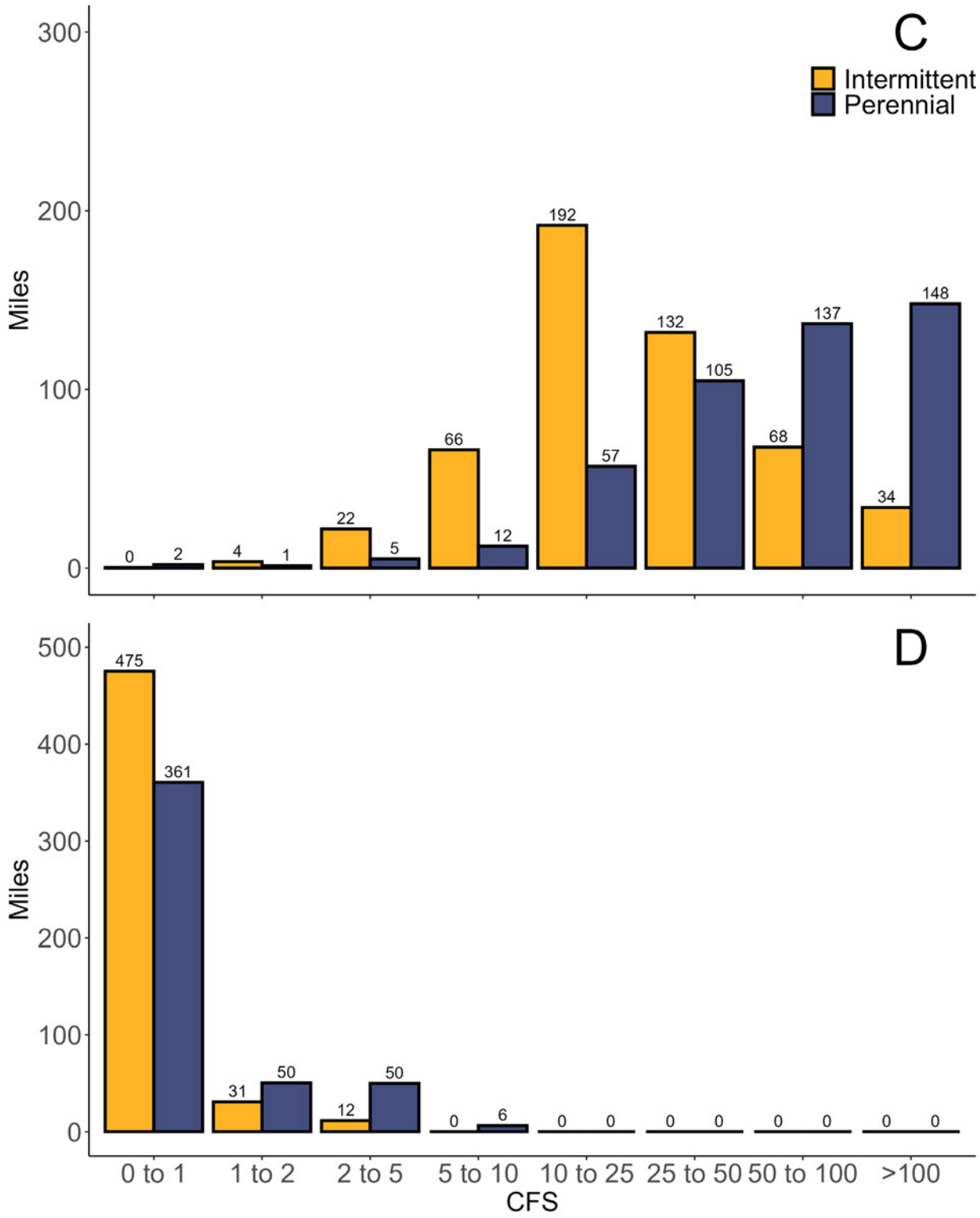


Figure D.9C-D—Modeled flow metrics for intermittent and perennial streams in the Ruby Mountains, including (C) maximum flood flow 1977-2006 and (D) mean summer base flow 1977-2006.

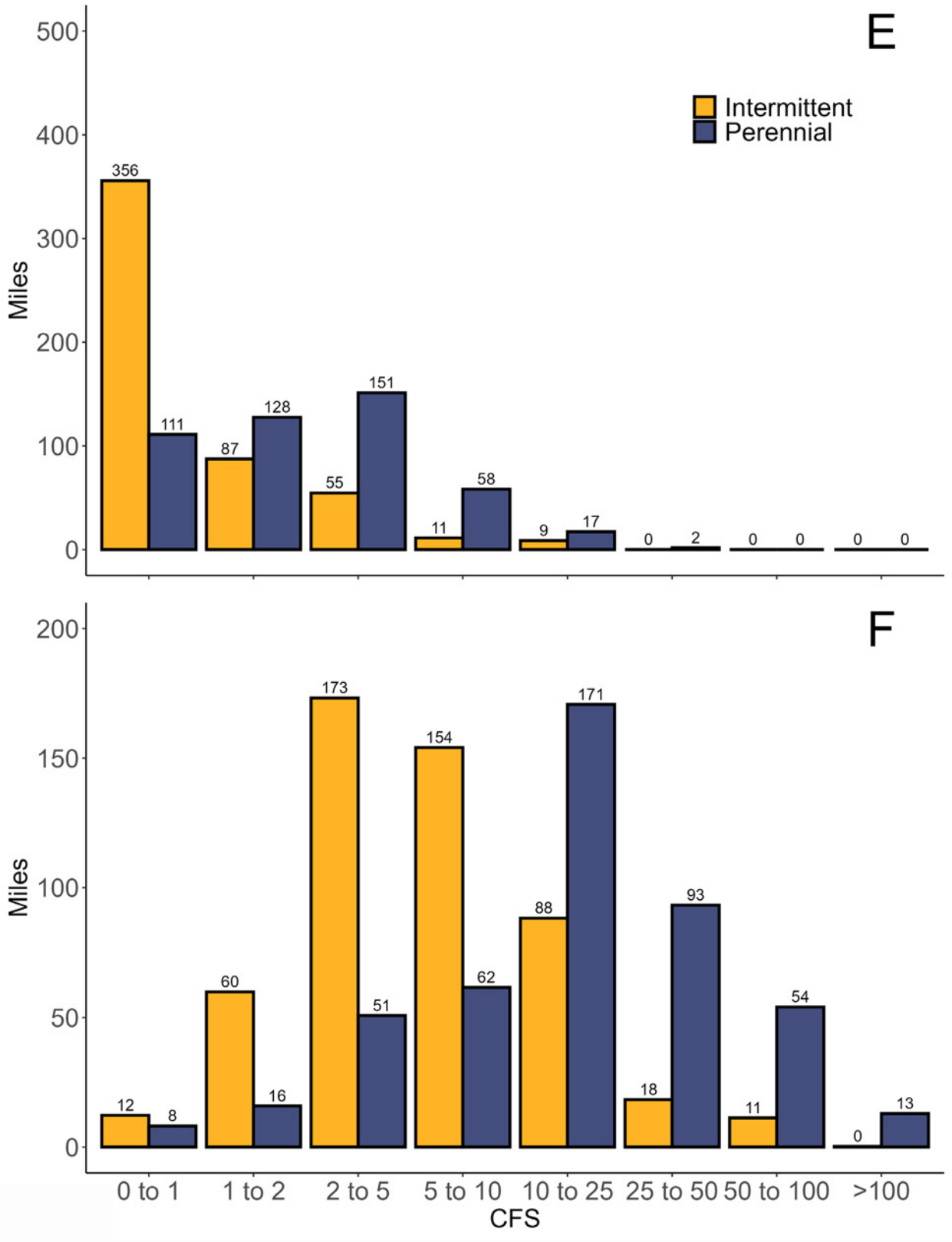


Figure D.9E-F—Modeled flow metrics for intermittent and perennial streams in the Ruby Mountains, including (E) mean annual flow 2030-2059 and (F) mean 1.5 year flood flow 2030-2059.

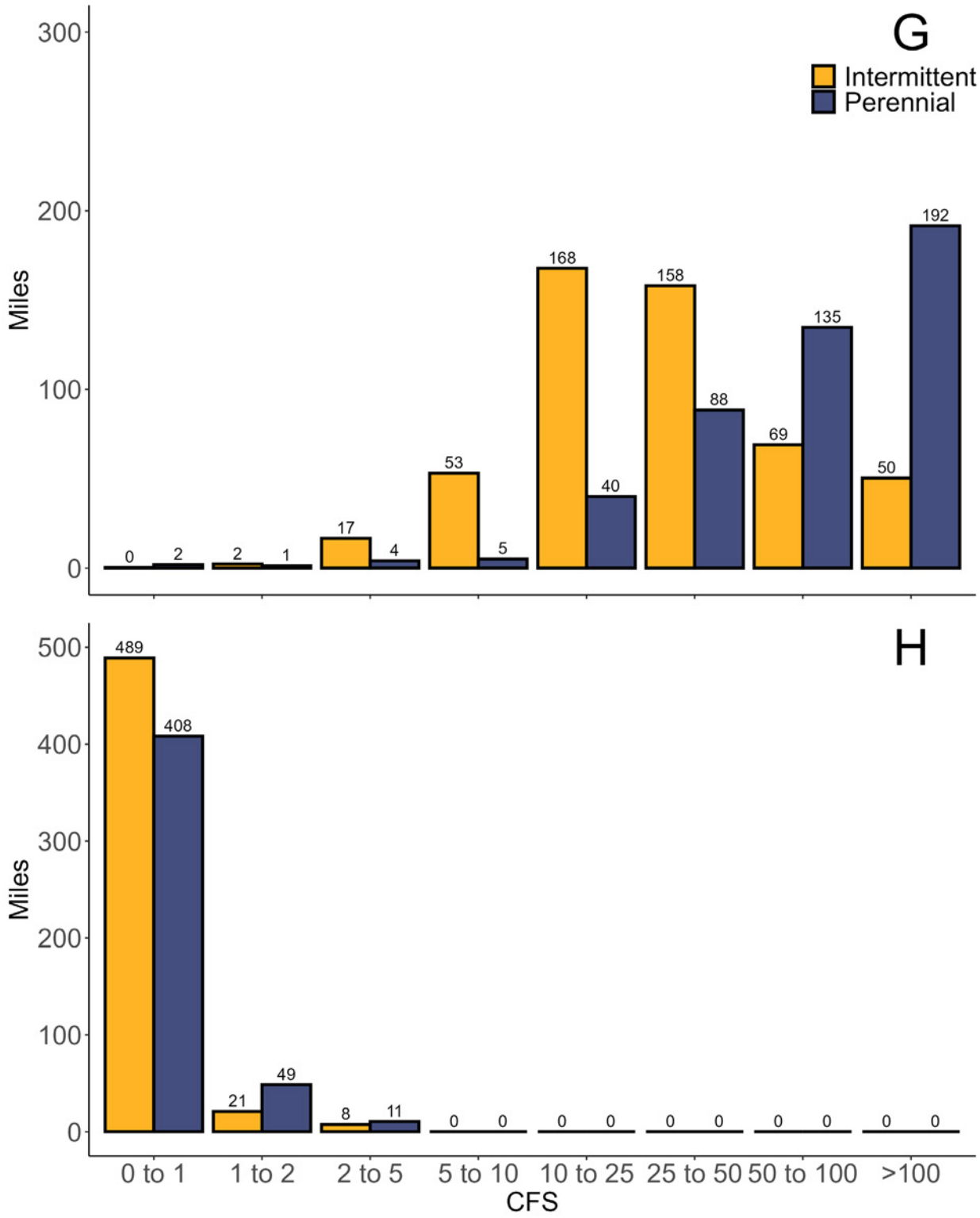


Figure D.9G-H—Modeled flow metrics for intermittent and perennial streams in the Ruby Mountains, including (G) maximum flood flow 2030-2059 and (H) mean summer base flow 2030-2059.

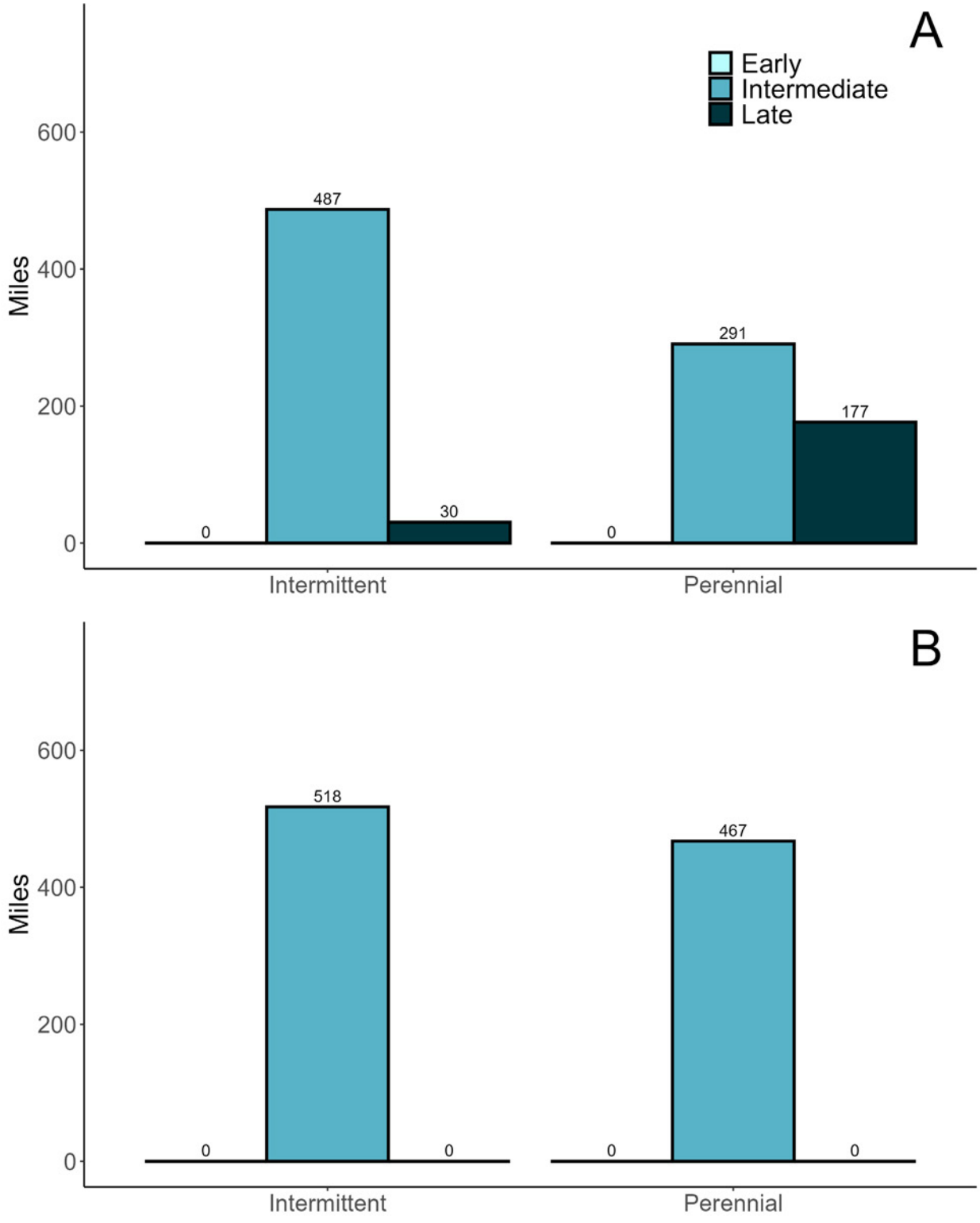


Figure D.10—Miles of intermittent and perennial streams in the Ruby Mountains unit with modeled intermediate or late hydrologic regimes for the time periods (A) 1977-2006 and (B) 2030-2059.

There were 0.0007 diversions per acre in the Ruby Mountains and one dam was located within the unit. The WCF flow characteristics attribute indicated that peak and base flows were likely maintained throughout most of the unit, but that the timing,

rate of change, and/or duration of mid-range discharges was altered, with 86 percent of watersheds classified in fair condition. The WCF habitat fragmentation attribute indicated that dewatering had potentially contributed to fragmentation of some aquatic habitats, with 50 percent of watersheds classified as functioning-at-risk and 50 percent classified as properly functioning.

Ninety-two percent of the Ruby Mountains was within an RMU and 95 percent of RMUs were active. Six percent of the unit was located within wild horse and burro territory. Of the nine riparian plots sampled in the Ruby Mountains, grazing was indicated as a disturbance at six plots and wildlife use was described as a disturbance in seven plots. The WCF indicated rangeland vegetation was in poor condition in 64 percent of watersheds. Rangelands in these areas had likely lost the capacity to capture, store, and safely release water from rainfall, runoff, and snowmelt. Rangeland vegetation was in functioning-at-risk condition in an additional 36 percent of watersheds. In these areas, rangelands had a reversible loss of capacity to capture, store, and safely release water from rainfall, runoff, and snowmelt. These rangelands in fair condition were vulnerable to irreversible degradation.

Modeled flow metrics for 2030 to 2059 (Wenger et al. 2010) suggest some flow regime parameters in the Ruby Mountains may be resistant to alterations in the coming decades (fig. D.9). Average daily flows, bankfull discharges, maximum modeled flows, and summer baseflows in perennial and intermittent streams are expected to remain mostly unchanged (figs. D.9E-D.9H). The timing of flows in the Ruby Mountains, however, are expected to experience major impacts. The unit is likely to lose all streams with snowmelt-dominated hydrographs. These intermittent and perennial streams are expected to transition to transient, intermediate hydrographs that receive half of their annual discharge between February 27 and April 18 (fig. D.10B).

Local riparian plots indicated flooding as a disturbance at two of the nine plots monitored in the Ruby Mountains. This included flooding that occurred in 2018 at Above Island Lake and in 2019 at Willow Tributary 1. Moderate conifer encroachment occurred along 4.4 percent of streams. Significant conifer encroachment occurred along 8.0 percent of streams. Moderate conversion of riparian cover to grass or shrub species occurred along 14.7 percent of streams. Significant conversion of riparian cover to grass or shrub species occurred along 14.1 percent of streams. The average WCF water quantity score was 2.1, with 86 percent of watersheds within the Ruby Mountains unit considered functional-at-risk with moderate departures from natural flow regimes. The remaining 14 percent of watersheds in this unit were classified as having impaired function and significant departures in magnitude, duration, and/or timing of natural flows. Changes in climate were apparent in the Ruby Mountains unit, with increased temperature in all four seasons and shifts in the timing and amount of precipitation (table D.1). Throughout the unit, winter temperatures had increased by 0.9 to 1.6 °F, with an average increase of 1.5 °F. Winter precipitation throughout the unit had increased between 0.18 and 0.63 inches, with an average increase of 0.52 inches.

Approximately 41 percent of streams had riparian areas that had converted to upland conifers, grasses, or shrubs, which provided evidence that surface water

and groundwater fluctuations in the Ruby Mountains unit were moderately altered from NRV (table D.2). More than half of Ruby Mountain watersheds were classified as functional-at-risk for water quantity, providing additional evidence of moderate alteration. None of the unit was in poor or very poor condition for either deviation in winter precipitation or winter temperature, providing no evidence of alteration. Overall, two indicators suggested surface water and groundwater fluctuations were moderately altered from NRV, and two indicators suggested no alteration. While the systems in the Ruby Mountains may not have experienced major changes in winter climate, RCAT output and the WCF water quantity indicator suggest other stressors have likely impacted water fluctuations. We estimated that surface water and groundwater fluctuations in the Ruby Mountains were **moderately altered** from NRV.

According to the SSI database there were 443 springs in the Ruby Mountains. Three spring surveys conducted between 1991 and 1997 were available for three sites. One site, an unnamed spring that is a tributary to Toyn Creek was moderately disturbed by diversions and cattle. Green Mountain Creek was mildly disturbed by cattle. Ruby 102 spring was highly disturbed by dredging. Flooding was not indicated as a disturbance at any of the sites. No reports included information on condition and there was therefore **insufficient information** to evaluate water fluctuations at GDEs in the Ruby Mountains.

Sierra Nevada

There were 1,057 miles of stream within the Sierra Nevada unit. Of these streams, 45 percent were perennial, 53 percent were intermittent or ephemeral. Modeled flow metrics for 1977 to 2006 (Wenger et al. 2010) indicated most intermittent streams in the Sierra Nevada had mean daily flows less than 5 cfs (fig. D.11A). Mean daily flows of perennial streams within the unit are variable, with most miles averaging between 2 to 25 cfs (fig. D.11A). Bankfull flooding in intermittent streams tends to occur at discharges between 2 and 25 cfs (fig. D.11B) and in perennial streams at flows over 10 cfs (fig. D.11B). Maximum modeled flows in some intermittent streams were greater than 100 cfs, but almost all perennial stream miles were estimated to experience maximum discharges above 100 cfs (fig. D.11C). Baseflows in intermittent streams tended to be small, less than 5 cfs (fig. D.11D). In contrast, many perennial streams maintained baseflows above 100 cfs (fig. D.11D). More streams had snowmelt-dominated hydrographs in the Sierra Nevada unit than any other considered in this assessment (fig. D.12A). About 500 miles each of intermittent and perennial streams were classified as having transient, intermediate hydrographs, receiving half their annual flow between February 27 and April 18.

The primary stressors in the Sierra Nevada unit were roads, dams and diversions, grazing, tree mortality, and fire. The Sierra Nevada unit had the highest road density of all units considered in this assessment. While the TCA indicated that 77 percent of the unit was in good or very good condition for road density, local riparian plot data and the WCF suggest roads are a likely stressor to surface water and groundwater fluctuations. There were 0.0011 road miles per acre, and 76 percent were classified as unimproved. Of the 43 riparian plots sampled in the Sierra Nevada unit, disturbance from roads was described at 28 percent and disturbance from OHV was described at 19 percent. The WCF indicated that there was a high probability that roads had

substantially altered the hydrologic regime within 19 percent of watersheds in the Sierra Nevada; there was moderate probability of substantially altered hydrologic regimes in an additional 58 percent of watersheds. According to the WCF, 73 percent of watersheds in the Sierra Nevada unit were in fair condition for road and trail maintenance, meaning best management practices for designed drainage features were applied to 50 to 75 percent of roads, trails, and water crossings in these areas. An additional 8 percent of watersheds were classified as impaired for road and trail maintenance, meaning best management practices were applied to less than 50 percent of road and trail features.

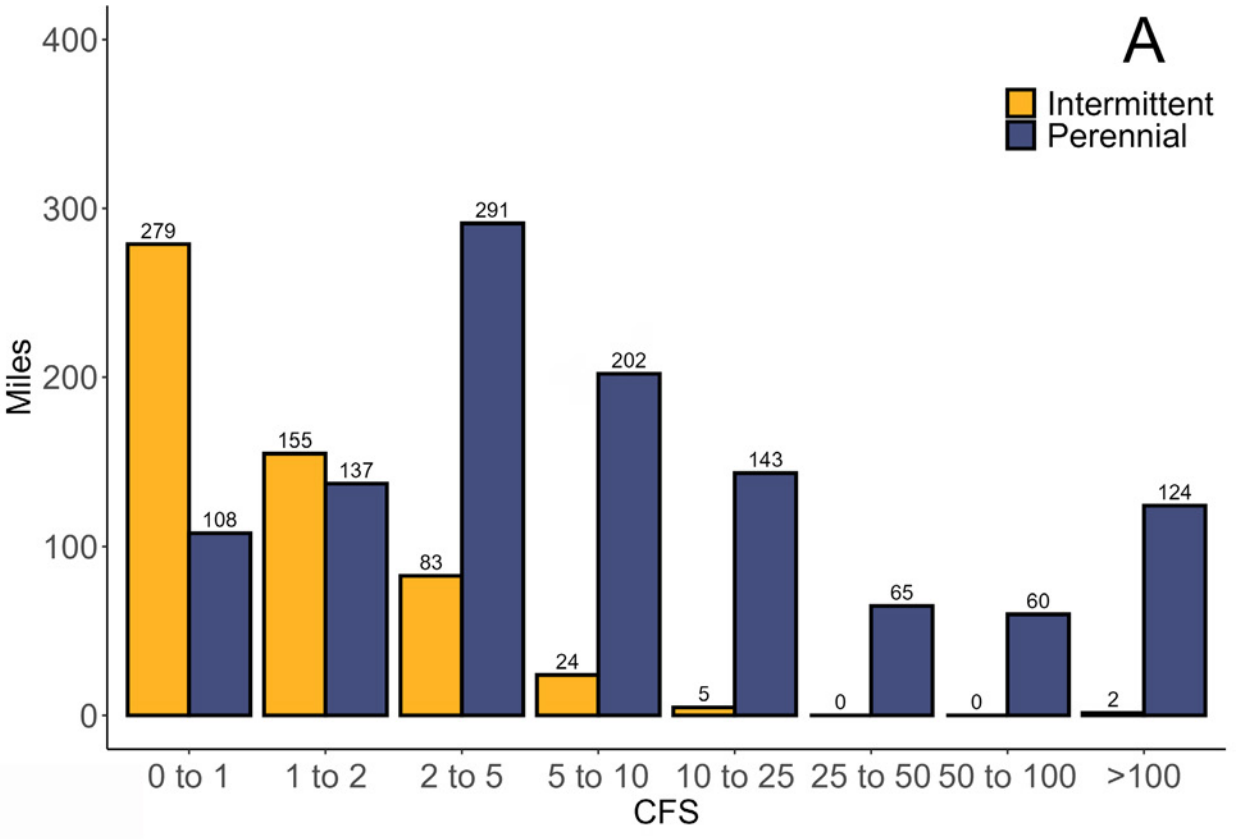


Figure D.11A—Modeled flow metrics for intermittent and perennial streams in the Sierra Nevada, mean annual flow 1977-2006.

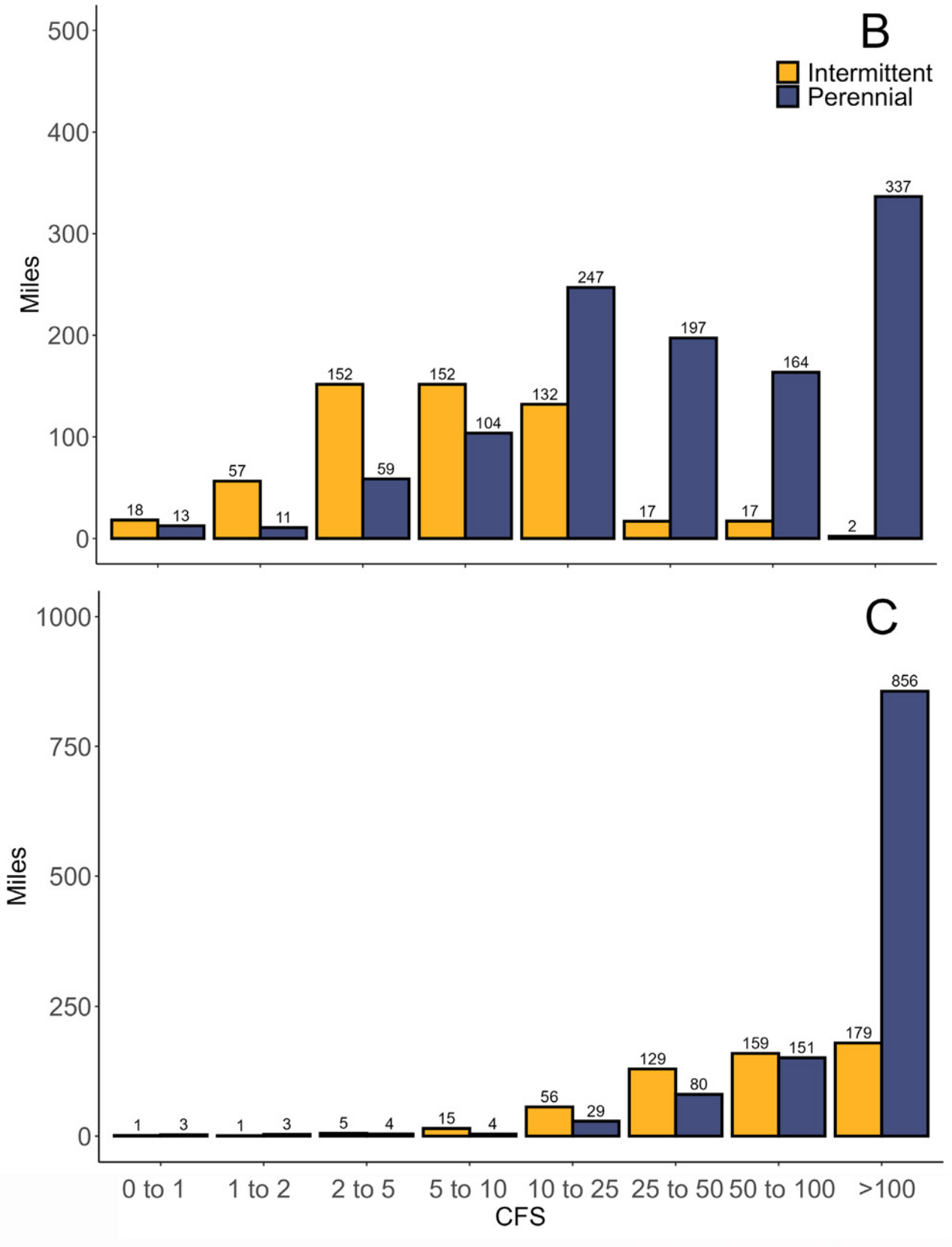


Figure D.11B-C—Modeled flow metrics for intermittent and perennial streams in the Sierra Nevada, including (B) mean 1.5 year flood flow 1977-2006 and (C) maximum flood flow 1977-2006.

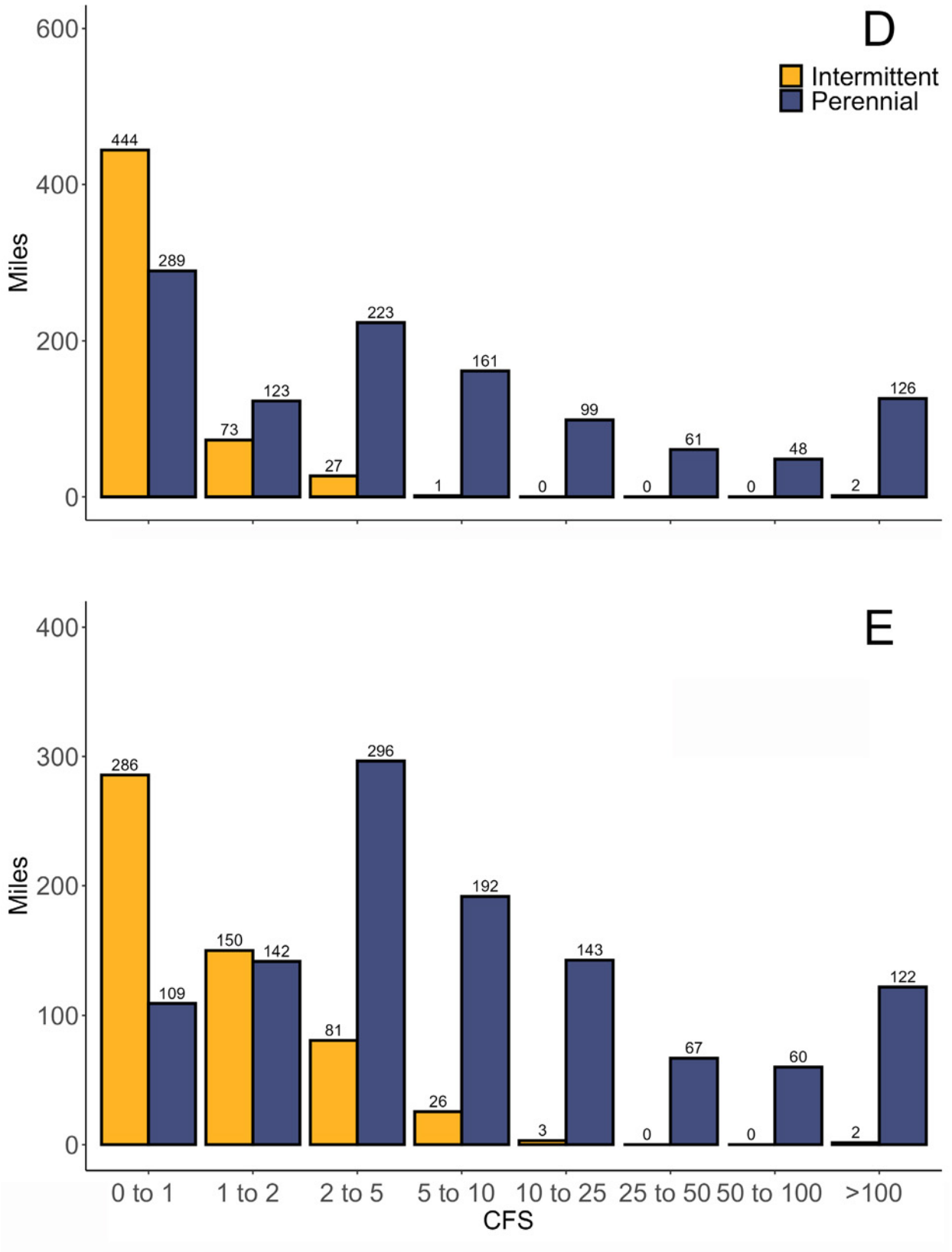


Figure D.11D-E—Modeled flow metrics for intermittent and perennial streams in the Sierra Nevada, including (D) mean summer base flow 1977-2006 and (E) mean annual flow 2030-2059.

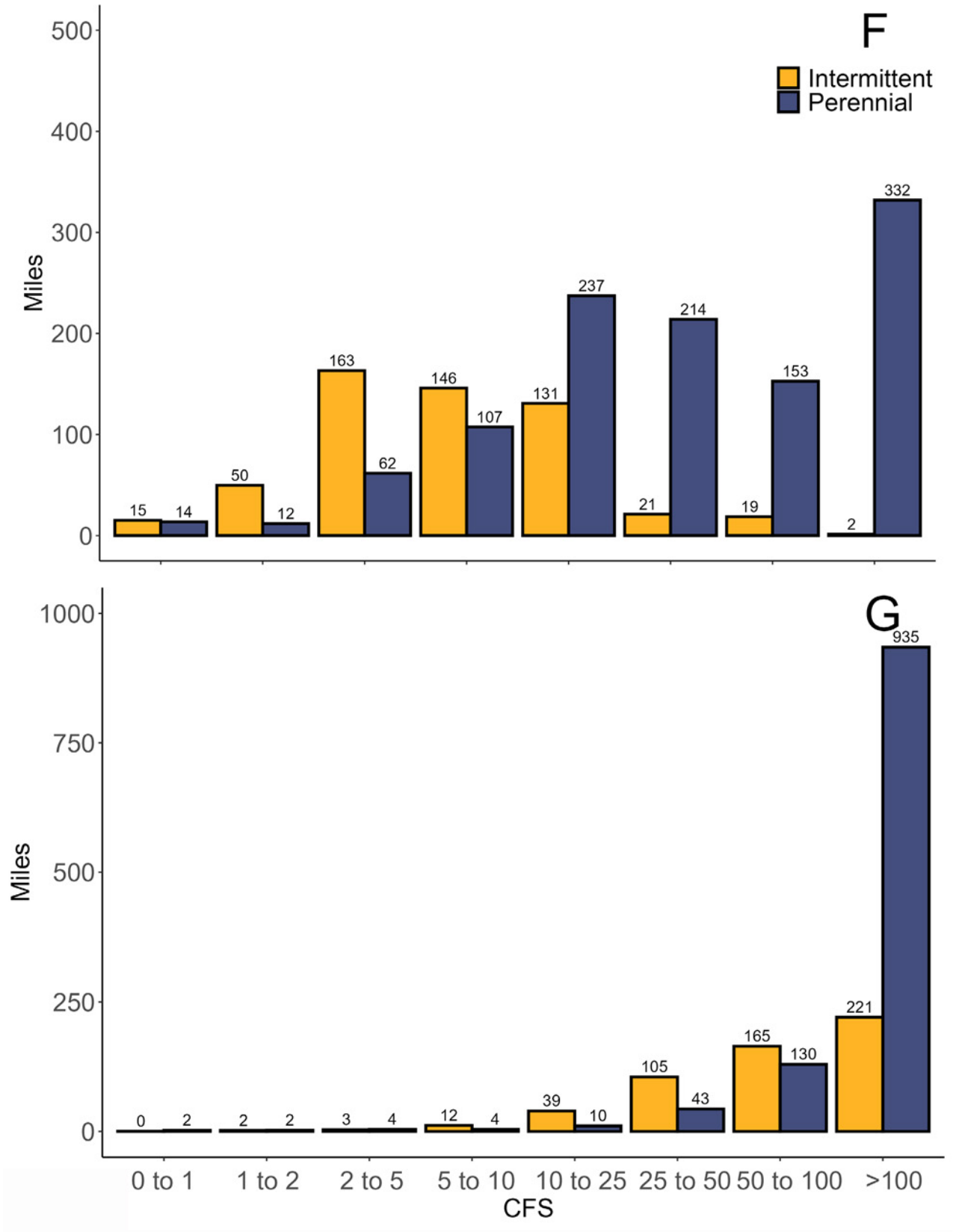


Figure D.11F-G—Modeled flow metrics for intermittent and perennial streams in the Sierra Nevada, including (F) mean 1.5 year flood flow 2030-2059 and (G) maximum flood flow 2030-2059.

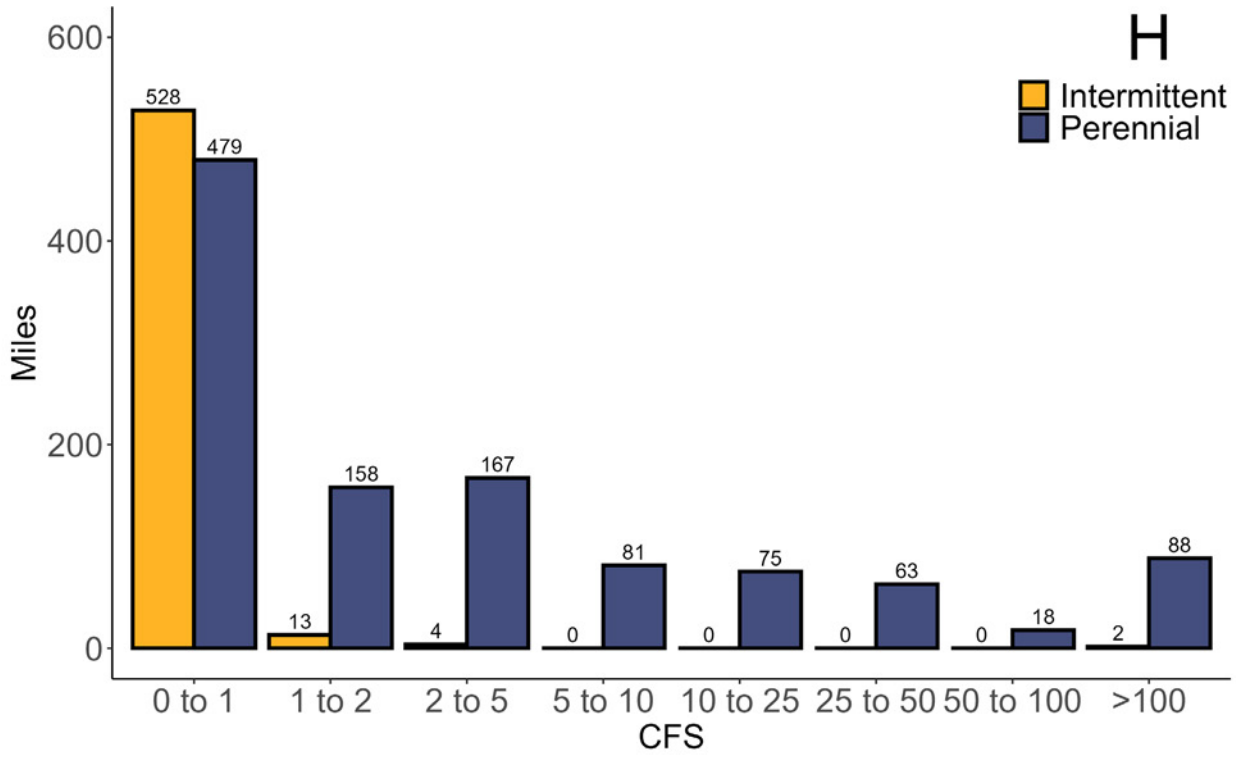


Figure D.11H—Modeled flow metrics for intermittent and perennial streams in the Sierra Nevada, mean summer base flow 2030-2059.

