

Chapter 1: Introduction and Overview

Jeanne C. Chambers, Jerry R. Miller, and Dru Germanoski

The Problem—Stream Incision and Meadow Degradation

Streams and riparian ecosystems are a particularly valuable resource in the arid to semi-arid Great Basin, supplying water for agriculture and domestic uses, forage for livestock, and habitat for diverse aquatic and terrestrial organisms. In upland watersheds of the central Great Basin, many of the streams and riparian ecosystems have been severely degraded (Chambers and Miller 2004b; Chambers and others 2004a). A primary cause of this degradation is ongoing stream incision (downcutting) that occurs during episodic high flow events (Miller and others 2001, 2004). Meadow complexes (areas with shallow water tables that are dominated largely by grasses and carices) are at especially high risk of degradation because they often occur in hydrologic and geomorphic settings that are susceptible to stream incision (Chambers and others 2004a, 2004b; Germanoski and Miller 2004; Jewett and others 2004). In many cases, streams have been isolated from their original floodplains, and there have been significant changes in channel pattern and form. As the channels have incised, the base level for groundwater discharge has been lowered, resulting in deeper water tables. Because riparian vegetation depends on groundwater availability, there have been changes in the structure and composition of meadow ecosystems (Wright and Chambers 2002; Chambers and others 2004a, 2004b). The net effect has been a decrease in the aerial extent of the riparian corridor and a loss of meadow ecosystems.

In this chapter, we briefly review the major causes of, and controls on, channel incision and meadow degradation in the central Great Basin and discuss a conceptual basis for meadow restoration and management. In subsequent chapters, we focus on our current understanding of meadow ecosystems and the development of management strategies. We begin with an overview of the geologic, climatic, and hydrologic setting of the central Great Basin.

Geological, Geographical, and Hydrologic Setting

Great Basin Physiography

The hydrologic Great Basin encompasses an area of over 500,000 km² and includes most of the state of Nevada and portions of California, Oregon, Idaho, Utah, and Arizona (fig. 1.1). Despite rugged topography and prominent topographic

relief, the region has no significant external surface drainage (Mifflin 1988). The Great Basin is part of the Basin and Range physiographic province that consists of over 400 discrete mountain ranges that are separated by intermontane basins (Dohrenwend 1987). The mountain ranges and basins are oriented in a north-south direction, vary in length from tens to hundreds of kilometers and are typically 15 to 25 km wide (fig. 1.2; Dohrenwend 1987). Basin elevations are about 1300 to 1600 m above sea level, while mountain ranges have elevations that exceed 3500 m (Stewart 1978).

The topography of the Basin and Range was produced by regional ongoing uplift and extensional tectonism that began in the Miocene (approximately 17 million years before present [BP]) (Stewart 1978; Thatcher and others 1999). Horizontal extension produced horst and graben structures. Horsts are up-thrown blocks of crustal material that are bounded by normal faults on either side. Basin-forming grabens are down-dropped crustal blocks, again bound by normal faults. Mountain ranges and basins also are formed by extension-driven rotation of crustal blocks (Stewart 1978). The high relief between mountain ranges and adjacent basins produces steep potential energy gradients that drive stream incision in the mountains and sediment transfer to the intermontane basins. As a result, the mountains are deeply incised, and mountain fronts are fringed by coalescing alluvial fans that grade into basin-fill alluvium and lacustrine deposits (fig. 1.3).

Great Basin Geology

Lithology and Structure. Bedrock within the Great Basin of central Nevada ranges from Late Precambrian to Tertiary in age and is composed of the full spectrum of rock types, including intrusive (plutonic) and extrusive (volcanic) igneous rocks, chemical and clastic sedimentary rocks and metamorphic rocks. From Late Precambrian through the Paleozoic, the area that is now the Great Basin consisted of a continental margin that was characterized by deposition of sediment from the western continental landscape. Clastic (primarily shale and sandstone) and chemical (primarily limestone) sedimentary rocks were produced in a marine sedimentary basin throughout the Paleozoic (Stewart 1978). The continental margin evolved into an active subduction zone that produced igneous plutons that intruded and metamorphosed the Paleozoic sedimentary rocks and generated explosive volcanic eruptions that mantled the landscape with ashflow tuffs, ignimbrites, rhyolite flows and, later, localized basaltic lavas.

