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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

Jeanne C. Chambers, Jerry R. Miller, Mark L. Lord,
David I. Board, Anna C. Knight

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Abstract

This report provides a multiscale approach for assessing the geomorphic sensitivity of streams and ecological resilience of riparian ecosystems, including meadows, in upland watersheds of the Great Basin to disturbances and management actions. Part I describes the key concepts needed to understand geomorphic sensitivity, ecological resilience, and ecological integrity. The watershed characteristics and components that influence sensitivity and resilience to disturbance are discussed, including the geomorphic characteristics of the stream channels and vegetation characteristics of the riparian ecosystems. A categorization of watershed sensitivity and resilience is provided to evaluate the past and likely future responses of the watersheds to disturbances and determine appropriate management strategies. Part II contains the information and protocols needed to categorize stream reaches and watersheds according to their relative sensitivity and resilience and evaluate their ecological integrity. The assessment involves collecting data on (1) watershed characteristics, (2) stream channel geomorphic and hydrologic characteristics, (3) riparian and meadow ecosystem vegetation characteristics, and (4) disturbance types and magnitudes. The assessments of watershed sensitivity and resilience are intended to provide the basis for prioritizing areas for conservation and restoration activities and determining the most effective strategies. The target audience is managers and stakeholders interested in assessing and adaptively managing Great Basin stream systems and riparian and meadow ecosystems.

Keywords: geomorphic sensitivity, ecological resilience, ecological integrity, Great Basin, watersheds, stream channels, riparian ecosystems, meadows, conservation, restoration, adaptive management

Cover: Cassia Creek watershed in southeastern Idaho. Courtesy photo by Anna Knight, U.S. Geological Survey.

Authors

Jeanne C. Chambers is a Senior Scientist (emeritus) with the USDA Forest Service, Rocky Mountain Research Station in Reno, Nevada.

Jerry R. Miller is a Professor at Western Carolina University, College of Arts and Sciences, Department of Geosciences and Natural Resources, in Cullowhee, North Carolina.

Mark L. Lord is a Professor at Western Carolina University, College of Arts and Sciences, Department of Geosciences and Natural Resources, in Cullowhee, North Carolina.

David I. Board is an Ecologist/Data Analyst with the USDA Forest Service, Rocky Mountain Research Station in Reno, Nevada.

Anna C. Knight is a Physical Science Technician with the USDOI U.S. Geological Survey Canyonlands Research Center in Moab, Utah.

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Table of Contents

Part II. Assessment Protocol

Appendices

Introduction

Determining appropriate management strategies for stream systems and riparian ecosystems in the Great Basin can be highly challenging. Great Basin watersheds, stream systems, and their associated riparian ecosystems exhibit a wide variety of geomorphic and hydrologic conditions and support numerous different vegetation communities. They often exhibit varying responses to both natural disturbances, such as floods, and anthropogenic disturbances, such as roads or developments in valley bottoms. Assessing the geomorphic sensitivity of streams and ecological resilience of riparian ecosystems provides the basis for understanding their past responses to disturbances and management actions and predicting how they are likely to respond in the future.

Effective use of geomorphic sensitivity (sensitivity) and ecological resilience (resilience) concepts provides information on the capacity of streams and riparian ecosystems to regain fundamental structures, processes, and functions, or in other words recover, when disturbances alter geomorphic and hydrologic regimes and vegetation communities. These concepts describe the capacity of the system to absorb change and remain in a dynamic equilibrium or stable state (Brunsden and Thornes 1979; Downs and Gregory 1993; Holling 1973) (see Appendix 1 for definitions). Assessments of geomorphic sensitivity are based largely on past and present watershed and stream channel characteristics and geomorphic and hydrologic processes. Assessments of ecological resilience are based largely on riparian vegetation characteristics—the adaptations of the species to geomorphic and hydrologic processes and their responses to disturbance. Developing an understanding of the relative sensitivity of watersheds and streams and resilience of riparian ecosystems provides the basis for determining their relative stability, whether a threshold has been crossed or is about to be crossed, and whether a new stable state has been reached after a threshold crossing. Thus, assessments of sensitivity and resilience can provide the basis for prioritizing areas for conservation and restoration activities and determining the most effective strategies.

Many current assessments of riparian and wetland ecosystems focus on characterizing a system's ecological integrity. Ecological integrity is defined as the structure, composition, and function of an ecosystem operating within the bounds of natural or historical disturbance regimes, and the ability of an ecosystem to support and maintain a full suite of organisms with composition, structure, and function comparable to similar systems in an undisturbed state (Bushman et al. 2019; Lemly et al. 2016). In general, assessments of ecosystem integrity evaluate current ecological conditions to provide information on anthropogenic disturbances that may be affecting the structure and function of a wetland or riparian ecosystem. Assessments of sensitivity and resilience differ from assessments of ecological integrity in that they allow managers to assess both the current conditions and potential conditions of not only riparian ecosystems and wetlands but also stream systems.