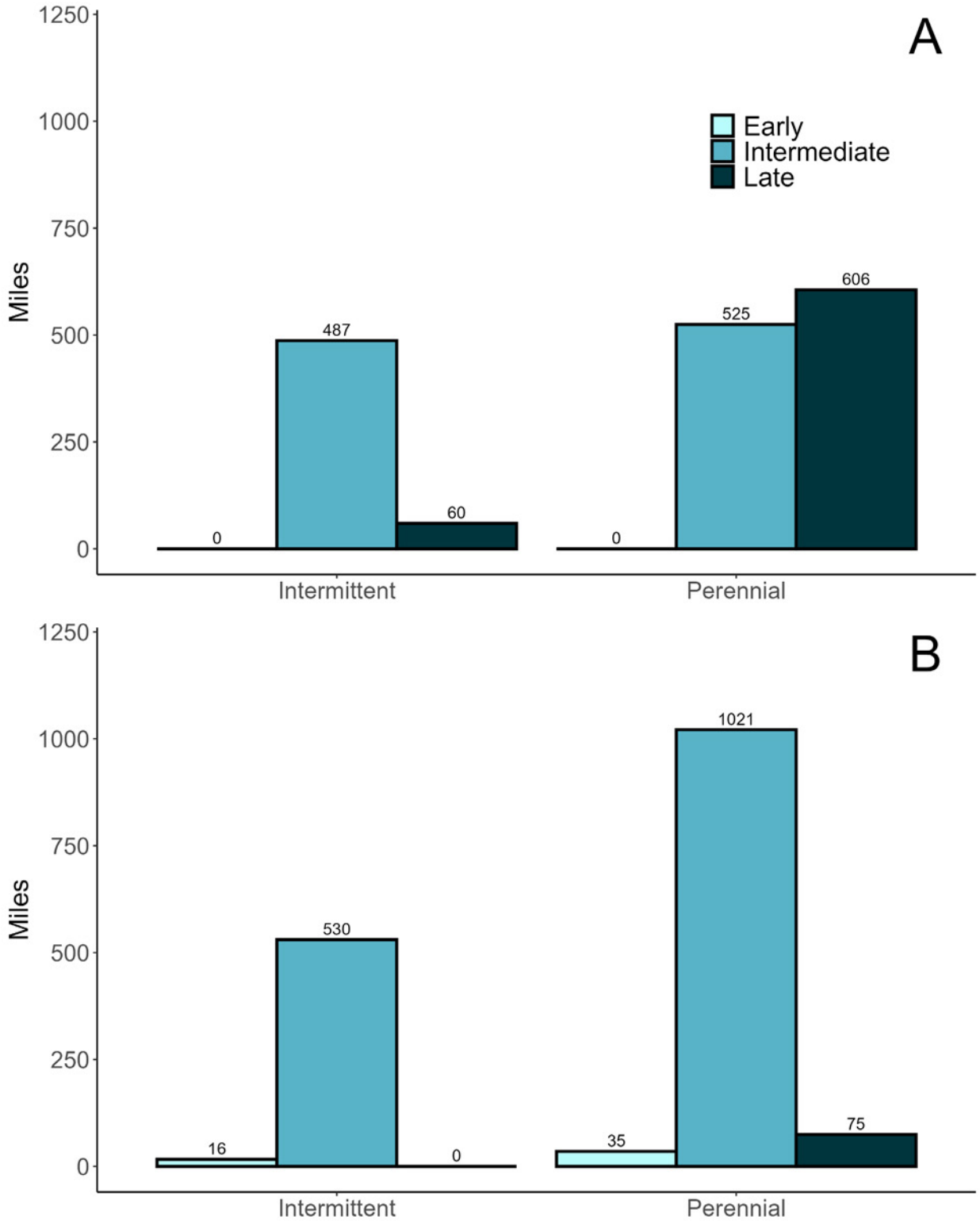


Figure D.12—Miles of intermittent and perennial streams in the Sierra Nevada unit with modeled intermediate or late hydrologic regimes for the time periods (A) 1977-2006 and (B) 2030-2059.

There were 0.0015 diversions per acre and 45 dams located within the Sierra Nevada unit. This was the highest diversion density and ratio of dams per stream mile of all geographic units on the HTNF. The WCF flow characteristics attribute indicated that

peak and base flows were likely maintained throughout most of the unit, but that the timing, rate of change, and/or duration of mid-range discharges was altered, with 79 percent of watersheds classified in functioning-at-risk condition. An additional 21 percent of watersheds in the Sierra Nevada unit were classified as impaired for flow characteristics, meaning the magnitude, duration, and/or timing of annual high and low flows were significantly departed from the natural hydrograph. The WCF habitat fragmentation attribute indicated that dewatering had potentially contributed to fragmentation of aquatic habitats, with 39 percent of watersheds classified as functioning-at-risk and 48 percent classified as impaired.

Fifty-five percent of the Sierra Nevada unit was within an RMU and 74 percent of RMUs were active. No wild horse and burro territory was present within the unit. Of the 43 riparian plots sampled in the Sierra Nevada unit, 77 percent identified grazing as a disturbance. Wildlife use was also noted as a disturbance in 77 percent of riparian plots. The WCF indicated rangeland vegetation was in fair condition in 100 percent of watersheds, meaning rangelands throughout the unit had experienced reversible loss in capacity to capture, store, and safely release water from rainfall, runoff, and snowmelt. Rangelands in the Sierra Nevada were vulnerable to irreversible degradation.

About 3 percent of forested lands in the Sierra Nevada experienced tree mortality between 2009 and 2013. An additional 10 percent of forested lands were impacted between 2014 and 2018. The WCF indicated there was imminent risk of abnormally high tree mortality in some watersheds in the Northern Mountains, with 12 percent classified as functioning-at-risk. The capacity of the forests in these areas to intercept precipitation and regulate snowmelt may be impacted.

Less than 1 percent of the Sierra Nevada unit had burned at mixed severity. According to the TCA, 28 percent of the Sierra Nevada unit was classified poor or very poor condition for uncharacteristic fire severity. No information was recorded for the WCF wildfire effects attribute.

Modeled flow metrics for 2030 to 2059 (Wenger et al. 2010) suggest some components of the flow regime may be resistant to alterations in the coming decades (fig. D.11). Average daily flows, bankfull discharges, maximum modeled flows, and summer baseflows in perennial and intermittent streams are expected to remain relatively unchanged (figs. D.11E-D.11H). The timing of flows in the Sierra Nevada, however, are expected to experience substantial impacts. Nearly all streams with late, snowmelt-dominated hydrographs are expected to transition to intermediate, transient hydrographs (fig. D.12B) and some transient streams will likely transition to early runoff systems that experience winter flooding and receive half their annual flow before February 27.

Local riparian plots indicated flooding as a disturbance at 10 of the 43 plots evaluated in the Sierra Nevada. This included flooding that occurred in 2010 at Carter Station Riparian and Lower Cottonwood Meadow, in 2012 at Wolf Meadow, Wolf Lake, Hope Valley 2 and 3, and in 2013 at Lower Horsethief, Upper Noble, Raymond Meadow, and Red Lake. Moderate conifer encroachment had occurred along 12 percent of streams. Significant conifer encroachment had occurred along 38 percent of streams. Moderate

conversion of riparian cover to upland grasses or shrubs had occurred along 1 percent of streams. Significant conversion to grasses and shrubs had occurred along 4 percent of streams. The average WCF water quantity score was 2.2, with 79 percent of watersheds within the Sierra Nevada unit considered functional-at-risk with moderate departures from natural flow regimes. The remaining 21 percent of watersheds in this unit were classified as having impaired function and significant departures in magnitude, duration, and/or timing of natural flows. Changes in climate were apparent in the Sierra Nevada unit, with increased temperature in all four seasons and shifts in the timing and amount of precipitation (table D.1). Throughout the unit, winter temperatures increased by 2.2 to 4.1 °F, with an average increase of 3.3 °F. On average, the Sierra Nevada unit lost 0.49 inches of winter precipitation; however, the changes in winter precipitation within this unit were variable. Some areas within the Sierra Nevada lost up to 3.5 inches of winter precipitation, whereas other locations received 0.74 inches more winter precipitation.

Approximately 55 percent of streams had riparian areas that had converted to upland conifers, grasses, or shrubs, which provided evidence that surface water and groundwater fluctuations were in the Sierra Nevada unit were moderately altered from NRV (table D.2). More than half of Sierra Nevada watersheds were classified as functional-at-risk for water quantity, providing additional evidence of moderate alteration. Nearly all the unit was in poor or very poor condition for deviation in winter temperature, providing evidence of substantial alteration. None of the unit was in poor or very poor condition for deviation in winter precipitation, providing no evidence of alteration. Overall, two indicators suggested surface water and groundwater fluctuations were moderately altered from NRV, one indicator suggested substantial alteration, and one indicator suggested no alteration. We estimated that surface water and groundwater fluctuations were likely **moderately altered** from NRV.

According to the SSI database there were 482 springs in the Sierra Nevada unit. Twelve surveys conducted between 1992 and 2019 were available at ten sites. Seven surveys included information on stressors, with diversions and recreation the most common disturbances. Four springs were impacted by diversions, with one classified as highly disturbed. Four springs were also impacted by recreation, with one classified as highly disturbed. Cattle and dredging were also disturbing some springs in the Sierra Nevada Unit. Flooding was not indicated as a disturbance at any of the seven sites. No reports included information on condition and there was therefore **insufficient information** to evaluate water fluctuations at GDEs in the Sierra Nevada Unit.

Spring Mountain National Recreation Area

There were 1,585 miles of stream within the SMNRA unit. Of these streams, 1 percent were perennial, 99 percent were intermittent or ephemeral. Modeled mean daily flows for 1977 to 2006 indicated most streams in the SMNRA received less than 2 cfs of discharge per day (fig. D.13A). The intermittent streams of this unit tended to experience bankfull floods at flows between 2 and 25 cfs (fig. D.13B). Maximum modeled floods were variable, with many intermittent streams experiencing flows above 100 cfs (fig. D.13C). Average daily summer baseflows were estimated to be less than 5 cfs in all

streams in SMNRA (fig. D.13D). All streams had intermediate, transient hydrographs, and received half their annual flow between February 27 and April 18 (fig. D.14A).

The primary stressors in SMNRA were roads, recreation, grazing, dams and diversions, and drought. The TCA indicated that 95 percent of SMNRA was in good or very good condition for road density. Local riparian plot data and the WCF, however, suggest roads have likely impacted groundwater and surface water fluctuations. There were 0.0001 road miles per acre within the SMNRA unit, and 90 percent were classified as unimproved. Disturbance from roads and OHVs was indicated at all six riparian plots monitored in SMNRA. The WCF indicated there was moderate probability that roads had substantially altered hydrologic regimes in 89 percent of SMNRA watersheds. According to the WCF, 92 percent of watersheds in SMNRA were in fair condition for road and trail maintenance, meaning best management practices for designed drainage features were applied to 50 to 75 percent of roads, trails, and water crossings in these areas.

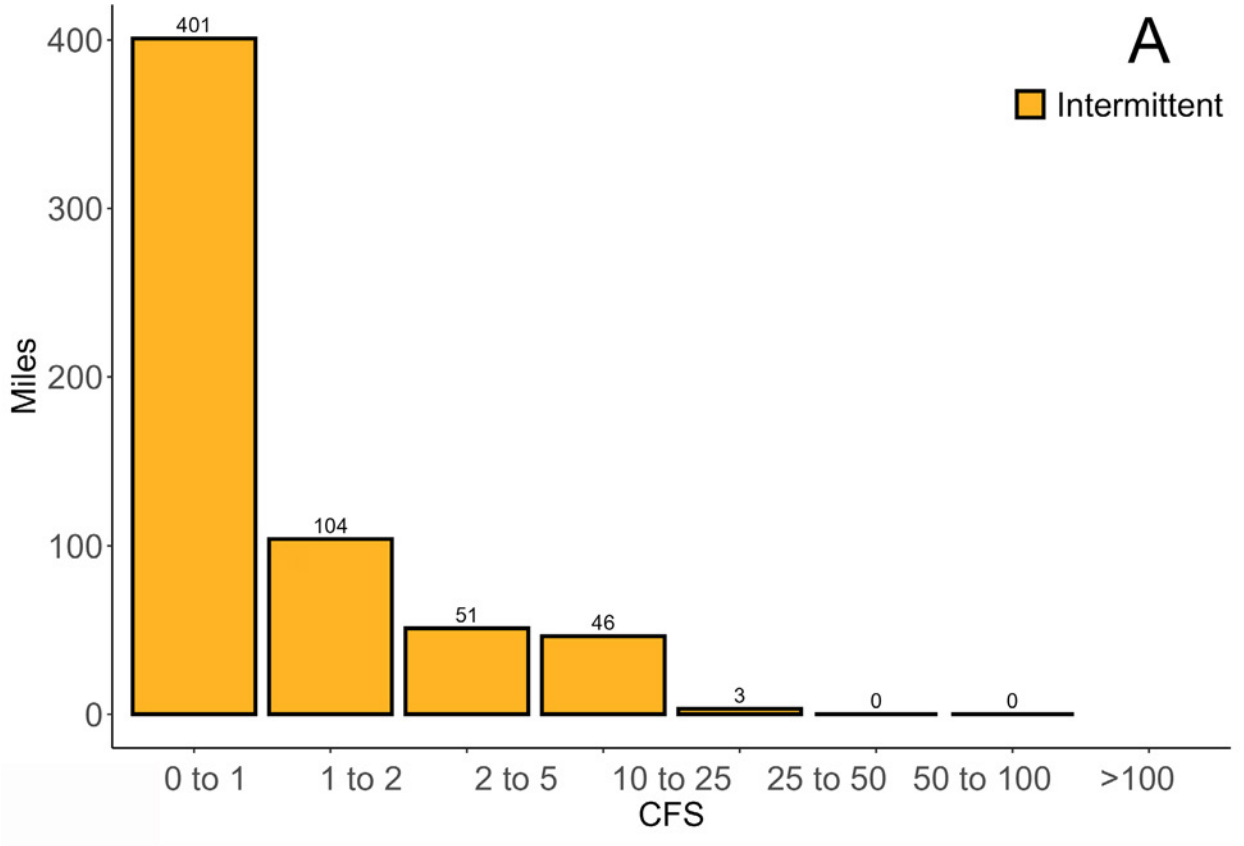


Figure D.13A—Modeled flow metrics for intermittent streams in the SMNRA, mean annual flow 1977-2006.

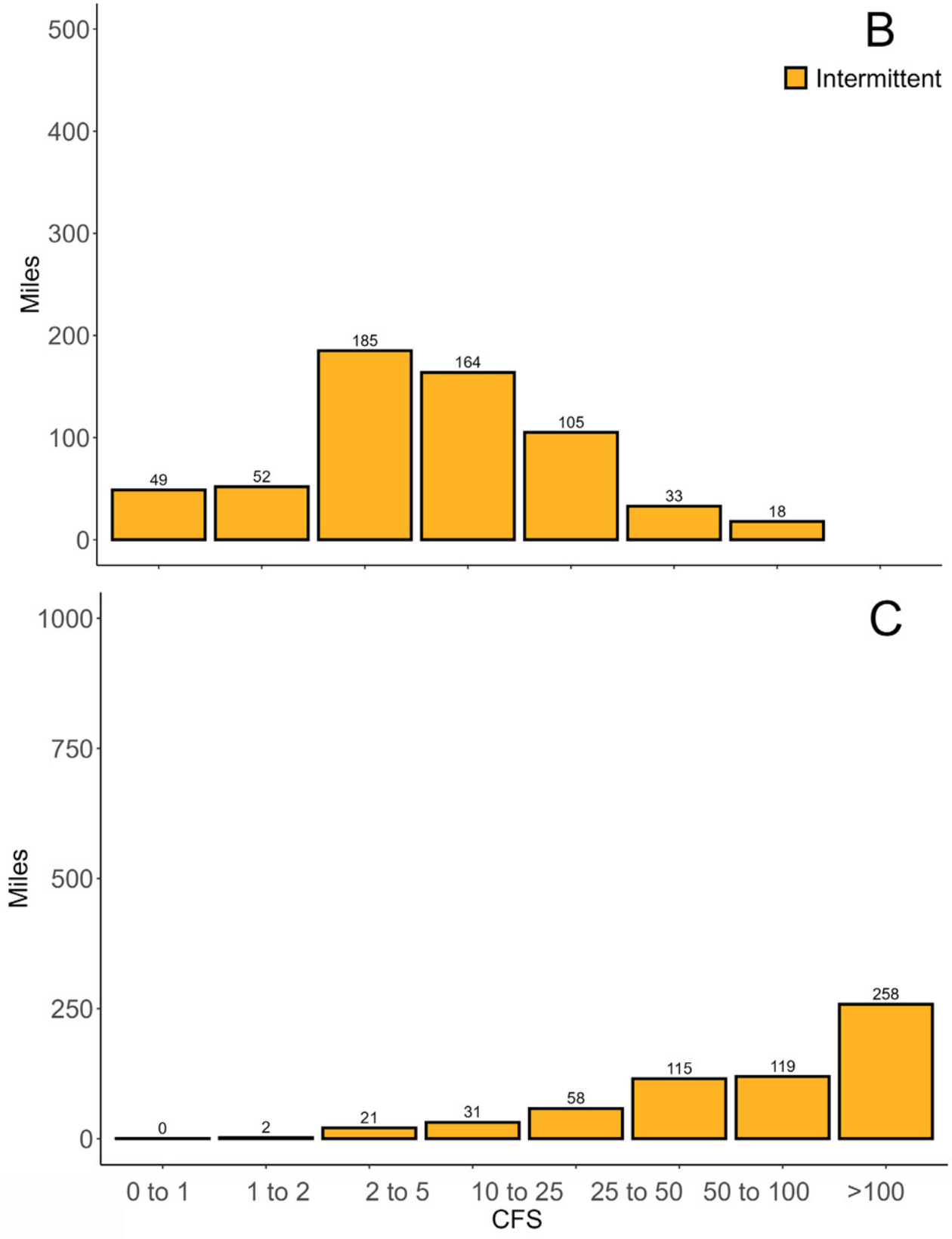


Figure D.13B-C—Modeled flow metrics for intermittent streams in the SMNRA, including (B) mean 1.5 year flood flow 1977-2006 and (C) maximum flood flow 1977-2006.

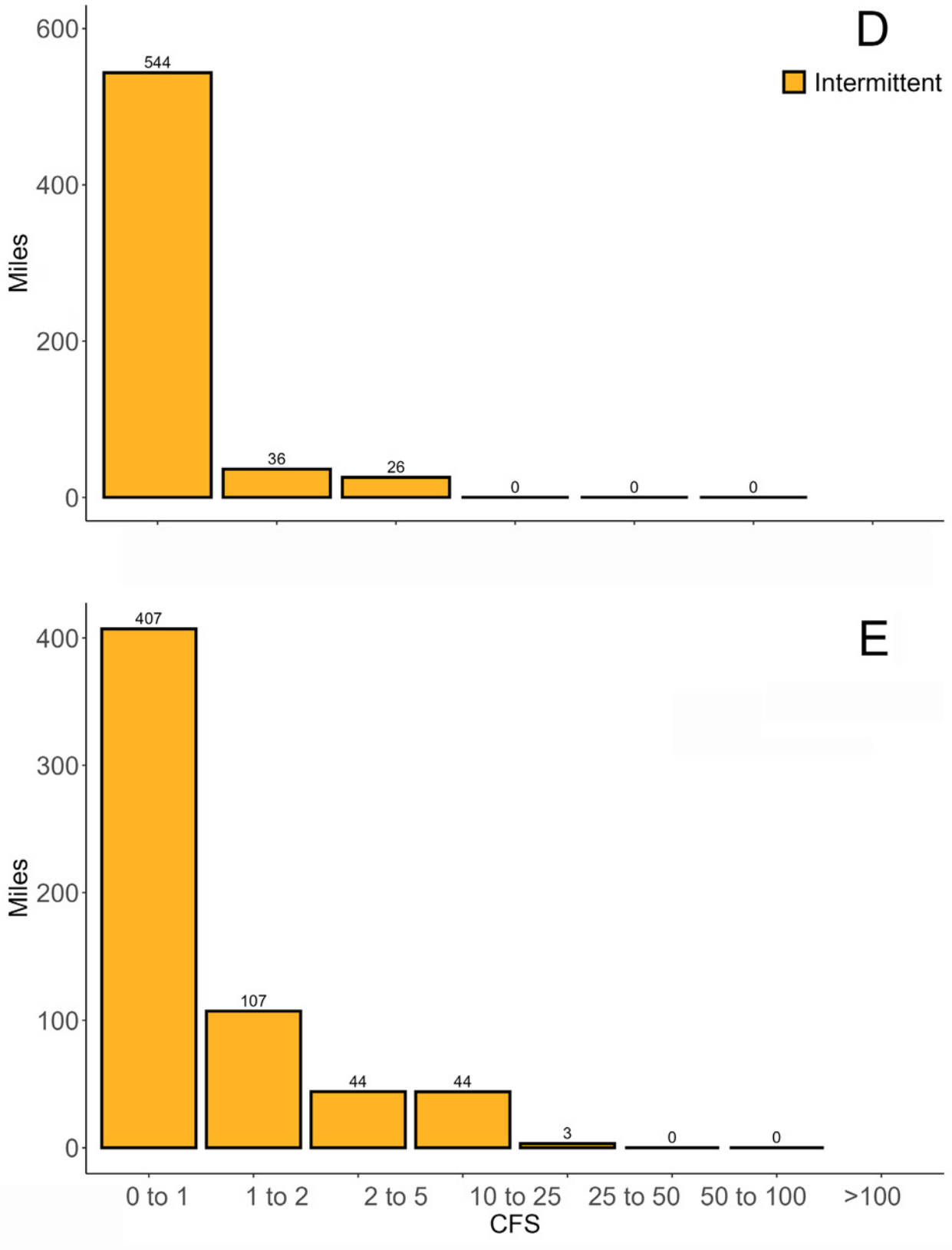


Figure D.13D-E—Modeled flow metrics for intermittent streams in the SMNRA, including (D) mean summer base flow 1977-2006 and (E) mean annual flow 2030-2059.

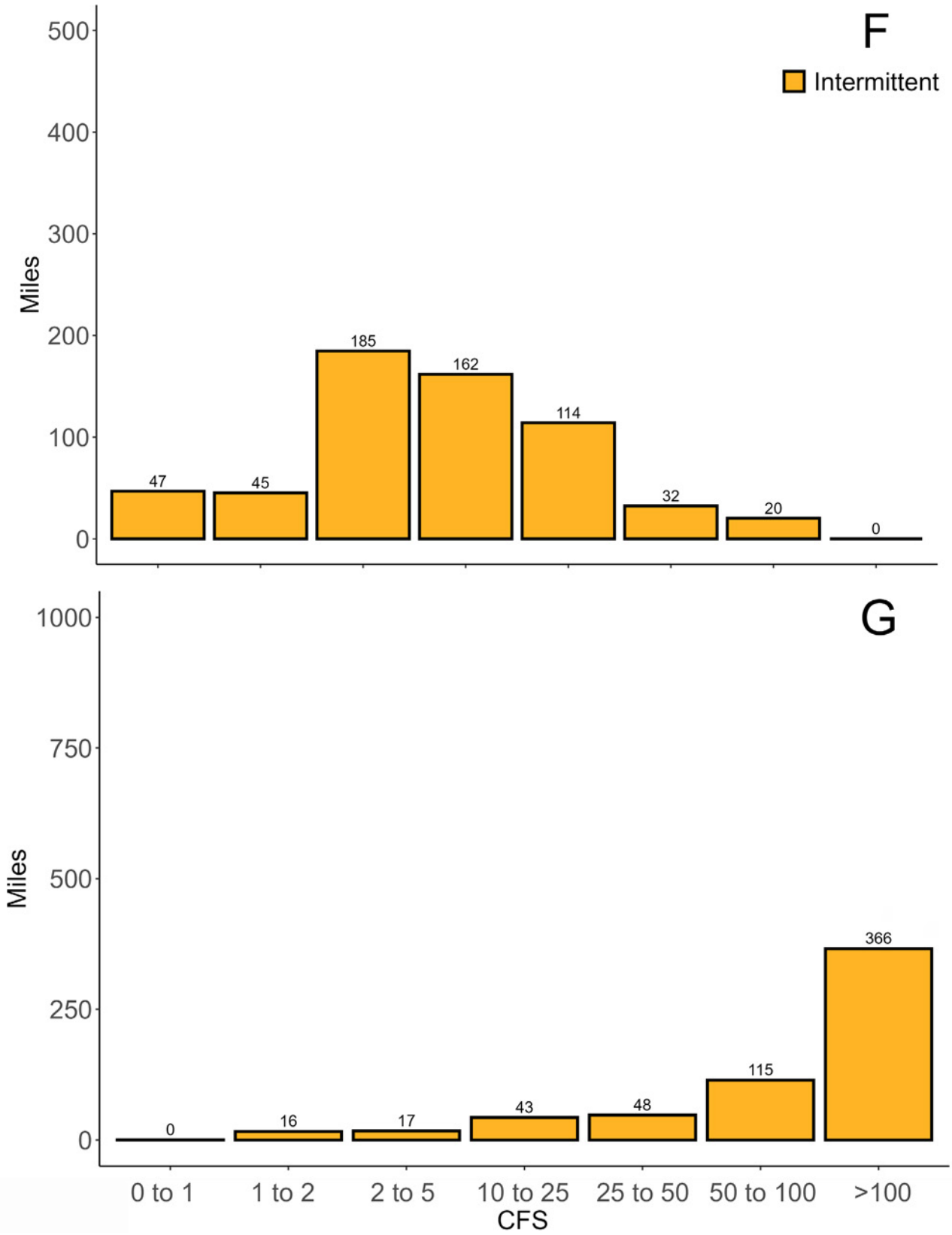


Figure D.13F-G—Modeled flow metrics for intermittent streams in the SMNRA, including (F) mean 1.5 year flood flow 2030-2059 and (G) maximum flood flow 2030-2059.

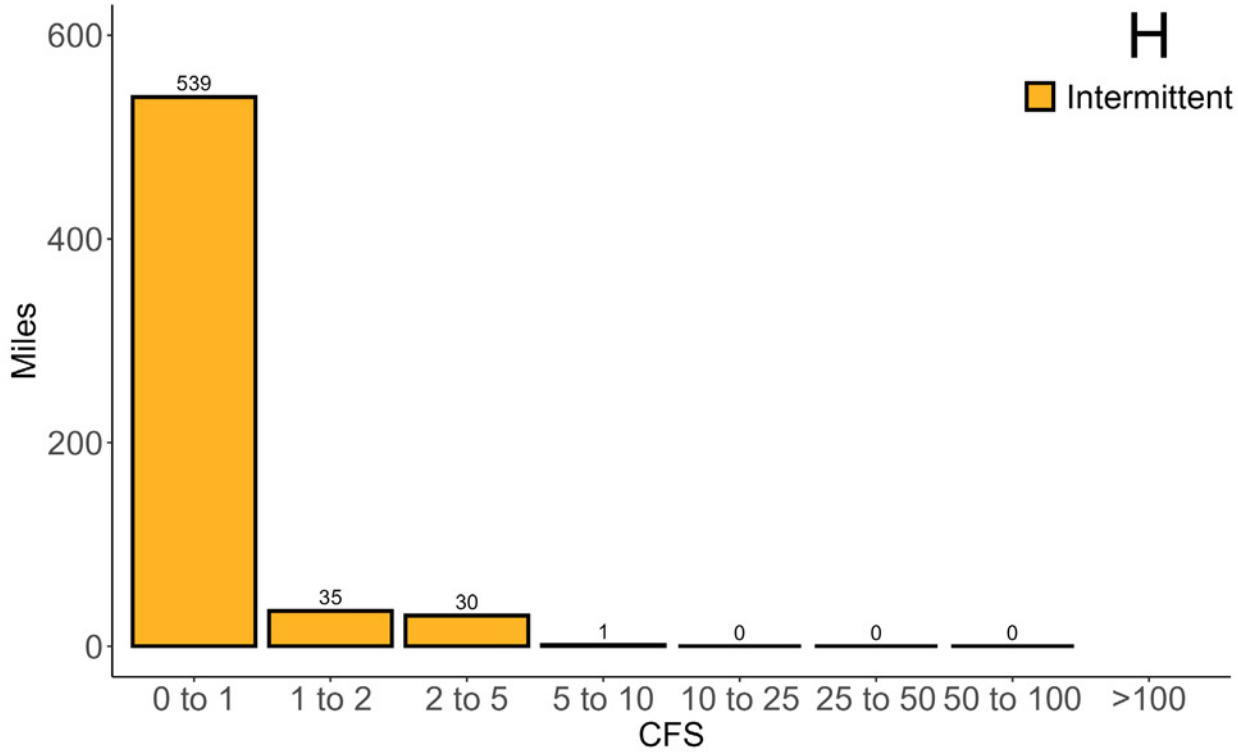


Figure D.13H—Modeled flow metrics for intermittent streams in the SMNRA, mean summer base flow 2030-2059.

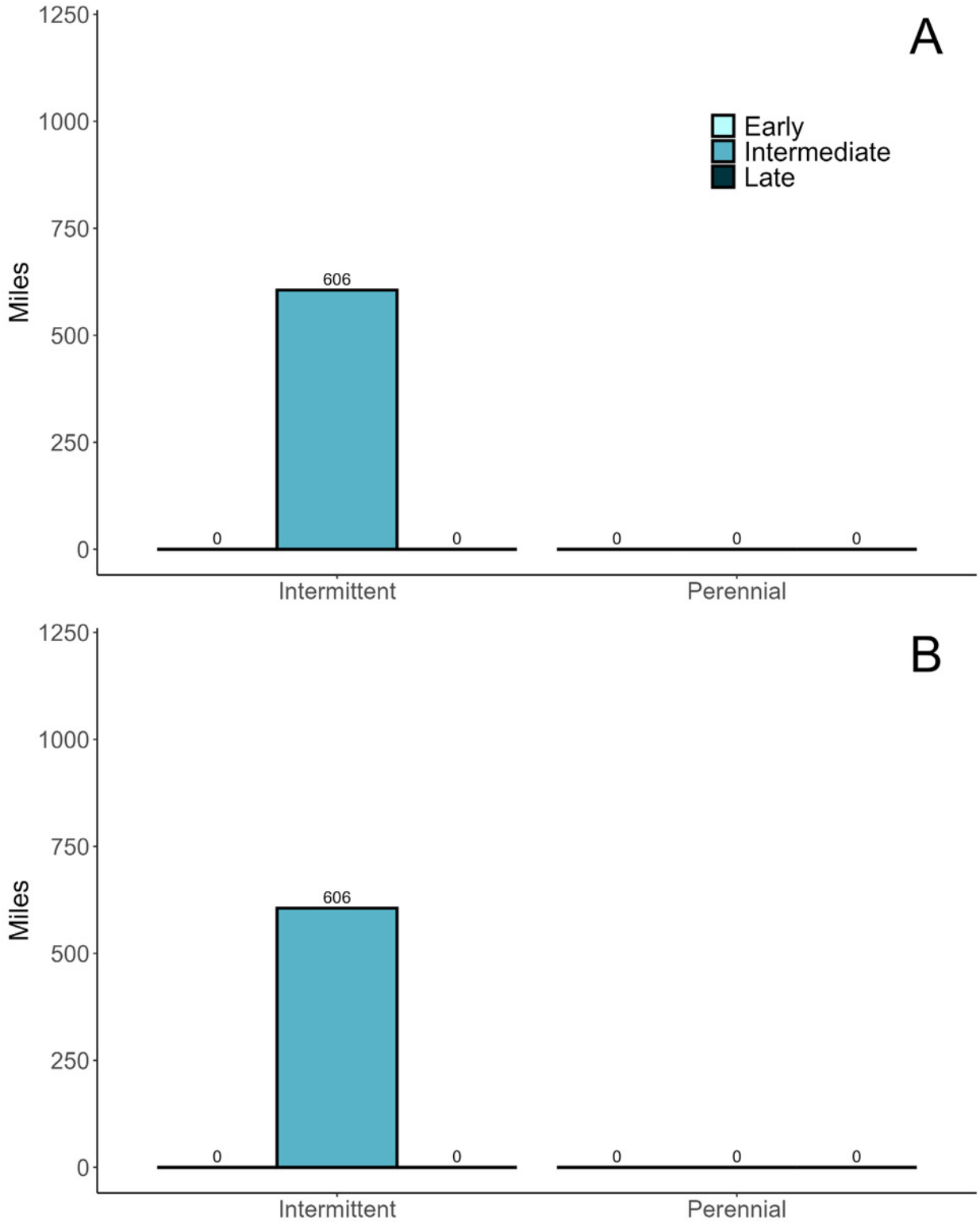


Figure D.14—Miles of intermittent and perennial streams in the SMNRA unit with modeled intermediate or late hydrologic regimes for the time periods (A) 1977-2006 and (B) 2030-2059.

There were 0.0005 diversions per acre in SMNRA and one dam was located within the unit. The WCF flow characteristics attribute indicated that peak and base flows were likely maintained throughout most of the unit, but that the timing, rate of change,

and/or duration of mid-range discharges was altered, with 100 percent of watersheds classified in functioning-at-risk condition. Additionally, the WCF habitat fragmentation attribute indicated that dewatering had potentially contributed to fragmentation of aquatic habitats, with 62 percent of watersheds classified as functioning-at-risk.

There were 0.0003 trail miles per acre in the SMNRA, which is a relatively low trail density compared to other units on the Forest. There was a higher density of recreation sites within floodplains in the SMNRA unit than any other considered in this assessment (0.0005 recreation sites per floodplain acre). Trails, camping, and OHVs were noted as a disturbance at all six riparian plots monitored in SMNRA. SSI reports described recreation as at least a mild disturbance at 24 percent of surveyed sites. Like roads, the WCF indicated best management practices for maintenance of trail drainage features had only been applied to between 50 and 75 percent of crossings in 93 percent of watersheds. There was moderate probability that these linear features had substantially altered hydrologic regimes in 88 percent of watersheds.

No RMUs were in SMNRA, but 51 percent of the unit was located within wild horse and burro territory. Disturbance by cattle, wild horses, and burros was described in both riparian plot data and SSI reports. Of the six riparian plots sampled within this unit, all were disturbed by grazing and wildlife use. SSI reports described at least mild disturbance from horses and burros at 39 percent of surveyed springs. Disturbance from cattle was captured at 14 percent of surveyed springs.

According to the TCA, 100 percent of the SMNRA was in poor or very poor condition for drought, suggesting this unit had experienced long term moisture deficits. Nearly all SMNRA is in Clark County, which according to the U.S. drought monitor experienced eight periods of drought since 2006. Prolonged drought occurred in SMNRA from December 2006 to December 2010, June 2011 to February 2017, November 2017 to March 2019, and a period of drought began in July 2020 and was ongoing at the time of this assessment. A small section of SMNRA was in Nye County, which experienced seven periods of drought since 2006. Prolonged droughts occurred in Nye County from December 2006 to January 2011, December 2011 to April 2019, and a drought period began in February 2020 and was ongoing at the time of this assessment.

Local riparian plots indicated flooding as a disturbance at two of the six plots evaluated in the SMNRA. This included flooding that occurred in 2013 at Willow 2 and Willow Wash 2. Moderate conifer encroachment occurred along 4 percent of streams. Significant conifer encroachment occurred along 15 percent of streams. Moderate conversion of riparian cover to upland grasses or shrubs occurred along less than 1 percent of streams. Significant conversion of riparian cover to upland grasses or shrubs occurred along 17 percent of streams. The average WCF water quantity score was 2.0, with 100 percent of watersheds within the SMNRA unit considered functional-at-risk with moderate departures from natural flow regimes. Changes in climate were apparent in the Ruby Mountains unit, with increased temperature in all four seasons and shifts in the timing and amount of precipitation (table D.1). Throughout the unit, winter temperatures increased by 2.9 °F. Winter precipitation throughout the unit decreased by 1.2 inches.

Approximately 37 percent of streams had riparian areas that had converted to upland conifers, grasses, or shrubs, which provided evidence that surface water and groundwater fluctuations in the SMNRA unit were moderately altered from NRV (table D.2). One hundred percent of SMNRA watersheds were classified as functional-at-risk for water quantity, providing additional evidence of moderate alteration. Nearly all the unit was in poor or very poor condition for deviation in winter temperature, providing evidence of substantial alteration. None of the unit was in poor or very poor condition for deviation in winter precipitation, providing no evidence of alteration. Overall, two indicators suggested surface water and groundwater fluctuations were moderately altered from NRV, one indicator suggested substantial alteration, and one indicator suggested no alteration. We estimated that surface water and groundwater fluctuations in SMNRA were likely **moderately altered** from NRV.

According to the SSI database there were 469 springs in the SMNRA. This unit has the highest spring density of all units considered in this assessment. We found 265 surveys conducted between 1991 and 2020 at 136 springs sites in the SSI database. Seventy-six reports included information on disturbance. Avalanches, fire, flood, drought, diversions, horse and burro activity, cattle, recreation, and dredging were described as stressors at sites throughout SMNRA. Twenty percent of sites with disturbance data were highly impacted by diversions, with an additional 12 percent of sites mildly or moderately disturbed by diversions. Sixteen percent of sites were highly disturbed by horse and burro activity, with an additional 18 percent mildly or moderately impacted. Drought had highly impacted two sites (Unnamed 56 and North Rainbow) in 2016, and one site (NNW of Lost Cabin) in 1998. Flooding was described as a disturbance at eight springs. Unnamed 50 was highly impacted by flooding in 1997. Mary Jane Falls, Fletcher Spring, Harris Spring, Little Falls, and Unnamed 31 were moderately impacted by flooding in 1994, 1998, or 2008. Upper Cougar and Peak were both mildly impacted by flooding in 1994. SEAP was implemented at ten springs in various years between 2007 and 2020. Two sites, Willow Creek and Macks Canyon, were sampled twice and provided some information on trends in condition. Both sites appeared stable. Willow Creek had very good aquifer functionality with excellent restoration potential in 2007 and 2010. Macks Canyon had good aquifer functionality with significant restoration potential in 2010 and 2020. Risk remained low at both sites over time. Aquifer functionality at the remaining sites was generally categorized as good or very good with low risk of changes in the future. The exception was Jaybird Spring, which had poor aquifer functionality and moderate risk. Despite many available spring surveys, only 4 percent included information on condition of water fluctuations in SMNRA. Additional inventory of condition is needed at GDE sites in SMNRA. There was **insufficient information** to evaluate water fluctuations at GDEs.

REFERENCES

Cleland, D.; Reynolds, K.; Vaughan, R.; [et al.]. 2017. Terrestrial condition assessment for national forests of the USDA Forest Service in the continental US Sustainability. 9(11): 2144. doi: 10.3390/su9112144.

Huxman, T.E.; Wilcox, B.P.; Breshears, D.D.; [et al.]. 2005. Ecohydrological implications of woody plant encroachment. Ecology. 86(2): 308-319.

Macfarlane, W.W.; Gilbert, J.T.; Jensen, M.L.; [et al.]. 2017. Riparian vegetation as an indicator of riparian condition: Detecting departures from historic condition across the North American West. Journal of Environmental Management. 202(2): 447–460.

Potyondy, J.P.; Geier, T.W. 2011. Watershed condition classification technical guide. FS-978. Washington, D.C.: United States Department of Agriculture, Forest Service. 49 p.

Safeeq, M.; Shukla, S.; Arismendi, I.; [et al.]. 2015. Influence of winter season climate variability on snow-precipitation ratio in the Western United States. International Journal of Climatology. 36(9): 3175–3190.

Wenger, S.J.; Luce, C.H.; Hamlet, A.F.; [et al.]. 2010. Macroscale hydrologic modeling of ecologically relevant flow metrics. Water Resources Research. 46: W09513. doi: 10.1029/2009WR008839.

APPENDIX E. Water Quality

Unit Summaries

Central Mountains

The primary stressors to water quality in the Central Mountains unit included roads, diversions, drought, grazing, recreation, soil conditions, and nitrogen deposition. There were 0.0007 road miles per acre in this unit and 94 percent of roads were unimproved. Of the 34 riparian plots monitored in the Central Mountains, roads were indicated as a disturbance at 82 percent. The WCF Proximity to Water attribute indicated more than a quarter of road and trail length was within 300 feet of waterbodies in 87 percent of watersheds in the Central Mountains. There were 0.003 diversions per acre and one dam located in this unit. The WCF Water Quantity indicator suggested these structures have moderately altered stream hydrographs in 94 percent of watersheds. The TCA indicated 100 percent of the Central Mountains were in poor or very poor condition for drought. Removal of flow by diversions and long-term moisture deficits driven by drought have potentially increased concentrations of salts, nutrients, and pollutants during. Half of the Central Mountains unit is within wild horse and burro territory and 98 percent of the unit is within a livestock grazing allotment. These areas may function as nonpoint sources of pollution that can contribute excess nutrients to aquatic systems. The WCF Rangeland Vegetation indicator suggests 91 percent of watersheds in the unit are in functioning-at-risk condition, meaning rangelands have suffered a reversible loss in capacity to limit redistribution of soil resources including nutrients and organic matter. While there were no established recreation sites within floodplains, there were 0.003 trail miles per floodplain acre. Riparian monitoring plots indicated disturbance from trails, camping, and OHVs at 35, 32, and 21 percent of reaches, respectively. The WCF indicated soil conditions may be impacting water quality throughout the unit. In approximately two-thirds of watersheds, soil nutrient and hydrologic cycling processes are impaired, there is evidence of accelerated surface erosion, and limited areas of soil contamination exist. The TCA classified the entire unit in very good condition for acid deposition, meaning long-term acidification of soils or surface waters are not an issue in the Central Mountains. In contrast, the TCA classified 37 percent of the unit in poor or very poor condition for nitrogen deposition, suggesting eutrophication of some waterbodies due to excess nitrogen is likely.

According to the NorWeST dataset, stream temperatures in the Central Mountains ranged from 3.90 °C to 19.10 °C between 1993 and 2011. During this period average stream temperature in the unit was 13.51 °C±.03. Temperatures in Central Mountain streams appear to be increasing, ranging from 4.01 °C to 19.21 °C between 2002 and 2011, with a mean of 13.61 °C ±.03. Stream temperatures are expected to increase further, with an expected mean of 14.28 °C ±.03 by mid-century and 14.87 °C ±.03 by the 2080s.