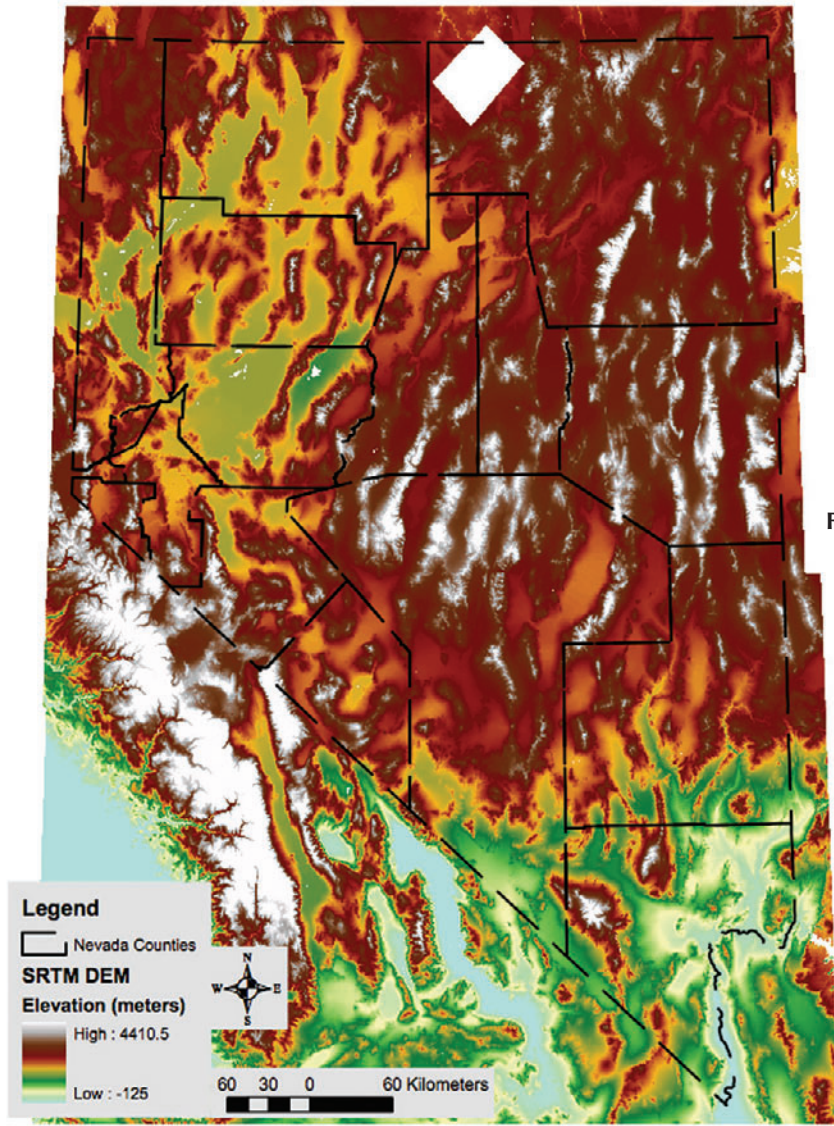


Figure 1.2. Digital elevation map for the Great Basin. White rectangle in top center reflects a gap in the elevation data. Map based on U.S. Geological Survey data files.



Figure 1.3. Alfalfa fields at the base of the alluvial apron on the east side of the Toiyabe Range that are irrigated by shallow groundwater.

The Lower Paleozoic units in the study area consist of sedimentary, low-grade metamorphic and volcanogenic rocks. In the northern portion of the study area, two distinct groups of Lower Paleozoic rocks are present: (1) a carbonate assemblage with minor shale and quartzite, and (2) an assemblage that consists of siliceous chert-rich sedimentary rocks, volcanic flows, and pyroclastic rocks (Stewart and McKee 1977). The siliceous rocks were deposited in the western portion of the depositional basin and then thrust over the carbonate rocks during the Antler Orogeny (Stewart and McKee 1977). In the southern portion of the study area, siliciclastics, including sandstones, siltstones, and shales, are more common than carbonates and have been metamorphosed to quartzites, phyllitic schists, phyllite, and slate (Kleinhampl and Ziony 1985).

During the Late Paleozoic, clastic sediment that was derived from the Antler orogenic belt was deposited across the deformed lower Paleozoic rocks. Pyroclastic volcanic rocks and clastic sedimentary rocks that were deposited in a marine back-arc basin to the west were subsequently thrust eastward during the Permian along the Golconda Fault over the coarse clastic units (Stewart and McKee 1977). Thus, Paleozoic rocks consist of a complex assemblage of rock types deposited in diverse depositional settings and thrust faulted and deformed during the Late Paleozoic Antler Orogeny.

The Paleozoic rocks were intruded by igneous plutons during the Mesozoic (primarily the Jurassic and Cretaceous), including the Austin pluton, which is the largest in the region. The Austin pluton is exposed at the surface in three areas near Austin in the Toiyabe Range. Petrologic characteristics suggest that the three exposures are part of a single large batholith that is separated by inliers of Paleozoic sedimentary rocks (Stewart and McKee 1977). The intrusive rocks primarily range from quartz monzonites to granodiorites in composition and are characterized by a platy sheet structure that makes some of the large plutons appear to be bedded (Stewart and McKee 1977).

Cenozoic age rocks are dominated by volcanic materials following the emplacement of scattered intrusive quartz monzonite and quartz diorite plutons in the Late Eocene to Early Miocene. The earliest phase of Tertiary volcanism was dominated by andesitic and dacitic lavas that were extruded during the early Oligocene. These extrusions were followed by a shift to rhyolite and quartz-latitude ash-flow tuffs in the late Oligocene. These rocks are capped by Miocene and Pliocene volcanics that range in composition from andesite to basalt with basaltic eruptions occurring into the Pleistocene (Stewart and McKee 1977).

Paleozoic rocks were folded, metamorphosed, and cut by low angle thrust faults from west to east during the Late Paleozoic Antler and Sonoma Orogenies and, to a lesser extent, during the Mesozoic Laramide Orogeny. Recent work in the Toiyabe Range in the center of the study area (fig. 1.1) indicates that the structural history of the Basin and Range is more complex than previously recognized and that there were elements of structural extension and transpression in the Late Paleozoic that produced normal faults perpendicular and tangential to the Toiyabe Range (Smith and Miller

1990). In the Miocene, the tectonic regime changed from compressional to an extensional regime that led to episodes of uplift and crustal extension that were responsible for development of the modern topography.

River incision into rising, fault-bounded horsts and rotationally uplifted mountain ranges coevolved with uplift and both processes continued throughout the Cenozoic. As a result, mountain uplands are deeply dissected by rivers that drain both east and west from the axis of each range into intermontane basins. Although the mountains are erosional landscapes with streams that flow directly on bedrock in many locations, valleys are locally floored by Holocene age alluvium to depths exceeding 50 m. Axial valley-fill sediment interfingers with alluvial fan sediment from side-valley tributaries. In many cases, fans prograde into the axial valleys as pronounced landforms. Hillslopes are mantled locally with a thin veneer of alluvium with scree chutes formed in zero-order tributaries. Soils are typically thin and poorly developed owing to the arid climate, steep slopes, and erosion.

Great Basin Hydrology

Distribution of Precipitation and Evapotranspiration.

The Great Basin is a semi-arid to arid region. Average annual precipitation varies from less than 150 to approximately 700 mm/yr (6 to 27.5 inches/yr; fig. 1.4) with the majority of the precipitation falling as snow during winter months. Precipitation varies significantly between individual mountain ranges and intervening basins and from mountain range to mountain range due to orographic effects (Mifflin 1988). The highest precipitation occurs in higher, broader mountain ranges because of the ability of high mountains to influence moist air masses moving across the basin from west to east.

In the Great Basin, evaporation potential exceeds annual precipitation because of the combination of low precipitation and high average temperatures. Similar to the spatial distribution of precipitation, the evaporation potential varies from range to range and between a mountain range and its adjacent basins. However, the trends are opposite of precipitation patterns; average annual temperature and evaporation potential is higher in intermontane basins than in mountain ranges, and annual average temperature varies inversely with elevation in the mountains. Therefore, the water supply is decidedly asymmetric with mountains serving as water sources and basins serving as "sinks."