This report provides a multiscale approach for assessing the sensitivity of streams and resilience of riparian ecosystems, including meadows, in upland watersheds of the Great Basin to disturbances and management actions. The approach builds on long-term work by the authors and their research and management partners on the sensitivity and resilience of these systems to disturbances (Chambers and Miller 2004, 2011a). The target audience is managers and stakeholders interested in assessing and adaptively managing Great Basin stream systems and riparian and meadow ecosystems.

Area of Application

This report applies to seven regions within the Great Basin (fig. 1). The focus is on watersheds with wadeable, perennial stream systems in the mountain ranges. The characteristics of each of the different regions are described in "Characterizing Ecoregions and Montane Perennial Watersheds of the Great Basin" (Board et al. 2020) and online at: https://www.fs.usda.gov/treesearch/pubs/61573.

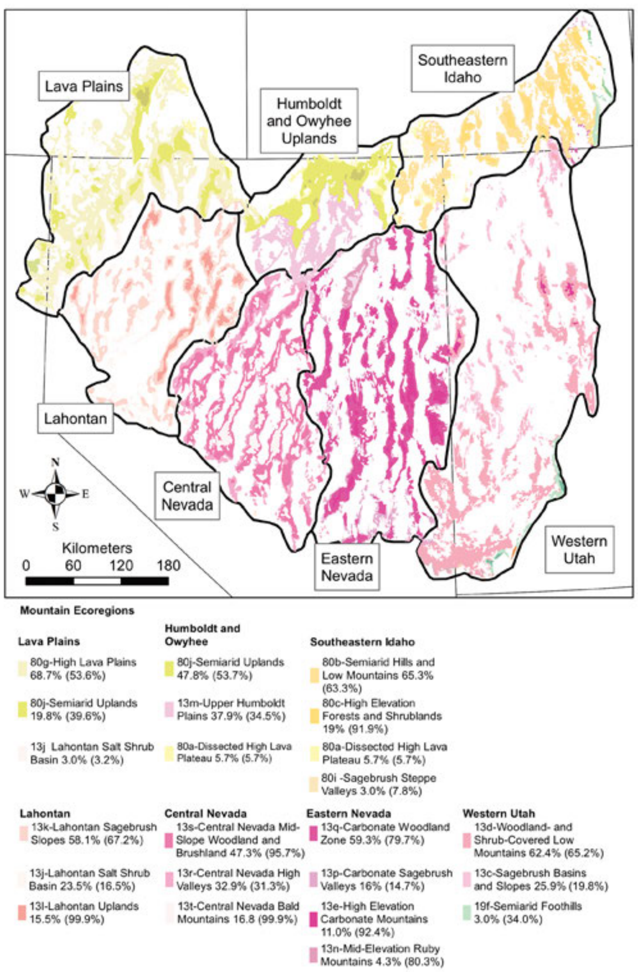


Figure 1—The seven regions with distinctive montane EPA level IV ecoregions (USEPA 2013) included in the study area—Lahontan, Central Nevada, Eastern Nevada, Western Utah, South Eastern Idaho, Humboldt and Owyhee uplands, and Lava Plains. The values show the percentage of the vegetation type in the overall area and (in parentheses) in the mountain ranges. Descriptions of each region and characterizations of the watersheds therein are in Board et al. (2020).

Use of this Report

The report is divided into two parts. Part I provides background information on sensitivity and resilience concepts and the responses of Great Basin streams and riparian ecosystems to disturbances and management actions. Part I also includes a categorization of sensitivity and resilience that can be used to evaluate the past and likely future responses of the watersheds to disturbance and determine appropriate management strategies. The information in Part I will be of interest to individuals seeking to gain a general understanding of Great Basin streams and riparian ecosystems and how to apply sensitivity and resilience concepts.

Part II provides a protocol for rapidly evaluating the sensitivity and resilience of the stream systems and riparian ecosystems within focal watersheds. In Part II, information and protocols are provided to assess (1) watershed characteristics, (2) stream channel characteristics and geomorphic and hydrologic processes, (3) riparian and meadow ecosystem vegetation characteristics, and (4) disturbance types and magnitudes. The assessment contains the necessary information to categorize stream reaches and watersheds according to their relative sensitivity and resilience and to evaluate their likely responses to management activities. It also includes information for evaluating and interpreting ecological integrity. Part II will be of interest to individuals wanting to know how to apply the assessment protocol.

Additional Resources

The data described in "Characterizing Ecoregions and Montane Perennial Watersheds of the Great Basin" are available at: https://doi.org/10.2737/RDS-2020-0059, and the map products can be accessed at: https://usfs.maps.arcgis.com/home/search.html?t=content&q=tags%3A%22Geomorphic%20Sensitivity%20and%20Ecological%20Resilience%20of%20Great%20Basin%20Streams%20and%20Riparian%20Ecosystems%22. A website has been created that contains the primary elements of both Part I and Part II of this report and it is available at: https://experience.arcgis.com/experience/49f171f01aed451d8bbebb5558638a6c. The website describes the sensitivity and resilience concepts, components, and categories and provides the necessary information and data forms to complete the assessment.