Floodplains make up 3.4 percent of the Central Mountains and 0.45 percent of the unit was classified as wetland. Riparian ecosystems in the Central Mountains have experienced limited conversion to alternative cover types that can impact water quality. Only 0.02 percent of riparian corridor miles have transitioned from native riparian

plants to agriculture. An additional 0.56 percent has converted to development. The WCF Riparian/Wetland Vegetation Condition indicator suggested native riparian and wetland vegetation in 76 percent of watersheds was impaired and not capable of dissipating stream energy, reducing erosion, filtering sediment, stabilizing streambanks, buffering stream temperature, or improving water quality (table E.1). An additional 18 percent of watersheds were classified as functional-at-risk for riparian/wetland vegetation condition.

According to 303d spatial data, 238 miles of streams in the Central Mountains were classified into one of the EPA's water quality categories. All beneficial uses were supported at 36 percent of these streams. Water quality in 5 percent of streams supported some beneficial uses, but data were insufficient to evaluate all uses. There was insufficient information to assess any uses at an additional 39 percent of these streams. Finally, one or more beneficial uses were not supported in 19 percent of assessed streams in the Central Mountains (table E.2). The causes for impairment at these streams include beryllium pollution, temperature, and *E. coli*. A single reservoir, Groves Lake, as included in the spatial data for assessed lakes. It was classified as having insufficient information to assess any beneficial uses. Most (87 percent) watersheds in the Central Mountains were rated as properly functioning for the WCF Impaired Waters attribute. These watersheds contained no state-listed impaired or threatened waterbodies. Ten percent of watersheds were classified as impaired, meaning more than 10 percent of stream miles or lake area in these watersheds are not fully supporting beneficial uses (table E.1). Nevertheless, most (78 percent) of watersheds in the Central Mountains were in poor condition according to the WCF Water Quality Problems attribute. These watersheds have extensive water quality problems including consumption advisories, excessive sediment or nutrients, contamination from active or abandoned mines, as well as strong evidence of acidification, eutrophication, or toxicity due to atmospheric deposition.

Thirty-two NDEP water quality monitoring stations are located on streams in the Central Mountains unit. Sites in Big, Big Sawmill, Stewart, and Washington Creeks suggest water quality in these systems is consistently classified as reference, or near natural conditions. In contrast, water quality in Birch, Clear, and Ophir Creeks, as well as S.F. Twin River/REF #PA01-0512 has consistently been classified as impaired since 2003. Several sites including Cottonwood, Kingston, Little Sawmill, and Wisconsin Creeks, as well as the Reese River and S.F. Twin River have experienced variable water quality conditions, with some trending from reference to impaired, impaired to reference, or not displaying any clear trend. Several sites have only been monitored once and more data is needed to evaluate these locations. Of the 85 times water quality stations in the Central Mountains has been monitored between 2003 and 2014, 42 sites have been classified as reference, 36 were impaired, and 7 were undetermined (table E.1).

Of the seven water quality indicators evaluated, two provided evidence of substantial alteration, one suggested moderate alteration, and four indicated no alteration. Based on these results, we estimate water quality in the Central Mountains is **within** NRV.

According to the SSI database there were 1,489 springs in the Central Mountains unit. Forty-three surveys conducted between 1991 and 2020 were available at 37 springs. Diversions and grazing were the most common disturbances, highly impacting 7 and 8 percent of springs, respectively. An additional 11 percent of springs were moderately disturbed by cattle. Neither fire nor dredging were indicated as disturbance at any of the surveyed springs. The Spring Ecosystem Assessment Protocol (SEAP) was completed at Mud Spring, Sidehill Spring, and Six Mile Spring in 2020. Mud Spring has been impacted by drought, cattle, and recreation, but water quality was rated as very good. Sidehill spring had also experienced high levels of disturbance from cattle, but the water quality remained in good condition. Stressor information was not included in the Six Mile Spring Report, and the water quality was rated as moderate. There was low risk to water quality and at least some restoration potential at all three sites. Additional inventory of condition is needed at GDE sites in the Central Mountains. There was **insufficient information** to evaluate water quality at GDEs.

Table E.1—Values of water quality indicators by unit.

Water quality indicator	Unit						
	Central Mountains	East Sierra	Eastern Mountains	Northern Mountains	Ruby Mountains	Sierra Nevada	SMNRA
% of watersheds in functioning-at-risk condition for WCF riparian and wetland vegetation	18	10	19	35	45	40	96
% of watersheds in impaired condition for WCF riparian and wetland vegetation	76	88	77	53	52	58	4
% of watersheds in functioning-at-risk condition for WCF water quality problems	6	8	5	5	2	2	8
% of watersheds in impaired condition for WCF water quality problems	78	93	79	58	52	60	4
% of watersheds in functioning-at-risk condition for WCF impaired waters	2	20	4	8	5	14	4
% of watersheds in impaired condition for WCF impaired waters	11	13	14	37	24	39	0
% of streams with riparian areas converted to agriculture	<1	<1	<1	<1	<1	1.2	0
% of streams with riparian areas converted to development	<1	1.3	<1	<1	0	3.7	<1
% of sites classified as reference by NDEP	49	25	29	49	65	40	0
% sites classified as impaired by NDEP	42	6	53	46	35	50	100
Does NDEP data suggest a decline in water quality?	No	No	No	No	No	No	No
% of streams listed by the state as impaired	<1	4	<1	4	2	8	0
# waterbodies listed by the state as impaired	0	2	1	1	1	2	0

Table E.2— State-listed 303(d) streams and causes of their impairment in the Central Mountains unit.

Waterbody	Cause of Impairment	Miles
Cottonwood Creek	Beryllium	7
Little Sawmill Creek	Temperature	4
Marysville Creek	*E. coli*	7
Reese Creek	Temperature	16
San Juan Creek	Beryllium	6
Stewart Creek	Beryllium	7

East Sierra

The primary stressors to water quality in the East Sierra unit included roads, dams or diversions, grazing, and nitrogen deposition. There were 0.0011 road miles per acre in this unit and 98 percent were unimproved. Additionally, there were 0.003 road miles per floodplain acre. Of the 3 riparian monitoring plots located in the East Sierra unit, only one plot indicated road disturbance. The WCF Proximity to Water attribute indicated 90 percent of watersheds were impaired, meaning more than a quarter of the road or trail length within the watershed was within 300 feet or otherwise hydrologically connected to streams and waterbodies. There were 0.0003 diversions per acre and six dams located in this unit. The WCF Water Quantity indicator suggested these structures have had moderate impacts on flow regimes in 88 percent of watersheds. Removal of flow by diversions have potentially increased concentrations of salts, nutrients, and any pollutants during some time periods. Eighteen percent of the East Sierra is within wild horse and burro territory and 87 percent of the unit is within a livestock grazing allotment. The WCF Rangeland Vegetation Condition indicator suggests 43 percent of watersheds in the unit are in functioning-at-risk condition, meaning rangelands within these watersheds have suffered a reversible loss in capacity to limit redistribution of soil resources including nutrients and organic matter (table E.1). An additional 58 percent of watersheds were classified as impaired for rangeland vegetation condition, meaning these areas had lost the ability to limit redistribution of nutrients and organic matter. Riparian monitoring plots indicated wildlife use as a disturbance in all three reaches and livestock grazing as a disturbance in one reach. The WCF indicated soil conditions may be impacting water quality throughout the unit. In 82 percent of watersheds, soil nutrient and hydrologic cycling processes are impaired, there is evidence of accelerated surface erosion, and limited areas of soil contamination exist. The TCA classified the entire unit in very good condition for acid deposition, meaning long-term acidification of soils or surface waters was not an issue. In contrast, the TCA classified 51 percent of the unit in poor or very poor condition for nitrogen deposition, suggesting eutrophication of some waterbodies due to excess nitrogen is likely.

According to the NorWeST dataset, stream temperatures in the East Sierra unit ranged from 4.71 °C to 20.65 °C between 1993 and 2011. During this period average stream temperature in the unit was 14.10 °C ±.06. Temperatures in East Sierra streams appear to be increasing, ranging from 4.81 °C to 20.75 °C between 2002 and 2011, with a mean

of 14.20 °C ±.06. Stream temperatures are expected to increase further, with an expected mean of 14.87 °C ±.06 by mid-century and 15.46 °C ±.06 by the 2080s.

Floodplains make up 2.9 percent of the East Sierra and 0.72 percent of the unit was classified as wetland. Riparian ecosystems in the East Sierra unit have experienced limited conversion to alternative cover types that can impact water quality. Only 0.9 percent of riparian corridor miles have converted from native riparian vegetation to agriculture. An additional 1.3 percent of corridors have converted to development. The WCF Riparian/Wetland Vegetation Condition indicator suggested native riparian and wetland vegetation in 88 percent of watersheds were impaired and not capable of dissipating stream energy, reducing erosion, filtering sediment, stabilizing streambanks, buffering stream temperature, or improving water quality. An additional 10 percent of watersheds were classified as functioning-at-risk for this indicator.

According to 303(d) spatial data, 117 miles of streams in the East Sierra were assessed for water quality. All beneficial uses were supported in 8.6 miles of Sweetwater Creek. Water quality in less than 1 mile of Rough Creek supported some beneficial uses, but data were insufficient to evaluate all uses. One or more beneficial uses were not supported in the remaining 93 percent of assessed streams in the East Sierra Unit (table E.3). Additionally, beneficial uses were not being supported in two waterbodies. Bridgeport Reservoir was impacted by mercury pollution and Topaz Lake was listed due to total phosphorus and temperature. Most (68 percent) watersheds in East Sierra were rated as properly functioning for the WCF Impaired Waters attribute. These watersheds contained no state-listed impaired or threatened waterbodies. Twelve percent of watersheds were classified as impaired, meaning more than 10 percent of stream miles or lake area in these watersheds are not fully supporting beneficial uses. Nearly all (93 percent) of watersheds in the East Sierra were in poor condition according to the WCF Water Quality Problems attribute. These watersheds have extensive water quality problems including consumption advisories, excessive sediment or nutrients, contamination from active or abandoned mines, as well as strong evidence of acidification, eutrophication, or toxicity due to atmospheric deposition. No watersheds were properly functioning, meaning there were no areas within this unit with minor or no water quality problems.

Table E.3—State-listed 303(d) impaired streams and cause of impairment in the East Sierra unit.

Waterbody	Cause of Impairment	Miles	State
Bodie Creek	Mercury, Total Phosphorus	11	NV
Bodie Creek	Mercury	<1	CA
Desert Creek	Cadmium	18	NV
East Walker River, below Bridgeport Reservoir	Sedimentation/Siltation, Manganese, Turbidity	8	CA
Rough Creek	Iron, Total Phosphorus	7	NV
Rough Creek	Mercury, Total Phosphorus	8	NV
Swauger Creek	Total Phosphorus, *E. coli*	13	CA
Walker River, East Fork	Total Phosphorus, Mercury, Temperature	24	NV
Walker River, East Fork	Total Phosphorus	<1	NV
Walker River, East Fork	Total Phosphorus, Temperature, Iron, Total Suspended Solids, Manganese, Beryllium	<1	NV
Walker River, West Fork	Temperature	16	NV
Walker River, West Fork	Total Phosphorus	<1	NV
Walker River, West Fork	Temperature	2	NV

Sixteen NDEP water quality monitoring stations are located on streams in the East Sierra unit. Sites in Desert and Sweet Water Creeks, as well as the East and West Forks of the Walker River suggest water quality in these systems is consistently classified as impaired with impacts of poor water quality to the biota. Several sites, including Bodie and Rough Creeks, as well as sections of Sweet Water Creek have experienced variable water quality condition, with most typically classified as reference, with occasional declines in water quality in some years. Finally, several sites have only been monitored once and more data is needed for these locations. Overall, of the 44 times water quality stations in the East Sierra unit have been monitored between 2000 and 2013, 11 have been classified as reference, 28 were impaired, and five were classified as undetermined (table E.1).

Of the seven water quality indicators evaluated, two provided evidence of substantial alteration, one suggested moderate alteration, and four indicated no alteration. Based on these results we estimate water quality in the East Sierra unit is **within** NRV.

According to the SSI database there were 187 springs in the East Sierra unit. Twenty-three spring surveys conducted between 1991 and 2009 were available at 20 springs. Diversions and grazing were the most common disturbances, both highly impacting 6 percent of springs. An additional 4 percent of springs were moderately disturbed by diversions. No reports included information on condition and there was insufficient information to evaluate water fluctuations at GDEs in the East Sierra Unit.

Eastern Mountains

The primary stressors to water quality in the Eastern Mountains included roads, diversions, recreation, invasive species, grazing, soil conditions, and drought. There were 0.0006 roads per acre in this unit and 99 percent of roads were unimproved. Additionally, there were 0.003 road miles per floodplain acre. Of the 49 riparian plots monitored in the Eastern Mountains, roads were a disturbance at 55 percent. The WCF Proximity to Water attribute indicated 79 percent of watersheds in the Eastern Mountains were impaired, meaning more than a quarter of road or trail length within the watershed was within 300 feet or otherwise hydrologically connected to streams and waterbodies. There were 0.0002 diversions per acre and two dams located in this unit. The WCF Water Quantity indicator suggested these structures had moderately impacted hydrographs in 84.9 percent of watersheds. The TCA indicated 100 percent of the unit was in poor or very poor condition for drought. Removal of flow by diversions and long-term moisture deficits driven by drought have potentially increased concentrations of salts, nutrients, and any pollutants during some time periods. There were 0.003 trail miles per acre and two designated recreation sites within the floodplains of this unit. Of the 49 riparian plots monitored in the Eastern Mountains, trails, camping, and OHVs were identified as disturbances at 43, 14, and 8 percent of reaches, respectively. The riparian areas along 9 miles of stream had experienced moderate or significant conversion to invasive species and noxious weeds were indicated as a disturbance at one quarter of riparian monitoring plots. One quarter of the Eastern Mountains is located within wild horse and burro territory and 98 percent of the unit is within a livestock grazing allotment. The WCF Rangeland Vegetation Condition indicator suggests 52 percent of watersheds have rangelands that have experienced a reversible loss in capacity to limit redistribution of soil resources including nutrients and organic matter. An additional 44 percent of watersheds have rangelands that have fully lost this capacity. Wildlife use and grazing were identified as disturbances at 88 and 90 percent of riparian monitoring plots, respectively. The WCF indicated soil conditions may be impacting water quality throughout the unit. In nearly two-thirds of watersheds, soil nutrient and hydrologic cycling processes are impaired, there is evidence of accelerated surface erosion, and limited areas of soil contamination exist.

According to the NorWeST dataset, stream temperatures in the Eastern Mountains unit ranged from 3.90 °C to 20.81 °C between 1993 and 2011. During this period average stream temperature in the unit was 12.73°C ±0.06. Temperatures in Eastern Mountains streams appear to be increasing, ranging from 4.01 °C to 20.91 °C between 2002 and 2011, with a mean of 12.83 °C ±0.06. Stream temperatures are expected to increase further, with an expected mean of 13.57 °C ±0.05 by mid-century and 14.21 °C ±0.05 by the 2080s.

Floodplains make up 1.9 percent of the Eastern Mountains and 0.3 percent of the unit was classified as wetland. Riparian ecosystems in the Eastern Mountains have experienced limited conversion to alternative cover types that can impact water quality. Only 0.04 percent of riparian corridor miles have transitioned from native riparian plants to agriculture. An additional 0.38 percent of corridor miles have converted to

development. The WCF Riparian/Wetland Vegetation Condition indicator suggested native riparian and wetland vegetation in 77 percent of watersheds were impaired and not capable of dissipating stream energy, reducing erosion, filtering sediment, stabilizing streambanks, buffering stream temperature, or improving water quality (table E.1). An additional 10 percent of watersheds were classified as functional-at-risk for riparian/wetland vegetation condition.

According to the 303(d) spatial data, 154 miles of streams were assessed for water quality. All beneficial uses were supported in 48 percent. Less than 1 percent of assessed stream miles supported some beneficial uses, but data were insufficient to evaluate all uses. There was insufficient information to assess 50 percent of stream miles. Finally, one or more beneficial uses were not supported in 2 percent of assessed streams in the Eastern Mountains unit. This impairment occurred along 3.3 miles of East Creek and was due to *E. coli*. A single waterbody, Cave Lake, was listed as impaired due to dissolved oxygen and pH. Most (82 percent) watersheds in the Eastern Mountains were rated as properly functioning for the WCF Impaired Waters attribute. These watersheds contained no state-listed impaired or threatened waterbodies. Fourteen percent of watersheds were classified as impaired, meaning more than 10 percent of stream miles or lake area in these watersheds are not fully supporting beneficial uses. According to the WCF Water Quality Problems attribute, 79 percent of watersheds in the Eastern Mountains had extensive water quality problems including consumption advisories, excessive sediment or nutrients, contamination from active or abandoned mines, as well as strong evidence of acidification, eutrophication, or toxicity due to atmospheric deposition (table E.1). Seventeen percent of watersheds were properly functioning, meaning these areas had minor or no water quality problems.

Twelve NDEP water quality monitoring stations are located on streams in the Eastern Mountains unit. Water quality in upper Steptoe Creek has consistently been classified as impaired with likely impacts to biota. Bird and Timber Creeks have experienced variable water quality conditions, with no clear trend in the data. Finally, most sites have only been monitored once and more data is needed to evaluate these locations. Of the 17 times, water quality stations in the Eastern Mountains have been monitored between 2004 to 2014, 5 sites were classified as reference, 9 were impaired, and 3 were undetermined (table E.1).

Of the seven water quality indicators, two provided evidence of substantial alteration, one suggested moderate alteration, and four indicated no alteration. Based on these results, we estimate water quality in the Eastern Mountains is **within** NRV.

According to the SSI database there were 807 springs in the Eastern Mountains unit. Sixty surveys conducted between 1991 and 2020 were available at 57 springs. Multiple protocols had been applied to assess the condition of the springs. Diversions and grazing by wild animals and livestock were commonly noted disturbances at most sites. Several sites had water permanently diverted or had regulated water flow by an impoundment or a dam. Two springs were moderately impacted by dredging and two springs were mildly or moderately disturbed by recreation activities. SEAP had been applied at 8 sites, with all reports indicating at least moderate impacts to water quality.

Water quality was rated as poor or very poor with no restoration potential at Indian Garden, Trail, and Red Rock. Additional inventory of condition is needed at GDE sites in the Eastern Mountains. There was **insufficient information** to evaluate water quality at GDEs.

Northern Mountains

The primary stressors to water quality in the Northern Mountains included roads, diversions, drought, recreation, invasive species, grazing, wildfire, soil conditions, and nitrogen deposition. There were 0.0011 road miles per acre in this unit and 94 percent were unimproved. Additionally, there were 0.003 road miles per floodplain acre. Of the 32 riparian plots monitored in the Northern Mountains, roads were indicated as a disturbance at 72 percent. The WCF proximity to roads attribute indicated 70 percent were impaired, meaning more than a quarter of the road or trail length within the watershed was within 300 feet or otherwise hydrologically connected to streams and waterbodies. There were 0.0011 diversions and 2 dams located in this unit. The WCF Water Quantity indicator suggested these structures had moderately altered stream hydrographs in 79 percent of watersheds. The TCA indicated 28 percent of the unit was in poor or very poor condition for drought. There were 0.002 trail miles per acre and two designated recreation sites within floodplains in this unit. Trails, camping, and OHVs were identified as disturbances at 72, 47, and 28 percent of riparian monitoring plots, respectively. Riparian areas associated with 4.8 miles of stream had experienced moderate or significant conversion to invasive species and noxious weeds were indicated as a disturbance at 34 percent riparian monitoring plots. Although wild horse or burro territory is not located in the Northern Mountains, 90 percent of the unit is within a grazing allotment. The WCF Rangeland Vegetation Condition indicator suggests 70 percent of watersheds in the unit are functional, but at risk, meaning rangelands within these watersheds have suffered a reversible loss in capacity to limit redistribution of soil resources including nutrients and organic matter. Wildlife use and grazing were identified as disturbances at 66 and 88 percent of units, respectively. According to the TCA, 23 percent of the unit was in poor or very poor condition for uncharacteristic fire severity and fire was identified as a disturbance at 19 percent of riparian monitoring plots. The WCF indicated soil conditions may be impacting water quality throughout the unit. In nearly two-thirds of watersheds, soil nutrient and hydrologic cycling processes are impaired, there is evidence of accelerated surface erosion, and limited areas of soil contamination exist. The TCA classified the entire unit in very good condition for acid deposition, meaning long-term acidification of soils or surface waters are not an issue in the Northern Mountains. In contrast, the TCA classified 74 percent of the unit in poor or very poor condition for nitrogen deposition, suggesting eutrophication of some waterbodies due to excess nitrogen is likely.

According to the NorWeST dataset, stream temperatures in the Northern Mountains unit ranged from 3.90 °C to 17.42 °C between 1993 and 2011. During this period average stream temperature in the unit was 12.66 °C ±0.03. Temperatures in Northern Mountain streams appear to be increasing, ranging from 4.01°C to 17.52°C between 2002 and 2011, with a mean of 12.73 °C ±0.03. Stream temperatures are expected to increase further, with an expected mean of 13.70 °C ±0.03 by mid-century and 14.41 °C ±0.03 by the 2080s.

Floodplains make up 3.3 percent of the Northern Mountains and 0.9 percent of the unit was classified as wetland. Riparian ecosystems in the Northern Mountains have experienced limited conversion to alternative cover types that can impact water quality. Only 0.11 percent of riparian corridor miles have transitioned from native riparian plants to agriculture (table E.1). An additional 0.34 percent of corridor miles have converted to development. The WCF Riparian/Wetland Vegetation Condition indicator suggested native riparian and wetland vegetation in 53 percent of watersheds were impaired and not capable of dissipating stream energy, reducing erosion, filtering sediment, stabilizing streambanks, buffering stream temperature, or improving water quality. An additional 35 percent of watersheds were classified as functional-at-risk for this indicator.

According to 303(d) spatial data, 519 miles of streams in the Northern Mountains were assessed for water quality. All beneficial uses were supported in 18 percent of these streams. Water quality in 10 percent of streams supported some beneficial uses, but data were insufficient to evaluate all uses. There was insufficient information to assess any uses in an additional 37 percent of streams. One reach of the Owyhee River, which composes less than 1 percent of assessed streams, was listed due to copper, iron, Total Phosphorus, and turbidity, but an EPA-approved TMDL exists for this site. Finally, one or more beneficial uses were not supported in 34 percent of assessed streams in the Northern Mountains (table E.4). A single, reservoir, Wild Horse, was impaired due to dissolved oxygen, mercury in fish tissue, pH, Total Phosphorus, and temperature. Most (55 percent) watersheds in the Northern Mountains were rated as properly functioning for the WCF Impaired Waters attribute. These watersheds contained no state-listed impaired or threatened waterbodies. Thirty-seven percent of watersheds were classified as impaired, meaning more than 10 percent of stream miles or lake area in these watersheds are not fully supporting beneficial uses. According to the WCF Water Quality Problems attribute, there were extensive water quality problems such as excessive sediment, nutrients, or chemicals or strong evidence of eutrophication in 58 percent of watersheds. There were minor or no water quality problems in 37 percent of watersheds.

Forty-seven NDEP water quality monitoring stations are located on streams in the Northern Mountains unit. Sites in Salmon Creek, Singas Creek, and Snow Canyon suggest water quality in these systems is consistently classified as reference, or near natural conditions. In contrast, water quality in Horse Canyon, Lye, McConnell, and Meadow Creeks, as well as the N.F. Little Humboldt, N.F. Humboldt, Owyhee River has consistently been classified as impaired since 2002. Several sites including Bruneau River, Cabin Creek, E.F. Quinn River, Jarbridge River (West), lower S.F. Quinn River, and Sammy Creek have experienced variable water quality conditions but appear to be improving. Upper E.F. Quinn River, Martin Creek, reaches of the Owyhee River, Road Creek, and Stonehouse Creek have experienced variable water quality conditions with no clear trend. Several sites have only been monitored once and more data is needed to evaluate these locations. Of the 112 times water quality stations in the Northern Mountains have been monitored between 2002 and 2014, 51 sites have been classified as impaired, 55 were classified as reference, and 6 were undetermined (table E.1).

Table E.4—State-listed 303(d) streams and cause for impairment in the Northern Mountains unit.

Waterbody	Cause for Impairment	Miles
Badger Creek	Iron	9
Bruneau River	Beryllium, Cadmium, pH, Temperature	25
Burns Creek	Total Dissolved Solids	4
Cottonwood Creek, North Fork	Temperature	5
Dry Creek	Alkalinity, Temperature, Turbidity, Cadmium, Copper, Iron, Zinc	3
Dry Creek	Nickel, Selenium, Sulfate, Total Dissolved Solid, Total Suspended Solids	<1
Gance Creek	Temperature	4
Goosey Lake Creek	Temperature	9
Gracie Creek	Sulfate, Total Dissolved Solids	2
Humboldt River, North Fork	Manganese, Sulfate, Total Dissolved Solids, Total Suspended Solids	2
Humboldt River, North Fork	Total Suspended Solids	1
Humboldt River, North Fork	Iron, Total Phosphorus, Temperature, Total Suspended Solid, Turbidity	<1
Humboldt River, North Fork	Total Suspended Solids	2
Jarbidge River	Beryllium, Cadmium, Copper, Lead, Silver, Zink	2
Jarbidge River, East Fork	Beryllium, Cadmium, Lead, Silver, Temperature	16
Jerritt Canyon Creek	Sulfate, Total Dissolved Solids	5
Little Humboldt River, North Fork	Temperature, Mercury in Fish Tissue	14
Martin Creek	Total Phosphorus	0
Mill Creek	Cadmium, Copper, Iron, Total pH, Total Suspended Solids, Turbidity	2
Mill Creek	Iron	5
Mill Creek	Nitrate, Total Phosphorus, Sulfate, Total Dissolved Solids, Total Suspended Solids	2
Owyhee River	Beryllium, Mercury in Fish Tissue	15
Pratt Creek	pH	5
Quinn River, East Fork	Total Phosphorus	21
Rio Tinto Gulch	Alkalinity, Manganese, Zinc	<1
Sammy Creek	pH, Selenium, Sulfate, Total Dissolved Solids, Total Suspended Solids	1
Sheep Creek	Total Phosphorus, Selenium, Nickel, Sulfate, Total Dissolved Solids, Total Suspended Solids, pH	2
Snow Canyon Creek	Sulfate, Total Dissolved Solids	6
Snow Canyon Creek, East Fork	Sulfate, Total Dissolved Solids	1
Sun Creek	Temperature	5
T Creek	Temperature	5
Tomasina Gulch	Arsenic, Iron	1
Water Canyon Creek	Selenium, Sulfate, Total Dissolved Solids, Total Suspended Solids	<1

Of the seven water quality indicators, two provided evidence of substantial alteration, one suggested moderate alteration, and four indicated no alteration. Based on these results, we estimate water quality in the Northern Mountains is **within** NRV.

According to the SSI database there were 1,304 springs in the Northern Mountains. 103 spring surveys conducted between 1991 and 2020 were available at 101 springs. Ten reports included information on disturbance. One site was highly disturbed by drought in 2013. Two sites were moderately disturbed by diversions. Horse and burro use had impacted two sites. Eight springs were moderately disturbed, and one was highly disturbed by cattle. Two sites were moderately disturbed, and one site was highly disturbed by recreation. SEAP protocols were implemented at six springs (Mud Circle Cienega, Mantid View, Alder, Libellula Warm, Wilderness Boundary, and Wildflower) in 2018 and at one spring (Veratrum Actual) in 2020. Water quality was rated as good with significant restoration potential at six springs. At Mud Circle Cienega, water quality was rated as moderate with some restoration potential. The risk to all seven evaluated sites was low, meaning it was likely that water quality would remain unchanged. Additional inventory of condition is needed at GDE sites in the Northern Mountains. There was **insufficient information** to evaluate water quality at GDEs.

Ruby Mountains

The primary stressors to water quality in the Ruby Mountains unit included roads, diversions, recreation, invasive species, grazing, drought, soil conditions, and nitrogen deposition. There were 0.0007 road miles per acre in this unit and 87 percent were unimproved. Additionally, there were 0.002 road miles per floodplain acre. Of the 9 riparian plots monitored in the Ruby Mountains, roads were indicated as a disturbance at 5. The WCF Proximity to Roads attribute indicated 64 percent of watersheds were impaired, meaning more than a quarter of road or trail length were within 300 feet or otherwise hydrologically connected to streams and waterbodies. There were 0.0007 diversions per acre and one dam in this unit. The WCF Water Quantity indicator suggested these structures had moderately altered stream hydrographs in 86 percent of watersheds. Additionally, the TCA indicated 20 percent of the unit was in poor or very poor condition for drought. There were 0.003 trail miles per acre and one established recreation site within the floodplain. Trails, camping, and OHVs were indicated as disturbances at 44, 33, and 33 percent of riparian monitoring plots, respectively. Riparian areas associated with 14.7 miles of stream had experienced moderate or significant conversion to invasive species and noxious weeds were indicated as a disturbance at 22 percent of riparian monitoring plots. Only 5 percent of the unit is within wild horse and burrow territory; however, 92 percent of the Ruby Mountains were within a grazing allotment. The WCF Rangeland Vegetation Condition indicator suggests 64 percent of watersheds were impaired, meaning rangelands in these watersheds had lost the capacity to limit redistribution of soil resources including nutrients and organic matter. The remaining 36 percent of watersheds were classified as functional-at-risk for rangeland vegetation condition, meaning the lost capacity of these rangelands was reversible. Wildlife use and grazing were indicated as disturbances at 67 and 78 percent of riparian monitoring plots, respectively. The WCF indicated soil conditions may be impacting water quality throughout the unit.

In approximately three-quarters of watersheds, soil nutrient and hydrologic cycling processes are impaired, there is evidence of accelerated surface erosion, and limited areas of soil contamination exist. The TCA classified the entire unit in very good condition for acid deposition, meaning long-term acidification of soils or surface waters are not an issue in the Ruby Mountains. In contrast, the TCA classified 96 percent of the unit in poor or very poor condition for nitrogen deposition suggesting eutrophication of some waterbodies due to excess nitrogen is likely.

According to the NorWeST dataset, stream temperatures in the Ruby Mountains unit ranged from 3.90 °C to 16.94 °C between 1993 and 2011. During this period average stream temperature in the unit was 11.21 °C ±0.07. Temperatures in Ruby Mountain streams appear to be increasing, ranging from 4.01 °C to 17.04 °C between 2002 and 2011, with a mean of 11.35 °C ±0.07. Stream temperatures are expected to increase further, with an expected mean of 12.02 °C ±0.07 by mid-century and 12.6 °C ±0.07 by the 2080s.

Floodplains make up 2.1 percent of the Ruby Mountains and 0.4 percent of the unit was classified as wetland. Riparian ecosystems in the Ruby Mountains have experienced limited conversion to alternative cover types that can impact water quality. Only 0.57 percent of riparian corridor miles have transitioned from native riparian plants to agriculture. An additional 0.01 percent of corridor miles have converted to development. The WCF Riparian/Wetland Vegetation Condition indicator suggested native riparian and wetland vegetation in 52 percent of watersheds was impaired and not capable of dissipating stream energy, reducing erosion, filtering sediment, stabilizing streambanks, buffering stream temperature, or improving water quality (table E.1). An additional 45 percent of watersheds were classified as functional-at-risk for this indicator.

According to 303(d) spatial data, 143 miles of streams in the Ruby Mountains were assessed for water quality. All beneficial uses were supported at 48 percent of assessed streams. Water quality in 5 percent of streams supported some beneficial uses, but data were insufficient to evaluate all uses. There was insufficient information to assess any uses in an additional 32 percent of evaluated streams. Finally, one or more beneficial uses were not supported in 15 percent of assessed streams in the Ruby Mountains (table E.5). The causes for impairment at these streams included temperature and turbidity. Two lakes, Angel and Overland, were included in the assessment. There was insufficient information to assess any uses at Angel Lake. Overland Lake was listed as impaired due to mercury in fish tissue. Most (71 percent) watersheds in the Ruby Mountains were rated as properly functioning for the WCF Impaired Waters attribute (table E.1). These watersheds contained no state-listed impaired or threatened waterbodies. Twenty-four percent of watersheds were classified as impaired, meaning more than 10 percent of stream miles or lake area in these watersheds are not fully supporting beneficial uses. According to the WCF Water Quality Problems attribute, there were extensive issues including consumption advisories, excessive sediment or nutrients, contamination from active or abandoned mines, as well as strong evidence of acidification, eutrophication, or toxicity due to atmospheric deposition in 52 percent of watersheds. There were minor or no water quality problems in 45 percent of watersheds.

Table E.5—State-listed 303(d) streams and the cause for impairment for streams in the Ruby Mountains.

Waterbody	Cause for Impairment	Miles
Green Mountain Creek	Temperature	6
Lamoille Creek	Temperature	<1
Pearl Creek	Temperature, Turbidity	5
Secret Creek	Temperature, *E. coli*	4
Toyn Creek	Temperature	1
Toyn Creek	Total Phosphorus, Temperature	7

Twelve NDEP water quality monitoring stations are located on streams in the Ruby Mountains unit. A single site in Angel Creek/Willow Creek suggested water quality in this system was consistently in reference, or near natural, conditions. In contrast, water quality in reaches of Rattlesnake Creek has consistently been classified as impaired since 2003. Several sites, including Lamoille, Smith, and Soldier Creeks, have experienced variable water quality conditions, with no clear trend. Finally, many sites have only been monitored once and more data is needed to evaluate these locations. Of the 37 times water quality stations in the Ruby Mountains have been monitored between 2002 and 2014, 13 sites were classified as impaired and 24 were reference (table E.1).

Of the seven water quality indicators, two provided evidence of substantial alteration, one suggested moderate alteration, and four indicated no alteration. Based on these results, we estimate water quality in the Ruby Mountains is **within** NRV.

According to the SSI database there were 443 springs in the Ruby Mountains. Three spring surveys conducted between 1991 and 1997 were available for three sites. One site, an unnamed spring that is a tributary to Toyn Creek was moderately disturbed by diversions and cattle. Green Mountain Creek was mildly disturbed by cattle. Ruby 102 spring was highly disturbed by dredging. No reports included information on condition and there was therefore **insufficient information** to evaluate water fluctuations at GDEs in the Ruby Mountains.

Sierra Nevada

The primary stressors to water quality in the Sierra Nevada included roads, diversions, recreation, invasive species, grazing, fire, soil conditions, and nitrogen deposition. There were 0.0011 road miles per acre in this unit and 76 percent were unimproved. Additionally, there were 0.0008 road miles per floodplain acre. Of the 43 riparian plots monitored in the Sierra Nevada, roads were a disturbance at 28 percent. The WCF Proximity to Water attribute indicated 52 percent of watersheds were impaired, meaning more than a quarter of road and trail length in the watershed was within 300 feet or otherwise hydrologically connected to streams and waterbodies. An additional 37 percent of watersheds were classified as functional-at-risk for road proximity to water. There were 0.002 diversions per acre and 45 dams in this unit. The WCF Water Quantity indicator suggested these structures had contributed to moderate alterations in stream hydrographs in 79 percent of watersheds. There were 0.0008 trail miles

per acre and 4 established recreation sites within floodplains in this unit. Trails, camping, and OHVs were identified as disturbances at 53, 33, and 19 percent of riparian monitoring plots, respectively. Riparian areas associated with 9 miles of stream had experienced moderate or significant conversion to invasive species. Noxious weeds were identified as a disturbance at 16 percent of riparian monitoring plots. Fifty-five percent of the Sierra Nevada unit was within a grazing allotment. The WCF Rangeland Vegetation Condition indicator suggests every watershed in the unit were functional-at-risk, meaning rangelands in throughout the whole Sierra Nevada had suffered a reversible loss in capacity to limit redistribution of soil resources including nutrients and organic matter. Wildlife use and grazing were both indicated as disturbances at 78 percent of riparian plots. The TCA classified 28 percent of the Sierra Nevada unit in poor or very poor condition for uncharacteristic fire severity, which was greater than all other units in the study area. Riparian monitoring plots, however, did not describe fire as a disturbance in any reaches. The WCF indicated soil conditions may be impacting water quality throughout the unit. In 87 percent of watersheds, soil nutrient and hydrologic cycling processes are impaired, there is evidence of accelerated surface erosion, and limited areas of soil contamination exist. The TCA classified the entire unit in very good condition for acid deposition, meaning long-term acidification of soils or surface waters are likely not an issue in Sierra Nevada. In contrast, the TCA classified 65 percent of the unit in poor or very poor condition for nitrogen deposition, suggesting eutrophication of some waterbodies due to excess nitrogen is likely.

According to the NorWeST dataset, stream temperatures in the Sierra Nevada unit ranged from 3.90 °C to 21.77 °C between 1993 and 2011. During this period average stream temperature in the unit was 11.54 °C ±0.07. Temperatures in Sierra Nevada streams appear to be increasing, ranging from 4.01 °C to 21.87 °C between 2002 and 2011, with a mean of 11.64 °C ±0.07. Stream temperatures are expected to increase further, with an expected mean of 12.31 °C ±0.07 by mid-century and 12.90 °C ±0.07 by the 2080s.

Floodplains make up 6.6 percent of the Sierra Nevada and 4.5 percent of the unit was classified as wetland. Riparian ecosystems in the Sierra Nevada have experienced limited conversion to alternative cover types that can impact water quality. Only 1.24 percent of riparian corridor miles have transitioned from native riparian plants to agriculture (table E.1). An additional 3.69 percent of corridor miles have converted to development. The WCF Riparian/Wetland Vegetation Condition indicator suggested native riparian and wetland vegetation in 58 percent of watersheds was impaired and not capable of dissipating stream energy, reducing erosion, filtering sediment, stabilizing streambanks, buffering stream temperature, or improving water quality (table E.1). An additional 40 percent of watersheds were classified as functional-at-risk for riparian/wetland vegetation condition.

According to 303(d) spatial data, 448 miles of streams in the Sierra Nevada were assessed for water quality. All beneficial uses were supported in 24 percent of these streams. Water quality in 11 percent of streams supported some beneficial uses, but data were insufficient to evaluate all uses in these reaches. There was insufficient information to assess any uses in an additional 12 percent of assessed streams. Two

percent of assessed streams were impaired for one or more designated uses but had a state-developed and EPA-approved TMDL in place. An additional 6 percent of assessed streams were also impaired and lacked a TMDL, but other control measures were expected to result in the attainment of water quality standards in a reasonable amount of time. Finally, one or more beneficial uses were not supported at 46 percent of assessed streams in the Sierra Nevada (table E.6). Nine lakes and reservoirs were assessed for water quality. Of these systems, Davis, Virginia, and Red Lake were supporting all beneficial uses. There was insufficient information to assess any uses in Hobart Reservoir and its tributaries, as well as Price's and Hunter Lake. One or more beneficial uses were not supported at Ambrosetti Pond and Twin Lake. Standards for temperature, total phosphorus, and turbidity were not met at Ambrosetti Pond. Upper Twin Lake was listed due to mercury. Many (48 percent) watersheds in the Sierra Nevada were rated as properly functioning for the WCF Impaired Waters attribute. These watersheds contained no state-listed impaired or threatened waterbodies. Thirty-nine percent of watersheds were classified as impaired, meaning more than 10 percent of stream miles or lake area in these watersheds are not fully supporting beneficial uses. According to the WCF Water Quality Problems attribute there were extensive issues consumption advisories, excessive sediment or nutrients, contamination from active or abandoned mines, as well as strong evidence of acidification, eutrophication, or toxicity due to atmospheric deposition in 60 percent of watersheds (table E.1). There were minor or no water quality problems in 39 percent of Sierra Nevada Watersheds.

Forty-one NDEP water quality monitoring stations are located on streams in the Sierra Nevada unit. Sites in Ash Canyon Tributary, Evans, upper Galena, upper Hunter, upper Thomas, and Upper Whites Creeks suggest water quality in these systems is consistently classified as reference, or near natural conditions. In contrast, water quality in Clear, Davis, and Thomas Creeks, as well as the East and West Forks of the Carson River have consistently been classified as impaired since 2000. Several sites, including lower Ash Canyon, upper Bryant, lower Franktown, and Winters Creek have experienced variable water quality, although conditions appear to be improving. Water quality appears to be declining in Browns, Daggett, and mid Galena Creek. Sites in upper Ash Canyon, lower Bryant, mid Hunter, Kings Canyon, and mid Whites Creeks, as well as sections of the Truckee River indicate water quality has been variable with no clear trend. Several sites have only been monitored once and more data is needed to evaluate these locations. Of the 162 times water quality stations in the Sierra Nevada have been monitored between 2000 And 2014, 65 sites have been classified as reference, 81 were impaired, and 16 were undetermined (table E.1).

Of the seven water quality indicators, two provided evidence of substantial alteration, two suggested moderate alteration, and three indicated no alteration. Based on these results, we estimate water quality in the Sierra Nevada unit is **moderately altered** from NRV.

According to the SSI database there were 482 springs in the Sierra Nevada unit. Twelve surveys conducted between 1992 and 2019 were available at ten sites. Seven surveys included information on stressors, with diversions and recreation the most common disturbances. Four springs were impacted by diversions, with one classified as highly

Table E.6—State-listed 303(d) streams and cause of impairment in the Sierra Nevada unit.