Major Rivers and Mountain Streams. The Basin and Range topography exerts tremendous control on the regional hydrology (fig. 1.5). The down-dropped grabens and intermontane basins create regionally significant depressions that capture surface water drainage for hundreds of square kilometers. In the most extreme case, basin elevation extends below sea level in Death Valley in the southwestern portion of the Basin and Range. Thus, the Great Basin is a unique region in North America because all major rivers in the region drain into lakes or sinks in intermontane basins, and no major rivers leave the region and drain to the ocean.

The longest river in the Great Basin is the Humboldt River, which drains from east to west across northern Nevada from

Average Annual Precipitation

Nevada

Period: 1961-1990 Unit: inches

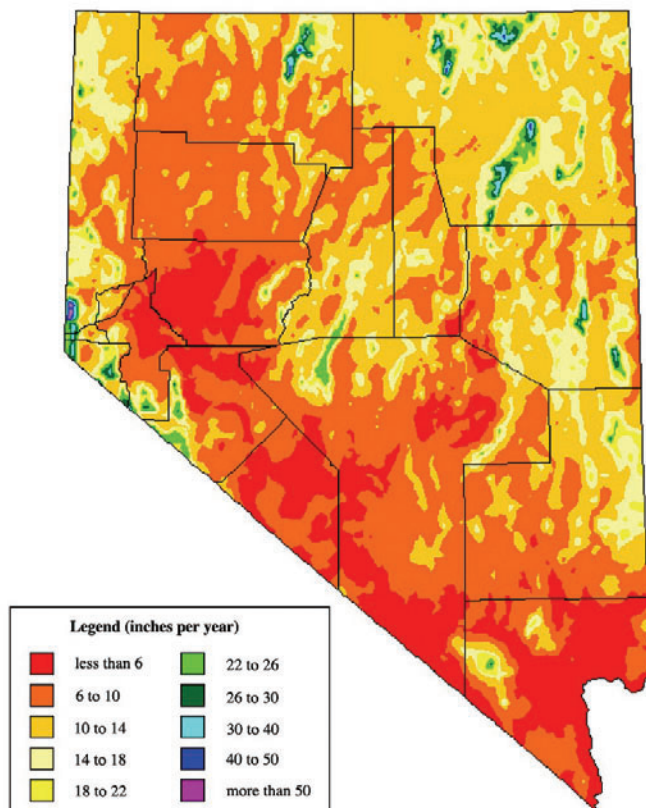


Figure 1.4. Average annual precipitation for the State of Nevada.

its headwaters in the East Humboldt Range, through Rye Patch Reservoir, to its terminus at Humboldt sink almost 500 km away. The Reese River rises in the southern portion of the Toiyabe Range and flows north to its junction with the Humboldt River at Battle Mountain. It is the second longest river in Nevada but, despite its regional prominence, the Reese River is intermittent and consists of alternating gaining and losing reaches. In fact, along many segments the valley floor lacks well-defined surface channels, and down-valley flow of water primarily occurs in the subsurface. The Reese River has flowed as a continuous surface water body from head to mouth only three times in the Twentieth Century. Other major rivers in the Great Basin are the Carson River, which drains into Carson Sink, and the Truckee River, which rises in the eastern Sierra and drains into Pyramid Lake. Many intermontane basins in the region do not have major streams or rivers and instead are occupied by playa lakes that capture all of the local drainage from the surrounding mountains.

The highest density of surface water streams occurs in the mountains because most precipitation in the region falls in the mountains, where evapotranspiration is relatively low. Mountain streams are fed by rainfall, snowmelt, and springs



Figure 1.5. River systems in the hydrologic Great Basin of Nevada.

that are distributed throughout the drainage basins particularly at mid to high elevations.

Discharge from mountain watersheds varies with drainage basin area, local mean annual precipitation, and percentage of the drainage basin that is at high altitude (Hess 2002). Because evapotranspiration potential increases from mountains to intermontane basins and because alluvial fan sediments at mountain fronts tend to be thick and permeable, most mountain streams are rarely integrated with the intermontane basin drainage system. Most of the time a significant percentage of water that is delivered to the mountain front from small mountain streams infiltrates into the alluvial-fill sediments. High evapotranspiration rates further deplete this surface water discharge as streams transition from cooler, more shaded confines of mountain valleys onto the apex of the mountain-front alluvial fans (fig. 1.3). Large watersheds that drain higher mountain systems like Big Creek and Kingston Canyon in the Toiyabe Range and Barley Creek in the Monitor Range are able to collect sufficient discharge to flow into the axes of intermontane basins more frequently. Surface water drainage networks are typically integrated as continuous surface water flow systems with a frequency of about several times per century under the current climatic regime. However, mountain watersheds may feed playa lakes and master drainage networks far out into the main basins as subsurface groundwater flow.

Causes of Degradation—Climate Change and Other Natural and Anthropogenic Disturbance

The causes of degradation of riparian corridors and meadow complexes in the central Great Basin are the result of complex and interrelated responses of geomorphic, hydrologic, and vegetation processes to natural and anthropogenic disturbances as well as changes in climate. Anthropogenic disturbances include all human activities that affect physical and biological processes within a watershed, and natural disturbances include phenomena such as floods, landslides, and wildfires. Climate change operates over longer temporal scales and larger spatial scales than natural disturbances and exerts a major control on watershed processes in arid and semi-arid ecosystems. Restoration and management activities must therefore take into account the significant effects of both past and present climate on geomorphic and fluvial processes in the Great Basin and, consequently, on riparian and aquatic ecosystems. In upland watersheds of the central Great Basin, climate-driven changes in hillslope and fluvial processes that occurred during the mid-to-late Holocene still influence the composition and pattern of riparian ecosystems over a broad range of scales (Miller and others 2001, 2004; Chambers and others 2004a). Paleocological and stratigraphic data collected in the central Great Basin indicate that a major drought occurred in the Region from approximately 2580 to 1900 years BP (Miller and others 2001; Tausch and others 2004). During this drought, most of the available fine-grained sediments were stripped from hillslopes and deposited on valley floors and side-valley alluvial fans (Miller and others 2001, 2004). As a consequence of this hillslope erosion, streams are currently sediment limited and exhibit a natural tendency to incise. Available geomorphic data indicate that over the past 2000 years, the dominant response of streams to both natural and anthropogenic disturbance has been incision. The most recent episode of incision began about 450 years BP before Anglo-American settlement of the region in 1860. However, incision has been more intense and pervasive during the past 150 years. Most of this recent incision occurs during episodic, high flow events that are highly variable both among and within years in these semi-arid ecosystems. In recent decades, high flow events capable of producing significant incision occurred in the mid-1970s, 1983, 1995, 1998, and 2005 due to high precipitation and rapid runoff (Chambers and others 1998; Germanoski and others 2001).