The approach in this report is intended to complement the EPA Level 2 Rapid Assessment Method for Nevada Wetlands (Bushman et al. 2019). This report focuses on streams and riparian ecosystems in upland watersheds in the Great Basin; the Bushman et al. (2019) rapid assessment method focuses on other wetland topographic settings, including riverine, lake fringe, depressions, and slopes, in Nevada. Other general assessments include the USDA Forest Service Level 1 inventory for groundwater-dependent ecosystems (USDA FS 2012), which focuses on springs, peatlands, marshes, seeps, fens, and swamps, and "The National Riparian Core Protocol: A riparian vegetation monitoring protocol for wadeable streams" (Merritt et al. 2017).

Photos—San Juan Creek in central Nevada in upper left. Courtesy photo by Robin Tausch. Upper right: Shoshone Creek in southern Idaho; lower left: Lamoille Canyon in northeast Nevada; lower right: Hanson Creek in northcentral Nevada. USDA photos by Jeanne Chambers.

Part I. Sensitivity and Resilience Concepts, Components, and Categories

Sensitivity and Resilience Concepts

What Are Geomorphic Equilibrium, Geomorphic Sensitivity, and Channel Stability, and How Are They Related?

Equilibrium of geomorphic systems refers to a balance between a set of driving forces that promote change (climate, gravity, tectonics) in the Earth's surface, and a set of resisting forces (governed by the resistance of the Earth's materials) to undergo change. For streams and rivers, the balance is often viewed in terms of the water or discharge that is available to erode and transport sediment, and the size and amount of sediment that is available for transport by the available flow (fig. 2). Equilibrium is a time-dependent concept (Schumm 1973). For our purposes, equilibrium is defined such that processes and channel form are adjusted to one another over years to centuries. Though changes in channel width, depth, slope, and so forth continually occur, the changes fluctuate around a mean condition. Streams in this type of equilibrium are often considered to be in dynamic equilibrium (fig. 3).

Sensitivity describes the capacity of the geomorphic system to absorb change and remain in a state of dynamic equilibrium over a period of years. It is a function of the likelihood that a given change in the controls of the system will produce a "sensible, recognizable, and persistent response" in the stream system and riparian corridor (Brunsden and Thornes 1979) or, in other words, a significant and permanent response. A system with low sensitivity can absorb more change and maintain equilibrium over a longer period of time than one with high sensitivity.

Channel stability is a function of the rate and amount of change in channel conditions (such as width, depth, and slope) over a few years, which may encompass a single event or multiple events. Relative channel stability may or may not be a good indicator of sensitivity to disturbance. For example, a highly dynamic stream channel (i.e., one undergoing frequent changes) may be in equilibrium with regard to erosion and transport processes and be characterized as having low sensitivity to disturbance over a longer timeframe. In contrast, a stream channel that recently has exhibited little mobility may be characterized as stable, but may not be in equilibrium with regard to longer term erosion and transport processes within the watershed; that is, its form may be altering, albeit slowly, in response to a disturbance.

Thresholds are defined as the limits to equilibrium. When the limits of equilibrium (thresholds) are crossed, the stream will respond by acquiring a new morphologic state as described by its width, depth, slope, pattern (straight, meandering, braided, or anabranching), and planimetric configuration (e.g., sinuosity, meander wavelength) (Ritter et al. 1999; Schumm 1973) (fig. 3).