Waterbody	Cause for Impairment	Miles	State
Alum Creek	Orthophosphate, pH, Total Phosphorus, Total Dissolved Solids, Temperature, Total Suspended Solids	5	NV
Brockliss Slough, including East and West Branches	Turbidity	17	NV
Carson River	Dissolved Oxygen, Temperature	5	NV
Carson River, East and West Forks and Carson River	Total Phosphorus, Turbidity,	4	NV
Carson River, East Fork	Fecal Coliform	42	CA
Carson River, East Fork	Dissolved Oxygen, Temperature	2	NV
Carson River, East Fork	Temperature	7	NV
Carson River, East Fork	Beryllium, Temperature	9	NV
Carson River, West Fork	Total Phosphorus	12	NV
Carson River, West Fork (Headwaters to Woodfords)	Chloride	19	CA
Carson River, West Fork (Woodfords to Paynesville)	Fecal Coliform	1	CA
Chalk Creek	Nitrate, Orthoposphate, Phosphorus, Selenium, Sulfate, Total Dissolved Solids, Temperature	4	NV
Clear Creek	Total Phosphorus	<1	NV
Dry Creek	*E. coli*	7	NV
Evans Creek	*E. coli*	<1	NV
Galena Creek	pH	4	NV
Indian Creek	Temperature, Total Phosphorus	5	NV
Indian Creek (Alpine County)	Fecal Coliform	2	CA
Monitor Creek	Aluminum	4	CA
Thomas Creek	*E. coli*	4	NV
Thomas Creek	Arsenic, Boron	2	NV
Truckee River	Temperature	3	NV
West Walker River	Boron	30	CA
Whites Creek, Middle Fork	Boron, *E. coli*, Total Phosphorus	1	NV
Whites Creek, North Fork	*E. coli*	1	NV
Wolf Creek (Alpine County)	Sedimentation/Siltation	13	CA

disturbed. Four springs were also impacted by recreation, with one classified as highly disturbed. Cattle and dredging were also disturbing some springs in the Sierra Nevada Unit. No reports included information on condition and there was therefore **insufficient information** to evaluate water quality at GDEs in the Sierra Nevada Unit.

Spring Mountain National Recreation Area

Stressors to water quality present in SMNRA included roads, recreation, invasive species, grazing, diversions, drought, soil conditions, and nitrogen deposition. There were 0.0010 road miles per acre in this unit and 90 percent were unimproved. Additionally, there were 0.006 road miles per floodplain acre. Of the six riparian plots monitored in the SMNRA, roads were indicated as a disturbance at 100 percent. The WCF Proximity to Water attribute indicated 92 percent of watersheds were impaired, meaning more than one quarter of road and trail length in the watershed was within 300 feet or otherwise hydrologically connected to streams and waterbodies. There were 0.0005 diversions per acre and one dam in this unit. The WCF Water Quantity indicator suggested these structures had contributed to moderate alterations in stream hydrographs in 100 percent of watersheds. There were 0.0003 trail miles per acre and 3 established recreation sites within floodplains in this unit. Trails, camping, and OHVs were identified as disturbances at 100 percent of riparian monitoring plots. Although R-CAT indicated no stream miles in SMNRA had converted from native riparian cover to invasive species, noxious weeds were identified as a disturbance at 67 percent of riparian monitoring plots. None of SMNRA is located within a range management unit, but 51 percent is located within wild horse and burro territory. No watersheds were rated using the WCF Rangeland Vegetation indicator, but local riparian monitoring plots indicated grazing and wildlife as disturbances at 100 percent of plots. The TCA classified 100 percent of SMNRA in poor or very poor condition for drought. Removal of flow by diversions and long-term moisture deficits driven by drought have potentially increased concentrations of salts, nutrients, and pollutants during some time periods. The WCF indicated soil conditions may be impacting water quality throughout the unit. In approximately nearly all (96 percent) watersheds, soil nutrient and hydrologic cycling processes are impaired, there is evidence of accelerated surface erosion, and limited areas of soil contamination exist. Finally, the TCA classified the entire unit in very good condition for acid deposition, meaning long-term acidification of soils or surface waters are likely not an issue in SMNRA. In contrast, the TCA classified 72 percent of the unit in poor or very poor condition for nitrogen deposition, suggesting eutrophication of some waterbodies is likely.

According to the NorWeST dataset, stream temperatures in the SMNRA unit ranged from 10.41 °C to 25.79 °C between 1993 and 2011. During this period average stream temperature in the unit was 20.22 °C ±0.12. Temperatures in SMNRA streams appear to be increasing, ranging from 10.52 °C to 25.89 °C between 2002 and 2011, with a mean of 20.33 °C ±0.12. Stream temperatures are expected to increase further, with an expected mean of 21.00 °C ±0.12 by mid-century and 21.58 °C ±0.12 by the 2080s.

Floodplains make up 1.8 percent of the SMNRA and .01 percent of the unit was classified as wetland. Riparian ecosystems in the SMNRA have experienced limited conversion to alternative cover types that can impact water quality. None of the riparian corridor

miles have transitioned from native riparian plants to agriculture (table E.1). Only 0.08 percent of corridor miles have converted to development. The WCF Riparian/Wetland Vegetation indicators suggested native riparian and wetland vegetation 96 percent of watersheds was impaired and not capable of dissipating stream energy, reducing erosion, filtering sediment, stabilizing streambanks, buffering stream temperature, or improving water quality (table E.1). An additional 4 percent of watersheds were classified as functional-at-risk for riparian/wetland vegetation condition.

Two streams within SMNRA, Willow Creek and Cold Creek, were assessed for water quality by the state of Nevada. There was insufficient information to assess any uses at both reaches. No lakes or reservoirs within the SMNRA were included on the impaired waterbodies list. Nearly all (96 percent) watersheds in the SMNRA were rated as properly functioning for the WCF Impaired Waters attribute. These watersheds contained no state-listed impaired or threatened waterbodies. The remaining watersheds were classified as functioning-at-risk, meaning less than 10 percent of stream miles or lake area in these watersheds are not fully supporting beneficial uses. Additionally, 89 percent of watersheds in the SMNRA were in properly functioning condition for the WCF Water Quality Problems attribute. These watersheds lack documented evidence of excessive sediment, nutrients, pollutants, or other water quality issues above natural levels. Only 4 percent of watersheds were rates as poor for extensive water quality problems including consumption advisories, excessive sediment or nutrients, contamination from active or abandoned mines, as well as strong evidence of acidification, eutrophication, or toxicity due to atmospheric deposition (table E.1).

Two NDEP water quality monitoring stations are located on streams in the SMNRA unit: Cold Creek and Willow Creek. Both sites were monitored in 2003 and 2005 and scored as impaired in both years.

We did not include NDEP indicators in our evaluation of water quality in SMNRA as only two sites had been monitored and these sites had not be sampled since 2005. Of the five remaining water quality indicators, one provided evidence of moderate alteration from NRV and four suggested no alteration. Based on these results, we estimate water quality within SMNRA is **within** NRV.

According to the SSI database there were 469 springs in the SMNRA. This unit has the highest spring density of all units considered in this assessment. We found 265 surveys conducted between 1991 and 2020 at 136 springs sites in the SSI database. Seventy-six reports included information on disturbance. Avalanches, fire, flood, drought, diversions, horse and burro activity, cattle, recreation, and dredging were described as stressors at sites throughout SMNRA. Twenty percent of sites with disturbance data were highly impacted by diversions, with an additional 12 percent of sites mildly or moderately disturbed by diversions. Sixteen percent of sites were highly disturbed by horse and burro activity, with an additional 18 percent mildly or moderately impacted. Drought had highly impacted two sites (Unnamed 56 and North Rainbow) in 2016, and one site (NNW of Lost Cabin) in 1998. Flooding was described as a disturbance at eight springs. Unnamed 50 was highly impacted by flooding in 1997. Mary Jane Falls, Fletcher Spring, Harris Spring, Little Falls, and Unnamed 31 were moderately impacted

by flooding in 1994, 1998, or 2008. Upper Cougar and Peak were both mildly impacted by flooding in 1994. SEAP was implemented at ten springs in various years between 2007 and 2020. Two sites, Willow Creek and Macks Canyon, were sampled twice and provided some information on trends in condition. Both sites appeared stable. Willow Creek had very good aquifer functionality with excellent restoration potential in 2007 and 2010. Macks Canyon had good aquifer functionality with significant restoration potential in 2010 and 2020. Risk remained low at both sites over time. Aquifer functionality at the remaining sites was generally categorized as good or very good with low risk of changes in the future. The exception was Jaybird Spring, which had poor aquifer functionality and moderate risk. Despite many available spring surveys, only 4 percent included information on condition of water fluctuations in SMNRA. Additional inventory of condition is needed at GDE sites in SMNRA. There was **insufficient information** to evaluate water fluctuations at GDEs.

APPENDIX F. Channel and Floodplain Dynamics

Unit Summaries

Central Mountains

The primary stressors to channel and floodplain dynamics in the Central Mountains included roads, diversions, grazing, and drought. The TCA and WCF agree that the Central Mountains are in good condition for overall road density; however, the proximity of roads to waterbodies likely impacts channel and floodplain dynamics. There were 0.0034 road miles per floodplain acre, which was the second highest floodplain road density of all units on the HTNF. The WCF indicated that more than 25 percent of road and trail length was located within 300 feet of waterbodies in 87 percent of watersheds in the Central Mountains. Additionally, local riparian plot data indicated disturbance from roads at 82 percent of plots in the Central Mountains. There were 0.0003 diversions per acre and one dam in this unit. The WCF indicated changes to the timing, rate of change, and/or duration of mid-range discharges had occurred in 94 percent of watersheds. Ninety-eight percent of the Central Mountains unit was within range management units and 49 percent was within wild horse and burro territory. Local riparian plot data indicated grazing and wildlife had disturbed 89 percent of plots monitored within the unit. The WCF indicated 91 percent of watersheds contained rangelands in functional-at-risk condition. These areas have moderate probability of soil compaction, increased overland flow, and incised channels. Finally, channels and floodplains in the Central Mountains have been exposed to significant drought, with 100 percent of the unit classified by the TCA to be in poor or very poor condition due to drought.

R-CAT estimated condition for 7,629 miles of stream in the Central Mountains. Of these channels, 3,693 miles were confined and 3,936 were unconfined. Nearly all (93 percent) of confined channels were classified as unimpacted. Of the unconfined reaches, 6 percent were in good condition, 37 percent were intact, 56 percent were in moderate condition, and 2 percent were in poor condition. The WCF indicated that 80 percent of watersheds were functional-at-risk for habitat fragmentation, meaning that connectivity of streams and their floodplains had been reduced by warming temperatures, aquatic organism passage blockage, or dewatering. The loss of large woody debris (LWD) from stream systems in the Central Mountains has likely impacted channel and floodplain dynamics, with LWD present but recruited into the system at less than natural rates because of management activities in 64 percent of watersheds. In an additional 36 percent of watersheds, wood is lacking and contributing to poor riparian habitat conditions that include unstable streambanks or inadequate pool formation. The WCF channel and floodplain dynamics attribute indicated 78 percent of watersheds were impaired and the remaining 22 percent were functioning, but at risk. This result suggests width-to-depth ratios and vertical stability have been altered, with many channels disconnected from their floodplains due to downcutting. Finally, according to the TCA, fire frequency and severity within floodplains is comparable to NRV, with 100 percent of riparian areas in the Central Mountains classified to be in very good condition for the uncharacteristic wildfire indicator. Of the six indicators, one provided evidence of substantial alteration, three suggested moderate alteration, and

two indicated no alteration. Based on these results, we estimate channel and floodplain dynamics in the Central Mountains are **moderately altered** from NRV (table F.1).

According to SSI, there were 1,489 springs in the Central Mountains unit. Forty-three surveys conducted between 1991 and 2020 were available at 37 springs in the SSI database. Diversions and grazing were the most common disturbances, highly impacting 7 and 8 percent of springs, respectively. An additional 11 percent of springs were moderately disturbed by cattle. Flooding was indicated as a mild disturbance at 2 percent of springs. SEAP was completed at Mud Spring, Sidehill Spring, and Six Mile Spring in 2020. These reports provided the only available data related to spring runout channel condition in the Central Mountains. It appears geomorphology at Mud Spring is intact (condition score = 5.5) with relatively low risk (risk score = 2.4). In contrast, it is likely that spring runout channels at Sidehill and Six Mile springs has been moderately altered (condition scores 3.2 and 3.5, respectively). Additional inventory of condition is needed at GDEs in the Central Mountains. There was **insufficient information** to evaluate spring runout channel condition in this unit.

Table F.1—Values of channel and floodplain dynamics indicators by unit.

Channel and floodplain dynamics indicators	Unit						
	Central Mountains	East Sierra	Eastern Mountains	Northern Mountains	Ruby Mountains	Sierra Nevada	SMNRA
% of watersheds in functioning-at-risk condition for WCF Channel Shape & Function	22	13	22	40	45	21	89
% of watersheds in impaired condition for WCF Channel Shape & Function	78	88	78	60	52	60	12
% of watersheds in funcitoning-at-risk condition for WCF Large Woody Debris	64	0	59	47	91	50	0
% of watersheds in impaired condition for WCF Large Woody Debris	36	100	20	47	5	19	4
% of watersheds in funcitoning-at-risk condition for WCF Habitat Fragmentation	80	85	37	74	50	39	62
% of watersheds in impaired condition for WCF Habitat Fragmentation	10	15	12	11	0	48	0
% of confined streams in impacted condition	7	18	11	11	17	22	4
% of unconfined streams in moderate condition	56	46	53	54	34	33	55
% of unconfined streams in poor condition	2	3	4	1	2	3	1
% of floodplain in poor or very poor condition for uncharacteristic fire	0	3	0	21	0	15	0

East Sierra

The primary stressors to channel and floodplain dynamics in the East Sierra unit included roads, diversions and dams, and grazing. The TCA suggests that 93 percent of the East Sierra unit is in good or very good condition for road density; however, the WCF indicates 58 percent of watersheds were in fair condition for road and trail density. Additionally, it appears the proximity of roads to waterbodies may impact channel and floodplain dynamics in the East Sierra. There were 0.0026 road miles per floodplain acre and the WCF indicated more than 25 percent of road and trail length is located within 300 feet of waterbodies in 90 percent of watersheds in the East Sierra unit. Of the three riparian plots sampled in the East Sierra unit, the Watergap West plot described disturbance from roads. There were 0.0003 diversions per acre and six dams in this unit. The WCF indicated changes to the timing, rate of change, and/or duration of mid-range discharges had occurred in 88 percent of watersheds. Eighty-seven percent of the East Sierra unit was within range management units and 95 percent of RMUs were active. The WCF indicated 43 percent of watersheds had moderate probability of soil compaction, increased overland flow, and incised channels due to a reversible degradation of rangelands. An additional 58 percent of watersheds had lost these functional processes of rangelands and were in poor condition. Impacts from grazing were also noted at the Watergap West riparian plot. Drought has likely had limited impacts on channel and floodplain dynamics in the East Sierra unit, with the TCA indicating 45 percent is in good or very good condition and only 6 percent in poor or very poor condition for drought.

R-CAT estimated condition for 2,801 miles of stream in the East Sierra unit. Of these channels, 1,186 miles were confined and 1,615 were unconfined. Most (82 percent) confined channels were classified as unimpacted. Of the unconfined reaches, 16 percent were in good condition, 35 percent were intact, 46 percent were in moderate condition, and 3 percent were in poor condition. The WCF indicated that 85 percent of watersheds were functional-at-risk for habitat fragmentation, meaning that connectivity had been reduced due to warming temperature, aquatic organism passage blockage, or dewatering. One hundred percent of watersheds that should contain large wood were lacking LWD such that riparian habitats were degraded with unstable banks or inadequate pool formation. The WCF channel shape and function attribute indicated 88 percent of watersheds were impaired and the remaining 12 percent were functioning, but at risk. This result suggests width-to-depth ratios and vertical stability have been altered, with many channels disconnected from their floodplains due to downcutting. Finally, according to the TCA, fire frequency and severity within floodplains is comparable to NRV, with 97 percent of riparian areas in the East Sierra classified to be in very good condition for the uncharacteristic wildfire indicator. Of the six indicators, two provided evidence of substantial alteration, one suggested moderate alteration, and three indicated no alteration. Based on these results, we estimate channel and floodplain dynamics in the East Sierra are **moderately altered** from NRV (table F.1).

According to the SSI database there were 187 springs in the East Sierra unit. Twenty-three surveys conducted between 1991 and 2009 were available at 20 springs. Diversions and grazing were the most common disturbances, both highly impacting 6

percent of springs. An additional 4 percent of springs were moderately disturbed by diversions. Flooding was indicated as a moderate disturbance at one spring, Huntoon, in 2001. No reports included information on geomorphology and there was **insufficient information** to evaluate spring runout channel condition at GDEs in the East Sierra unit.

Eastern Mountains

The primary stressors to channel and floodplain dynamics in the Eastern Mountains included roads, dams and diversions, grazing, and drought. The TCA and WCF agree that the Eastern Mountains are in good condition for overall road density; however, the proximity of roads to waterbodies likely impacts channel and floodplain dynamics. There were 0.0033 road miles per floodplain acre. The WCF indicated that more than 25 percent of road and trail length was located within 300 feet of waterbodies in 79 percent of watersheds in the Eastern Mountains. Additionally, local riparian plot data indicated disturbance from roads at 55 percent of plots in the Eastern Mountains. There were 0.0002 diversions per acre and two dams in this unit. The WCF indicated changes to the timing, rate of change, and/or duration of mid-range discharges had occurred in 86 percent of watersheds. Ninety-eight percent of the Eastern Mountains unit was within range management units and 24 percent was within wild horse and burro territory. Local riparian plot data indicated 90 and 88 percent of plots monitored within this unit were disturbed by grazing and wildlife, respectively. The WCF indicated 44 percent of watersheds contained rangelands in impaired condition. Degradation in these areas has resulted in the loss of properly functioning ecological processes and it is likely these conditions have contributed to greater bank erosion. Rangelands in an additional 52 percent of watersheds were functional, but at risk. These areas have moderate probability of soil compaction, increased overland flow, and incised channels. Finally, channels and floodplains in the Eastern Mountains have been exposed to significant drought, with 100 percent of the unit classified by the TCA to be in poor or very poor condition due to drought.

R-CAT estimated condition for 3,786 miles of stream in the Eastern Mountains unit. Of these channels, 2,765 miles were confined and 1,021 were unconfined. Most (89 percent) of confined channels were classified as unimpacted. Of the unconfined reaches, 10 percent were in good condition, 33 percent were intact, 53 percent were in moderate condition, and 4 percent were in poor condition. The WCF indicated that 52 percent of watersheds were properly functioning for habitat fragmentation, meaning that connectivity in most watersheds was maintained. The loss of large woody debris (LWD) from stream systems in the Eastern Mountains appears to be an issue, with LWD present but recruited into the system at less than natural rates because of riparian management activities in 59 percent of watersheds. In an additional 20 percent of watersheds, wood is lacking and contributing to poor habitat conditions that include unstable streambanks or inadequate pool formation. The WCF channel shape and function attribute indicated 78 percent of watersheds were impaired and the remaining 22 percent were functioning, but at risk. This result suggests width-to-depth ratios and vertical stability have been altered, with many channels disconnected from their floodplains due to downcutting. Finally, according to the TCA, fire frequency and

severity within floodplains is comparable to NRV in most locations, with 98 percent of riparian areas in the Eastern Mountains classified to be in good or very good condition for the uncharacteristic wildfire indicator. Of the six indicators, one provided evidence of substantial alteration, two suggested moderate alteration, and three indicated no alteration. Based on these results, we estimate channel and floodplain dynamics in the Eastern Mountains are **moderately altered** from NRV (table F.1).

According to the SSI database, there were 807 springs in the Eastern Mountains unit. Sixty surveys conducted between 1991 and 2020 were available at 57 springs. Multiple protocols had been applied to assess the condition of these springs. Diversions and grazing by wild animals and livestock impacted most sites. Water at several sites was permanently diverted or regulated by impoundments or dams. SEAP had been applied at 8 sites, with all reports indicating that geomorphology, including spring runout channel condition, was at least moderately impacted at each spring. The least impacted springs included Indian, Sage Hen, and Easter, which scored 4.8, 4, and 4, respectively. Geomorphology at Little Tom Plain, and Red Rock was slightly more altered, with scores of 3.4 and 3, respectively. Finally, conditions were poor at Indian Garden, Shellback, and Trail springs, which all scored between 2 and 3. Springs with altered geomorphology tended to also experience high risk and low restoration potential compared to less altered GDEs. Additional inventory of condition is needed at GDE sites in the Eastern Mountains. There was **insufficient information** to evaluate water fluctuations at GDEs.

Northern Mountains

The primary stressors to channel and floodplain dynamics in the Northern Mountains unit included roads, diversions, and grazing. The TCA suggests that 100 percent of the Northern Mountains unit is in good or very good condition for road density; however, the WCF indicates 59 percent of watersheds were in functional-at-risk condition for road and trail density. It appears the proximity of roads to waterbodies may impact channel and floodplain dynamics in the Northern Mountains. There were 0.0030 road miles per floodplain acre. The WCF indicated more than 25 percent of road and trail length is located within 300 feet of waterbodies in 70 percent of watersheds. Additionally, local riparian plot data indicated disturbance from roads at 72 percent of plots in the Northern Mountains. There were 0.0011 diversions per acre. The WCF indicated changes to the timing, rate of change, and/or duration of mid-range discharges had occurred in 79 percent of watersheds, with dams and diversions within these watersheds operated to partially mimic natural flow regimes. In the remaining 21 percent of watersheds, dams and diversions are operated such that they fail to mimic natural hydrographs, and the magnitude, duration, and/or timing of high and low flows are significantly departed from the natural hydrograph. Ninety percent of the Northern Mountains unit was within range management units and 94 percent of RMUs were classified as active. The WCF indicated 70 percent of watersheds contain watersheds in functional-at-risk condition for rangeland vegetation. These areas have moderate probability of soil compaction, increased overland flow, and incised channels. An additional 28 percent of watersheds were classified by the WCF as having impaired rangeland vegetation conditions, with high probability of soil compaction, increased

overland flow, and incised channels. Impacts from grazing were noted at 88 percent of riparian plots surveyed in the Northern Mountains unit.

R-CAT estimated condition for 4,191 miles of stream in the Northern Mountains unit. Of these channels, 2,243 miles were confined and 1,948 were unconfined. Most (89 percent) of confined channels were classified as unimpacted. Of the unconfined reaches, 32 percent were in good condition, 13 percent were intact, 54 percent were in moderate condition, and 1 percent were in poor condition. The WCF indicated that 74 percent of watersheds were functional-at-risk for habitat fragmentation, meaning that connectivity had declined due to warming temperature, aquatic organism passage blockage, or dewatering. The loss of large woody debris (LWD) from stream systems in the Northern Mountains appears to be an issue, with LWD present but recruited into the system at less than natural rates because of riparian management activities in 47 percent of watersheds. In an additional 47 percent of watersheds, wood is lacking and contributing to poor riparian habitat conditions that include unstable streambanks or inadequate pool formation. Although more than 50 percent of watersheds are not classified as impaired or functioning-at-risk for large woody debris, we considered this evidence of moderate alteration. The WCF channel shape and function attribute indicated 60 percent of watersheds were impaired and the remaining 40 percent were functioning, but at risk. This result suggests width-to-depth ratios and vertical stability have been altered, with many channels disconnected from their floodplains due to downcutting. Finally, according to the TCA, fire frequency and severity within floodplains is comparable to NRV in most locations, with 75 percent of riparian areas in the Northern Mountains classified to be in very good condition for the uncharacteristic wildfire indicator. Of the six indicators, one provided evidence of substantial alteration, three suggested moderate alteration, and two indicated no alteration. Based on these results, we estimate channel and floodplain dynamics in the Northern Mountains are **moderately altered** from NRV (table F.1).

According to the SSI database, there were 1,304 springs in the Northern Mountains. 103 spring surveys conducted between 1991 and 2020 were available at 101 springs. Ten reports included information on disturbance. One site was highly disturbed by drought in 2013. Two sites were moderately disturbed by diversions. Horse and burro activity had impacted two sites. Eight springs were moderately disturbed, and one was highly disturbed by livestock. Recreate was a moderate disturbance at two sites and a substantial disturbance at one site. SEAP protocols were implemented at six springs (Mud Circle Cienaga, Mantid View, Alder, Libellula Warm, Wilderness Boundary, and Wildflower) in 2018 and at one spring (Veratrum Actual) in 2020. These reports provided the only available data related to geomorphology and spring runout channel condition at GDEs in the Northern Mountains. Geomorphology at all springs was at least mildly impacted. Mantid View Spring received a score of 5.2, meaning it was in nearly pristine condition for geomorphology. This site is a moderate risk of further degradation. Libellula Warm, Veratrum Actual, Wilderness Boundary, and Wildflower all scored between 4 and 5, indicating moderate impacts to geomorphology, including spring runout channel condition. These sites had low risk of further degradation. Alder Spring scored 3.6, with relatively low risk of further degradation. Geomorphology appears to be substantially altered at Mud Circle Cienega (score=1.7) and this site has

high risk for increased degradation. Additional inventory of condition is needed at GDE sites in the Northern Mountains. There was **insufficient information** to evaluate spring runout channel condition at GDEs.

Ruby Mountains

The primary stressors to channel and floodplain dynamics in the Ruby Mountains unit included roads, recreation, diversions, grazing, and loss of forest cover. The TCA and WCF agree that the Ruby Mountains are generally in good condition for overall road density. The TCA suggests 99 percent of the unit is in good or very good condition and the WCF indicates 67 percent of watersheds are in proper functioning condition for road density; however, the proximity of roads to waterbodies is an issue that is likely impacting channel and floodplain dynamics. There were 0.0021 road miles per floodplain acre. The WCF indicated 64 percent of watersheds in Ruby Mountains are in poor condition for the proximity to water attribute, suggesting more than 25 percent of road and trail length within a watershed is located within 300 feet of waterbodies. An additional 19 percent of watersheds were classified as impaired for proximity to water, meaning between 10 and 25 percent of road and trail length is within 300 feet of streams and waterbodies. Local riparian plot data indicated disturbance from roads and OHVs at 56 and 33 percent of plots in the Ruby Mountains, respectively. The Ruby Mountains had the highest floodplain trail density of all units on the Forest (0.003 miles per floodplain acre). Trails were noted as a disturbance at 44 percent of riparian plots evaluated within the unit and camping was noted as a disturbance at 33 percent. There were 0.0007 diversions per acre. The WCF indicated changes to the timing, rate of change, and/or duration of mid-range discharges had occurred in 86 percent of watersheds. Ninety-two percent of the Ruby Mountains unit was within range management units and 96 percent of RMUs were classified as active. The WCF indicated 64 percent of watersheds were classified as impaired for rangeland vegetation. These areas have high probability of soil compaction, increased overland flow, and incised channels. Impacts from grazing were noted at 67 percent of riparian plots surveyed in the Ruby Mountains unit. Finally, the WCF indicated 62 percent of watersheds were impaired due to loss of forest cover. These areas have lost more than 15 percent of forest cover, which can impact runoff, erosion, sediment supply, bank stability, and recruitment of large woody debris.

R-CAT estimated condition for 1,151 miles of stream in the Ruby Mountains unit. Of these channels, 847 miles were confined and 304 were unconfined. Most (83 percent) of confined channels were classified as unimpacted. Of the unconfined reaches, 36 percent were in good condition, 29 percent were intact, 34 percent were in moderate condition, and 2 percent were in poor condition. The WCF indicated that 50 percent of watersheds were functional-at-risk for habitat fragmentation, meaning connectivity had declined due to warming temperatures, aquatic organism passage blockage, or dewatering. The loss of large woody debris (LWD) from stream systems in the Ruby Mountains appears to be an issue, with LWD present but recruited into the system at less than natural rates because of riparian management activities in 91 percent of watersheds. The WCF channel shape and function attribute indicated 52 percent of watersheds were impaired and an additional 45 percent were functioning, but at risk. This result suggests width-to-

depth ratios and vertical stability have been altered, with many channels disconnected from their floodplains due to downcutting. Finally, according to the TCA, fire frequency and severity within floodplains is comparable to NRV, with 100 percent of riparian areas in the Ruby Mountains classified to be in very good condition for the uncharacteristic wildfire indicator. Of the six indicators, one provided evidence of substantial alteration, two suggested moderate alteration, and three indicated no alteration. Based on these results, we estimate channel and floodplain dynamics in the Ruby Mountains are **moderately altered** from NRV (table F.1).

According to the SSI database, there were 443 springs in the Ruby Mountains. Three spring surveys conducted between 1991 and 1997 were available for three sites. One site, an unnamed spring that is a tributary to Toyn Creek was moderately disturbed by diversions and cattle. Green Mountain Creek was mildly disturbed by cattle. Ruby 102 spring was highly disturbed by dredging. No reports included information on condition and there was therefore **insufficient information** to evaluate spring runout channels at GDEs in the Ruby Mountains.

Sierra Nevada

The primary stressors to channel and floodplain dynamics in the Sierra Nevada unit included roads, dams and diversions, grazing, and loss of forest cover. The TCA and WCF agree that most of the unit is in good condition for road density, with the TCA indicating 77 percent of the unit is in good or very good condition and the WCF classifying 58 percent of watersheds in proper functioning condition for road density; however, the proximity of roads to waterbodies was potentially impacting channel and floodplain dynamics. There were 0.0008 road miles per floodplain acre. The WCF indicated 52 percent of watersheds in Sierra Nevada are in poor condition for the proximity to water attribute, suggesting more than 25 percent of road and trail length within a watershed is located within 300 feet of waterbodies. An additional 37 percent of watersheds were classified as impaired for proximity to water, meaning between 10 and 25 percent of road and trail length is within 300 feet of streams and waterbodies. Local riparian plot data indicated disturbance from roads and OHVs at 28 and 19 percent of plots in the Ruby Mountains, respectively. There were 0.002 diversions per acre and 0.02 dams per stream mile, the highest diversion density and dam ratio of all units considered in this assessment. The WCF indicated changes to the timing, rate of change, and/or duration of mid-range discharges had occurred in 79 percent of watersheds. The remaining 21 percent of watersheds were classified as impaired for flow characteristics, meaning significant departures in high and low flows had occurred. Only 55 percent of the Sierra Nevada was located within a range management unit, however the WCF indicated 100 percent of watersheds were impaired for rangeland vegetation condition. These areas have moderate probability of soil compaction, increased overland flow, and incised channels. Impacts from grazing were noted at 77 percent of riparian plots surveyed in the Sierra Nevada unit. Finally, the WCF indicated 89 percent of watersheds were in good condition for forest cover; however, the percentage of tree mortality within the unit increased from 2.9 percent in 2009-2013 to 10.3 percent in 2004-2018.

R-CAT estimated condition for 2,283 miles of stream in the Sierra Nevada unit. Of these channels, 1,374 miles were confined and 909 were unconfined. Most (78 percent) of confined channels were classified as unimpacted. Of the unconfined reaches, 30 percent were in good condition, 33 percent were intact, 33 percent were in moderate condition, and 3 percent were in poor condition. The WCF indicated that 48 percent of watersheds were impaired for habitat fragmentation, meaning that connectivity had declined due to warming temperature, aquatic organism passage blockage, or dewatering. An additional 39 percent of watersheds were rated by the WCF to be functioning-at-risk for habitat fragmentation. Although more than 50 percent of watersheds were not classified as impaired, we considered this evidence of substantial alteration. The loss of large woody debris (LWD) from stream systems in the Sierra Nevada appears to be an issue, with LWD present but recruited into the system at less than natural rates because of riparian management activities in 50 percent of watersheds. In an additional 19 percent of watersheds, wood is lacking and contributing to poor riparian habitat conditions that include unstable streambanks or inadequate pool formation. The WCF channel shape and function attribute indicated 60 percent of watersheds were impaired and an additional 21 percent were functioning, but at risk. This result suggests width-to-depth ratios and vertical stability have been altered, with many channels disconnected from their floodplains due to downcutting. Finally, according to the TCA, fire frequency and severity within floodplains is comparable to NRV, with 85 percent of riparian areas in the Northern Mountains classified to be in good or very good condition for the uncharacteristic wildfire indicator. Of the six indicators, two provided evidence of substantial alteration, one suggested moderate alteration, and three indicated no alteration. Based on these results, we estimate channel and floodplain dynamics in the Sierra Nevada are **moderately altered** from NRV (table F.1).

According to the SSI database, there were 482 springs in the Sierra Nevada unit. Twelve surveys conducted between 1992 and 2019 were available at ten sites. Seven surveys included information on stressors, with diversions and recreation the most common disturbances. Four springs were impacted by recreation, with one classified has highly disturbed. Cattle and dredging had also impacted some springs in the Sierra Nevada unit. No reports included information on condition and there was therefore **insufficient information** to evaluate spring runout channel condition at GDEs in the Sierra Nevada.

Spring Mountain National Recreation Area

The primary stressors to channel and floodplain dynamics in the SMNRA unit included roads, recreation, dams and diversions, and drought. The TCA and WCF agree that the SMNRA unit in good condition for overall road density. According to the WCF, 77 percent of watersheds were in good condition for road density and the TCA classified 95 percent of the unit in good or very good condition for road density; however, the proximity of roads to streams and waterbodies appears to be a stressor that is likely impacting channel and floodplain dynamics in this unit. There were 0.006 road miles per floodplain acre. The WCF showed 92 percent of watersheds were in poor condition for the proximity to water attribute, suggesting more than 25 percent of road and trail length within a watershed is located within 300 feet of waterbodies. Additionally, all six

riparian plots evaluated in SMNRA described disturbance from roads and OHVs. Trail density throughout the unit and within the floodplain was relatively low compared to other units on the Forest: 0.0003 and 0.001 miles per acre, respectively. SMNRA had three recreation sites located within the floodplain. Additionally, camping was described as a disturbance at all six riparian plots evaluated in SMNRA. There were 0.0005 diversions per acre and one dam. The WCF indicated changes to the timing, rate of change, and/or duration of mid-range discharges had occurred in 100 percent of watersheds. The TCA classified 100 percent of the SMNRA unit in poor or very poor condition for drought. Grazing by wildlife may be a stressor to channel and floodplain dynamics in SMNRA. No range management units were present within the unit and the WCF did not evaluate rangeland vegetation conditions in any of the SMNRA watersheds; however, all six riparian plots surveyed within the unit noted disturbance from grazing and wildlife use.

R-CAT estimated condition for 1,585 miles of stream in the SMNRA unit. Of these channels, 1,105 miles were confined and 480 were unconfined. Nearly all (96 percent) of confined channels were classified as unimpacted. Of the unconfined reaches, 10 percent were in good condition, 34 percent were intact, 55 percent were in moderate condition, and 1 percent were in poor condition. The WCF indicated that 58 percent of watersheds were functional-at-risk for habitat fragmentation, meaning that connectivity had declined due to warming temperature, aquatic organism passage blockage, or dewatering. Many watersheds within the unit evolved without the presence of large woody debris. Of those watersheds for which large wood is an important ecosystem component, 96 percent were classified by WCF as properly functioning for large wood recruitment. The WCF channel shape and function attribute indicated 12 percent of watersheds were impaired and the remaining 88 percent were functioning, but at risk. This result suggests width-to-depth ratios and vertical stability have been altered, with many channels disconnected from their floodplains due to downcutting. Finally, according to the TCA, fire frequency and severity within floodplains is comparable to NRV, with 89 percent of riparian areas in the SMNRA classified to be in very good condition for the uncharacteristic wildfire indicator. Of the six indicators, none provided evidence of substantial alteration, three suggested moderate alteration, and three indicated no alteration. Based on these results, we estimate channel and floodplain dynamics in the SMNRA are **moderately altered** from NRV (table F.1)

According to the SSI database, there were 469 springs in the SMNRA. This unit has the highest spring density of all units assessed in this report. We found 265 surveys conducted between 1991 and 2020 at 136 spring sites in the SSI database. Seventy-six reports included information on disturbance. Avalanches, fire, flood, drought, diversions, horse and burro activity, cattle, recreation, and dredging were described as stressors at sites throughout the SMNRA. Twenty percent of sites with disturbance data were highly impacted by diversions, with an additional 12 percent mildly or moderately disturbed. Sixteen percent of sites were highly disturbed by horse and burro activity, with an additional 18 percent mildly or moderately impacted. Drought had highly impacted two sites (Unnamed 56 and North Rainbow) in 2016, and one site (NNW of Lost Cabin) in 1998. Flooding was described as a disturbance at eight springs. SEAP was implemented at ten springs between 2007 and 2020. Two sites, Willow Creek and

Macks Canyon, were sampled twice and provided some information on trends in spring runout channel condition. Both appeared relatively stable. Geomorphology at Willow Creek remained in moderate condition with moderate risk of further degradation. Macks Canyon was in good condition for geomorphology in both 2010 and 2020, with relatively low risk of increased degradation that was consistent over time. An additional site monitored in Macks Canyon in 2020 was in near pristine geomorphologic condition with moderate risk of degradation. Geomorphology, including condition of spring runout channels, at CC and Unnamed 10 springs were in moderate condition with moderate risk. Finally, geomorphology appeared to be impacted at Unnamed 50, Big Timber, and Jaybird. These sites also experienced moderate to high risk of further impacts to spring runout channels. Despite many available spring surveys, only 4 percent included information on condition of water fluctuations in SMNRA. Additional inventory is needed at GDE sites and there was **insufficient information** to evaluate spring runout channel condition in SMNRA.

APPENDIX G. Composition and Structure of Riparian and Groundwater-Dependent Ecosystems

Methods

We used several datasets and literature review to describe composition and structure of riparian and groundwater dependent ecosystems. We summarized field data from the Humboldt-Toiyabe National Forest (HTNF) vegetation plot monitoring program (Weixelman et al. 1997), the Rocky Mountain Research Station (RMRS) riparian meadow studies program (Chambers and Miller 2011), the Springs Stewardship Institute's (SSI) Springs Online database, and the UC Davis Sierra Nevada Meadows Assessment (SNMVA) program (Viers et al. 2013). We analyzed GIS data produced by the HTNF, the Desert Research Institute (DRI), RMRS, and the SNMVA. We also examined photographs of riparian areas and GDEs from these projects, as well as the PacFish/InFish Biological Opinion Monitoring Program (PIBO), and our own site visits. We summarized field data results for each of the seven geographic units. We produced GIS results separately for the dispersed areas that comprise the Central Mountains, Eastern Mountains, and Northern Mountains geographic units. The remaining geographic units were treated as individual areas.

We used GIS data from the HTNF to identify riparian dominance groups present in valley bottoms throughout the forest. We delineated valley bottoms using the Valley Bottom Extraction Tool in ArcGIS (Macfarlane et al. 2017). We clipped polygons of existing vegetation (FS VEG) to these valley bottoms to create a riparian vegetation layer. Classification methods varied among the geographic units in the shapefiles, so we reclassified polygons to a standardized vegetation scheme that approximates the dominance group classification of Manning and Padgett (1995). To describe vegetation associated with GDEs, we obtained the SSI Anomaly layer from the DRI. This layer identifies riparian and wetland vegetation associated with springs mapped by the SSI. Vegetation types were classified based on National Wetland Inventory methods. We also clipped the FS VEG layer to a shapefile of polygons representing potential fens (Smith and Lemly 2019). We used this layer to identify dominance groups present at potential fens, most of which have not been visited for vegetation sampling.

To best represent current conditions on the ground, we limited our analysis of vegetation plot data to samples collected between the years 2000 and 2019. We used riparian cover data to identify dominance groups, riparian communities, and abundant plant species in each geographic unit. We determined the percentage of plots that contained unsuitable cover of vegetation indicative of management problems, using criteria developed by the HTNF for wet meadow plots and riparian corridor plots (table G.1). We also calculated the percentage of plots judged by HTNF crews to be in low, moderate, or high vegetation condition, based on the ecological status of the plant communities observed.

Table G.1A—Desired riparian plant species and species indicative of management problems, identified to evaluate desired conditions at riparian forest plots.