The rate and magnitude of stream incision in central Great Basin watersheds have been increased by anthropogenic disturbances. Roads that are located in valley bottoms are perhaps the major human-related cause of recent stream incision and riparian area degradation in the central Great Basin. The effects of roads on stream systems have been clearly documented for other locations (USDA Forest Service 1997; Jones and others 2000; Trombulak and Frissel 2000). In the central Great Basin, several cases of “road captures” have been documented and many other cases have been observed where streams were diverted onto road surfaces during high

flows (Lahde 2003). These diversions result in increased shear stress and stream power and, ultimately, localized stream incision (Lahde 2003). Once initiated, knickpoint migration often results in stream incision along the channel.

There is no direct evidence linking regional stream incision to overgrazing by livestock in the central Great Basin, but overgrazing has undoubtedly had localized effects on stream channels. Effects similar to those for road captures have been documented for livestock trails elsewhere in the western United States (Trimble and Mendel 1995) and likely occur for off-road vehicle trails. Also, overgrazing by livestock has been shown to negatively affect stream bank and channel stability and often has been associated with localized changes in stream morphology (see reviews in Trimble and Mendel 1995; Belsky and others 1999; National Research Council 2002). Generalized effects of overgrazing by livestock on riparian ecosystems include undesirable changes in species composition and structure, soil properties, biogeochemical cycling, and water quality. These effects are well documented elsewhere (see reviews in Kauffman and Krueger 1984; Skovlin 1984; Clary and Webster 1989; National Research Council 1992, 2002; Fleischner 1994; Ohmart 1996; Belsky and others 1999).

Processes That Influence Stream Incision and Meadow Ecosystems

Stream and restoration ecologists have recognized for some time that effective management and restoration approaches must not only address the appropriate scales but also must be process based (Frissell and others 1986; Goodwin and others 1997). Recent research in the central Great Basin illustrates the close linkages among watershed, valley segment, and reach-level controls and geomorphic, hydrologic, and vegetation processes (Lord and others 2009). Watersheds differ in sensitivity to both natural and anthropogenic disturbance and, thus, in the likelihood of stream incision (Germanoski and Miller 2004). Ecologists use the terms “resistance” and “resilience” to evaluate the sensitivity of ecosystems to disturbance. Resistance refers to the ability of an ecosystem to maintain characteristic processes despite various stressors or disturbances, while resilience refers to the capacity to regain the same processes over time following stress or disturbance (Society for Ecological Restoration International 2002). Major disturbances can result in threshold crossings and new ecological states characterized by different ecological processes. Similarly, geomorphologists describe the sensitivity of landforms to disturbance as the propensity for a change in the environment to result in a new equilibrium state (Schumm and Brackenridge 1987; Germanoski and Miller 2004). Watershed sensitivity to disturbance is influenced by factors such as the erosional resistance of the underlying bedrock and channel-forming materials and watershed relief, morphometry, and hydrology. In the central Great Basin, watershed sensitivity to disturbance and, thus, stream incision is related to watershed characteristics such as geology, size, relief, and morphometry and valley

segment attributes such as gradient, width, and substrate size (Germanoski and Miller 2004). Watersheds that are highly sensitive to disturbance exhibit a greater response to more frequent, lower magnitude runoff events than watersheds that are less sensitive to disturbance.

The combined geomorphic and hydrologic characteristics of the watersheds determine the pattern and composition of riparian vegetation at watershed to valley segment scales (Chambers and others 2004a, 2004b). Thus, watershed, valley-segment, and stream reach attributes, such as those that characterize basin sensitivity to disturbance, also have good predictive value for riparian ecosystems, including the presence, characteristics, and ecological condition of meadow complexes. For example, flood-dominated watersheds that are characterized by tertiary volcanic rock, high-relief, narrow valleys, bedrock control, minimal sediment storage, and multiple discontinuous terraces rarely have the geomorphic or hydrologic conditions to support meadow ecosystems (Chambers and others 2004b; Germanoski and Miller 2004). In contrast, fan-dominated watersheds that are characterized by prominent side-valley alluvial fans or side-valley tributary deposits (graded fans) often have the geomorphic and hydrologic conditions necessary to support meadow complexes.

Watersheds with prominent side-valley alluvial fans have been well-studied in the central Great Basin (Germanoski and Miller 2004; Jewett and others 2004; Miller and others 2001, 2004) and provide an excellent example of how watershed characteristics influence the occurrence of meadows and processes that cause meadow degradation over time. The most recent period of fan aggradation in the region occurred during the first half of the drought that occurred from about 2500 to 1300 years BP. In some cases, the fans extended across the entire width of the valley floor and impinged on opposing hillslopes, blocking down-valley transport of water and sediment along the axial stream channel. Significant quantities of sediment were deposited upstream of these fans, resulting in a reduction in valley floor gradient and an increase in valley floor width. The toes of the fans were subsequently breached, and fan sediments were carried down valley, causing several meters of aggradation along the riparian corridor. Today, watersheds with well-developed fans often are characterized by stepped-valley profiles and riparian corridors that exhibit abrupt changes in local geomorphic, hydrologic, and vegetation attributes. Meadow ecosystems typically occur upstream of side-valley alluvial fans where necessary conditions (bedrock highs, finer textured sediments, and/or springs) exist to maintain shallow water tables. Woody vegetation (willows, rose, aspen, and cottonwood) typically occurs at the fan and above the meadow complex. Many fans serve as local base-level controls that determine the rate and magnitude of upstream incision. These fans are subject to stream incision due to high shear stress associated with high flow events. Consequently, meadow ecosystems that are located immediately upstream of alluvial fans often are at risk of degradation due to stream incision through fan deposits.