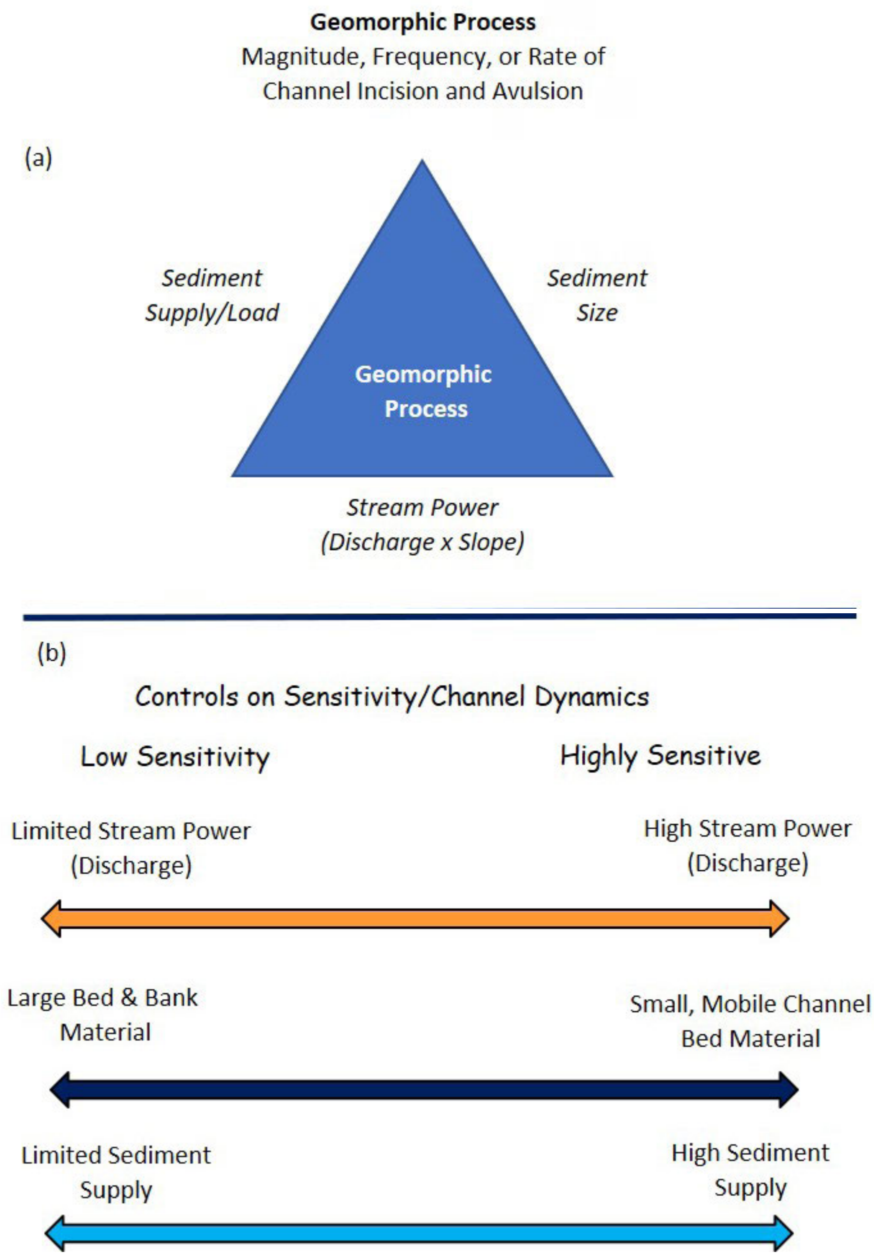


Figure 2—Schematic of the dominant geomorphic responses to disturbance in the Great Basin: channel incision and avulsion. The rate of incision and frequency of avulsions are controlled by stream power, sediment size, and sediment load (a). These factors also control channel sensitivity at the stream reach scale (b).

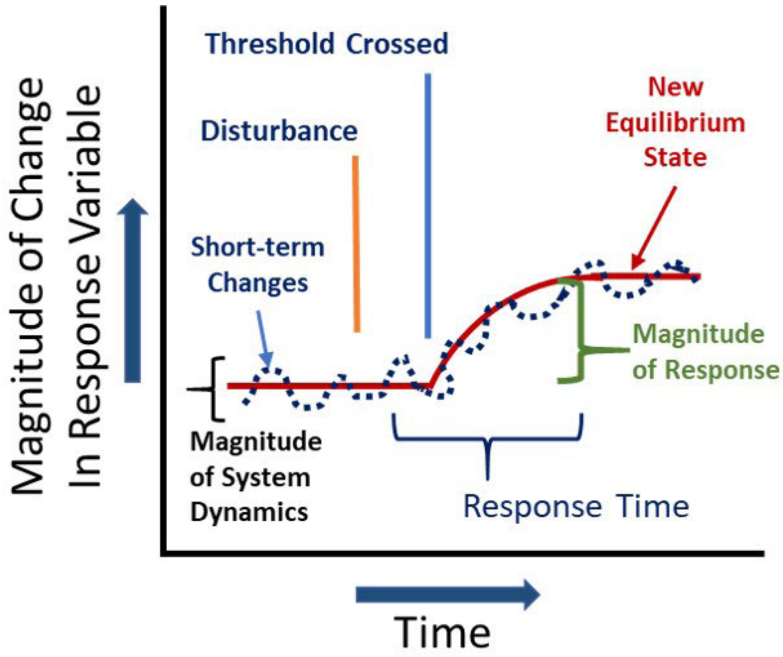


Figure 3—Schematic of the dynamic equilibrium of a stream system, including the geomorphic responses of the system to disturbance and threshold-crossing events. The blue dashed line represents a change in the response variable around the mean condition (red solid line). When the mean condition is constant, the system is in a state of dynamic equilibrium over a given period. (Figure patterned after Bull 1991.)

How Are Geomorphic Sensitivity and Ecological Resilience Related?

Similar to geomorphic sensitivity, ecological resilience describes the amount of disturbance that a riparian ecosystem can endure before it is transformed into an alternative equilibrium or stable state (Holling 1973). Factors that affect ecological resilience of riparian and meadow ecosystems are (1) geomorphic sensitivity of the stream system and (2) influence of past disturbances on the recovery potential of the vegetation. If the riparian vegetation has the potential to return to the reference state, a stream system with relatively low geomorphic sensitivity typically will exhibit relatively high ecological resilience. Conversely, a stream system with relatively high geomorphic sensitivity typically will exhibit relatively low ecological resilience. For example, a stream channel characterized by large channel bed sediments may be in equilibrium with regard to erosion and transport processes and be characterized by low geomorphic sensitivity and high ecological resilience to disturbance. In contrast, low-relief and low-gradient valley floors with deep alluvium in the valley bottoms are prone to rapid incision (downcutting) and are characterized by high geomorphic sensitivity and low ecological resilience. This is because incision results in changes in channel pattern and form that usually lead to decreases in water tables and degradation of the riparian ecosystem. If the riparian vegetation has lost the potential to return to the reference state due to factors such as improper livestock grazing, herbicide applications to eliminate woody species, or invasions of nonnative plants, ecological resilience will be low regardless of geomorphic sensitivity.