Plot	Desired vegetation	Problem forbs and graminoids (Desired conditions ≤ 25 % relative cover)	Problem shrubs (Desired conditions ≤ 30 % relative cover)
Riparian corridor	**Forbs:** *Thalictrum* spp. (meadow-rue), *Aquilegia formosa* (western columbine), *Aconitum columbianum* (Columbian monkshood), *Maianthemum stellatum* (starry false lily of the valley), *Osmorhiza* spp. (sweetcicely)	**Forbs:** *Rumex* spp. (sorrel), *Cirsium* spp. (thistle), *Taraxacum officinale* (dandelion), *Achillea millefolium* (common yarrow), *Descurainia pinnata* (western tansymustard), *Artemisia ludoviciana* (white sagebrush), *Symphyotrichum* spp. (aster), *Urtica dioica* (stinging nettle), *Chorispora tenella* (crossflower), *Thlaspi arvense* (field pennycress), *Potentilla* spp. (cinquefoil), *Tragopogon dubius* (yellow salsify), *Hackelia floribunda* (manyflower stickseed), *Ceratocephala testiculata* (curveseed butterwort), *Alyssum* spp. (madwort), *Camelina microcarpa* (littlepod false flax), *Nemophila pedunculata* (littlefoot nemophila)	*Rosa woodsii* (Woods' rose), *Chrysothamnus viscidiflorus* (yellow rabbitbrush), *Ericameria nauseosa* (rubber rabbitbrush), *Artemisia tridentata* (big sagebrish)
	Graminiods: *Elymus glaucus* (blue wildrye), *Leymus cinereus* (basin wildrye), *Elymus trachycaulus (slender wheatgrass), Leymus triticoides* (beardless wildrye), *Elymus lanceolatus* (thickspike wheatgrass), *Bromus marginatus* (mountain brome), *Poa secunda* (Sandberg bluegrass), *Poa fendleriana* (muttongrass), *Poa cusickii* (Cusick's bluegrass), *Agrostis pallens* (seashore bentgrass), *Koeleria macrantha* (prairie Junegrass), *Calamagrostis canadensis* (bluejoint), *Melica spectabilis* (purple oniongrass), *Carex microptera* (smallwing sedge), *Carex vesicaria* (blister sedge), *Carex vallicola* (valley sedge), *Carex athrostachya* (slenderbeak sedge), *Scirpus microcarpus* (panicled bulrush), *Carex praegracilis* (clustered field sedge)	**Graminoids:** *Poa pratensis* (Kentucky bluegrass), *Arrhenatherum elatius* (tall oatgrass), *Bromus inermis* (smooth brome), *Bromus tectorum* (cheatgrass), *Poa bulbosa* (bulbous bluegrass), *Carex douglasii* (Douglas' sedge)	
	Shrubs: *Amelanchier alnifolia* (Saskatoon serviceberry), *Ribes* spp. (current), *Prunus virginiana* (chockecherry), *Alnus incana* (gray alder), *Betula occidentalis* (water birch), *Salix* spp. (willow), *Cornus sericea* (redosier dogwood), *Rhus trilobata* (fragrant sumac), *Symphoricarpos* spp. (snowberry), *Rosa woodsii ultramontana* (Woods' rose), *Shepherdia* spp. (buffaloberry), *Mahonia repens* (creepy barberry)		

Table G.1B—Desired riparian plant species and species indicative of management problems, identified to evaluate desired conditions at wet meadow plots.

Plot	Desired vegetation	Problem graminoids (Desired conditions ≤ 20 % relative cover)	Problem forbs and shrubs (Desired conditions ≤ 5 % relative cover)
Wet meadow	**Forbs:** *Mimulus primuloides* (primrose monkeyflower), *Dodecatheon alpinum* (alpine shootingstar), *Erigeron peregrinus* (subalpine fleabane), *Caltha leptosepala* (white marsh marigold), *Platanthera dilatata* (scentbottle), *Gentiana* spp. (gentian), *Parnassia* spp. (grass of Parnassus), *Allium validum* (Pacific onion), *Ranunculus cymbalaria* (alkali buttercup), *Stellaria longipes* (longstalk starwort), *Pedicularis groenlandica* (elephanthead lousewort), *Viola* spp. (violet), *Sidalcea* spp. (checkerbloom), *Polygonum bistortoides* (American bistort), *Botrychium* spp. (moonwort), *Equisetum* spp. (horsetail) **Graminoids:** *Deschampsia caespitosa* (tufted hairgrass), *Calamagrostis canadensis* (bluejoint), *Agrostis humilis* (alpine bentgrass), *Hierochloe hirta* ssp. *arctica* (northern sweetgrass), *Carex nebrascensis* (Nebraska sedge), *Carex microptera* (smallwing sedge), *Carex aquatalis* (water sedge), *Carex utriculata* (Northwest Territory sedge), *Carex scopulorum* (mountain sedge), *Carex simulata* (analog sedge), *Carex pellita* (woolly sedge), *Carex illota* (sheep sedge), *Carex jonesii* (Jones' sedge), *Carex luzulina* (woodrush sedge), *Carex magellanica* (boreal bog sedge), *Carex lenticularis* (lakeshore sedge), *Carex nervina* (Sierra sedge), *Carex praeceptorum* (early sedge), *Carex vesicaria* (blister sedge), *Carex aurea* (golden sedge), *Juncus drummondii* (Drummond's rush), *Juncus mertensianus* (Mertens' rush), *Juncus nevadensis* (Sierra rush), *Juncus saximontanus* (Rocky Mountain rush), *Juncus longistylis* (longstyle rush), *Juncus ensifolius* (swordleaf rush), *Scirpus microcarpus* (panicled bulrush), *Poa secunda* (Sandberg bluegrass), *Deschampsia* spp., (hairgrass) *Calamagrostis scopulorum* (ditch reedgrass), *Glyceria striata* (fowl mannagrass), *Glyceria grandis* (American mannagrass), *Phleum alpinum* (alpine timothy), *Carex praegracilis* (clustered field sedge), *Carex athrostachya* (slenderbeak sedge) **Shrubs:** *Salix* spp. (willows), *Ledum glandulosum* (Labrador tea); *Kalmia microphylla* (alpine laurel)	**Forbs:** *Rumex* spp. (sorrel), *Cirsium* spp. (thistle), *Cicuta douglasii* (western water hemlock), *Thermopsis rhombifolia* (prairie thermopsis), *Taraxacum officinale* (dandelion), *Achillea millefolium* (common yarrow), *Symphyotrichum* spp. (aster), *Veratrum californicum* (California false hellebore), *Iris missouriensis* (Rocky Mountain iris), *Potentilla* spp. (cinquefoil), *Epilobium* spp. (willowherb), *Penstemon* spp. (penstemon), *Urtica dioica* (stinging nettle), *Equisetum* spp. (horsetail), *Nemophila brevifolia* (basin nemophila), *Poa pratensis* (Kentucky bluegrass), *Poa palustris* (fowl bluegrass), *Alopecurus* spp. (foxtail), *Hordeum* spp. (barley), *Agrostis stolonifera* spp. (bentgrass), *Arrhenatherum elatius* (tall oatgrass), *Bromus inermis* (smooth brome), *Bromus tectorum* (cheatgrass), *Poa bulbosa* (bulbous bluegrass), *Muhlenbergia filiformis* (pullup muhly), *Carex douglasii* (Douglas' sedge), *Eleocharis* spp. (spikerush), *Juncus arcticus* (arctic rush)	**Shrubs:** *Rosa woodsii* (Woods' rose), *Artemisia tridentata* (big sagebrush)

We summarized data collected in meadow plots of the Central Mountains and Sierra Nevada geographic units to describe composition and structure of these riparian ecosystems. We used photographs and site descriptions to infer dominance groups, communities, and common plant species.

To determine if the observed plant species, communities, and dominance groups are expected under the NRV, we compiled a list of dominant plant species from descriptions of the terrestrial ecological systems (NatureServe 2018) identified in the LANDFIRE Biophysical Setting raster (table G.2). We also included dominant species expected under PNC conditions in the riparian ecological types compiled by Weixelman et al. (1996, 1999).

Table G.2—Dominant species expected in riparian corridors and meadows, based on LANDFIRE biophysical models and Weixelman et al. (1996, 1999) PNC type descriptions.

Growth form	Species
Coniferous trees	*Abies concolor* (white fir), *Abies lasiocarpa* (subalpine fir), *Juniperus osteosperma* (Utah juniper), *Juniperus scopulorum* (Rocky Mountain juniper), *Picea engelmannii* (Engelmann spruce), *Pseudotsuga menziesii* (Douglas-fir), *Pinus contorta* ssp. *Murrayana* (Sierra lodgepole pine)
Tall deciduous trees	*Acer negundo* (boxelder), *Populus angustifolia* (narrowleaf cottonwood), *Populus balsamifera* ssp. *trichocarpa* (black cottonwood), *Populus fremontii* (Fremont cottonwood), *Populus tremuloides* (quaking aspen)
Low deciduous trees	*Alnus incana* (gray alder), *Betula occidentalis* (water birch)
Nonwillow shrubs	*Artemisia cana* (silver sagebrush), *Artemisia tridentata* ssp. *tridentata* (basin big sagebrush), *Cornus sericea* (redosier dogwood), *Dasiphora fruticosa* (shrubby cinquefoil), *Prunus virginiana* (chokecherry), *Rhus trilobata* (fragrant sumac), *Ribes* spp.(current), *Shepherdia argentea* (silver buffaloberry), *Symphoricarpos* spp. (snowberry)
Tall willows	*Salix boothii* (Booth's willow), *Salix drummondiana* (Drummond's willow), *Salix exigua* (narrowleaf willow), *Salix geyeriana* (Geyer willow), *Salix irrorata* (dewystem willow), *Salix lasiolepis* (arroyo willow), *Salix lemmonii* (Lemon's willow), *Salix lucida* (shining willow), *Salix lutea* (yellow willow), *Salix monticola* (park willow)
Low willows	*Salix eastwoodiae* (mountain willow), *Salix oresetra* (sierra willlow), *Salix planifolia* (diamondleaf willow)
Graminoids	*Bromus* spp. (brome grass), *Calamagrostis* spp. (bluejoint grass), *Carex* spp. (sedges), *Deschampsia cespitosa* (tufted hairgrass), *Elymus glaucus* (blue wildrye), *Elymus trachycaulus* (slender wheatgrass), *Glyceria striata* (fowl mannagrass), *Juncus arcticus* (arctic rush), *Poa cusickii* (Cusick's bluegrass), *Poa secunda* (Sandberg bluegrass), *Muhlenbergia richardsonis* (mat muhly)
Forbs	*Aconitum columbianum* (Columbian monkshood), *Aquilegia formosa* (western columbine), *Iris missouriensis* (Rocky Mountain iris), *Maianthemum stellatum* (starry false lily of the valley), *Mertensia* spp. (bluebells), *Osmorhiza berteroi* (sweet cicely), *Sphenosciadium capitellatum* (woollyhead parsnip), *Thalictrum fendleri* (Fendler's meadow-rue), *Thalictrum occidentale* (western meadow-rue)

We found survey reports for 447 springs in the HTNF. For each of these springs, we determined survey dates and the protocols used. Available data varied among projects

and protocols. Using site descriptions, photographs, and data from these reports, we describe dominance groups associated with springs ecosystems, common plant species, nonnative plants, and aquatic invertebrates.

We used observations of disturbances to calculate the percentages of riparian cover plots, meadows, and springs that showed signs of various stressors. We also reviewed literature and examined photographs to describe ongoing and past stressors to riparian areas and GDEs in each geographic unit.

Unit Summaries

Central Mountains

Settings

This geographic unit consists of four separate areas covering six mountain ranges. Perennial and intermittent streams are present in the Monitor-Hot Creek, Toiyabe-Shoshone, and Toquima areas. Some intermittent stream reaches are present in the Paradise area. Vegetation was measured in 56 riparian meadows in 2005 and 2006. These meadows are distributed among the Monitor-Hot Creek, Toiyabe-Shoshone, and Toquima areas. Riparian vegetation cover was measured at 43 plots between 2000 and 2019 in these areas as well.

We found survey reports for 59 springs in the Central Mountains unit. Surveys were conducted at 23 springs in 2020 using Stevens et al. level 1 and 2 protocols. In 1991, 1992, and 2005, 35 surveys were conducted using Sada and Pohlman protocols. One spring was visited in 2016 by the Nevada Heritage program.

Riparian Dominance Groups and Communities

The FS VEG layer indicates upland woody vegetation composes 84 to 99 percent of valley bottom cover in the areas of this geographic unit (table G.3). Among these areas, 0.01 to 20 percent of valley bottom cover is herbaceous-dominated, 0.2 percent to 8 percent is riparian shrub-dominated, 0 to 3 percent is tall deciduous tree-dominated, 0 to 0.4 percent is conifer-dominated, and 0 to 0.1 percent is low deciduous tree dominated.

Most riparian corridor cover plots in the Central Mountains (86 percent) were herbaceous dominated. Other plots were dominated by tall deciduous trees (9 percent), tall willows (2 percent), and nonwillow shrubs (2 percent). Herbaceous-dominated communities had high cover of dry graminoids including *Carex douglasii*, *Distichlis spicata*, *Danthonia* spp., and *Muhlenbergia richardsonis*; mesic graminoids including *Juncus arcticus* and *Poa pratensis*; and wet graminoids including *Carex aquatilis*, and *Carex nebrascensis*. Nonwillow shrubs included *Artemisia tridentata* and *Ericameria nauseosa*, tall deciduous trees included *Populus tremuloides* and tall willows included *Salix lutea*.

Table G.3—Percent cover of riparian dominance groups mapped by FS VEG in valley bottoms of geographic units and sub areas.

Geographic unit	Area	Conifer	Herbaceous	Low deciduous	Riparian shrub	Tall deciduous	Upland woody
Central Mountains	Monitor-Hot Creek	0.01	0.1	0	4	1	94
	Paradise	0	0.01	0	0.2	0	99
	Toiyabe-Shoshone	0.4	2	0.1	8	3	86
	Toquima	0.2	0.02	0.1	3	1	96
East Sierra	NA	0.4	3	0	2	1	89
Eastern Mountains	Quinn-Grant	0.2	1	0	3	1	95
	Schell Creek	8	1	0	8	6	77
	Snake	14	3	0	7	6	70
	Ward	4	1	0	2	3	90
	White Pine	0.2	1	0	1	1	97
Northern Mountains	Jarbidge	3	7	0.4	16	10	63
	Santa Rosa	0	5	0	0.1	11	83
Ruby Mountains	NA	3	5	0	5	34	51
Sierra Nevada	NA	25	13	1	4	3	27

NA: not applicable.

In riparian meadows, 49 percent of vegetation dominance groups were herbaceous, 33 percent were nonwillow shrub, 15 percent were tall willow, and 3 percent were tall deciduous. Water table depth and proximity to springs are important drivers of composition in these meadows (Trowbridge et al. 2011). Herbaceous communities include dry meadow types dominated by *Poa pratensis*, *Juncus arcticus*, *Poa secunda*, *Carex douglasii*, and *Pascopyrum smithii*. Mesic meadow types were dominated by *Juncus arcticus*, *Poa pratensis*, *Taraxacum officinale*, *Carex nebrascensis*, and *Symphyotrichum spathulatum*/Wet meadow types were dominated by *Carex nebrascensis*, *Juncus arcticus*, *Poa pratensis*, *Deschampsia cespitosa*, and *Epilobium* spp. Nonwillow shrub communities include dry shrub meadow types dominated by *Artemisia tridentata*, *Juncus arcticus*, *Ericameria nauseosus*, *Chrysothamnus viscidiflorus*, and *Poa secunda*. Mesic shrub meadow types were dominated by *Artemisia tridentata*, *Juncus arcticus*, *Ericameria nauseosus*, *Poa* spp., and *Erigeron divergens*. Wild rose types were dominated by *Rosa woodsii*, *Artemisia tridentata*, *Poa pratensis*, *Thinopyrum intermedium*, and *Ericameria nauseosus*. Tall deciduous tree communities were dominated by *Populus angustifolia*, *Populus tremuloides*, *Poa pratensis*, and *Taraxacum officinale*. Low deciduous trees include *Betula occidentalis*. Tall willows include *Salix exigua*, and *Salix geyeriana*.

Riparian Vegetation Ratings

All of the four riparian corridor plots measured in the geographic unit contained suitable cover of problem vegetation. Of the 39 wet meadow plots, 74 percent had unsuitable levels of problem vegetation. Condition of riparian vegetation was moderate to high in 67 percent of riparian corridor plots and was moderate to high in 58 percent of wet meadow plots.

Extent of Riparian Departure

According to R-CAT results, vegetation along most (58 percent) stream miles has moderately or significantly departed from the expected composition and structure. Conifer encroachment is the most frequent cause of conversion (47.3 percent of stream miles) from riparian vegetation, followed by upland grassland/shrubland encroachment (10.3 percent).

GDE Flora and Fauna

There are 142.5 acres of GDE vegetation associated with mapped springs in Monitor-Hot Creek area, 7.5 in the Paradise area, 250.1 in the Toiyabe-Shoshone area, and 95.6 in the Toquima area. Among these areas, percent coverage of riparian vegetation at GDEs varies from 52.1 to 83.9 percent, coverage of herbaceous wetland varies from 11.6 to 25.4 percent, and coverage of shrub wetland varies from 0 to 27.3 percent (table G.4). At potential fens, the FS VEG layer indicates that cover of herbaceous-dominated communities varies from 0 to 19.1 percent, cover of riparian shrub-dominated communities varies from 46.9 to 71.5 percent, cover of tall deciduous tree-dominated communities varies from 0 to 13.3 percent, and cover of conifer-dominated communities varies from 0 to 1.2 percent (table G.4).

Among springs where riparian and wetland vegetation were reported in SSI survey reports, 76 percent had herbaceous-dominated communities, 29 percent had nonnative species, 24 percent had tall willow-dominated communities, 20 percent had nonwillow shrub-dominated communities, 4 percent had conifer-dominated communities, and 4 percent had tall deciduous-dominated communities. Herbaceous communities were often dominated by graminoids including *Juncus arcticus*, *Distichlis spicata*, and several sedge species. *Agrostis stolonifera* and *Bromus tectorum* has invaded areas near several springs. Aquatic invertebrates were observed at 22 percent of springs where fauna was reported. Springsnails (*Pyrgulopsis* spp.) were abundant at several springs, despite impacts from cattle and other ungulates. Of the 15 springs given condition scores, 10 (67 percent) were pristine or good and 5 (33 percent) were moderate.

Table G.4—Classification and cover of plant communities at GDEs in geographic units and sub areas.

Geographic unit	Area	SSI anomaly			FS VEG at fens				
		Herbaceous	Riparian	Shrub	Herbaceous	Riparian Shrub	Tall Deciduous	Conifer	Upland
Central Mountains	Monitor-Hot Creek	25.4	52.1	22.4	0.0	65.9	8.5	0.0	25.6
	Paradise	16.6	83.9	0.0	0.0	71.5	0.0	0.0	28.5
	Toiyabe-Shoshone	11.6	61.2	27.3	19.1	57.1	0.0	0.0	23.9
	Toquima	25.4	58.6	15.0	0.0	46.9	13.3	1.2	38.6
East Sierra*	NA	3.2	86.6	10	62.9	4.2	4.8	2.6	25.6
Eastern Mountains	Quinn-Grant	19.4	62.1	18.3	49.7	22.9	2.0	0.0	25.3
	Schell Creek	21.7	41.1	36.5	5.4	42.2	18.1	0.2	34.1
	Snake	28.1	40.6	31.4	9.0	13.1	4.7	3.2	70.0
	Ward	9.4	90.4	0.0	0.0	4.5	14.4	1.6	79.4
	White Pine	9.2	84.3	6.3	80.6	3.2	0.0	0.0	16.2
Northern Mountains	Jarbidge	9.0	70.4	18.3	26.5	14.4	12.8	7.4	38.9
	Santa Rosa	15.3	69.2	12.8	28.9	0.0	5.8	0.0	65.3
Ruby Mountains	NA	16.7	70.1	12.3	22.4	19.1	22.5	18.7	17.3
Sierra Nevada*	NA	8.0	85.0	5.6	50.0	17.4	5.3	10.1	17.2
SMNRA	NA	0.0	99.9	0.0	NA	NA	NA	NA	NA

* Data apply only to the portion in Nevada.

Disturbance to Riparian Ecosystems and GDEs

Disturbances were examined at 40 riparian cover plots. Impacts included livestock grazing (observed at 90 percent of plots), wildlife (85 percent), roads (70 percent), trails (43 percent), camping (25 percent), flood (20 percent), OHV use (18 percent), and noxious weeds (8 percent). Impacts at springs included cattle (58 percent of springs), diversions (25 percent), damming/excavation (9 percent), feral ungulates (4 percent), native ungulates (2 percent), and recreation (2 percent). Dominance of *Agrostis stolonifera*, *Artemisia tridentata*, *Bromus tectorum*, *Carex nebrascensis*, *Iris missouriensis*, *Juncus arcticus*, *Poa pratensis*, *Rosa woodsii*, and *Taraxacum officinale* indicates effects of livestock use and stream incision at riparian areas and GDE sites.

Central Mountains Summary

Throughout this geographic unit, a variety of riparian plant communities are found in meadows, along small streams, and at GDEs. Meadow vegetation is affected by stream incision and water table declines, which are driven by watershed characteristics, climatic cycles, and anthropogenic influences such as roads (Miller et al. 2011). Significant encroachment of conifer and upland vegetation has occurred along most stream miles. Vegetation and soil conditions reflect the long-term impacts of livestock grazing on meadows and springs. Restoration and active management have, however, retained the ecological function at several of these sites (Chambers and Miller 2011). Based on these results, we determined that composition and structure is **moderately altered** from the NRV for riparian corridors, meadows, and springs. Given that results were moderately consistent between spatial data indicators and field data indicators for riparian ecosystems, we have higher confidence in our determination for riparian ecosystems that for springs, for which there were fewer spatial data available. There is insufficient information to determine NRV status of fens in this geographic unit.

East Sierra

Settings

Perennial streams are present in the northern and western portion of this unit. Intermittent streams are distributed throughout. Riparian cover was measured at four plots between 2000 and 2019. We found survey reports for 22 springs in the unit, but 148 have been mapped by the SSI. At 13 springs, the most recent survey was conducted in 1991 using the Sada and Pohlman protocol. This protocol was also used at springs most recently surveyed in 2001, 2008, and 2009. At six springs, the most recent visits were conducted for Nevada Heritage springsnail surveys in 1993, 2008, or 2009.

Riparian Dominance Groups and Communities

The FS VEG layer indicated that 89 percent of valley bottom cover is composed of upland woody vegetation, 3 percent is herbaceous-dominated, 2 percent is riparian shrub-dominated, 1 percent is tall deciduous tree-dominated, and 0.4 percent is conifer-dominated.

Three riparian cover plots were dominated by herbaceous vegetation, and one was nonwillow shrub-dominated. *Juncus arcticus* was abundant in herbaceous-dominated

plots. The nonwillow shrub-dominated plot had high coverage of *Artemisia cana*, *Poa secunda*, *Carex douglasii*, and *Hesperochiron californicus*.

Riparian Vegetation Ratings

All four wet meadow plots had unsuitable cover of problem vegetation. Condition of riparian vegetation was low in two of the plots, moderate in one plot and high in one plot.

Extent of Riparian Departure

According to R-CAT results, vegetation along most (61 percent) stream miles has moderately or significantly departed from the expected composition and structure, the highest percentage of any unit. Conifer encroachment is the most frequent cause of conversion (47.5 percent), followed by upland grassland/shrubland encroachment (10.4 percent).

GDE Flora and Fauna

There are 37.5 acres of GDE vegetation associated with mapped springs in the portion of this unit that is in Nevada. Riparian vegetation makes up 86 percent of these GDE acres, 10 percent is shrub wetland, and 3 percent is herbaceous wetland. The FS VEG layer indicated that potential fens are primarily composed of herbaceous-dominated communities (63 percent) and tall deciduous tree-dominated communities (5 percent).

Among springs where riparian and wetland vegetation was visible in photographs, 100 percent appeared to have herbaceous-dominated communities, 83 percent appeared to have nonwillow shrub-dominated communities, 50 percent appeared to have tall willow-dominated communities, and 17 percent appeared to have deciduous-dominated communities. Springsnails were abundant at several springs, despite impacts from cattle and modifications for stock water.

Disturbance to Riparian Ecosystems and GDEs

Disturbances were examined at 3 riparian cover plots. Wildlife impacts were observed at all plots. Impacts from livestock grazing, flooding, OHV use, and roads were each observed at one plot. Impacts to springs included cattle (60 percent of springs), diversion (50 percent), damming/excavation (31 percent), recreation (13 percent), and feral ungulates (6 percent). Several springs were diverted for mining operations. The presence of *Carex douglasii*, and *Juncus arcticus* indicate effects of livestock use in riparian sites. Additional stressors, including roads, recreation, and invasive plants, have been reported in the East Walker River Basin, which includes much of this geographic unit (Kattelmann 2012).

East Sierra Summary

Recently collected data are too sparse for us to evaluate the composition and structure of riparian corridors, meadows, or GDEs in this geographic unit. Several springs have been impacted by livestock grazing and diversions. Riparian meadows have been affected by livestock use as well. Additional work is needed to document the effects of these stressors on other riparian communities.

Eastern Mountains

Settings

This geographic unit consists of five areas that cover six mountain ranges. Perennial and intermittent streams are present in the Quinn-Grant, Schell Creek, Snake, and White Pine areas. Intermittent streams are present in the Ward area. Riparian cover was measured at 64 plots between 2000 and 2019. We found survey reports for 79 springs in the geographic unit. Surveys were conducted at 21 springs in 2020 using Stevens et al. level 1 and 2 protocols. In 2019, surveys were conducted at six springs using Stevens et al. level 1 protocol. In 2012, 47 springs were surveyed using USFS GDE Level 1 protocols. Five additional springs were surveyed between 1991 and 1996 using Nevada Heritage Program and Sada and Pohlmann protocols.

Riparian Dominance Groups and Communities

The FS VEG layer indicates that upland woody vegetation composes 70 to 97 percent of valley bottom cover in the areas of this geographic unit. Among these areas, 1 percent to 8 percent of valley bottom cover is riparian shrub-dominated, 1 to 6 percent is tall deciduous tree-dominated, 1 to 3 percent is herbaceous-dominated, and 0.2 to 14 percent is conifer-dominated (table G.3).

Most riparian cover plots (82 percent) were herbaceous dominated. Other plots were dominated by tall deciduous trees (9 percent), willows (3 percent), low deciduous trees (3 percent), and nonwillow shrubs (2 percent). Herbaceous-dominated communities had high cover of dry graminoids including *Leymus cinereus*, *Muhlenbergia*, and *Thinopyrum intermedium*; mesic graminoids including *Juncus arcticus* and *Poa pratensis*; and wet graminoids including *Carex nebrascensis* and *Carex aquatilis*. Low deciduous trees included *Betula occidentalis*, nonwillow shrubs included *Artemisia cana* and *Artemisia nova*, tall deciduous trees included *Populus tremuloides*, and willows included *Salix exigua*. Cottonwoods (*Populus* spp.) Are present along some streams as well.

Riparian Vegetation Ratings

All of the seven riparian corridor plots measured in the geographic unit contained suitable cover of problem vegetation. Of the 57 wet meadow plots, 75 percent had unsuitable cover of problem vegetation. Condition of vegetation was moderate or high in 57 percent of riparian corridor plots. Among wet meadow plots, condition was moderate or high in 48 percent.

Extent of Riparian Departure

According to R-CAT results, vegetation along 48 percent of stream miles has moderately or significantly departed from the expected composition and structure. Conifer encroachment is the most frequent cause of conversion (40 percent), followed by upland/grassland encroachment (8.2 percent). Encroachment of conifers and upland vegetation into meadows was reported in the Ward area by Abele et al. (2010).

GDE Flora and Fauna

There are 26.0 acres of GDE vegetation associated with mapped springs in the Quinn-Grant area, 154.5 acres in the Schell Creek area, 22.0 acres in the Snake area, 3.2 acres

in the Ward area, and 3.2 acres in the White Pine area. Among these GDEs, percent coverage of riparian vegetation varies from 40.6 to 90.4 percent, coverage of herbaceous wetland varies from 9.2 to 28.1 percent, and coverage of shrub wetland varies from 0 to 36.5 percent (table G.4). At potential fens, the FS VEG layer indicates that cover of herbaceous-dominated communities varies from 0 to 80.6 percent, cover of riparian shrub-dominated communities varies from 3.2 to 42.2 percent, cover of tall deciduous tree-dominated communities varies from 0 to 18.1 percent, and cover of conifer-dominated communities varies from 0 to 3.2 percent.

Among springs where riparian and wetland vegetation was reported, 80 percent had nonnative species, 88 percent had herbaceous-dominated communities, 46 percent had nonwillow shrub-dominated communities, 12 percent had tall willow-dominated communities, 8 percent had tall deciduous-dominated communities, and 4 percent had conifer-dominated communities. Herbaceous communities were often dominated by graminoids including *Juncus arcticus*, *Carex nebrascensis*, and *Eleocharis quinqueflora*. *Agrostis stolonifera* and *Bromus tectorum* have invaded areas near several springs. Stands of *Populus tremuloides* are present at several springs as well. Aquatic invertebrates were observed at 57 percent of springs where fauna was reported. Springsnails were abundant at several springs.

Disturbance to Riparian Ecosystems and GDEs

Disturbances were examined at 47 riparian plots. Impacts included livestock grazing (observed at 89 percent of plots), wildlife (87 percent), roads (53 percent), trails (43 percent), flood (30 percent), noxious weeds (26 percent), camping (13 percent), fire (13 percent), mining (6 percent), and OHV use (6 percent). Impacts at springs included native ungulates (54 percent of springs), cattle (46 percent), horses/feral ungulates (5 percent), diversion (34 percent), damming/excavation (18 percent), and recreation (17 percent). Among springs given condition scores (25), 12 (48 percent) were pristine or good, 6 (24 percent) were moderate, and 7 (28 percent) were poor. Some springs have nonfunctional diversions. Other springs are diverted, but wetland vegetation and aquatic communities remain protected. The presence of *Agrostis stolonifera*, *Bromus tectorum*, *Carex nebrascensis, Juncus arcticus*, and *Poa pratensis* indicate effects of livestock use at riparian and GDE sites. In the Ward Mountain area, dominance of *Artemisia tridentata* and *Rosa wooddsii* indicate departure from natural conditions as a result of stream incision, diversions, and other stressors (Abele et al. 2010).

Eastern Mountains Summary

A variety of riparian dominance groups and communities occur in this unit, but most are confined to narrow stream corridors and small GDEs. Livestock grazing has impacted composition and structure of riparian areas and GDEs throughout this unit. Many springs have been altered to provide water for stock. Based on these results, we determined that composition and structure is **moderately altered** from the NRV for riparian corridors, meadows, and springs. Given agreement between spatial data indicators and field data indicators for riparian ecosystems, we have higher confidence in our determination for riparian ecosystems that for springs, for which there were

fewer spatial data available. There is insufficient information to determine NRV status of fens in this geographic unit.

Northern Mountains

Settings

This geographic unit consists of two separate areas covering several mountain ranges. Perennial and intermittent streams are distributed throughout both the Jarbidge and Santa Rosa areas. Riparian cover was measured at 140 plots between 2000 and 2019. We found survey reports for 110 springs in the geographic unit, most of which were in the Jarbidge area. Surveys were conducted at 106 of these springs between 2010 and 2020 using Stevens et al. Level 1or Level 2 protocols and Sada and Pohlmann protocols. In 1991, 1992, and 1995, and 2009 surveys were conducted using Sada and Pohlman protocols.

Riparian Dominance Groups and Communities

In the Jarbidge area, the FS VEG layer indicates that 63 percent of valley bottom cover is upland woody vegetation, 16 percent is riparian shrub-dominated, 10 percent is tall deciduous tree-dominated, 7 percent is herbaceous-dominated, 3 percent is conifer-dominated, and 0.4 percent is low deciduous tree-dominated. The FS layer indicates that 83 percent of valley bottom cover in the Santa Rosa area is upland woody vegetation, 11 percent is tall deciduous tree-dominated, 5 percent is herbaceous-dominated, and 0.1 percent is riparian shrub-dominated.

Most riparian cover plots (67 percent) were herbaceous-dominated. Other plots were dominated by tall deciduous trees (20 percent), willows (5 percent), nonwillow shrubs (4 percent), and tall willows (2 percent). Herbaceous-dominated communities had high cover of dry graminoids including *Carex douglasii*, *Danthonia* spp., *Leymus cinereus*, and P*oa cusickii*; mesic graminoids including *Juncus arcticus*, and *Poa pratensis*; and wet graminoids including *Carex aquatilis*, *Carex nebrascensis*, and *Deschampsia cespitosa*. Nonwillow shrubs included *Artemisia cana*, tall deciduous trees included *Populus balsamifera* and *Populus tremuloides*, and willows included S*alix geyeriana*, *Salix boothii*, and *Salix lutea*.

Riparian Vegetation Ratings

Of the 30 riparian corridor plots measured in this unit, 20 percent had unsuitable cover of problem vegetation. Of the 110 wet meadow plots, 93 percent had unsuitable cover of problem vegetation. Condition of riparian vegetation was moderate or high in 40 percent of riparian corridor plots. Among wet meadow plots condition was moderate or high in 59 percent.

Extent of Riparian Departure

According to R-CAT results, vegetation along most (76 percent) stream miles has moderately or significantly departed from the expected composition and structure. Upland grassland/shrubland encroachment is the most frequent cause of conversion (65.9 percent), followed by conifer encroachment (9.3 percent).

GDE Flora and Fauna

There are 158.2 acres of GDE vegetation associated with mapped springs in the Jarbidge area. Riparian vegetation makes up 70 percent of these GDEs. 18 percent is shrub wetland, 9 percent is herbaceous wetland, and 2 percent is forested wetland. The FS VEG layer indicates that potential fens in this area are primarily composed of upland vegetation (39 percent of fen area), herbaceous-dominated communities (27 percent), riparian shrub-dominated communities (14.4 percent), and tall deciduous tree-dominated communities (13 percent). The Santa Rosa area has 217.7 acres of GDE vegetation associated with mapped springs. Riparian vegetation makes up 69 percent of these acres, 15 percent is herbaceous wetland, 13 percent is shrub wetland, and 3 percent is forested wetland. The FS VEG layer indicates that potential fens in this area are primarily composed of upland vegetation (65 percent), herbaceous-dominated communities (29 percent), and tall deciduous tree-dominated communities (8 percent).

Among springs where riparian and wetland vegetation was reported, 69 percent had nonnative species. Herbaceous-dominated communities were present at most (88 percent) springs, with *Veratrum californicum* often the dominant species. Springs also had conifer- (34 percent), tall deciduous- (13 percent), tall willow- (12 percent), low deciduous- (4 percent), and nonwillow shrub-dominated communities (2 percent). Aquatic invertebrates were observed at 64 percent of springs where fauna was reported.

Disturbance to Riparian Ecosystems and GDEs

Disturbances were examined at 33 riparian plots. Impacts included livestock grazing (observed at 91 percent of plots), wildlife (70 percent), roads (67 percent), trails (48 percent), noxious weeds (33 percent), flood (27 percent), OHV use (27 percent), camping (27 percent), and fire (18 percent).

Impacts to springs included native ungulates (19 percent), cattle (13 percent), diversions (3 percent), feral ungulates (2 percent), and recreation (2). Among springs given condition scores (97) 89 percent were pristine or good, 2 percent were moderate, a 4 percent were poor. Presence of *Bromus tectorum*, *Carex douglasii*, *Iris missouriensis*, and *Juncus arcticus* indicate effects of livestock grazing at riparian cover plots and springs.

Northern Mountains Summary

A variety of dominance groups and riparian communities occur along the extensive stream networks of the Jarbidge and Santa Rosa areas. Watersheds have been influenced by historical activities such as beaver trapping, livestock use, road construction, and mining. In recent years, management for bull trout habitat has improved the condition of riparian and aquatic habitat in the Jarbidge River watershed (Johnson et al. 2005; McNeil et al. 1997). Riparian cover plot results suggest that herbaceous-dominated communities are in poorer condition than communities dominated by woody plants. Livestock grazing appears to have had less of an effect on springs than in other geographic units. Based on these results, we determined that composition and structure is **moderately altered** from the NRV for riparian corridors,

meadows, and springs. Because of some disagreement between riparian spatial data and field data, as well as a lack of spatial data for springs, we are only moderately confident in this determination. There is insufficient information to determine NRV status of fens in this geographic unit.

Ruby Mountains

Settings

This unit includes the Ruby Mountains and East Humboldt Mountains. Perennial and intermittent streams are present throughout the unit. Riparian cover was measured at 45 plots between 2000 and 2019. We found survey reports for five springs in the unit. Two of these springs were surveyed in 1991 using Sada and Pohlmann protocols. This protocol was also used at a spring survey in 1997. Two springs were surveyed as part of the Nevada Heritage project, one in 1991 and the other in 1993.

Riparian Dominance Groups and Communities

The FS VEG layer indicates that 51 percent of valley bottom cover is upland woody vegetation, 34 percent is tall deciduous tree-dominated, 5 percent is riparian shrub-dominated, 5 percent is herbaceous-dominated, and 3 percent is conifer-dominated.

Most riparian cover plots (78 percent) were herbaceous-dominated. Other plots were dominated by tall deciduous trees (16 percent), willows (2 percent), tall willows (2 percent) and nonwillow shrubs (2 percent). Herbaceous-dominated communities had high cover of dry graminoids including *Leymus cinereus* and *Poa bulbosa*; mesic graminoids including *Carex aquatilis*, *Carex douglasi*, *Jucus arcticus*, and *Poa secunda*; and wet graminoids including *Carex nebrascensis*, *Carex scopulorum*. Nonwillow shrubs included *Artemisia cana*, tall deciduous trees included *Populus tremuloides*, and willows included *Salix lutea* and *Salix scoulerii*.

Riparian Vegetation Ratings

Six of the seven riparian corridor plots measured in this unit had suitable cover of problem vegetation. Of the 38 wet meadow plots, 61 percent had unsuitable cover of problem vegetation. Condition of vegetation was moderate or high in 43 percent of riparian corridor plots. Among wet meadow plots, condition was moderate or high in 48 percent

Extent of Riparian Departure

According to R-CAT results, vegetation along 43 percent of stream miles has moderately or significantly departed from the expected composition and structure. Upland grassland/shrubland encroachment is the most frequent cause of conversion (28.8 percent) followed by conifer encroachment (12.4 percent).

GDE Flora and Fauna

There are 105.5 acres of GDE vegetation associated with mapped springs in this unit. Riparian vegetation makes up 70 percent of these GDEs, 17 percent is herbaceous wetland, 12 percent is shrub wetland, and 1 percent is forested wetland. The FS VEG layer indicates that potential fens are primarily composed of herbaceous-dominated

communities (22 percent of fen area), tall deciduous tree-dominated communities (22 percent), coniferous tree-dominated communities (19 percent), and riparian shrub-dominated communities (19 percent). Aquatic invertebrates, including springsnails, were observed at three of the springs. Vegetation composition was not included in spring survey reports.

Disturbance to Riparian Ecosystems and GDEs

Disturbance was measured at 16 plots. Impacts include livestock grazing (81 percent of plots), roads (69 percent), wildlife (69 percent), trails (63 percent), noxious weeds (44 percent), camping (38 percent), OHV use (19 percent), and flooding (13 percent). Riparian vegetation has been impacted by diversion of streams and livestock grazing, resulting in a shift from herbaceous-dominant types to woody shrubs, though in some areas herbaceous and willow-dominated types have increased following implementation of grazing regulations (Rikart et al. 2013).

One spring was disturbed by cattle, one was diverted, and one was excavated. The presence of *Agrostis stolonifera*, *Carex douglasii*, *Carex nebrascensis*, *Poa pratensis*, *Poa bulbosa, and Rosa woodsii* indicate effects of livestock use at riparian sites.

Ruby Mountains Summary

Woody riparian vegetation is abundant in this geographic unit. Riparian cover plot analysis indicated that herbaceous-dominated communities are in poorer condition than woody riparian areas. This result may reflect long-term effects of livestock grazing that have been documented in this area. Additional surveys are needed to evaluate composition and structure of vegetation associated with GDEs. Based on these results, we determined that composition and structure is **moderately altered** from the NRV for riparian corridors and meadows. We have high confidence in this determination because of general agreement between spatial data and field data indicators. There is insufficient information to determine NRV status of GDEs in this geographic unit.

Sierra Nevada

Settings

This unit includes the Carson Range and Sierra Nevada Range. Perennial and intermittent streams are present throughout the unit. Potential fens are abundant in the southwestern portion of the unit. Riparian cover was measured at 70 plots between 2000 and 2019. We found survey reports for 16 springs in the Sierra Nevada unit, all of which were in Nevada. Seven of these springs were surveyed in 2019 as part of the Nevada Reno Area project, using the Stevens et al. Level 1 GDE protocol. Five were surveyed in 2009 using the Sada and Pohlman protocol. This protocol was also used at springs surveyed in 1992 and 1995. One spring was surveyed by the Nevada Heritage Project in 2009.

Riparian Dominance Groups and Communities

The FS VEG layer indicates that 27 percent of valley bottom cover is composed of upland woody vegetation, 25 percent is conifer-dominated, 13 percent is herbaceous-

dominated, 4 percent is riparian shrub-dominated, 3 percent is tall deciduous tree-dominated, and 1 percent is low deciduous tree-dominated.

Most riparian cover plots (84 percent) were herbaceous dominated. Other plots were dominated by tall deciduous trees (11 percent) and nonwillow shrubs (4 percent). Herbaceous-dominated communities had high cover of mesic graminoids including *Carex utriculata*, *Juncus arcticus*, and *Poa cusickii*; and wet graminoids including *Carex scopulorum*, and *Muhlenbergia richardsonis*. Nonwillow shrubs include *Artemisia cana*, tall Deciduous trees include *Populus tremuloides*, and willows include *Salix eastwoodiae*, *Salix exigua*, *Salix geyeriana*, *Salix lemmonii*, and *Salix lutea* (Weixelman et al. 1999).

Assessments of riparian communities in the Carson and Walker River watersheds report woody riparian communities dominated by *Populus tremuloides*, *Populus balsamifera L.* ssp. *Trichocarpa*, *Alnus incana*, *Betula occidentalis*, *Salix exigua*, *Salix lemmonii*, *Salix lucida*, *Salix lutea*, *Salix lasiolepis*, *Rosa woodsii*, and *Cornus sericea* (Kattelmann 2012; Zeier et al. 2004). Herbaceous vegetation includes *Deschampsia cespitosa*, *Poa pratensis*, *Leymus triticoides*, *Equisetum arvense*, *Juncus arcticus*, and *Carex* spp.