Regardless of the watershed characteristics and cause of disturbance, stream incision lowers the base level for groundwater discharge and may result in deeper water

tables. Meadow complexes occur along hydrologic gradients (Weixelman and others 1996; Castelli and others 2000) that are influenced by the rates and magnitudes of incision along the axial channels and development and entrenchment of surface channels within meadows (Wright and Chambers 2002; Chambers and others 2004a, 2004b; Jewett and others 2004). At one end of the hydrologic gradient, wet meadow ecological types exist with water tables at or near the ground surface and limited, shallow, and discontinuous surface channels. Prior to incision, shallow overland flow typically predominates during spring snowmelt and periods of high runoff. At the other end of the hydrologic gradient, dry meadow and sagebrush ecological types exist that have water tables from 150 to 250 cm below the ground surface and that seldom experience overland flows. As stream incision progresses and water tables drop, wetter meadow ecological types are progressively converted to drier meadow types. In the worst case scenario, the hydrologic regime and riparian vegetation are so severely affected that meadow complexes are replaced by drier plant communities that are dominated by sagebrush and wetter meadow plant communities exist only within the stratigraphic record.

Conceptual Basis for Restoration and Management

Restoring and maintaining riparian ecosystems in the Great Basin is a management priority but has proven difficult because of ongoing and widespread stream incision and failure of standard stream stabilization measures such as livestock management or instream structures to prevent or reverse this degradation (Clary 1995; Kondolf 1995; Kaufman and others 1997; Clary and Kinney 2002; Wohl 2004). Many streams and riparian ecosystems in upland watersheds of the central Great Basin are currently functioning as nonequilibrium systems due to depletion of hillslope sediments during the mid-to-late Holocene drought and the tendency for stream incision (Chambers and others 2004b; Germanoski and Miller 2004; Miller and others 2004). Some streams have adjusted to the current geomorphic conditions and have reached their maximum depth of incision under the current sediment and hydrologic regime. Others are still adjusting and will continue to incise because of channel heterogeneity and lack of hillslope sediments. In many cases, incised streams have crossed geomorphic thresholds and, because of the changes in stream processes and groundwater regimes, riparian ecosystems also have crossed thresholds. Threshold crossings occur when a system does not return to the original state following disturbance, and can be defined based on the limits of natural variability within systems (Ritter and others 1999).

For stream systems and riparian ecosystems in the central Great Basin that have crossed geomorphic and hydrologic thresholds, return to the predisturbance state is not an ecologically or economically viable goal. The restoration and management potential of a stream system or riparian ecosystem must be based on current, not historic, conditions.

Chambers and others (2004b) defined the goal of restoration and management activities as reestablishing and maintaining sustainable fluvial systems and riparian ecosystems that exhibit both characteristic processes and related biological, chemical, and physical linkages among system components (modified from Natural Research Council 1992). In this context, sustainable stream systems and riparian ecosystems exhibit natural variability, yet maintain characteristic processes, including rates and magnitudes of geomorphic activity, hydrologic flux and storage, biogeochemical cycling and storage, and biological activity and production (Christensen and others 1996; Wohl and others 2005). Sustainable ecosystems provide valuable ecosystem services, including high quality water, habitat for aquatic and terrestrial organisms, forage and browse, and recreational opportunities.

Reestablishing and maintaining riparian ecosystems in the central Great Basin and elsewhere requires an integrated and interdisciplinary approach that addresses the geomorphic, hydrologic and biological components of the system (Chambers and others 2004b; Wohl and others 2005). As illustrated above, and as has been advocated elsewhere, a critical first step is to develop an understanding of the causes

of degradation and of the underlying physical and biotic processes (Goodwin and others 1997; Wissmar and Beschta 1998; Wohl and others 2005). Once developed, this integrated understanding of riparian ecosystems can be used for prioritizing restoration and management activities and for determining appropriate techniques.

Developing the necessary understanding for effective management/restoration of riparian areas requires addressing appropriate spatial and temporal scales. A watershed can be viewed as a hierarchical system containing different spatial and temporal scales that are nested within one another (Schumm and Lichty 1965; Frissell and others 1986; Newbury and Gaboury 1993). Scales can range from an entire watershed (10^1 to 10^6 years, km^2) to individual events or particles (<10 years, $<0.10 \text{ cm}^2$). A watershed perspective and the historical evaluation of different scales provide a more complete understanding of riparian ecosystems and their interactions with the geomorphic and hydrologic regime (Wissmar and Beschta 1998). Scales that are addressed here are the watershed, riparian corridor, valley segment, and stream reach (fig. 1.6). The riparian corridor is the integrated network of stream channels and adjacent geomorphic