What Is Ecological Integrity and How Is It Related to Ecological Resilience?

Ecological integrity describes the current ecological conditions of riparian and meadow ecosystems based on abiotic and biotic indicators of composition, structure, and function. Measures of ecological integrity provide information on the effects of both natural and anthropogenic disturbances on current conditions such as relative stream bank stability, water quality, riparian or meadow plant species composition and health, and presence of animal species.

A system with relatively low sensitivity and moderate to high resilience can exhibit either low or high ecological integrity. Unless a threshold has been crossed to an undesirable state, systems with moderate to high resilience but low ecological integrity due to factors such as improper livestock grazing or high recreational use often have the capacity to regain more favorable ecological conditions with proper management (fig. 4). Once a threshold has been crossed, active restoration often is required to return the system to a desired state.

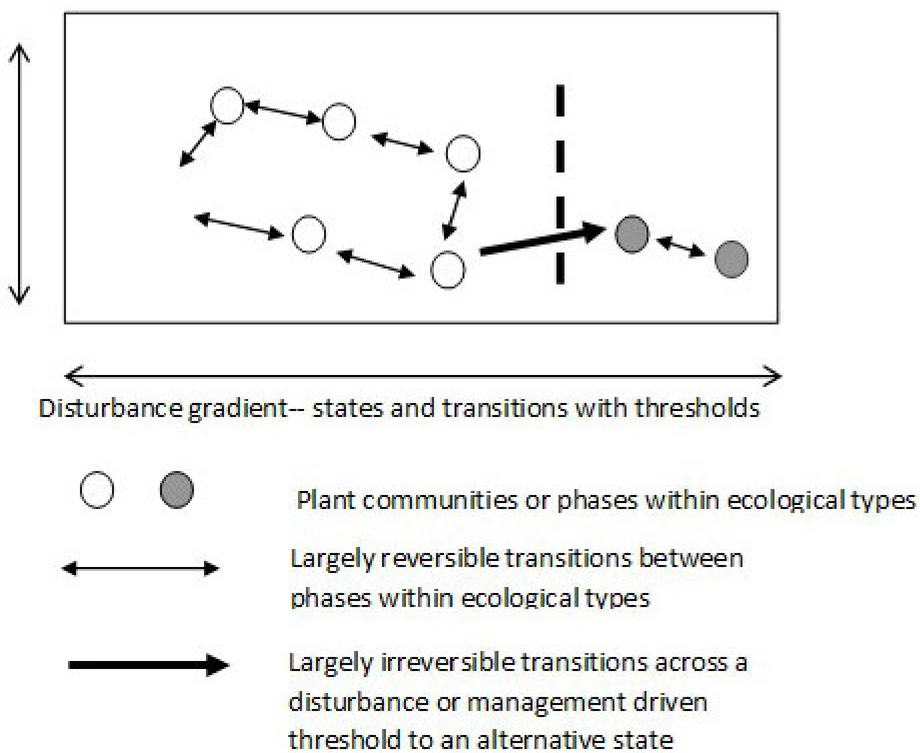


Figure 4—Riparian and meadow plant communities or phases that occur along both environmental and disturbance gradients as indicated by the dashed vertical lines. Changes in plant communities occur as a result of changes in water availability and levels of disturbance, such as livestock grazing or recreational use. If the magnitude of the change is not too large and the conditions causing the change can be ameliorated, the transitions between communities often are reversible. However, if the change cannot be ameliorated, largely irreversible thresholds to new alternative states can result. (Figure from Chambers et al. 2004a.)

A system with high sensitivity and low ecological resilience can also exhibit low or high ecological integrity prior to a disturbance, such as incision or avulsion, which results in a significant geomorphic and vegetation response. For example, channel incision can lead to a drop in the water table, which can reduce access to groundwater by riparian vegetation, changing vegetation composition (Loheide and Gorelick 2007). These systems will respond favorably to proper management. However, following incision or avulsion, the system can transition to alternative states or even new ecological site types (fig. 5). Ecological integrity may be reduced for a significant period of time as indicated by unstable stream banks, changes in species composition, and species invasions. Once the system adjusts to the new geomorphic and hydrologic conditions, it can regain ecological resilience over time given proper management (fig. 5).