Riparian Vegetation Ratings

Of the eight riparian corridor plots measured in this unit, six had suitable cover of problem vegetation. Of the 62 wet meadow plots, 84 percent had unsuitable cover of problem vegetation. Condition of vegetation was moderate or high in 63 percent of riparian corridor plots. Among wet meadow plots, condition was moderate or high at 67 percent.

Extent of Riparian Departure

According to R-CAT results, vegetation along most (60 percent) stream miles has moderately or significantly departed from the expected composition and structure. Conifer encroachment is the most frequent cause of conversion (49.7 percent) followed by upland/grassland encroachment (5.5 percent).

GDE Flora and Fauna

There are 22.9 acres of GDE vegetation associated with mapped springs in the portion of this unit in Nevada. Riparian vegetation makes up 85 percent of this GDE area, 8 percent is herbaceous wetland, 6 percent is shrub wetland and 0.2 is forested wetland. Aquatic invertebrates, including springsnails, were observed at seven springs (64 percent of those with fauna reported). Vegetation composition was not included in survey reports.

The FS VEG layer indicated that potential fens are primarily composed of herbaceous-dominated communities (50 percent of fen area), riparian shrub-dominated communities (17 percent), and conifer-dominated communities (10 percent). Surveys of fens in adjacent national forests of the Sierra Nevada Range report dominance of trees including *Pinus contorta*; shrubs including *Vaccinium ulignosum*; graminoids including *Carex lasiocarpa*, *Carex limosa*, *Carex simulata*, *Carex utricula*, and J*uncus nevadensis*, and forbs including *Menyanthes trifoliata*, *Mimulus primuloides*, and *Triantha occidentalis* (Sikes et al. 2013). Wetland plant associations at these fens are

listed in table G.5. These associations represent coniferous tree-, low deciduous tree-, tall willow-, low willow-, nonwillow shrub-, and herbaceous-dominated communities.

Disturbance to Riparian Ecosystems and GDEs

Disturbances were measured at 57 plots. Impacts include wildlife (79 percent of plots), livestock grazing (75 percent), trails (42 percent), flooding (37 percent), roads (26 percent), camping (25 percent), OHV use (14 percent), noxious weeds (12 percent), and mining (4 percent). Impacts to springs included excavation/damming (43 percent of springs), diversions (36 percent), recreation (31 percent), cattle (7 percent), and native ungulates (7 percent). The presence of types dominated by *Agrostis stolonifera*, *Bromus hordeaceus*, *Cardaria draba*, *Carex nebrascensis*, *Iris missouriensis*, *Juncus arcticus*, *Poa pratensis*, *Rosa woodsii* indicate effects of livestock use.

Stressors to riparian vegetation include recreation impacts, replacement by noxious weeds, and livestock grazing (Kattelmann 2012; Loomis et al. 2007). Long-term effects of historical livestock grazing continue to impact meadows, as well as local effects of ongoing livestock use (Herbst and Kane 2004; Hunt et al. 2018). Meadows with incised stream channels have conifer and sagebrush encroachment issues (Fair et al. 2018). Lingering effects of timber harvest, log drives, and mining may affect streams and riparian ecosystems in the Sierra Nevada as well (Kattelmann and Embury 1996; Zeier et al. 2004). Riparian ecosystems are also currently affected by decades of fire suppression, which has resulted in conifer encroachment into meadows and increased risk of high-severity fire in woody riparian areas (Gross and Coppoletta 2013; Kattelmann 2012).

Sierra Nevada Summary

Research and restoration is ongoing to support recovery of threatened, endangered and sensitive species associated with riparian meadows in this range. There is less information available about composition and structure of springs and other GDEs within much of the unit, however. Impacts of current livestock grazing are localized and relatively minor, but roads, heavy recreational use, and effects of past overgrazing are ongoing management concerns (Gross and Coppoletta 2013). In some meadows, beaver dams have helped to slow erosion and maintain dominance of herbaceous- and willow-dominated riparian communities (Fair et al. 2018; Hunt et al. 2015). Based on these results, we determined that composition and structure is **moderately altered** from the NRV for riparian corridors and meadows. Because of some disagreement between spatial data and field data indicators, we are only moderately confident in this determination. There is insufficient information to determine NRV status of GDEs in this geographic unit.

SMNRA

Settings

This geographic unit covers the Spring Mountains. Intermittent streams are distributed throughout the unit, but perennial reaches are limited to four streams (Coles-Ritchie 2013). Riparian cover was measured at 3 plots between 2000 and 2019. We found survey reports for 156 springs in geographic unit. Many protocols have been used, including

Stevens et al. Level 1and Level 2, Sada and Pohlmann, and USFS GDE Level 1. Spring ecosystems occur across elevations, from high elevation conifer-dominated zones to low elevation desert scrub. Because of the scarcity of perennial streams and lack of fens in this unit, springs are essential to the distribution of riparian vegetation and aquatic invertebrates.

Riparian Dominance Groups and Communities

We did not examine vegetation composition in valley bottoms because the FS VEG layer produced for other units was not available for the SMNRA.

All riparian cover plots were herbaceous-dominated. Herbaceous-dominated communities had high cover of *Ericameria nauseosa*, *Leymus cinereus*, *Juncus arcticus*, *Poa pratensis*. *Salix lasiolepis* dominates riparian communities across a range of elevations (Coles-Ritchie 2013). *Salix geyeriana*, *Rosa woodsii*, and *Ribes* spp. are present as well. Nonnative species include *Bromus tectorum*, *Dactylis glomerata*, *Melilotus officinalis*, *Poa pratensis*, *Taraxacum officinale*, *Thinopyrum intermedium*, and *Verbascum thapsus* (Entrix 2008).

Riparian Vegetation Ratings

The three wet meadow plots measured in this unit had unsuitable cover of problem vegetation. Condition of riparian vegetation was low in each plot.

Extent of Riparian Departure

According to R-CAT results, vegetation along 37 percent of stream miles has moderately or significantly departed from the expected composition and structure. Conifer encroachment is the most frequent cause of conversion (19.2 percent), followed by upland grassland/shrubland encroachment (17.9 percent).

GDE Flora and Fauna

There are 48.6 acres of GDE vegetation associated with mapped springs in this unit. Riparian vegetation makes up 100 percent of this GDE area. Among springs where riparian and wetland vegetation was reported, 65 percent had nonnative species. Herbaceous-dominated communities were present at most (72 percent) springs, with *Aquilegia formosa*, *Dodecatheon redolens*, and *Carex aurea* often the dominant species. Springs also had conifer- (32 percent), low deciduous- (3 percent), tall deciduous- (7 percent), tall willow- (13 percent), and nonwillow shrub- (57 percent) dominated communities. Nonnative vegetation observed at springs includes *Tamarix*. Species richness of plants increases with the length of spring runout channels (Fleishman et al. 2006).

Aquatic invertebrates were observed at 58 percent of springs where fauna was reported. Springsnails are often abundant despite impacts of cattle, feral horses/burros, and elk. Diversion and drought are likely more serious stressors for these species. Macroinvertebrate species richness was greatest at slightly disturbed springs and springs with the highest rates of discharge (Sada et al. 2005). The presence of riparian vegetation at springs is associated with increased species richness and abundance of butterflies (Fleishman et al. 2005).

Disturbance to Riparian Ecosystems and GDEs

Disturbances were measured at the three riparian cover plots. All were impacted by camping, grazing, OHV use, roads, trails, and wildlife. Two were impacted by noxious weeds and one was impacted by flood. Streams are also impacted by diversion, road crossings, recreation, and wild horses and burros (Coles-Ritchie 2013; Entrix 2008).

Impacts to springs included feral ungulates (31 percent of springs), diversions (30 percent), native ungulates (13 percent), recreation (17 percent), excavation/damming (8 percent), and cattle (7 percent). Saltcedar is present at several SMNRA springs. Additional stressors include avalanches, fires, and floods. Among springs given condition scores (8), 50 percent were pristine or good, 38 percent moderate, 12 percent poor. The presence of types dominated by *Bromus tectorum*, *Carex nebrascensis*, and *Rosa woodsii* indicate effects of past livestock use at riparian and GDE sites.

SMNRA Summary

Springs, which are well-studied in this unit, are the primary sources of water for aquatic ecosystems, riparian ecosystems, and anthropogenic uses. Springs occur in a variety of settings, which is reflected in the composition of plants and animals associated with these GDEs. Many springs have been altered by wild horses, burros, elk, diversions, and recreational impacts. Based on these results, we determined that composition and structure is **moderately altered** from the NRV for riparian corridors, meadows, and springs. Given the lack of field data for riparian ecosystems and limited spatial data for springs, we have low confidence in our determinations.

Table G.5—Wetland plant associations observed in California national forests that are adjacent to Sierra Nevada and East Sierra geographic units of the HTNF.

Dominance group	Association
Coniferous tree	*Pinus contorta* ssp. *murrayana*/*Carex* spp.
	Pinus contorta ssp. *murrrayana/Rhododendron occidentale*
	Pinus contorta ssp. *murrrayana/Vaccinium uliginosum–Rhododendron columbianum*
Low deciduous tree	*Alnus incana*
Tall willow	*Salix jepsonii*
	Salix lemmonii/*Carex* spp.
	Salix lemmonii/mesic forb
Low willow	*Salix brachycarpa*/mesic forb
	Salix eastwoodiae
	Salix orestera/*Carex*
	Salix orestera/moss

Table G.5 continued.

Dominance group	Association
Nonwillow shrub	*Dasiphora fruticosa*/*Carex aquatilis*
	Kalmia polifolia/*Sphagnum* spp
	Rhododendron columbianum/*Pinus contorta* ssp. *Murrayana*
	Vaccinium uliginosum/*Aulacomnium palustre*–*Sphagnum* spp.
Herbaceous	*Allium validum*
	Bistorta bistortoides–*Mimulus primuloides*
	Mimulus primuloides
	Camassia quamash/*Sphagnum subsecundum*
	Camassia quamash/*Sphagnum subsecundum*
	Carex aquatilis
	Carex illota
	Carex luzulina/*Ptychostomum* spp.
	Carex utriculata
	Carex vesicaria
	Carex alma
	Carex amplifolia
	Carex canescens
	Carex capitata
	Carex echinata
	Carex jonesii–*Bistorta bistortoides*
	Carex limosa–*Menyanthes trifoliata*
	Carex nebrascensis
	Carex scopulorum
	Carex simulata
	Carex simulata–*Carex utriculata*
	Carex subnigricans–*Deschampsia cespitosa*
	Deschampsia cespitosa–*Carex nebrascensis*
	Deschampsia cespitosa–*Perideridia parishi*
	Eleocharis quinqueflora
	Eleocharis quinqueflora/*Drepanocladus*
	Eleocharis quinqueflora/*Philonotis* spp.-*Ptychostomum* spp.
	Juncus arcticus var. *Balticus*
	Juncus nevadensis

Table G.5 continued.

Dominance group	Association
Herbaceous	*Juncus oxymeris*/*Philonotis* spp.
	Juncus oxymeris–Eleocharis parishii/*Philonotis* spp.
	Phalacroseris bolanderi–Eriophorum crinigerum
	Phalacroseris bolanderi
	Phalacroseris bolanderi/*Philonotis* spp.–*Sphagnum* spp.
	Kobresia myosuroides–Thalictrum alpinum
	Muhlenbergia filiformis
	Narthecium californicum
	Rhynchospora alba
	Scirpus microcarpus
	Sphagnum-graminoid
	Veratrum californicum/*Salix* spp.

REFERENCES

Abele, S.L.; Low, G.; Provencher, L. 2010. Ward Mountain Restoration Project: An ecological assessment and landscape strategy for native ecosystems in the Ward Mountain landscape. Report to the Bureau of Land Management and US Forest Service, Ely, Nevada. 307 p.

Chambers, J.C.; Miller, J.R., 2011. Geomorphology, hydrology, and ecology of Great Basin meadow complexes-implications for management and restoration. Gen. Tech. Rep. RMRS-GTR-258. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 125 p., 258.

Coles-Ritchie, M. 2013. Report on SMNRA Riparian Inventory 2012. Report on file. 51 pp.

Entrix 2008. Characterization of the Spring Mountains National Recreation Area. A report prepared for the USDA Forest Service Spring Mountains National Recreation Area Humboldt-Toiyabe National Forest. Contract No. AG-9360-C-06-0003. 72 pp.

Fair, J.; Hunt, L.; Hanley, M.; Dyste, J., 2018. Restoring Carson Meadows, Assessment and Prioritization. A report by American Rivers submitted to the National Fish and Wildlife Foundation. 39 p.

Fleishman, E.; Murphy, D.D.; Austin, G.T. 2005. Biodiversity patterns of spring-associated butterflies in a Mojave Desert mountain range. Journal of the Lepidopterists Society, 59: 89.

Fleishman, E.; Murphy, D.D.; Sada, D.W. 2006. Effects of environmental heterogeneity and disturbance on the native and non-native flora of desert springs. Biological Invasions, 8: 1091.

Gross, S.; Coppoletta, M. 2013. Historic Range of Variability for Meadows in the Sierra Nevada and South Cascades. USDA Forest Service, California. 64 p.

Herbst, D.B.; Kane, J.M. 2004. Macroinvertebrate Monitoring for the Bagley Valley Watershed Restoration Project on the Humboldt-Toiyabe National Forest. 18 p.

Hunt, L.; Fair, J.; Dyste, J.; Odland, M. 2015. Restoring Walker Meadows: Assessment and Prioritization. A report by American rivers to the National Fish and Wildlife Foundation. 30 p.

Johnson, G.L.; Haskins II, R.L.; Layton, R. 2005. Species management plan for the Nevada portion of the Jarbidge River drainage basin. 37 p.

Kattelmann, R.; Embury, M. 1996. Sierra Nevada Riparian areas. In Sierra Nevada Ecosystem Project, University of California (System). Centers for Water and Wildland Resources, 1996. Sierra Nevada Ecosystem Project Final Report to Congress: Assessments and scientific basis for management options (Vol. 2). Centers for Water and Wildl Ornia. 66 p.

Kattelmann, R. 2012. East Walker River Assessment. Eastern Sierra Land Trust. 177 p.

Ledbetter, J.D.; Stevens, L.E.; Springer, A.; Brandt, B. 2014. Springs Inventory Database. Online Database. Springs and Springs-Dependent Species Database. Vers. 1.0. Springs Stewardship Institute, springsdata.org.

Loomis, D.; Champion, S.; Gassaway, L.; Hale, S.; Kling, J.; Easton, M.; Williams, K.; Bonesteel, M. 2007. East Carson River Strategy. Carson Ranger District, Humboldt-Toiyabe National Forest. 43 pp.

Manning, M.E.; Padgett, W.G. 1995. Riparian community type classification for Humboldt and Toiyabe national forests, Nevada and eastern California. US Dept. of Agriculture, Forest Service, Intermountain Region. 306 p.

Macfarlane, W.W.; Gilbert, J.T.; Jensen, M.L.; Gilbert, J.D.; Hough-Snee, N.; McHugh, P.A.; Wheaton, J.M.; Bennett, S.N. 2017. Riparian vegetation as an indicator of riparian condition: Detecting departures from historic condition across the North American West. Journal of Environmental Management. 202: 447–460.

Mcneill, M.E.; Frederick, J.; Whalen, B. 1997. Jarbidge River Watershed Analysis. Jarbidge Ranger District, Humboldt-Toiyabe National Forest. 52 p.

Miller, J.; Germanoski, D.; Waltman, K.; Tausch, R.; Chambers, J. 2001. Influence of late Holocene hillslope processes and landforms on modern channel dynamics in upland watersheds of central Nevada. Geomorphology 38: 373-391.

Miller, J.R.; Germanoski, D.; Lord, M.L., 2011. Geomorphic Processes Affecting Meadow Ecosystems. Geomorphology, Hydrology, and Ecology of Great Basin Meadow Complexes—Implications for Management and Restoration, [chapter 3]. In: Chambers, Jeanne C.; Miller, Jerry R., eds. Geomorphology, hydrology, and ecology of Great Basin meadow complexes-implications for management and restoration. Gen. Tech. Rep. RMRS-GTR-258. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. pp 24-44.

NatureServe. 2018. International Ecological Classification Standard: Terrestrial Ecological Classifications. NatureServe Central Databases. Arlington, VA. U.S.A. 685 p. Data current as of 28 August 2018.

Rickart, E.A.; Bienek, K.G.; Rowe, R.J. 2013. Impact of livestock grazing on plant and small mammal communities in the Ruby Mountains, northeastern Nevada. Western North American Naturalist 73: 505-515.

Sada, D.W.; Fleishman, E.; Murphy, D.D., 2005. Associations among spring-dependent aquatic assemblages and environmental and land use gradients in a Mojave Desert mountain range. Diversity and Distributions, 11: 91-99.

Sikes, K.; Cooper, D.J.; Weis, S.; Keeler-Wolf, T.; Barbour, M.; Ikeda, D.; Stout, D.; Evens, J. 2013. Fen conservation and vegetation assessment in the National Forests of the Sierra Nevada and adjacent mountains, California. Unpublished report to the United States Forest Service, Region 5. 314 p.

Smith, G.; Lemly, J. 2019. Fen Mapping for the Humboldt-Toiyabe National Forest. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado. 39 p.

Solem, S.J. et al. 2013. Final program report for 2010-2012. Monitoring and evaluation for conserving biological resources of the Spring Mountains National Recreation Area. 189p.

Trowbridge, W.; Chambers, J.C., Germanoski, D.; Lord, M.L.; Miller, J.R.; Jewett, D.G. 2011. Characterization of meadow ecosystems based on watershed and valley segment/reach scale characteristics [chapter 7]. In: Chambers, Jeanne C.; Miller, Jerry R., eds. Geomorphology, hydrology, and ecology of Great Basin meadow complexes-implications for management and restoration. Gen. Tech. Rep. RMRS-GTR-258. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. pp.95-112.

Viers, J.H.; Purdy, S.E.; Peek, R.A.; Fryjoff-Hung, A.; Santos, N.R.; Katz, J.V.E.; Emmons, J.D.; Dolan, D.V.; Yarnell S.M. 2013. Montane Meadows in the Sierra Nevada: Changing Hydroclimatic Conditions and Concepts for Vulnerability Assessment. Center for Watershed Sciences Technical Report (CWS-2013-01), University of California, Davis. 63 p.

Weixelman, D.; Zamudio, D.C.; Zamudio, K.A. 1996. Central Nevada riparian field guide. US Department of Agriculture, Forest Service, Intermountain Region.

Weixelman, D.; Zamudio, D.C.; Zamudio, K.A.; Tausch, R.J. 1997. Classifying ecological types and evaluating site degradation. Rangeland Ecology & Management/Journal of Range Management Archives 50: 315-321.

Weixelman, D.; Zamudio, D.C.; Zamudio, K.A. 1999. Eastern Sierra Nevada Riparian Field Guide. Department of Agriculture, Forest Service, Intermountain Region. 121p.

Zeier, C.; Picciani, J.; Waters, D.; Kiesse, M.; Swanson, S.; Dvorsky, J.; Celio, C. 2004. Upper Carson River Watershed Stream Corridor Condition Assessment. 188 p.

APPENDIX H. Watershed Maps

Maps begin on next page.

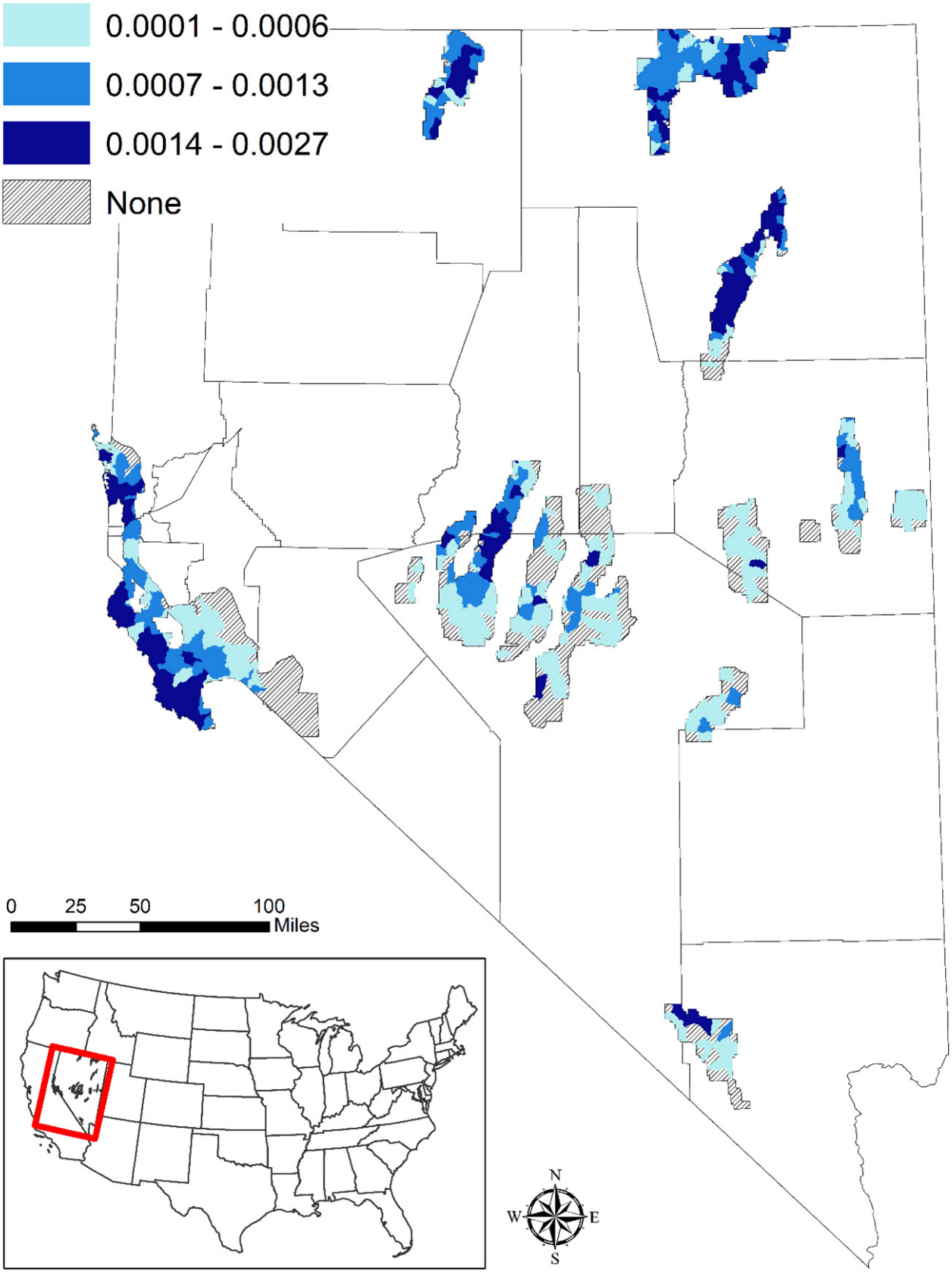


Figure H.1—Perennial stream density in miles per acre within 12-digit HUC watersheds on the Humboldt-Toiyabe National Forest. Data from the National Hydrography Dataset.

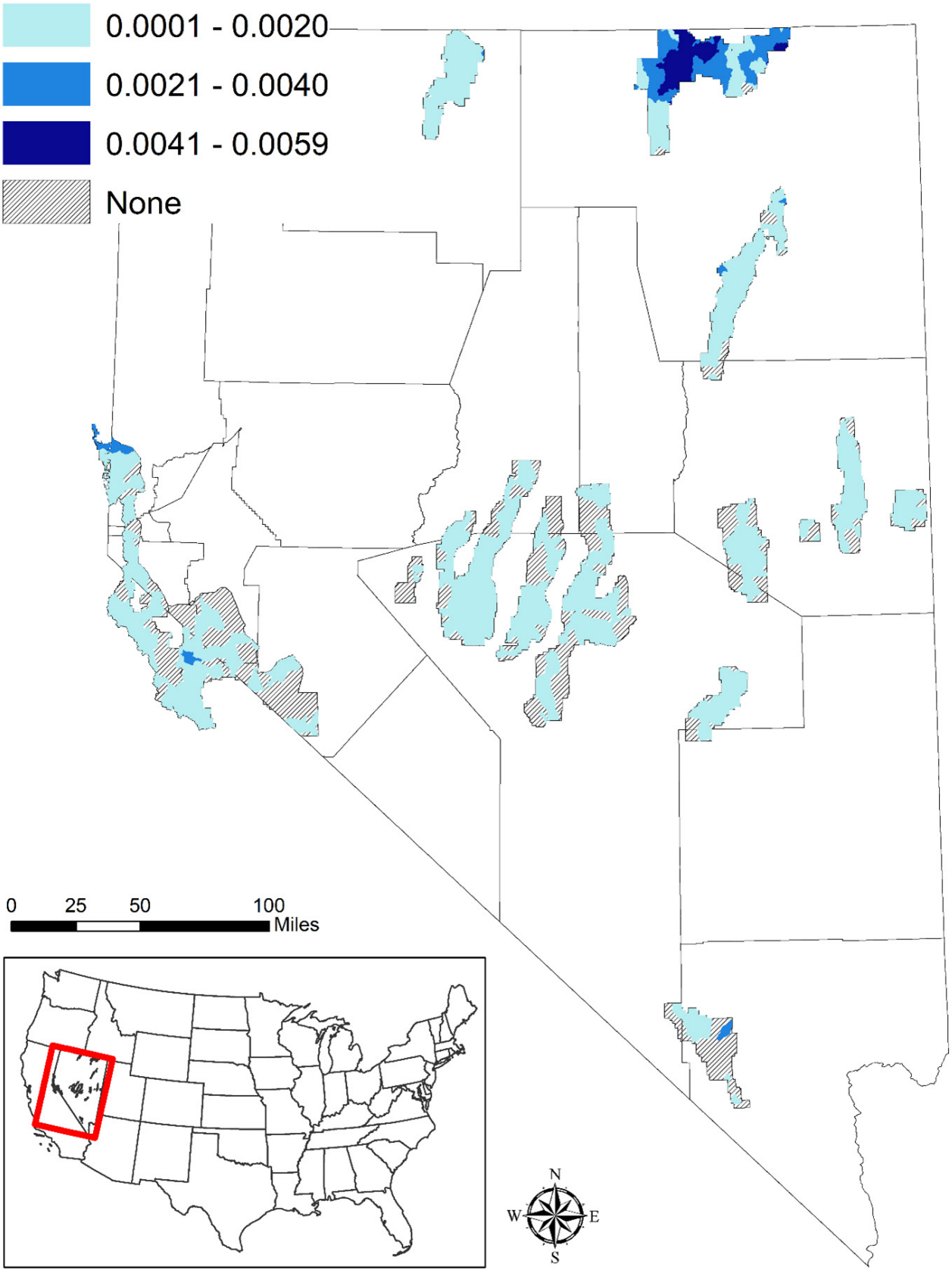


Figure H.2—Intermittent stream density in miles per acre within 12-digit HUC watersheds on the Humboldt-Toiyabe National Forest. Data from the National Hydrography Dataset.

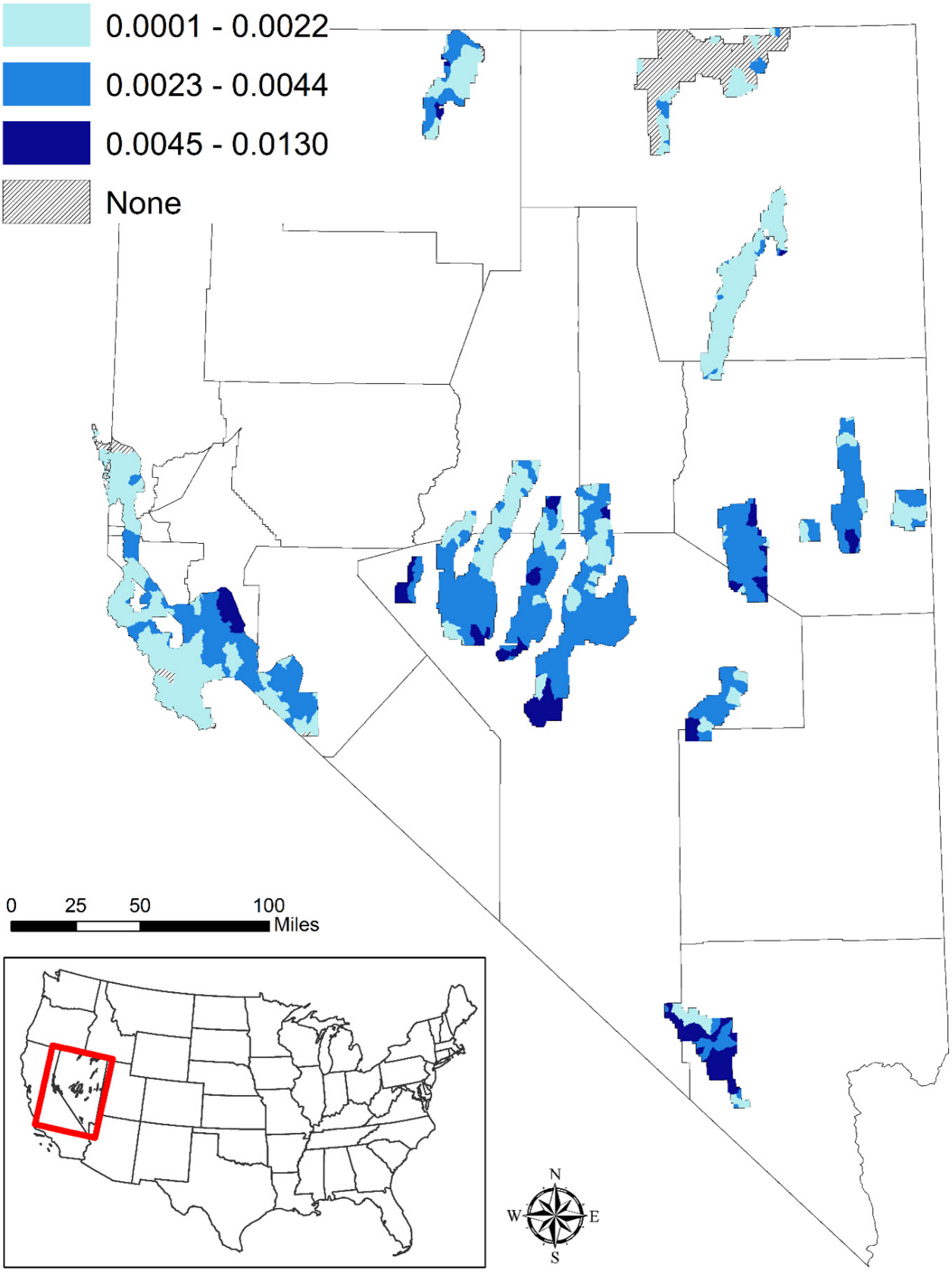


Figure H.3—Ephemeral stream density in miles per acre within 12-digit HUC watersheds on the Humboldt-Toiyabe National Forest. Data from the National Hydrography Dataset.

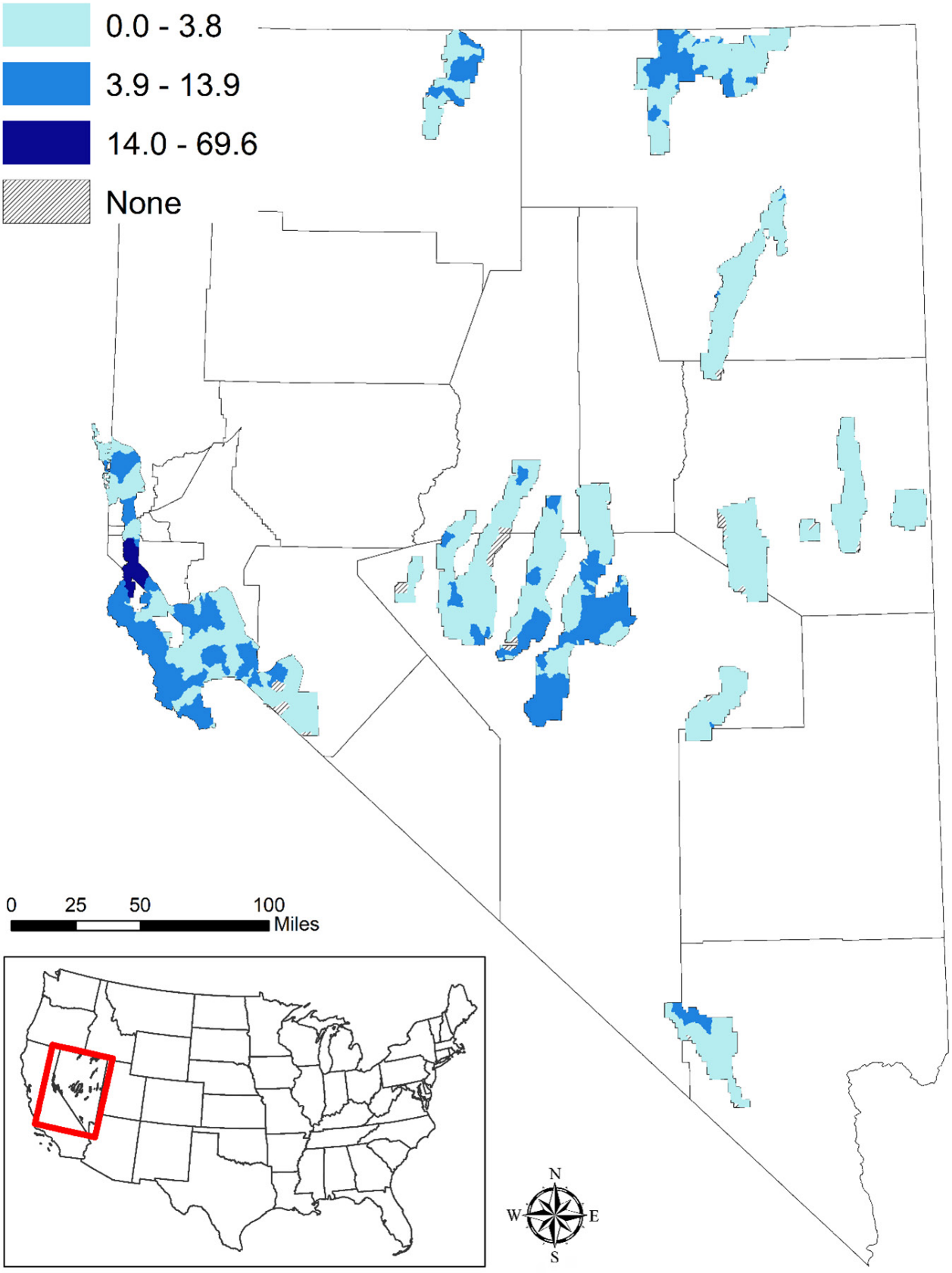


Figure H.4—Percent of 12 digit HUC watershed located within the 50-year floodplain. Data from the U.S. Forest Service National Riparian dataset.

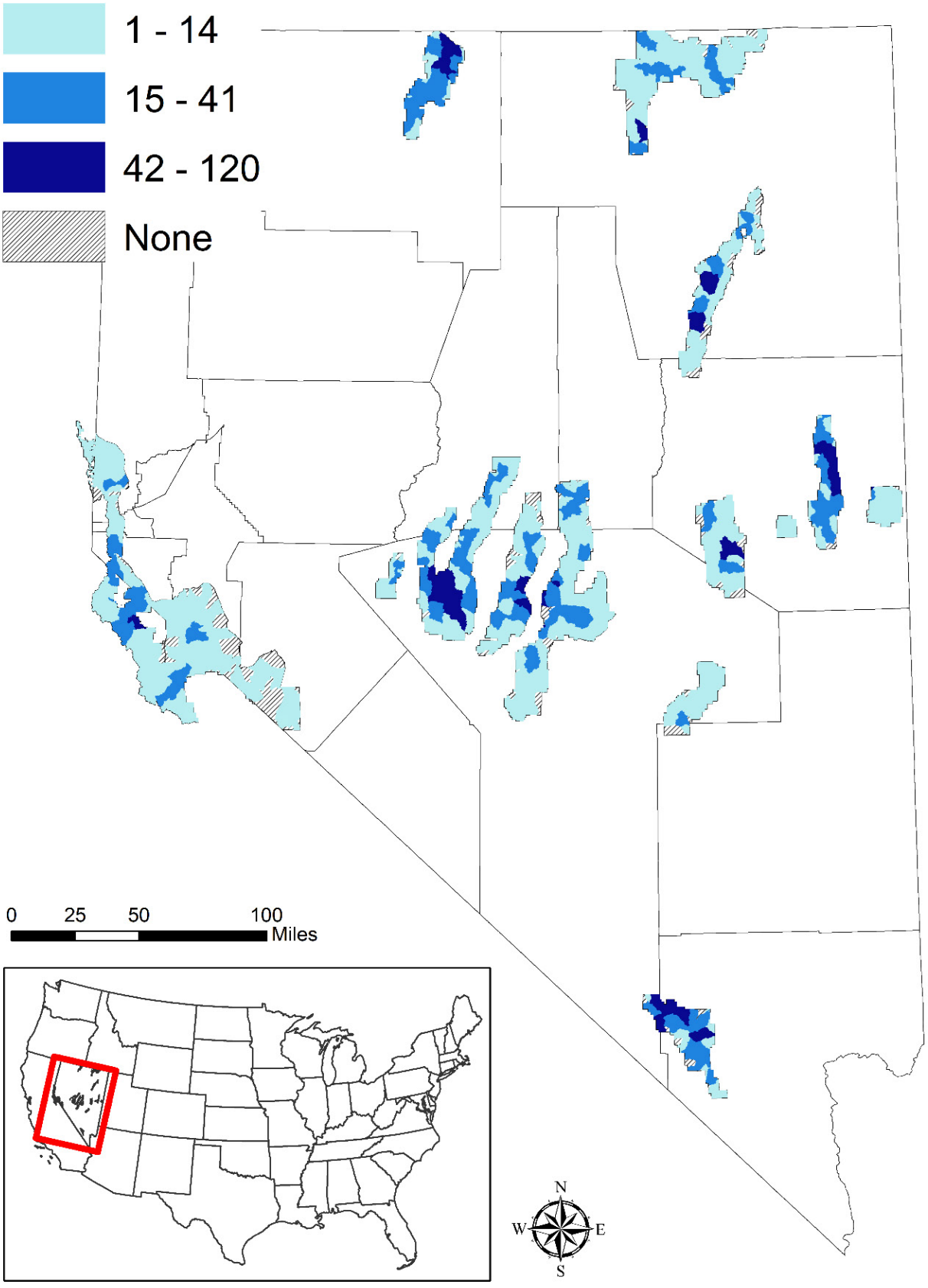


Figure H.5—Number of springs in each 12-digit HUC on the Humboldt-Toiyabe National Forest. Data from the Spring Stewardship Institute database.

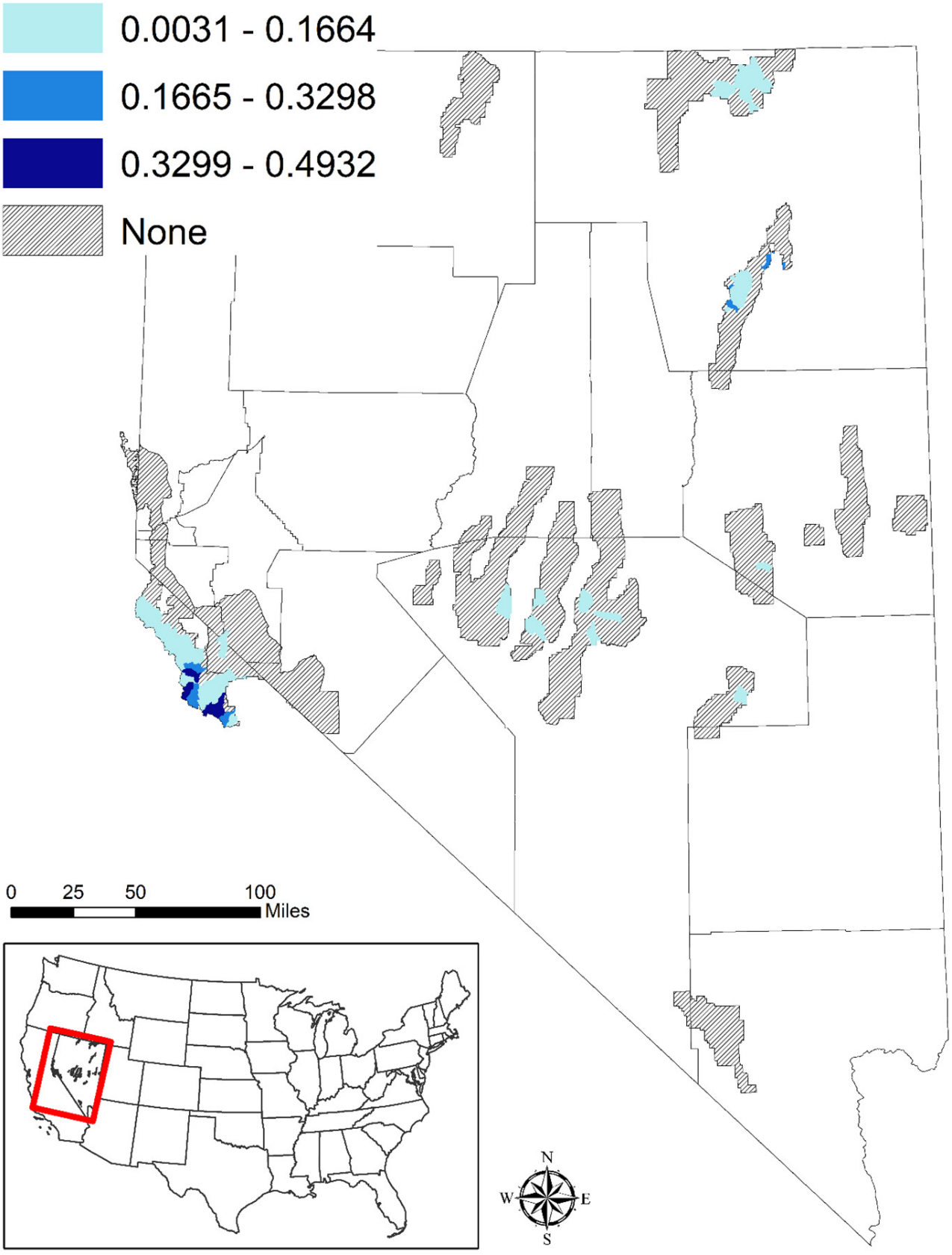


Figure H.6—Percent of watershed classified as a likely fen. Data from the Colorado Natural Heritage Program.