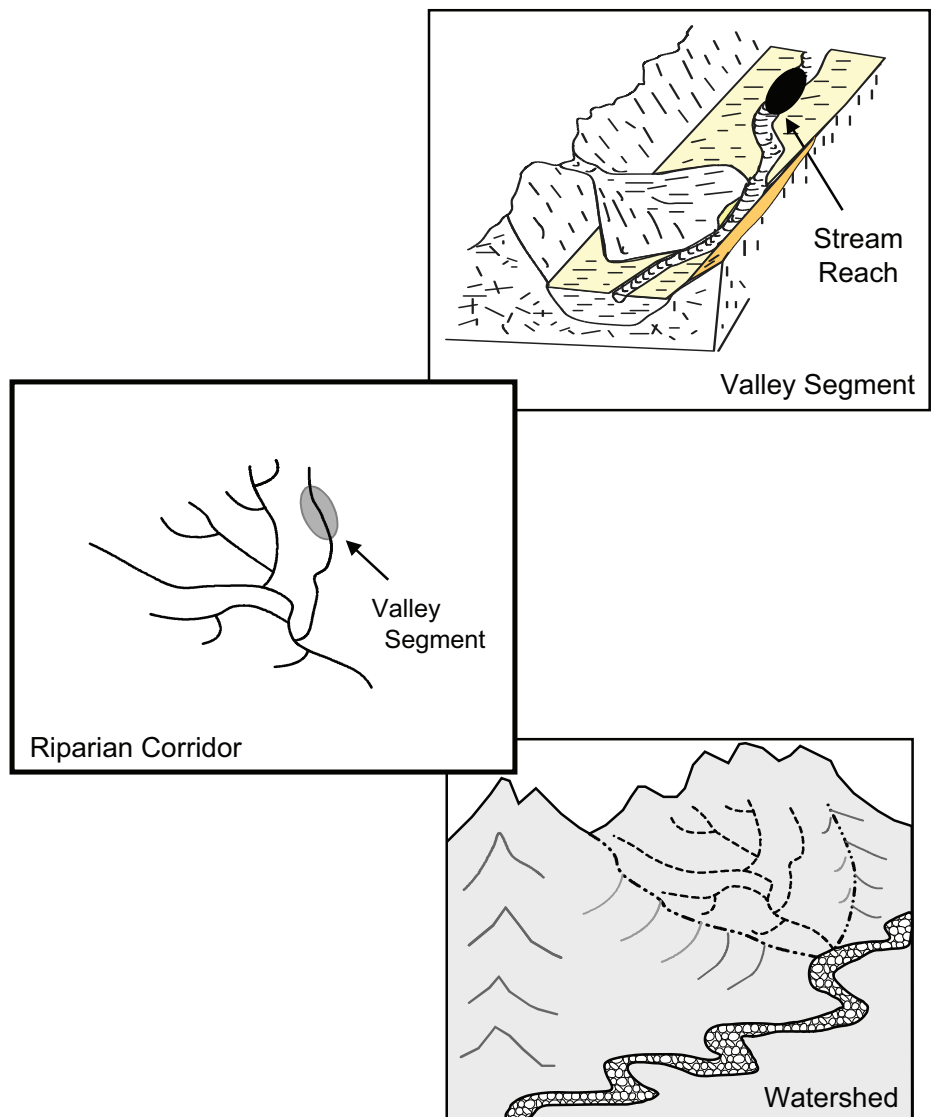


Figure 1.6. Spatial scales of study.

surfaces (in other words, floodplain and terraces) that are located primarily on alluvial deposits in valley bottoms. The riparian corridor receives water and sediment from surrounding hillslopes and represents a pivotal interface between surface and groundwater flow systems. Characteristics of watersheds and riparian corridors are often closely related to sensitivity of watersheds to disturbance, likelihood of stream incision (Germanoski and Miller 2004), and dominant vegetation types within the watershed (Chambers and others 2004b). Nested within riparian corridors are valley segments that have semi-uniform valley characteristics (slopes, widths, and geologic materials) and similar climatic conditions. The smallest components in our hierarchy are stream reaches or sections of the valley segments with relatively uniform channel morphology, bed material composition, bank conditions, and woody debris. Characteristics of valley segments and stream reaches determine the geomorphic setting and hydrologic regime of riparian ecosystems and, thus, site-specific geomorphic, hydrologic, and vegetation processes that influence resistance and resilience of riparian ecosystems to high flow events and other perturbations (Chambers and others 2004b; Jewett and others 2004).

Objectives and Contents of This Report

In 1992, a USDA Forest Service, Rocky Mountain Research Station ecosystem management project on restoring and maintaining sustainable riparian ecosystems was initiated to address the problems associated with stream incision and riparian ecosystem degradation in the central Great Basin (see Chambers and Miller 2004b). A collaborative project was developed with the U.S. Environmental Protection Agency's (USEPA) Office of Research and Development in 2002 to build on the results of the ecosystem management project and to develop management options for addressing the current effects of stream incision on meadow complexes. This report contains the results of the collaborative Forest Service and EPA project, which was based on a coarse-scale assessment of 56 individual meadow systems coupled with more detailed, fine-scale analyses of 6 of those meadows (fig. 1.7). It provides the necessary understanding and tools to develop effective restoration and management programs for meadow complexes in the central Great Basin. The approach used by the collaborative project is reflected in the report's contents. First, the causes of degradation and underlying geomorphic, hydrologic, and biotic processes operating within the meadows are examined. Then, we examine the factors required to evaluate the sensitivity or, conversely, resistance of streams and their associated meadow complexes to stream incision. Finally, management and treatment options are developed based on an understanding of both the causes of degradation and the underlying processes. The specific components of this report are as follows:

- An understanding of the geomorphic and hydrologic controls on Great Basin meadow complexes;

- An understanding of the geomorphic, hydrologic, and vegetation processes that affect watershed and meadow sustainability;
- Information on the factors needed to evaluate sensitivity to disturbance for both watersheds and meadow complexes;
- Information on the value of biodiversity indicators for aquatic and terrestrial macro-invertebrates for evaluating restoration outcomes and ecological conditions of meadows and their associated stream systems;
- A characterization of meadow complexes that exist within central Great Basin watersheds based on watershed and valley segment/reach-scale attributes; and
- Methods for maintaining or restoring the stream systems and vegetation communities associated with riparian meadows.

References

- Belsky, A.J.; Matzke, A.; Uselman, S. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. *Journal of Soil and Water Conservation*. 51: 419-431.
- 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.
- Chambers, J.C.; Farleigh, K.; Tausch, R.J.; Miller, J.R.; Germanoski, D.; Martin, D.; Nowak, C. 1998. Understanding long- and short-term changes in vegetation and geomorphic processes: the key to riparian restoration. In: Potts, D.F., ed. *Rangeland management and water resources*. Herndon, VA: American Water Resources Association and Society for Range Management: 101-110.
- Chambers, J.C.; Miller, J.R. eds. 2004a. *Great Basin Riparian Ecosystems—Ecology, Management and Restoration*. Covelo, CA: Island Press. 303 p.
- Chambers, J.C.; Miller, J.R. 2004b. 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*. Covelo, CA: Island Press: 1-24.
- Chambers, J.C.; Miller, J.R.; Germanoski, D.; Weixelman, D.A. 2004a. Process based approaches for managing and restoring riparian ecosystems. In: Chambers, J.C.; Miller, J.R., eds. *Great Basin Riparian Ecosystems—Ecology, Management, and Restoration*. Covelo, CA: Island Press: 261-292.
- Chambers, J.C.; Tausch, R.J.; Korfmacher, J.L.; Miller, J.R.; Jewett, D.G. 2004b. 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*. Covelo, CA: Island Press: 196-231.
- Clary, W.P.; Webster, B.F. 1989. Managing grazing of riparian areas in the Intermountain Region. Gen. Tech. Rep. INT-263. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 11 p.
- Clary, W.P. 1995. Vegetation and soil responses to grazing simulation on riparian meadows. *Journal of Range Management*. 48: 18-25.
- Clary, W.P.; Kinney, J.W. 2002. Streambank and vegetation response to simulated cattle grazing. *Wetlands*. 22: 139-148.
- Christensen, N.L.; Bartuska, A.M.; Brown, J.H.; Carpenter, S.; D'Antonio, C.; Francis, R.; Franklin, J.F.; MacMahon, J.A.; Noss, R.F.; Parsons, D.J.; Peterson, C.H.; Turner, M.G.; Woodmansee,