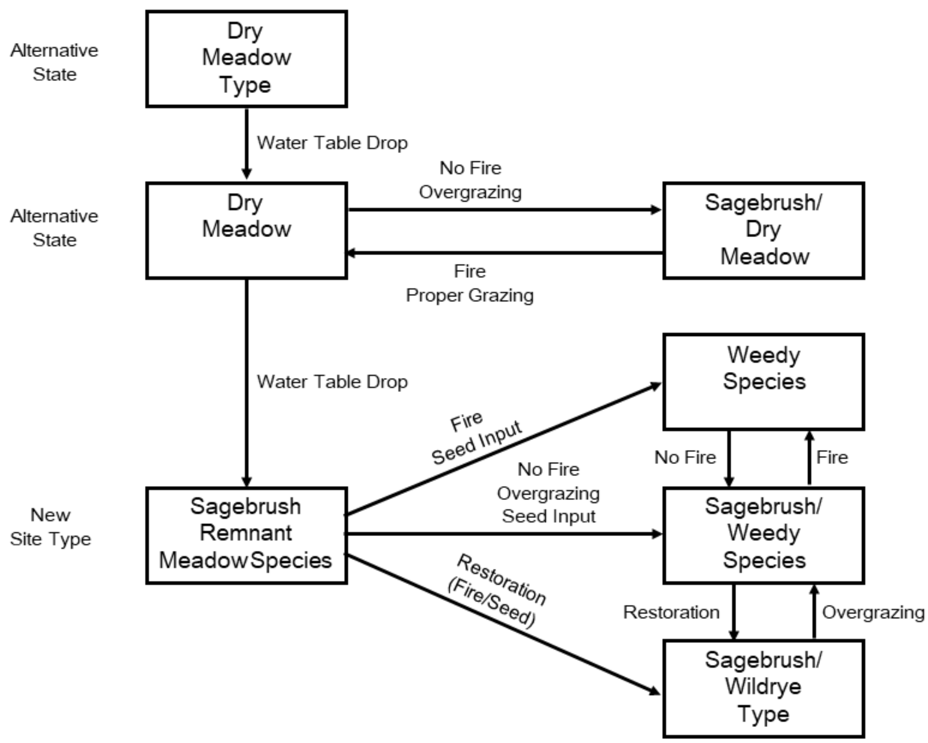


Figure 5—States and transitions that occur in dry meadows in the Great Basin with progressive lowering of the water table due to channel incision or avulsion. Minor lowering of the water table results in an alternative state in which the amount of sagebrush depends on fire and livestock grazing. A larger drop in the water table results in a threshold crossing and a new site type dominated by sagebrush, which is susceptible to conversion to weedy species following fire or overgrazing. Sagebrush = *Artemisia tridentata* ssp. *tridentata*; Wildrye = *Leymus cinereus*. (Figure from Wright and Chambers 2002.)

What Is the Importance of Understanding the Dominant Geomorphic Processes and the Effects of Disturbance on Those Responses?

A geomorphic process is defined as any action (e.g., erosion or deposition) that occurs when an alteration in a driving force induces a change in the Earth's surface. The response in the morphology of the surface (stream or river channel) represents the amount of change that occurs and is characterized in terms of the type, magnitude, and rate of change (fig. 3). Not all responses are long-term. For example, the width and depth of a stream channel are often affected by rare, extreme floods, but they may return to a close approximation of their preflood form following the event if a threshold has not been crossed.

Documentation of the past processes that characterize an upland watershed or stream reach is critical because it provides insights into how the channel is likely to respond to future disturbances and the rate and magnitude of the processes that occur. Rate and magnitude are particularly important in that both are closely related to sensitivity and resilience. For example, a channel that exhibits rapid and significant (meters) incision in response to a disturbance is likely to be highly sensitive and have low resilience.

Why Use a Multiscale Approach?

Geomorphic processes along any segment of the drainage network depend on the generation and availability of water and sediment within the watershed. Water and sediment do not vary systematically within a watershed. Consequently, the spatial variations in water and sediment, when combined with other local controlling factors (e.g., bedrock outcrops or landslides), lead to geomorphic processes that often change abruptly downstream, particularly within mountainous terrain. Moreover, the controlling factors change with the spatial scale of the analysis (Brierley and Fryirs 2005; Montgomery 1999).

In this report, the focus is on watersheds, basin types, watershed segments, and stream reaches (fig. 6). A watershed is defined as the area that drains precipitation, mainly by a stream or river and its associated tributaries, to a common outlet. Basin type is defined as the part of a watershed that is characterized by homogeneous valley and upland morphologic traits including geology, topography, landforms, and processes. Watersheds may be characterized by a single basin type or sometimes two or more basin types if landscape morphology, landforms, and processes vary spatially within the watershed.