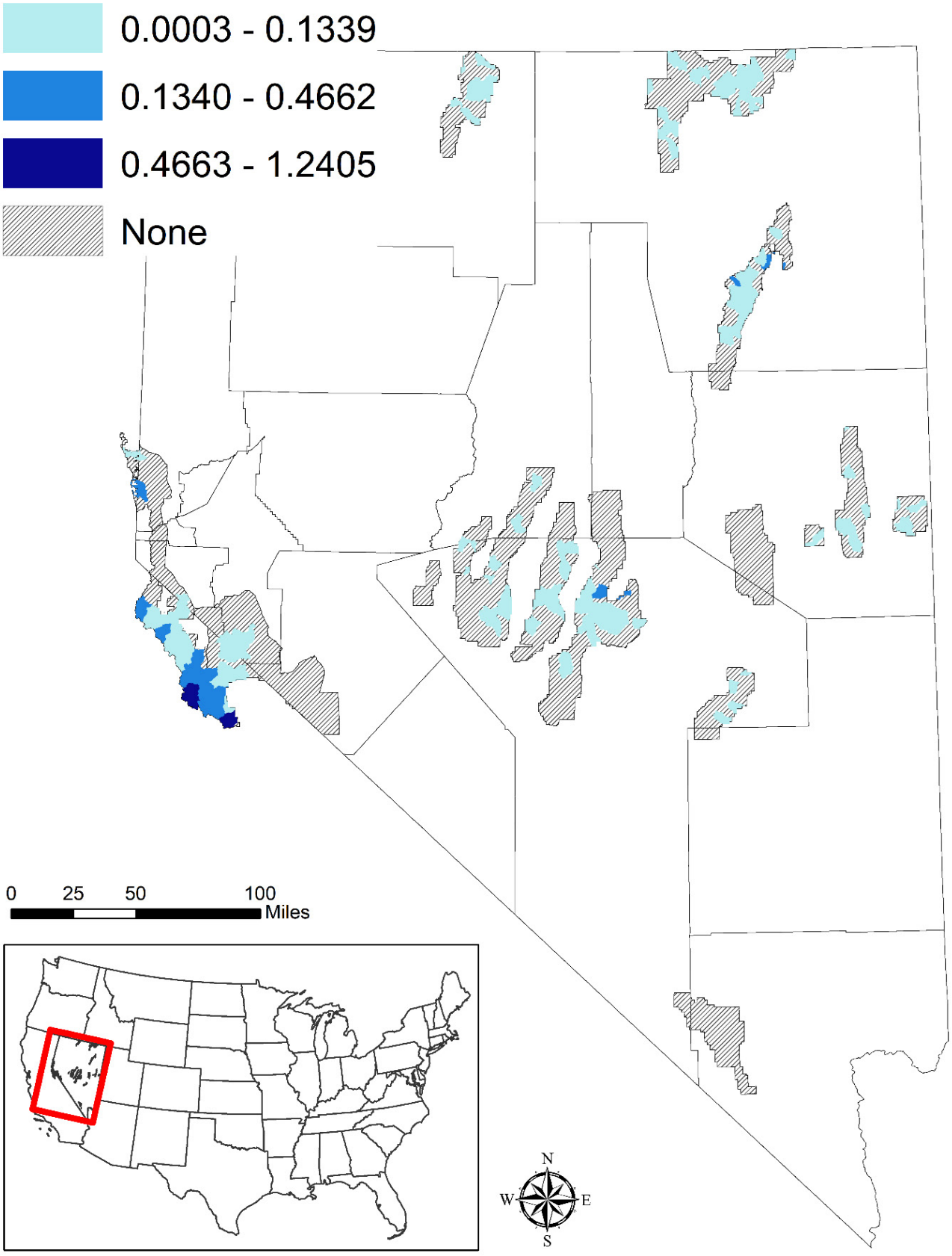


Figure H.7—Percent of watershed classified as a possible fen. Data from the Colorado Natural Heritage Program.

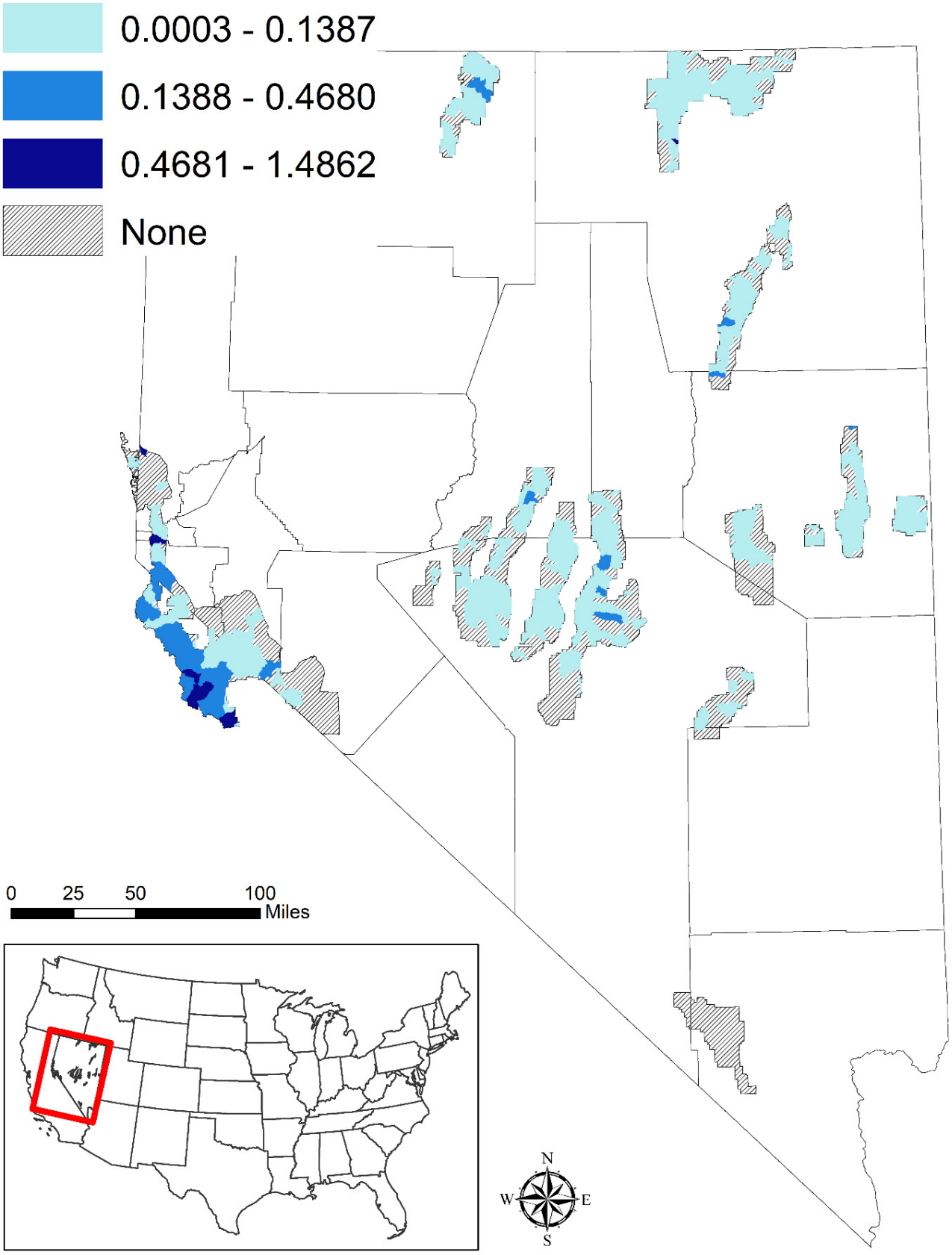


Figure H.8—Percent of watershed classified as a low confidence fen. Data from the Colorado Natural Heritage Program.

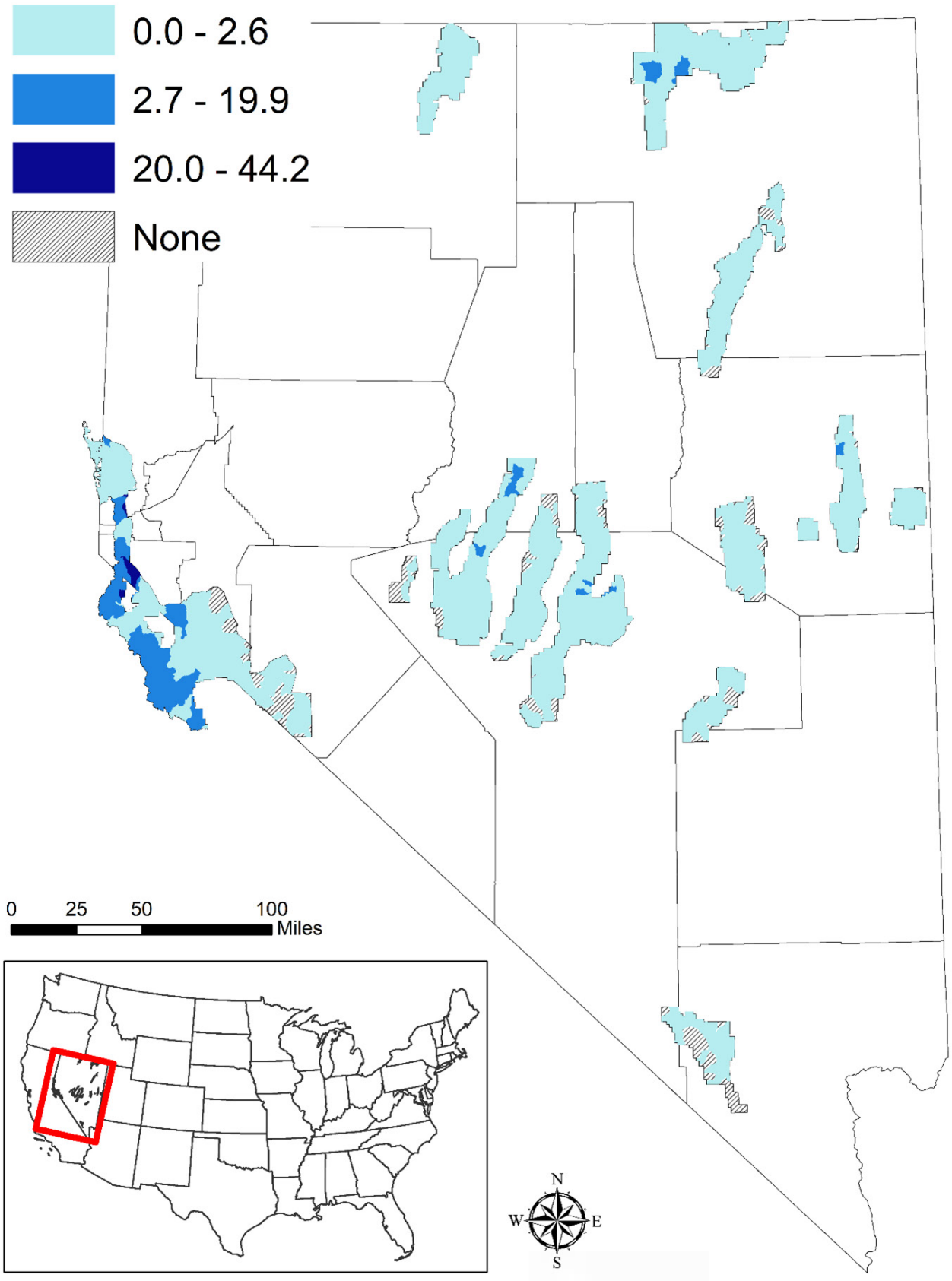


Figure H.9—Percent of watershed classified as a wetland. Data from the National Wetlands Inventory.

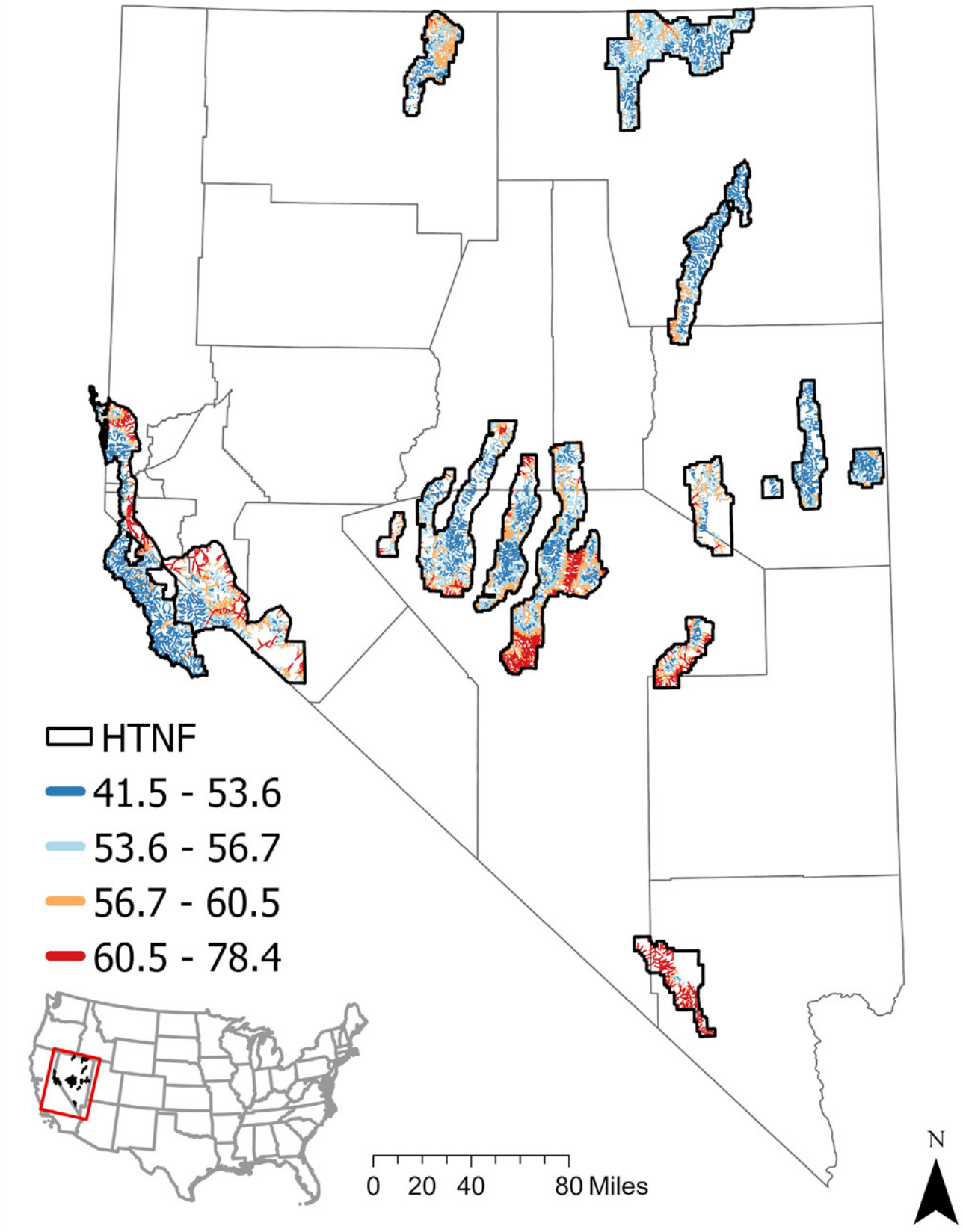


Figure H.10—Modeled mean August stream temperature 1993 to 2011. Data from the NorWEST Stream Temperature Model.

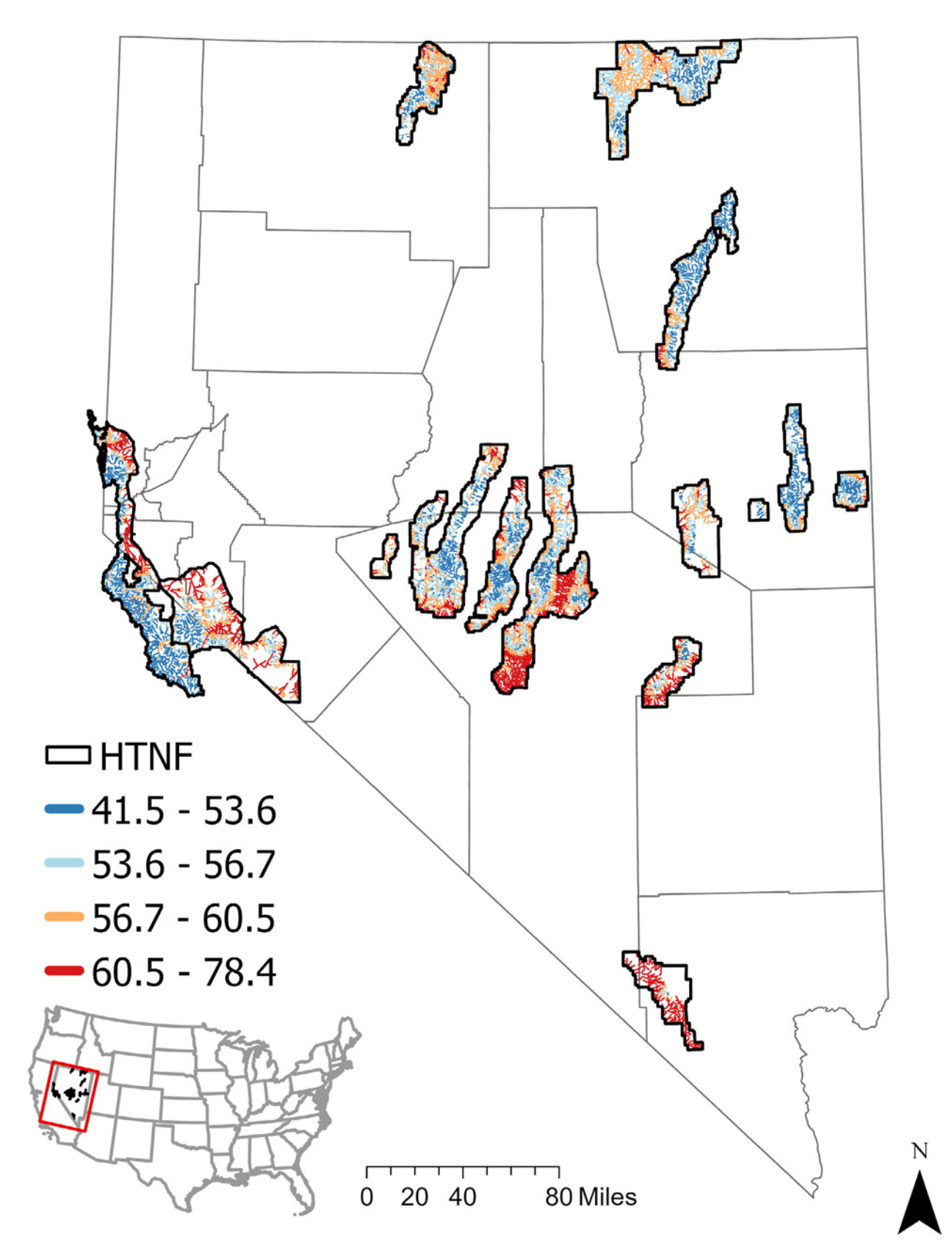


Figure H.11—Modeled mean August stream temperature 2040s using A1B prediction. Data from the NorWeST Stream Temperature Model.

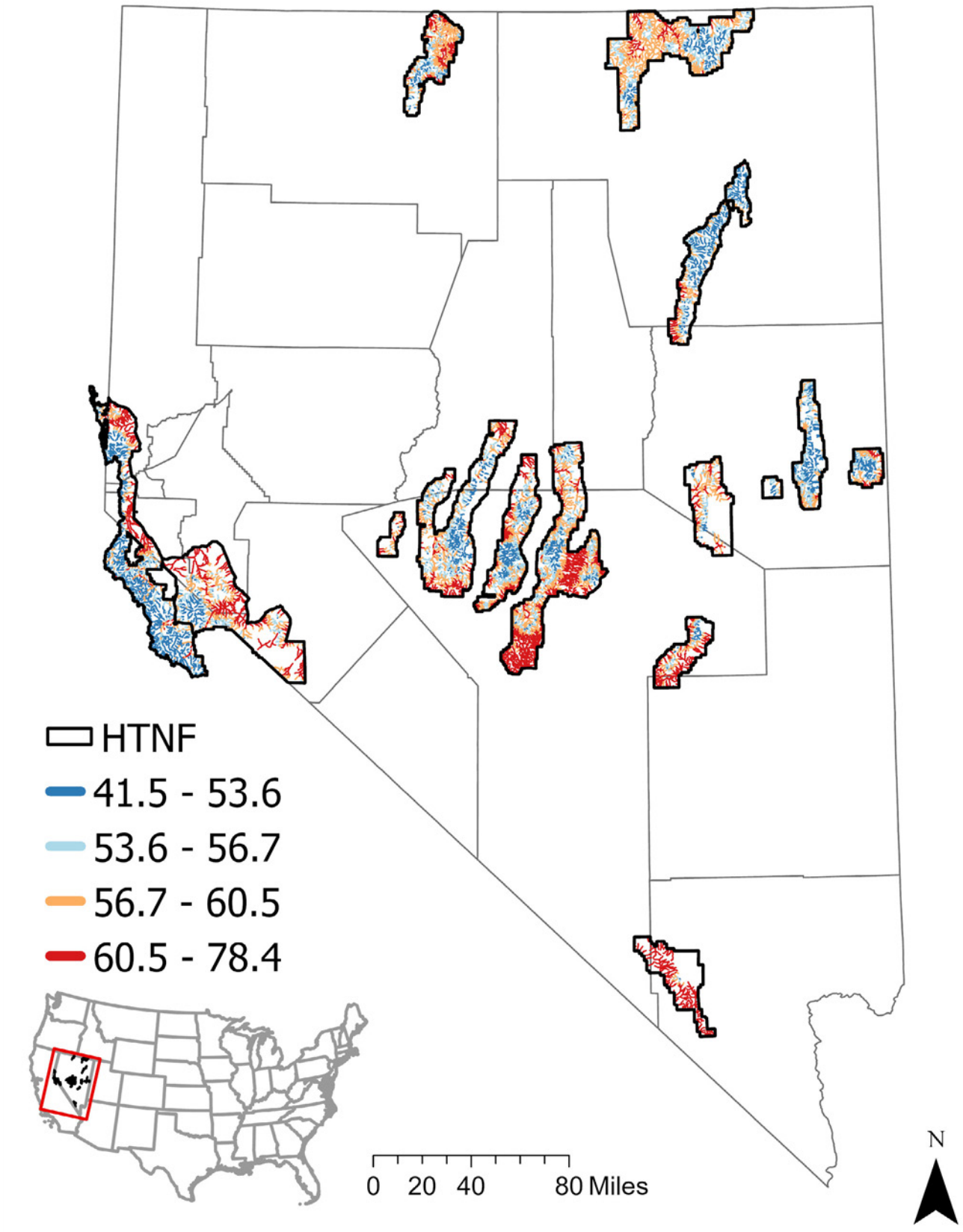


Figure H.12—Modeled mean August stream temperature 2080s using A1B prediction. Data from the NorWeST Stream Temperature Model.

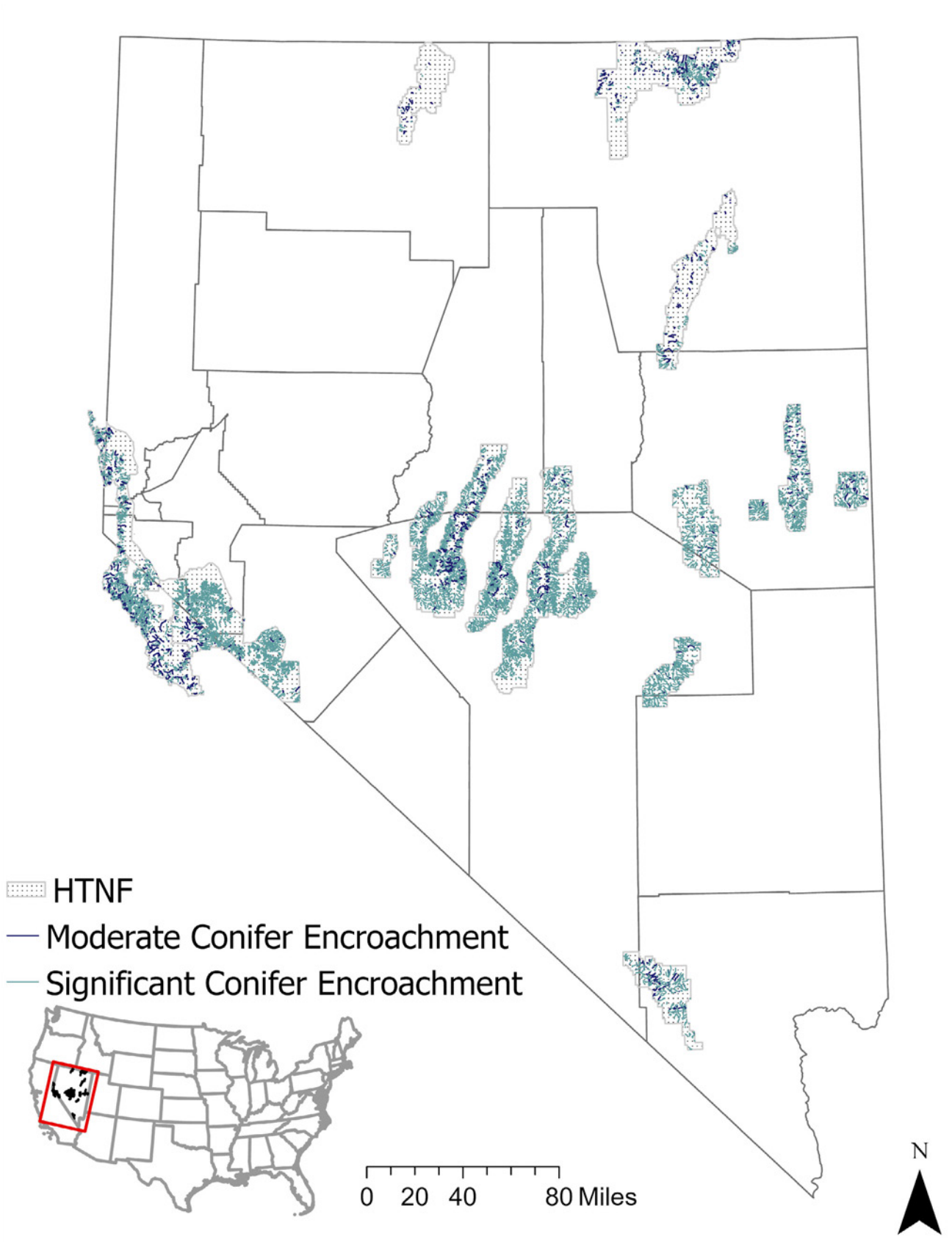


Figure H.13—Stream reaches with riparian areas that have experienced moderate or significant conversion to conifer cover. Data from R-CAT riparian vegetation departure.

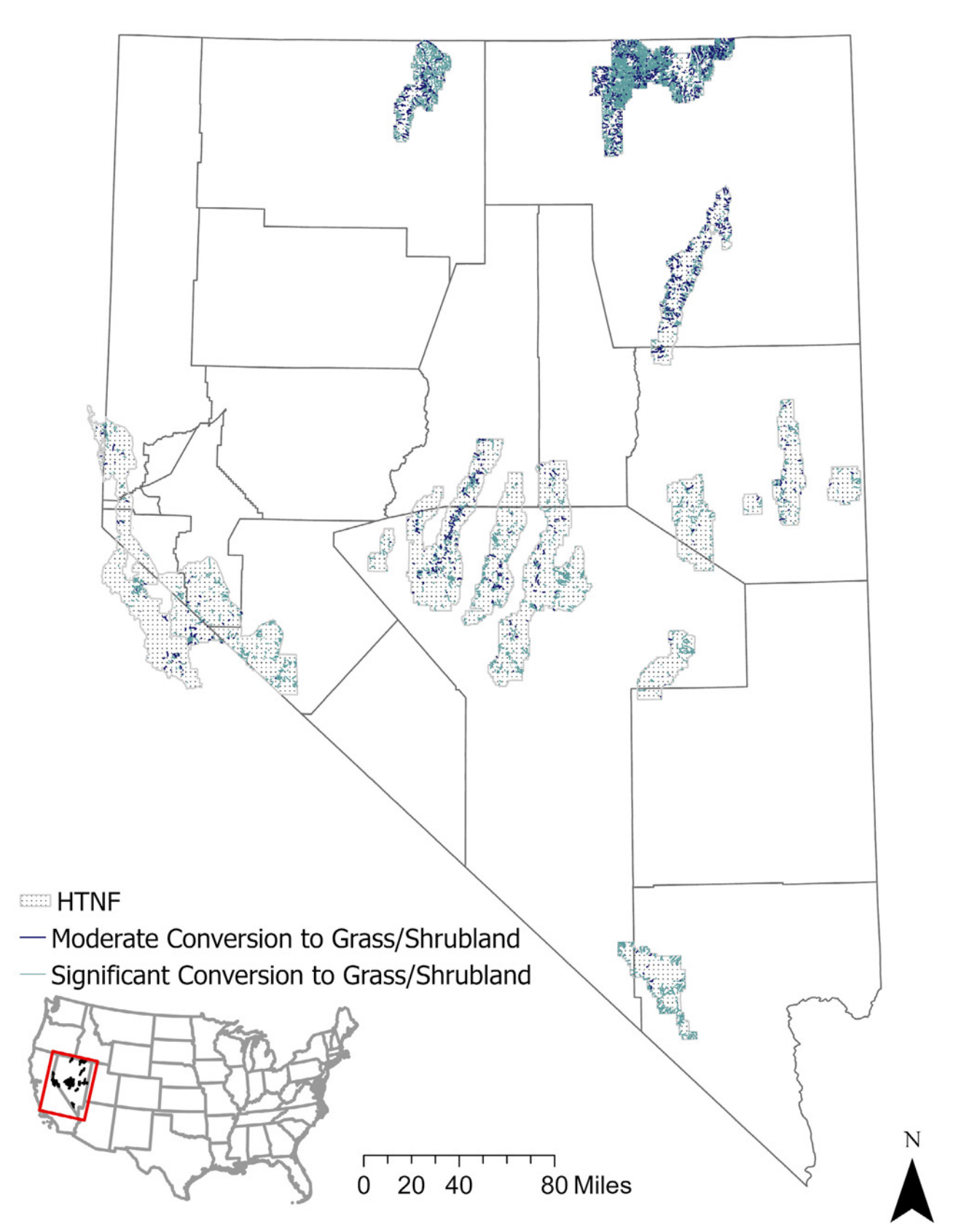


Figure H.14—Stream reaches with riparian areas that have experienced moderate or significant conversion to upland grass or shrub cover. Data from R-CAT riparian vegetation departure.

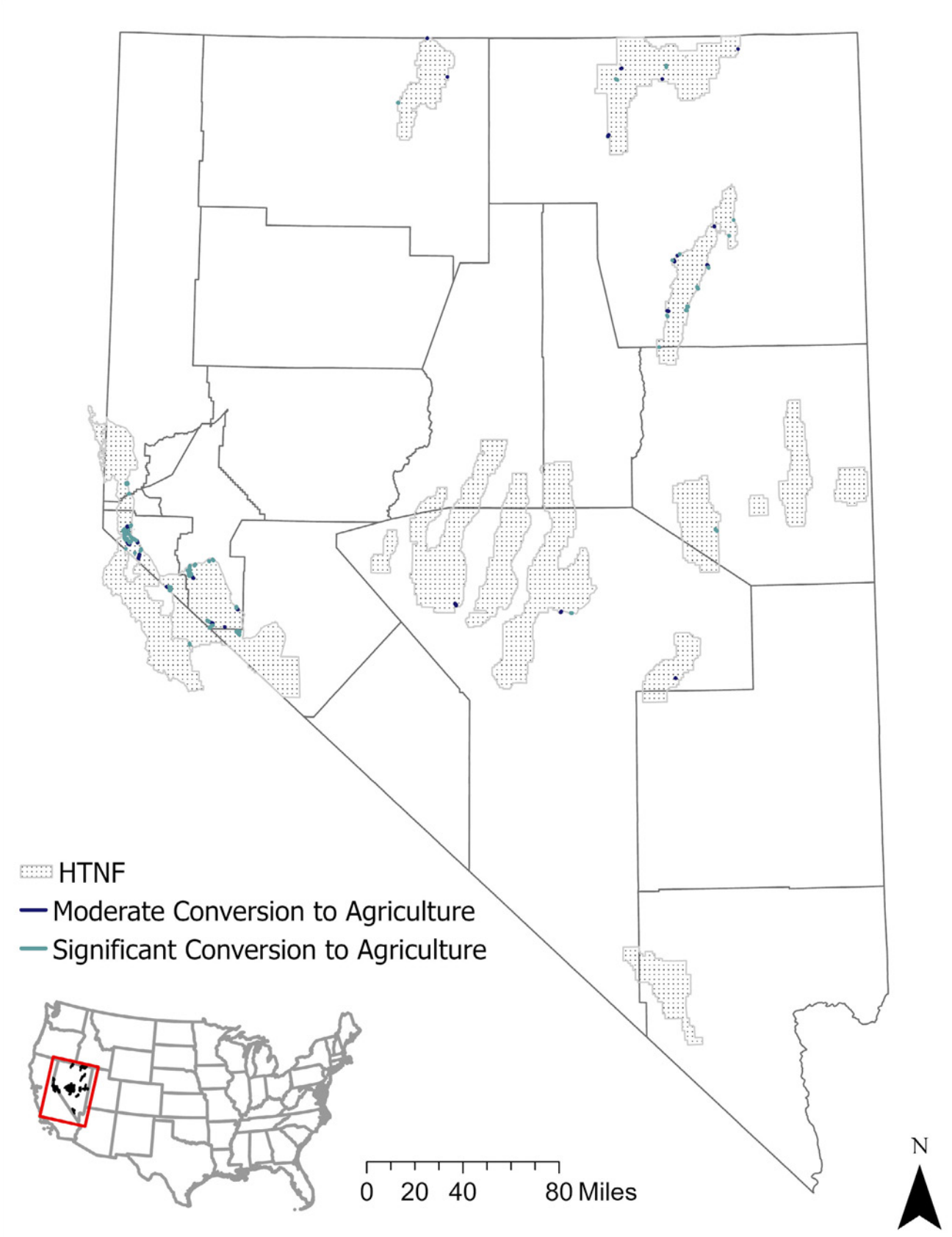


Figure H.15—Stream reaches with riparian areas that have experienced moderate or significant conversion to agriculture. Data from R-CAT riparian vegetation departure.

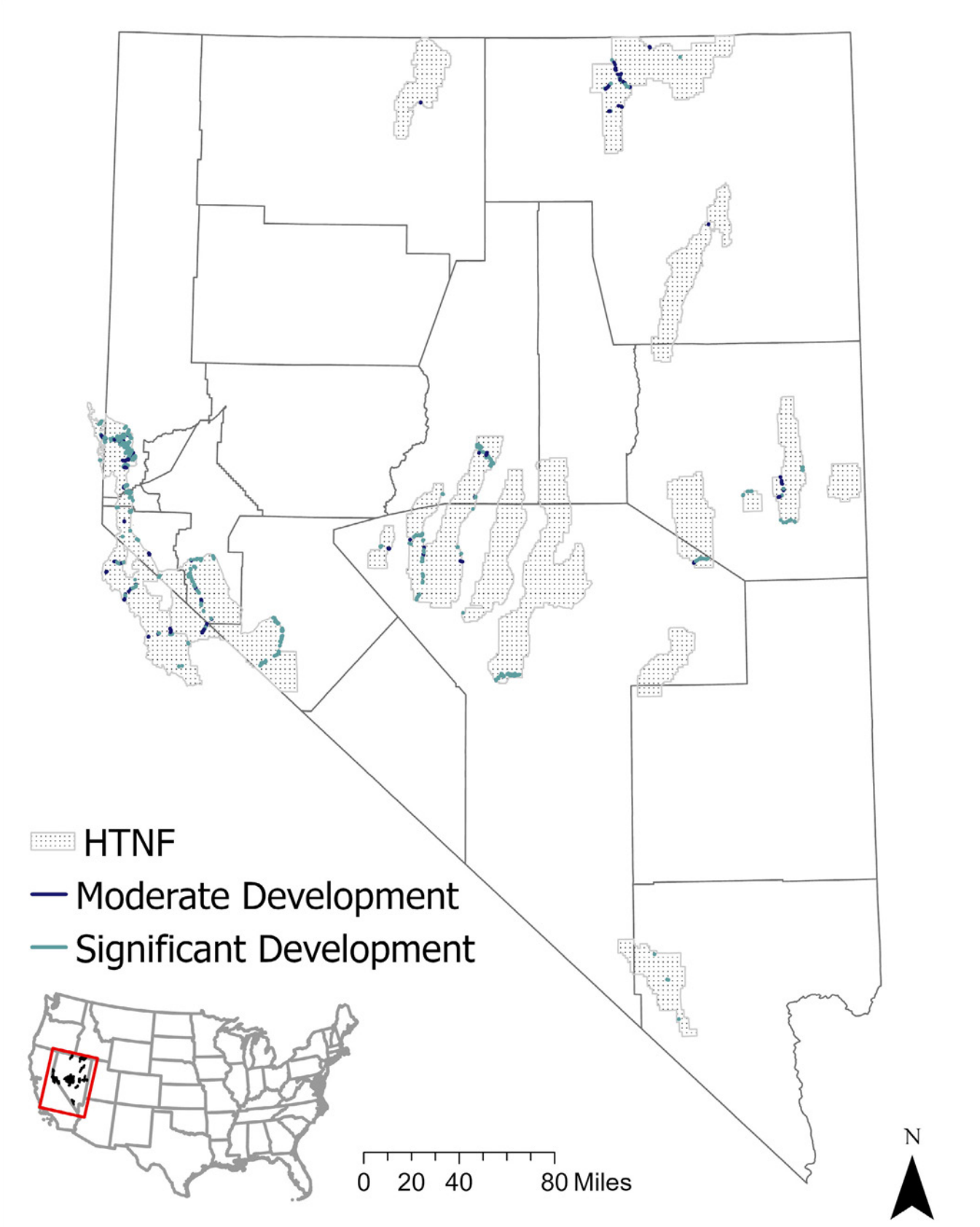


Figure H.16—Stream reaches with riparian areas that have experienced moderate or significant conversion to development. Data from R-CAT riparian vegetation departure.