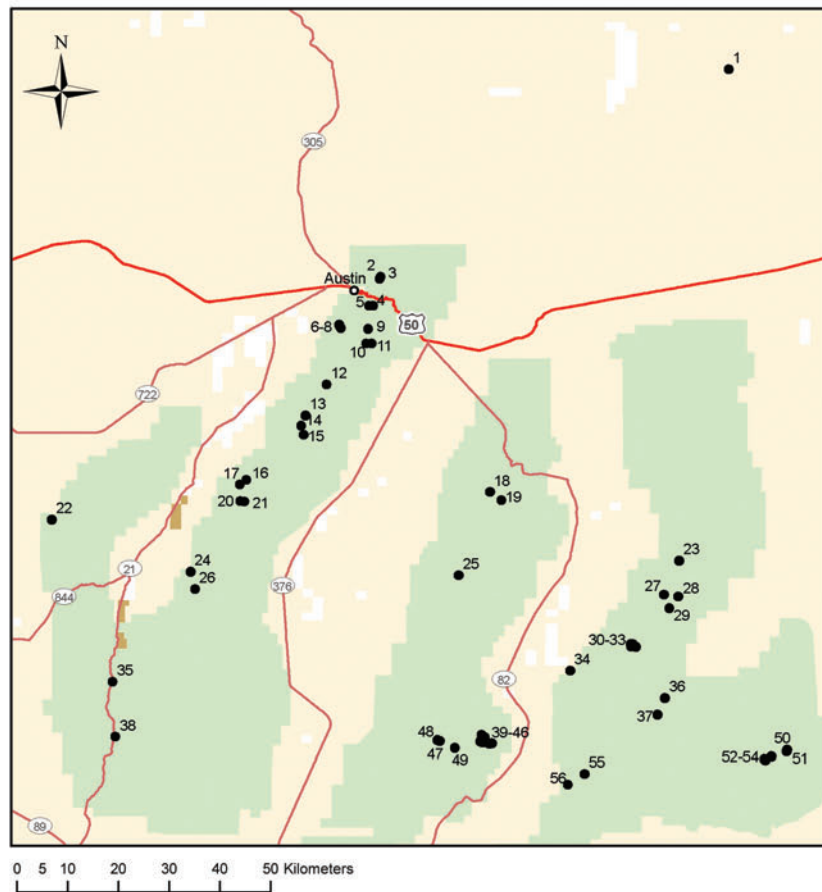


Figure 1.7. Locations of the meadow complexes evaluated by the project and discussed in this report. Land ownership designations: Forest Service = green; Bureau of Land Management = tan; Bureau of Indian Affairs = brown; nonfederal = white.



- | | | |
|--------------------|-------------------------|----------------------|
| 1. Red Canyon | 20. San Juan 1 | 39. Corcoran main 3 |
| 2. Emigrant 1 | 21. San Juan 2 | 40. Corcoran main 2 |
| 3. Emigrant 2 | 22. Lebeau | 41. Corcoran main 1 |
| 4. Cahill 2 | 23. Willow | 42. Corcoran 5 |
| 5. Cahill 3 | 24. Mohawk | 43. Corcoran 4 |
| 6. Johnson 1 | 25. West Northumberland | 44. Corcoran 3 |
| 7. Johnson 2 | 26. South Crane | 45. Corcoran 2 |
| 8. Johnson 3 | 27. West Dobbin | 46. Corcoran 1 |
| 9. Birch Tributary | 28. Stargo | 47. Meadow 2 |
| 10. Birch 1 | 29. East Dobbin | 48. Meadow 1 |
| 11. Birch 2 | 30. Wadsworth 1 | 49. Round Mountain |
| 12. Big Creek | 31. Wadsworth 3 | 50. Six Mile 1 |
| 13. Kingston 3 | 32. Wadsworth 2 | 51. Six Mile 2 |
| 14. Kingston 1 | 33. Wadsworth 4 | 52. Little Cow |
| 15. Kingston 0 | 34. Mosquito | 53. Fandango 1 |
| 16. Washington | 35. Indian Valley | 54. Fandango 2 |
| 17. Cottonwood | 36. Danville | 55. Barley 1 |
| 18. Corral 2 | 37. Green Monster | 56. Barley Tributary |
| 19. Corral 1 | 38. Cloverdale | |

- R.G. 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. *Ecological Applications*. 6: 665-691.
- Dohrenwend, J.C. 1987. Basin and Range. In: Graf, W.L., ed. *Geomorphic Systems of North America: Boulder, CO: Geological Society of America, Centennial Special Volume 2: 303-342.*
- Fleischner, T.L. 1994. Ecological costs of livestock grazing in western North America. *Conservation Biology*. 8: 629-644.
- Frissel, C.A.; Liss, W.J.; Warren, C.E.; Hurley, M.D. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environmental Management*. 10: 199-214.
- Germanoski, D.; Ryder, C.; Miller, J.R. 2001. Spatial variation of incision and deposition within a rapidly incised upland watershed, central Nevada. *Proceedings of the 7th Interagency Sedimentation Conference; 25-29 March 2001; Reno, NV: Subcommittee on Sedimentation. v. 2: 141-148.*
- Germanoski, D.; Miller, J.R. 2004. Basin sensitivity to channel incision in response to natural and anthropogenic disturbance. In: Chambers, J.C.; Miller, J.R., eds. *Great Basin Riparian Ecosystems—Ecology, Management, and Restoration*. Covelo, CA: Island Press: 88-123.
- Goodwin, C.N.; Hawkins, C.P.; Kershner, J.L. 1997. Riparian restoration in the western United States: overview and perspective. *Restoration Ecology*. 5: 4-14.