Dividing the watershed or basin type into watershed segments and reach-scale units, which are controlled by the watershed's upstream and downstream characteristics and local geologic, biotic, and morphologic controls, provides the basis for field assessment (fig. 6). A watershed segment contains one or more stream reaches and is characterized by similar valley materials (e.g., bedrock, colluvium, alluvium), valley morphologic characteristics (e.g., width, gradient, relief), landforms types (e.g., terraces, alluvial fans), and processes. A stream reach is defined as a segment of the drainage network with homogeneous channel (width, depth, gradient, planimetric configuration, pattern) and channel bed features (e.g., pools or riffles, step or pools, bars, knickpoints) and valley floor landforms (e.g., terraces, floodplains). Morphologic elements at the stream reach scale provide important insights into active channel processes and include knickpoints and terraces (indicative of incision), anabranching channels (indicative of avulsion), and undercut banks and failed slabs (indicative of bank erosion by mass wasting). The extent and spatial distribution of reach types also provides insights into the basin's existing geomorphic condition and sensitivity.

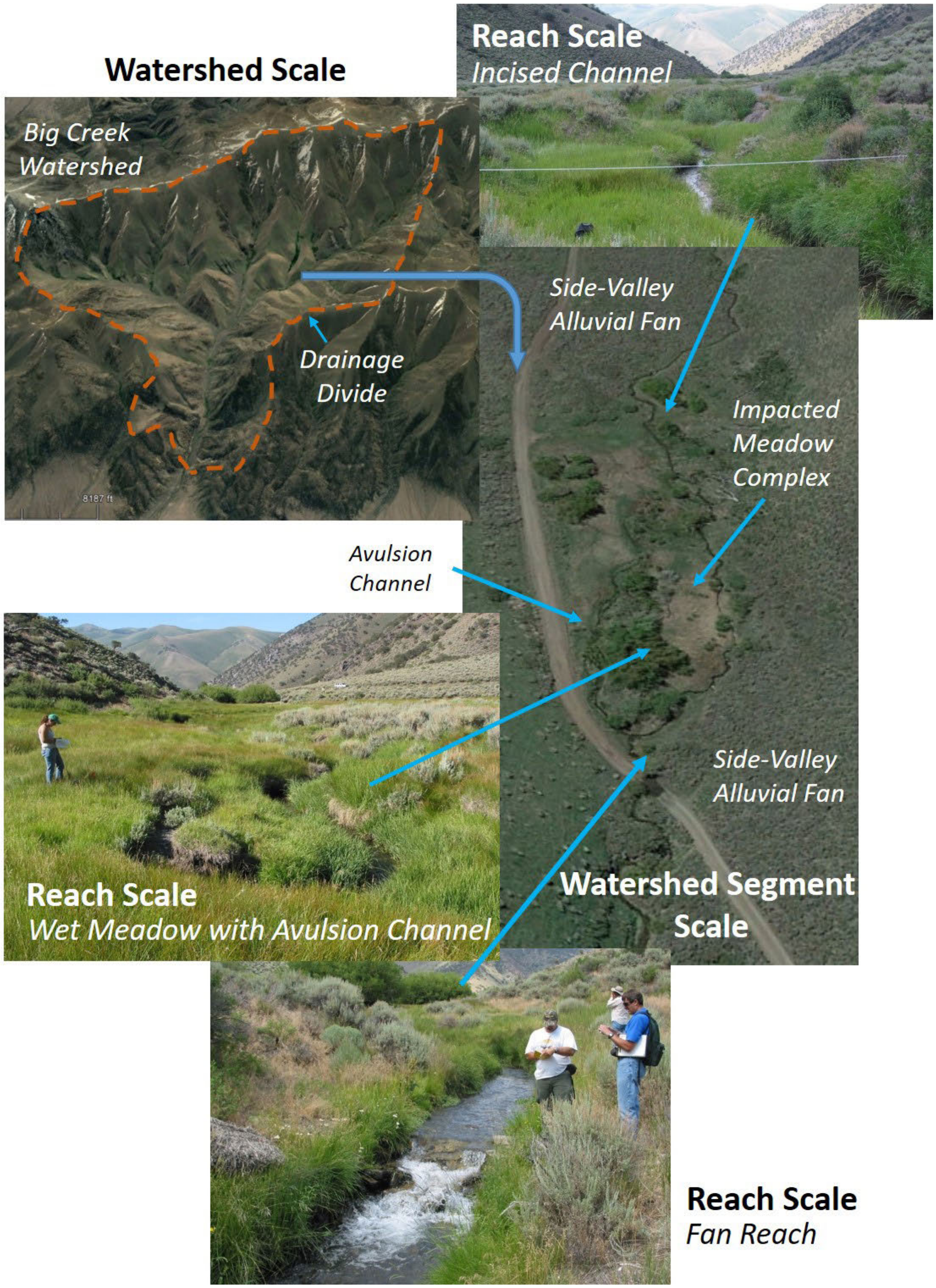


Figure 6—The spatial scales used in this report. The largest scale is the watershed. Watersheds are divided into one or more basin types depending on the underlying geology, topography, landscape morphology, and processes. Basin types can be divided further into watershed segments and stream reaches for more-detailed assessment. Watershed segments have similar valley geologic materials, morphology, and landforms. Stream reaches make up watershed segments and have homogeneous channel and valley floor landforms (e.g., terraces, floodplains), channel bed features (e.g., pools and riffles, steps and pools, bars, knickpoints), and sediment sizes. Photos taken by the authors and used with their permission.