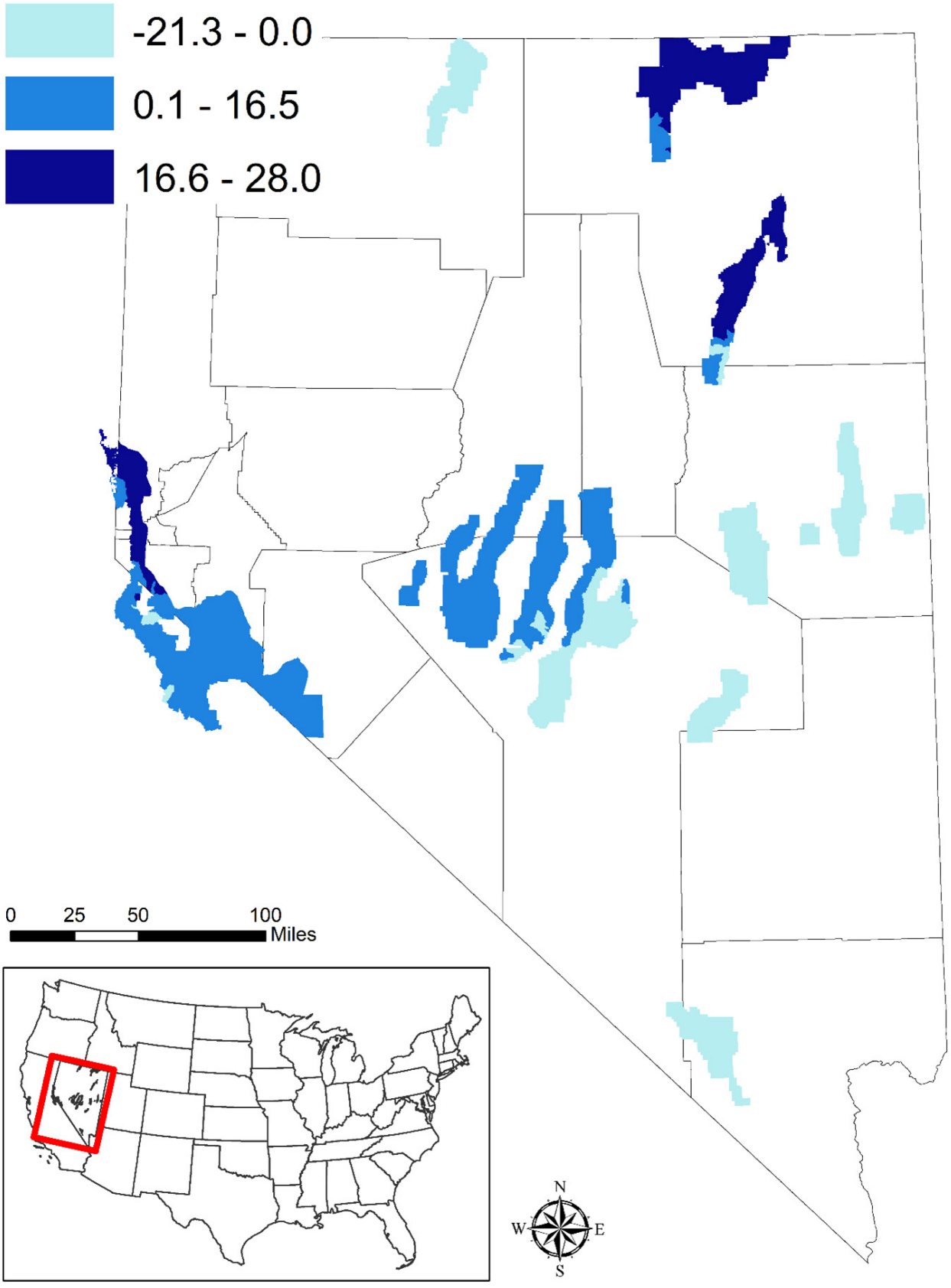


Figure H.17—Percentage deviation in fall precipitation from 2010 to 2014 compared to the previous century. Based on TCA and PRISM data.

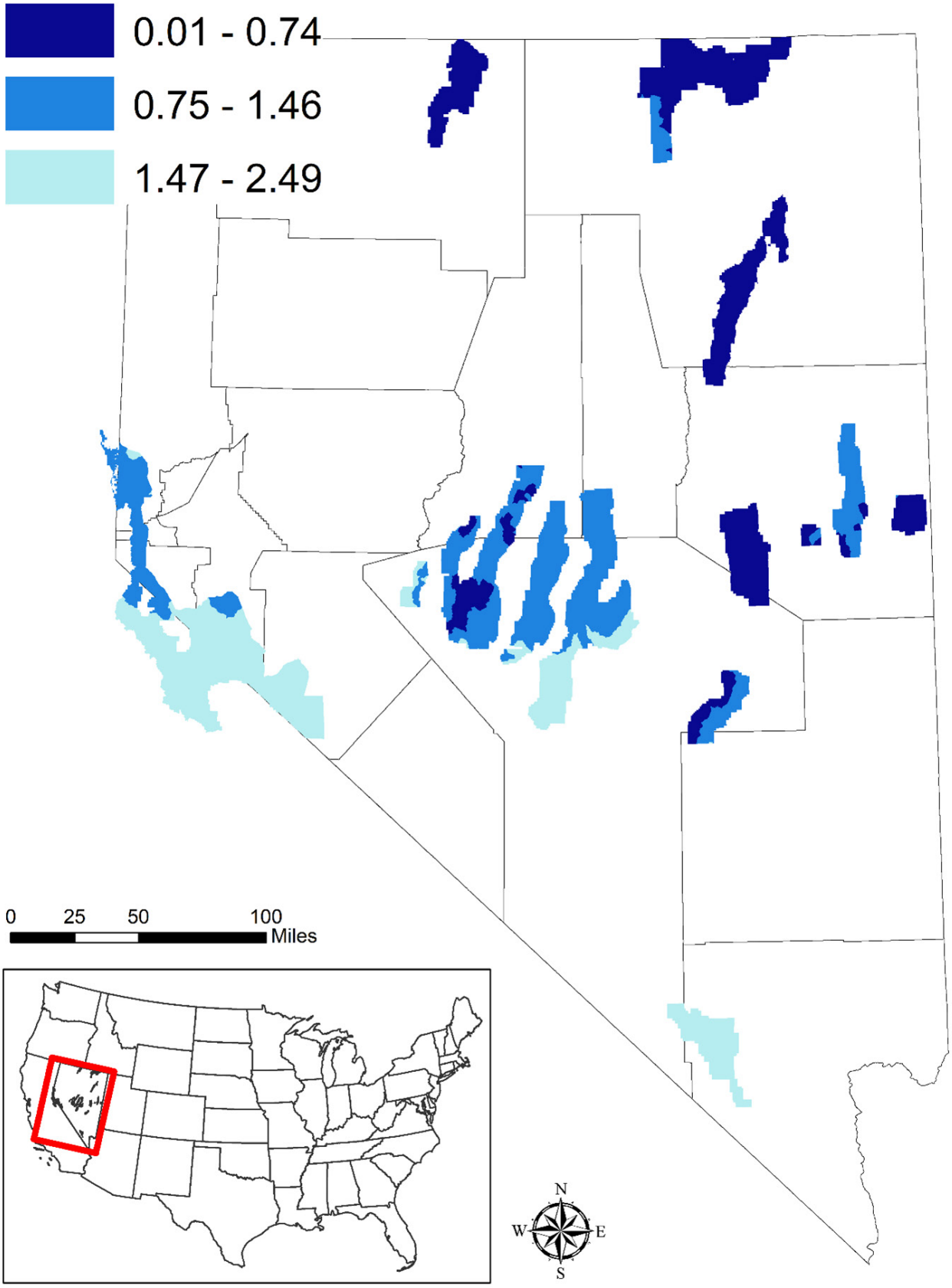


Figure H.18—Deviation in fall temperature (°F) from 2010 to 2014 compared to the previous century. Based on TCA and PRISM data.

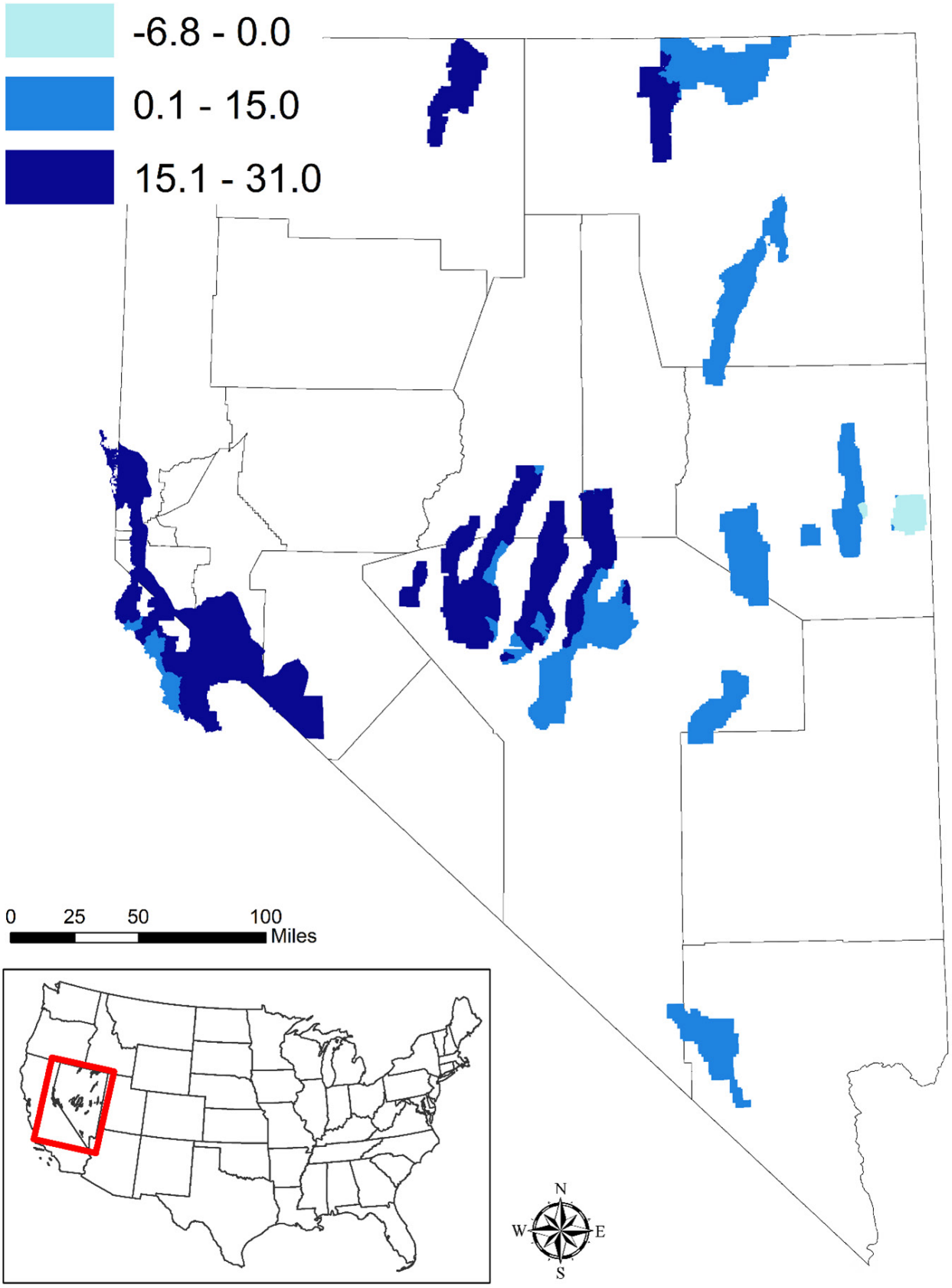


Figure H.19—Percentage deviation in winter precipitation from 2010 to 2014 compared to the previous century. Based on TCA and PRISM data.

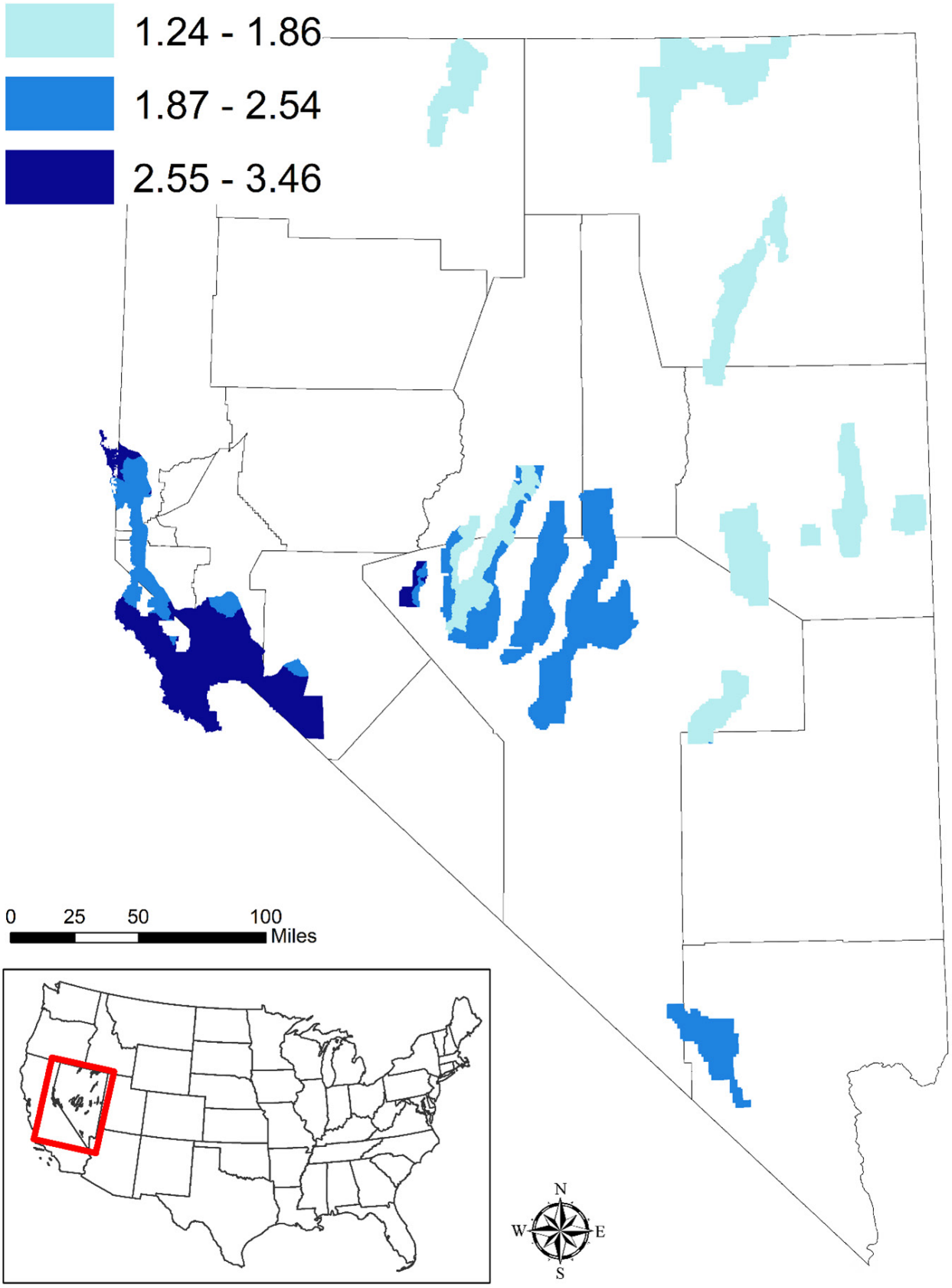


Figure H.20—Deviation in winter temperature (°F) from 2010 to 2014 compared to the previous century. Based on TCA and PRISM data.

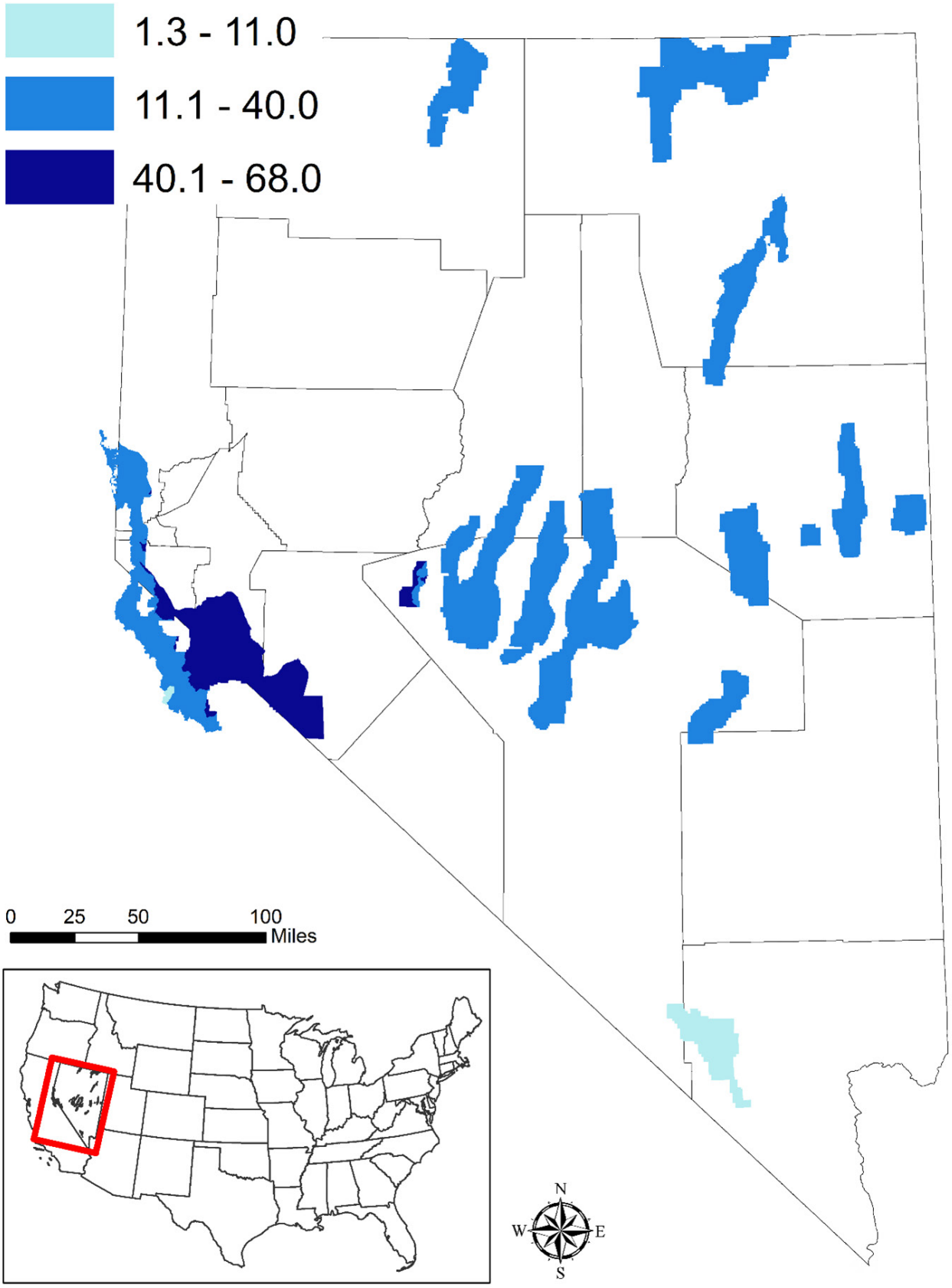


Figure H.21—Percentage deviation in spring precipitation from 2010 to 2014 compared to the previous century. Based on TCA and PRISM data.



Figure H.22—Deviation in spring temperature (°F) from 2010 to 2014 compared to the previous century. Based on TCA and PRISM data.

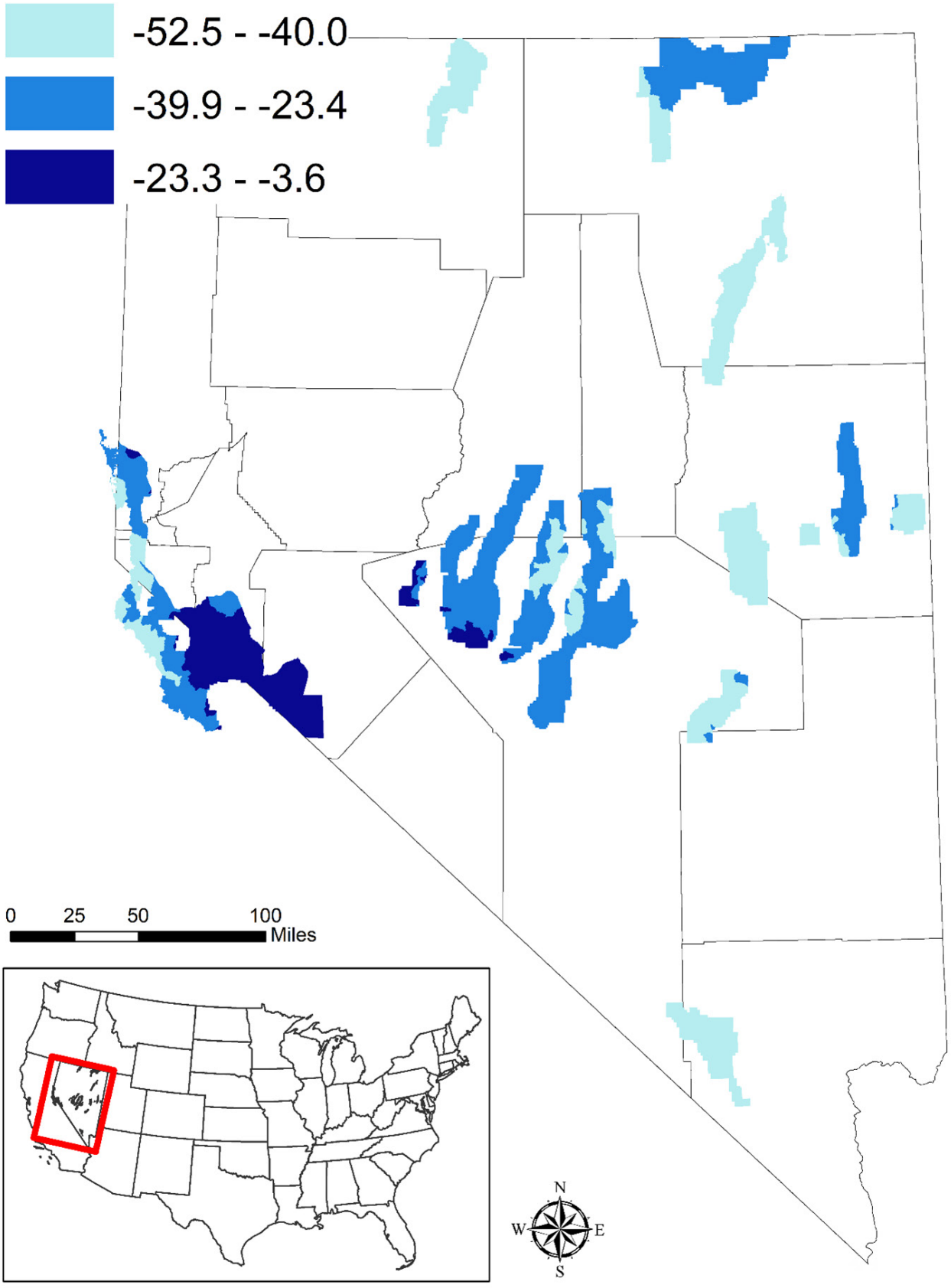


Figure H.23—Percentage deviation in summer precipitation from 2010 to 2014 compared to the previous century. Based on TCA and PRISM data.

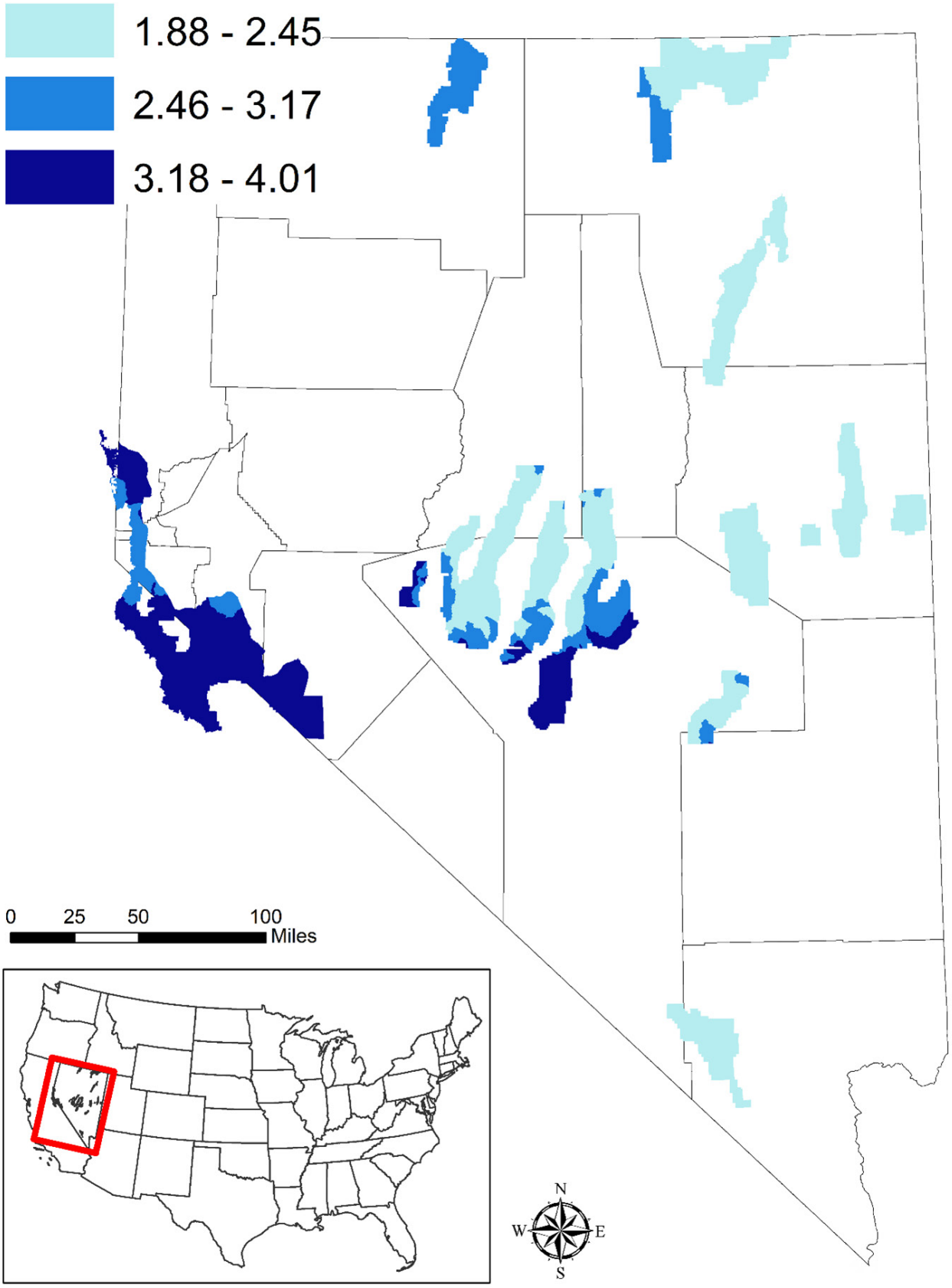


Figure H.24—Deviation in summer temperature (°F) from 2010 to 2014 compared to the previous century. Based on TCA and PRISM data.

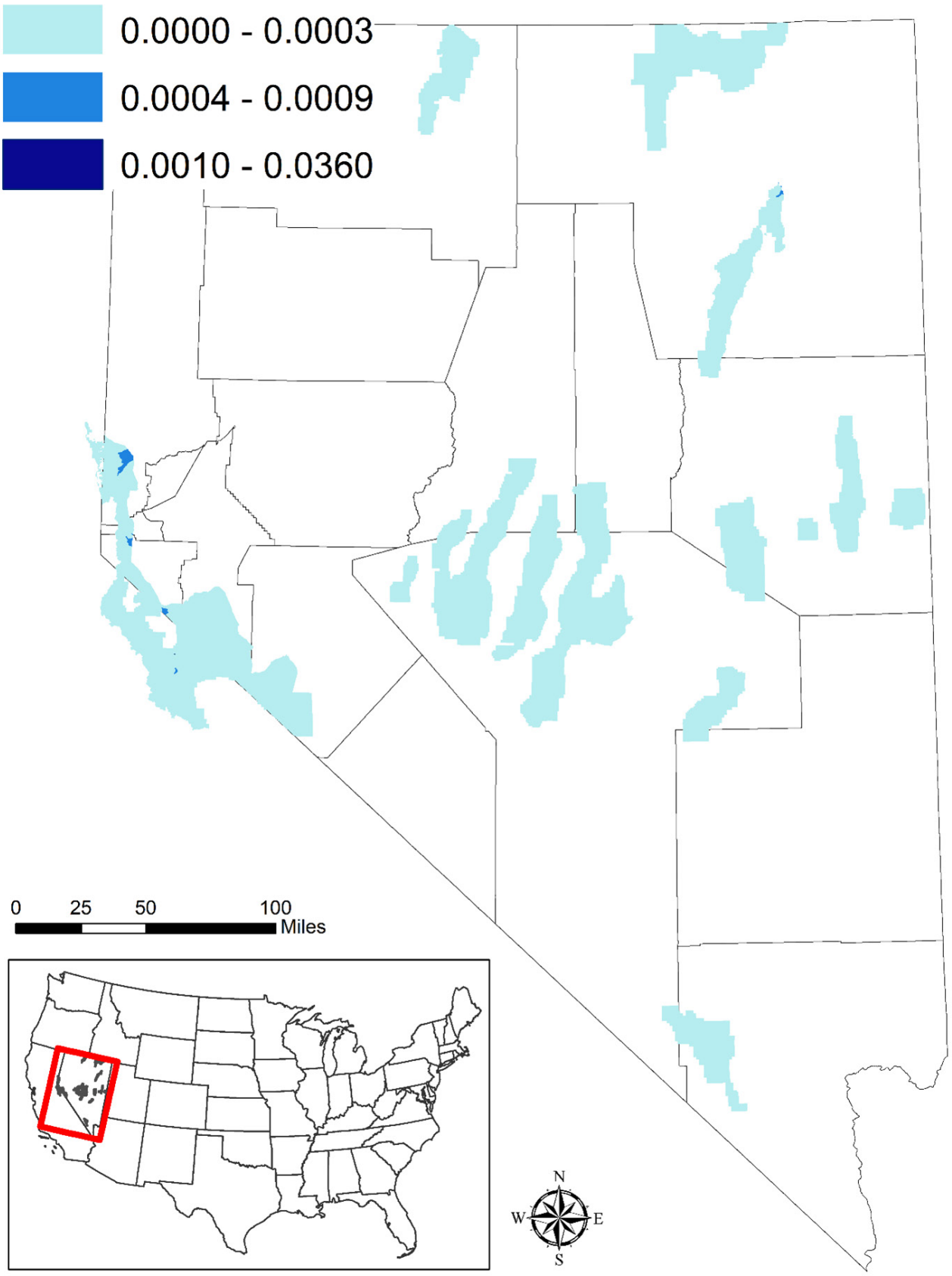


Figure H.25—Dam density (dams/acre) within 12 digit HUC watersheds.

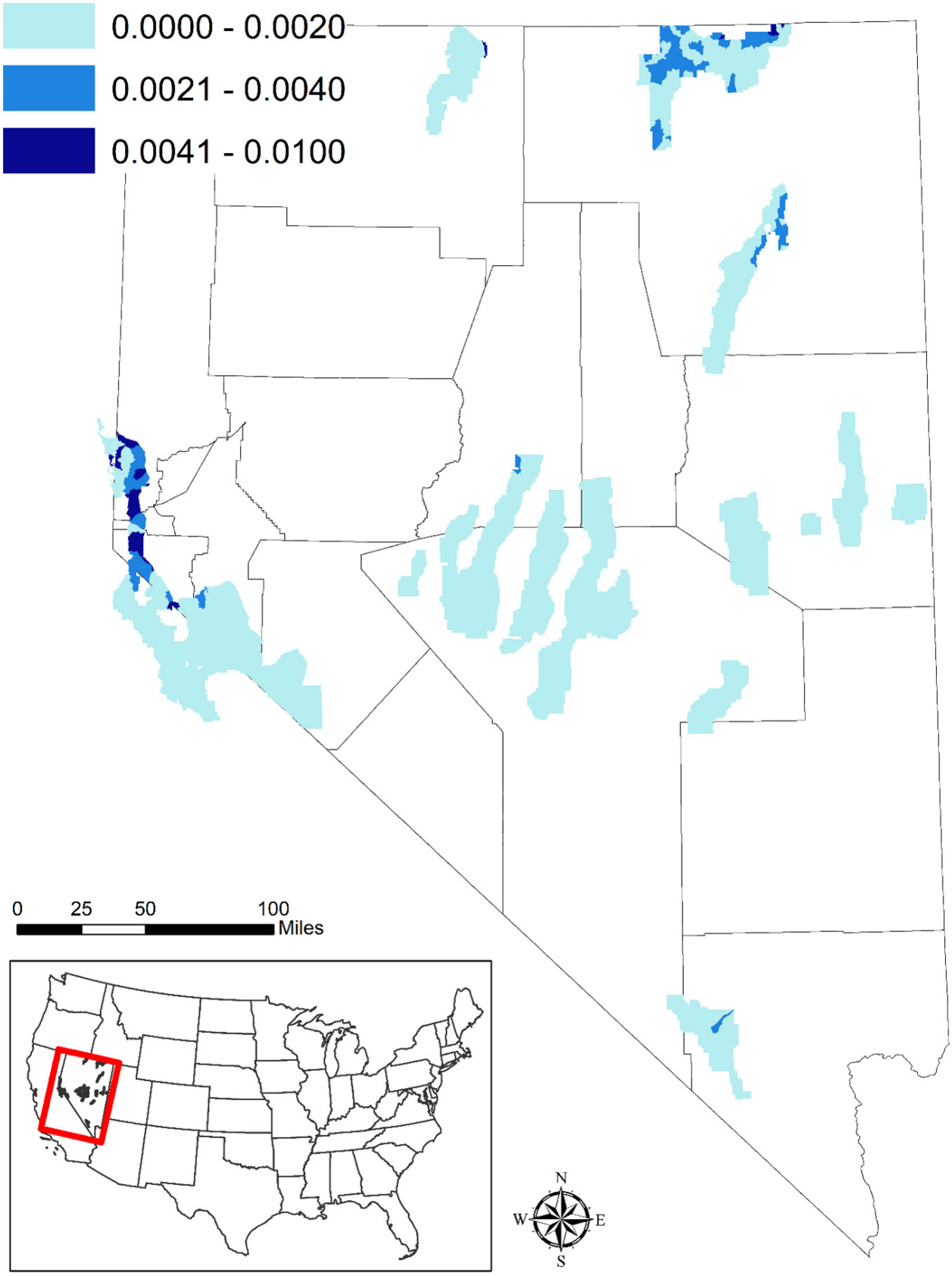


Figure H.26—Diversion density (diversions/acre) in 12 digit HUC watersheds. Data from state points of diversion GIS layer.

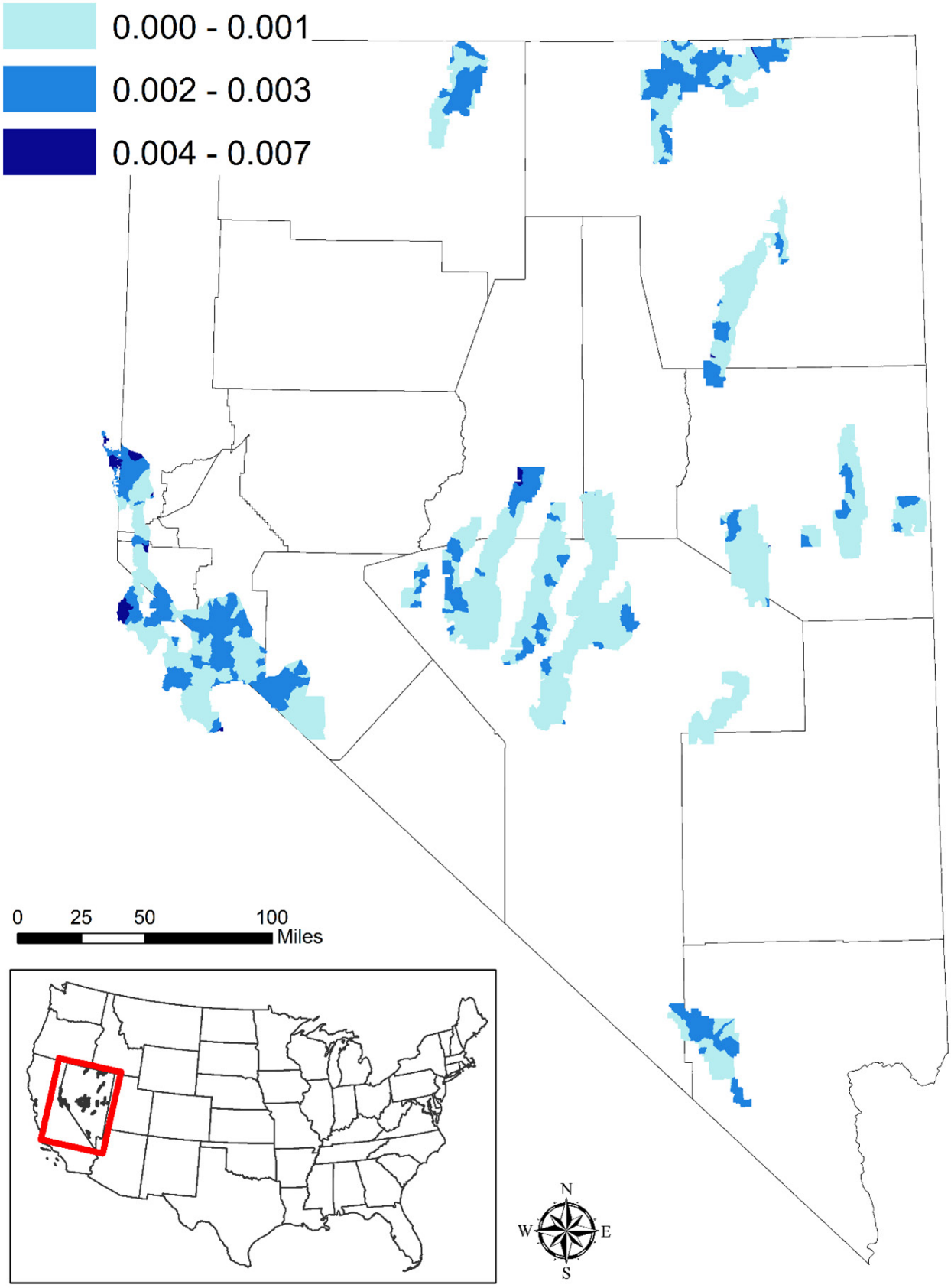


Figure H.27—Road density (miles/acre) in 12 digit HUC watersheds. Data from the TCA.

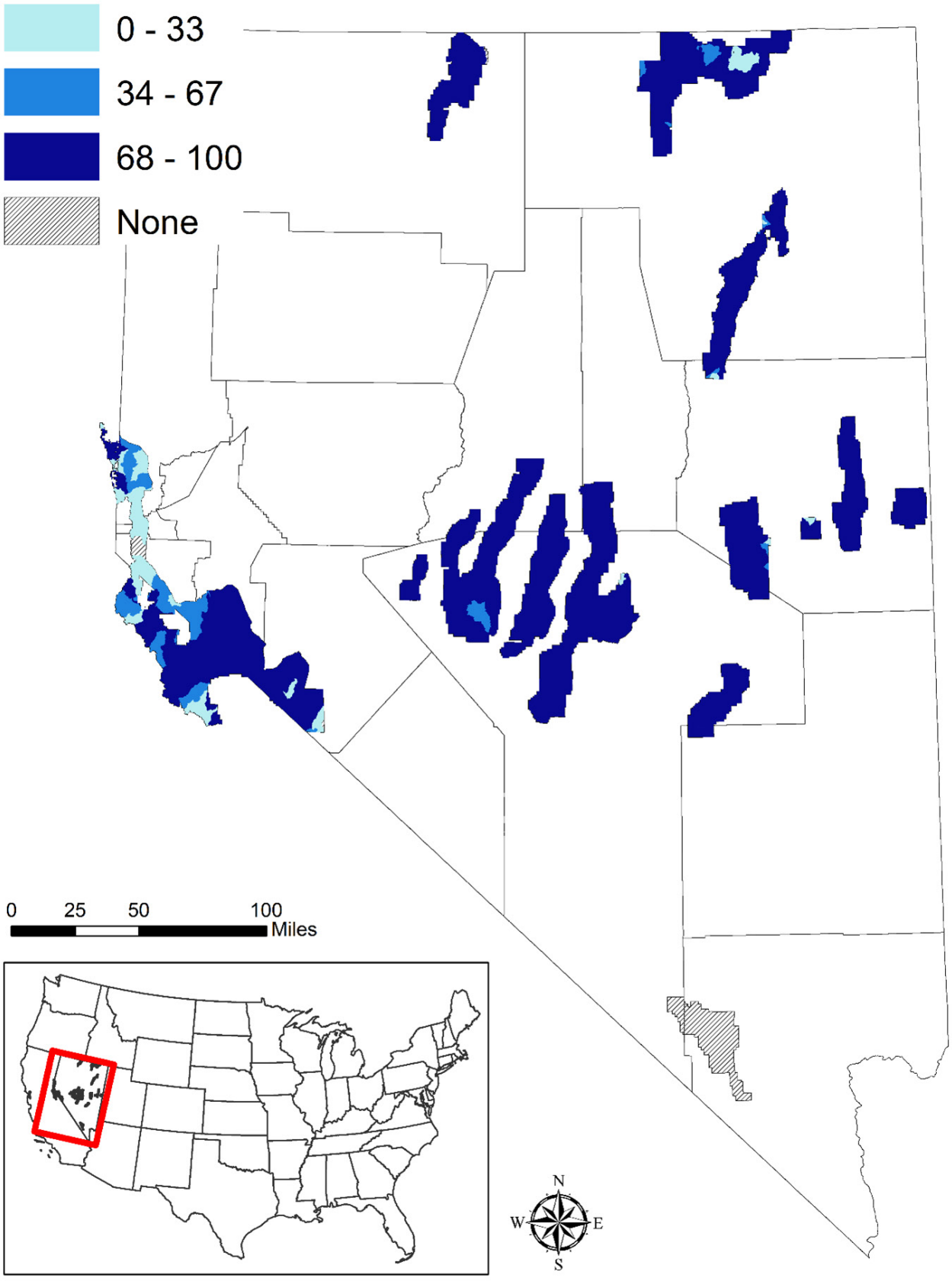


Figure H.28—Percent of 12 digit HUC watershed within a range management unit. Data from US Forest Service National Dataset.

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