- Hess, G.W.; Bohman, L.R. 1996. Techniques for estimating monthly mean streamflow at gaged sites and monthly streamflow duration characteristics at ungaged sites in central Nevada. U.S. Geological Survey Open-File Report 96-559. 15 p.
- Hess, G.W. 2002. Updated techniques for estimating monthly streamflow duration characteristics at ungaged and partial-record sites in central Nevada. U.S. Geological Survey Open-File Report 02-168. 16 p.
- Jewett, D.G.; Lord, M.; Miller, J.R.; Chambers, J.C. 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. Covelo, CA: Island Press: 124-161.
- Jones, J.A.; Swanson, F.J.; Wernipie, B.C.; Sjyder, K.U. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. *Conservation Biology*. 14: 76-85.
- Kauffman, J.B.; Krueger, W.C. 1984. Livestock impacts on riparian ecosystems and streamside management implications...a review. *Journal of Range Management*. 37: 430-438.
- Kauffman, J.B.; Beschta, R.L.; Otting, N.; Lytjen, D. 1997. An ecological perspective of riparian and stream restoration in the western United States. *Fisheries*. 22: 12-24.
- Kleinhampl, F.J.; Ziony, J.I. 1985. Geology of northern Nye County, Nevada. Nevada Bureau of Mines and Geology. Bulletin 99A. 172 p.
- Kondolf, G.M.; Larson, M. 1995. Historical channel analysis and its application to riparian and aquatic habitat restoration. *Aquatic Conservation*. 5: 108-126.
- Lahde, D. 2003. The influence of secondary roads on stream incision in watersheds of the central Great Basin. Department of Natural Resources and Environmental Sciences, University of Nevada, Reno. Thesis. 106 p.
- Meizer, O.E. 1916. Groundwater in Big Smoky Valley, Nevada. U.S. Geological Survey, Water Supply Paper 375: 85-116.
- Lord, M.; Miller, J.; Germanoski, D.; Jewett, D.; Villarroel, L.; Tury, R.; Walsh, D.; Chambers, J. 2009. Do reach-scale geomorphically defined process zones predict sensitivity of channel systems and hydrologic processes in the mountains of the central Great Basin? *Geological Society of America Abstracts with Programs*. 41: 624.
- Miffin, M.D. 1988. Region 5, Great Basin. In: Back, W.; Rosenshein, J.S.; Seaber, P.R., eds. *Hydrogeology: Boulder, CO: Geological Society of America, The Geology of North America*. O-2: 69-86.
- Miller, J.; Germanoski, D.; Waltman, K.; Tausch, R.; Chambers, J. 2001. Influence of late Holocene processes and landforms on modern channel dynamics in upland watersheds of central Nevada. *Geomorphology*. 38: 373-391.
- Miller, J.R.; House, K.; Germanoski, D.; Tausch, R.J.; Chambers, J.C. 2004. Fluvial geomorphic responses to Holocene climate change. In: Chambers, J.C.; Miller, J.R., eds. *Great Basin Riparian Ecosystems—Ecology, Management, and Restoration*. Covelo, CA: Island Press: 49-87.
- National Research Council. 1992. Restoration of aquatic ecosystems: science, technology, and public policy. Washington, DC: National Academy Press. 552 p.
- National Research Council. 2002. Riparian areas: functions and strategies for management. Washington, DC: National Academy Press. 428 p.
- Newbury, R.; Gaboury, M. 1993. Exploration and rehabilitation of hydraulic habitats in streams using principles of fluvial behaviour. *Freshwater Biology*. 29: 195-210.
- Ohmart, R.D. 1996. Historical and present impacts of livestock grazing on fish and wildlife resources in western riparian habitats. In: Krausman, P.R., ed. *Rangeland Wildlife*. Denver, CO: Society for Range Management: 245-279.
- Ritter, D.F.; Kochel, R.C.; Miller, J.R. 1999. The disruption of Grassy Creek: implications concerning catastrophic events and thresholds. *Geomorphology*. 29: 323-338.
- Schumm, S.A.; Brackenridge, G.R. 1987. River response. In: Ruddiman, W.F.; Wright, H.E., Jr., eds. *North America and adjacent oceans during the last deglaciation, the geology of North America*, volume K-3. Boulder, CO: Geological Society of America: 221-240.
- Schumm, S.A.; Lichty, R.W. 1965. Time, space, and causality in geomorphology. *American Journal of Science*. 263: 110-119.
- Skovlin, J.M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: National Research Council; National Academy of Sciences, corp. eds. *Developing Strategies for Range Management*. Society for Range Management. Boulder, CO: Westview Press: 1001-1103.
- Smith, D.L. 1992. History and kinematics of Cenozoic extension in the northern Toiyabe Range, Lander County, Nevada. *Geological Society of America Bulletin*. 104: 789-801.
- Smith, D.L.; Miller, E.L. 1990. Late Paleozoic Extension in the Great Basin, western United States. *Geology*. 18: 712-715.
- Society for Ecological Restoration International. 2002. The SERI Primer on Ecological Restoration. Science and Policy Working Group. Available: www.seri.org.
- Stewart, J.H. 1978. Basin-range structure in western North America: a review. *Geological Society of America Memoir*. 152: 1-31.
- Stewart, J.H.; McKee, E.H. 1977. Geology and mineral deposits of Lander County, Nevada. Part I Geology. Nevada Bureau of Mines and Geology. Bulletin 88.
- Tausch, R.J.; Nowak, C.L.; Mensing, S.W. 2004. Climate change and associated vegetation dynamics during the Holocene: the paleoecological record. In: Chambers, J.C.; Miller, J.R., eds. *Great Basin Riparian Ecosystems—Ecology, Management, and Restoration*. Covelo, CA: Island Press: 24-48.
- Thatcher, W.; Foulger, G.R.; Julian, B.R.; Svarc, J.; Quilty, E.; Bawden, G.W. 1999. Present-day deformation across the Basin and Range Province, western United States. *Science*. 283: 1714-1718.
- Trimble, S.W.; Mendel, A.C. 1995. The cow as a geomorphic agent—a critical review. *Geomorphology*. 13: 233-253.
- Trombulak, S.C.; Frissell, C.A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology*. 14: 18-30.
- USDA Forest Service. 1997. The water/road interaction technology series: an introduction. San Dimas, CA: Technology and Development Program.
- Weixelman, D.A.; Zamudio, D.C.; Zamudio, K.A. 1996. Central Nevada riparian field guide. R6-ECOL-TP. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region.
- Wissmar, R.C.; Beschta, R.L. 1998. Restoration and management of riparian ecosystems: a catchment perspective. *Freshwater Biology*. 40: 571-585.
- Wohl, E. 2004. *Disconnected rivers: linking rivers to landscapes*. New Haven, CT: Yale University Press. 301 pages.
- Wohl, E.; Angermeier, P.L.; Bledsoe, B.; Kondolf, G.M.; MacDonnell, L.; Merritt, D.M.; Palmer, M.A.; Poff, N.L.; Tarboton, D. 2005. River restoration. *Water Resources Research*. 41:10301.
- Wright, M.J.; Chambers, J.C. 2002. Restoring riparian meadows currently dominated by *Artemisia* using threshold and alternative state concepts—aboveground vegetation response. *Applied Vegetation Science*. 5: 237-246.