Primary Components

Different factors influence the responses of watersheds, basin types, stream reaches, and the riparian ecosystems that they support to disturbance. A set of key questions about four primary components are used to describe and evaluate sensitivity and resilience to disturbance and ecological integrity of streams and riparian ecosystems within the Great Basin (fig. 7). The multiscale approach presented here focuses on watersheds, basin types, and stream reaches. The four components, developed in the sections that follow, are: (1) watershed and basin type characteristics, (2) stream channel and stream reach characteristics, (3) vegetation characteristics, and (4) disturbance history.

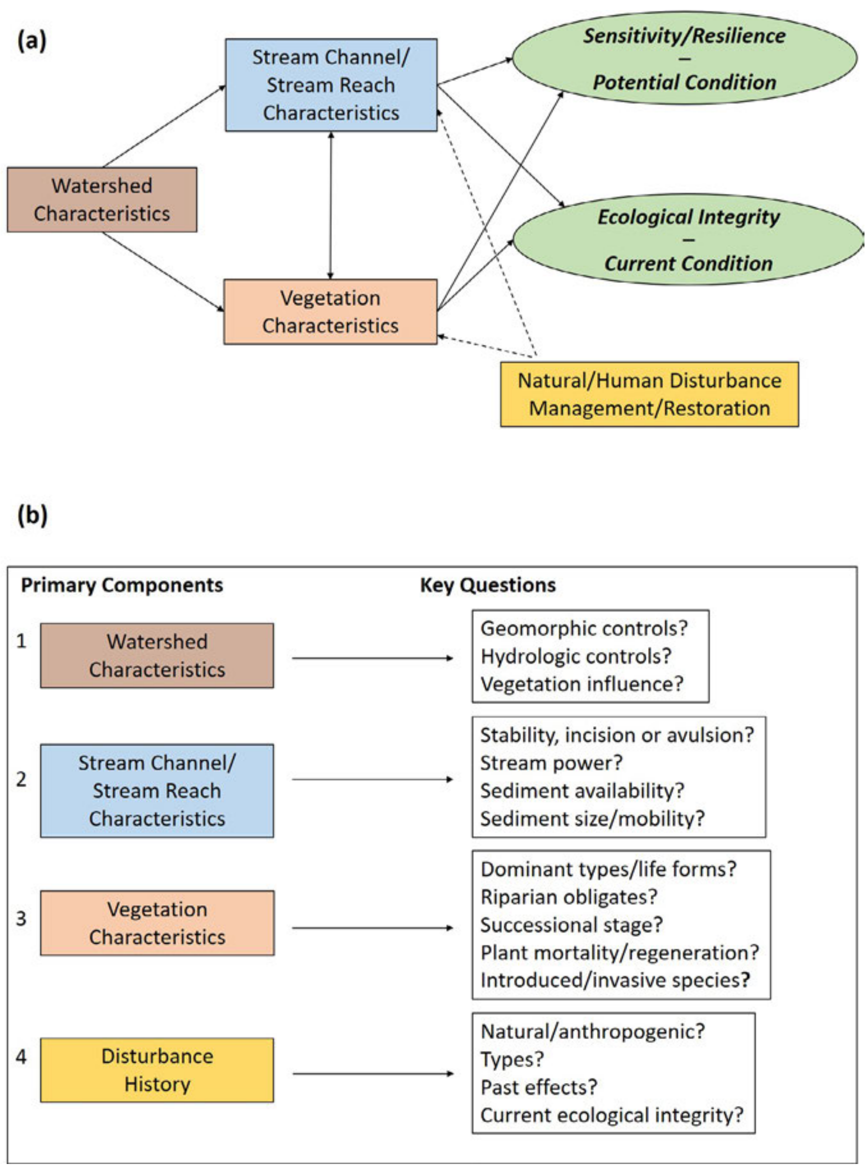


Figure 7—The approach used in this field guide to evaluate geomorphic sensitivity, ecological resilience, and ecological integrity. Top (a): the four primary components that influence sensitivity, resilience, and integrity and their relationships. Bottom (b): the key questions used to assess each of the four primary components.

Component 1—Watershed Characteristics

Watershed-scale Controls on Geomorphic Responses

Geomorphic processes that operate along stream channels within the upland watersheds are governed by their hydrologic regime (i.e., frequency and magnitude of flows) and sedimentologic regime (i.e., sediment size and amount) (Lane 1955; Ritter et al. 2011). Thus, watershed morphometry has been extensively used to infer geomorphic processes at a range of spatial scales (e.g., Thornbrugh et al. 2018). A first step in assessing the type, magnitude, and rate of geomorphic processes within these watersheds is to characterize their morphology, geology, hydrology, and vegetation (fig. 8). The watershed-scale data that are available for mapping the primary physical and climatological characteristics of upland watersheds in the Great Basin are in Appendix 2, table A.2.1, and a description of their use is in Appendix 2, exhibit A.2.1.

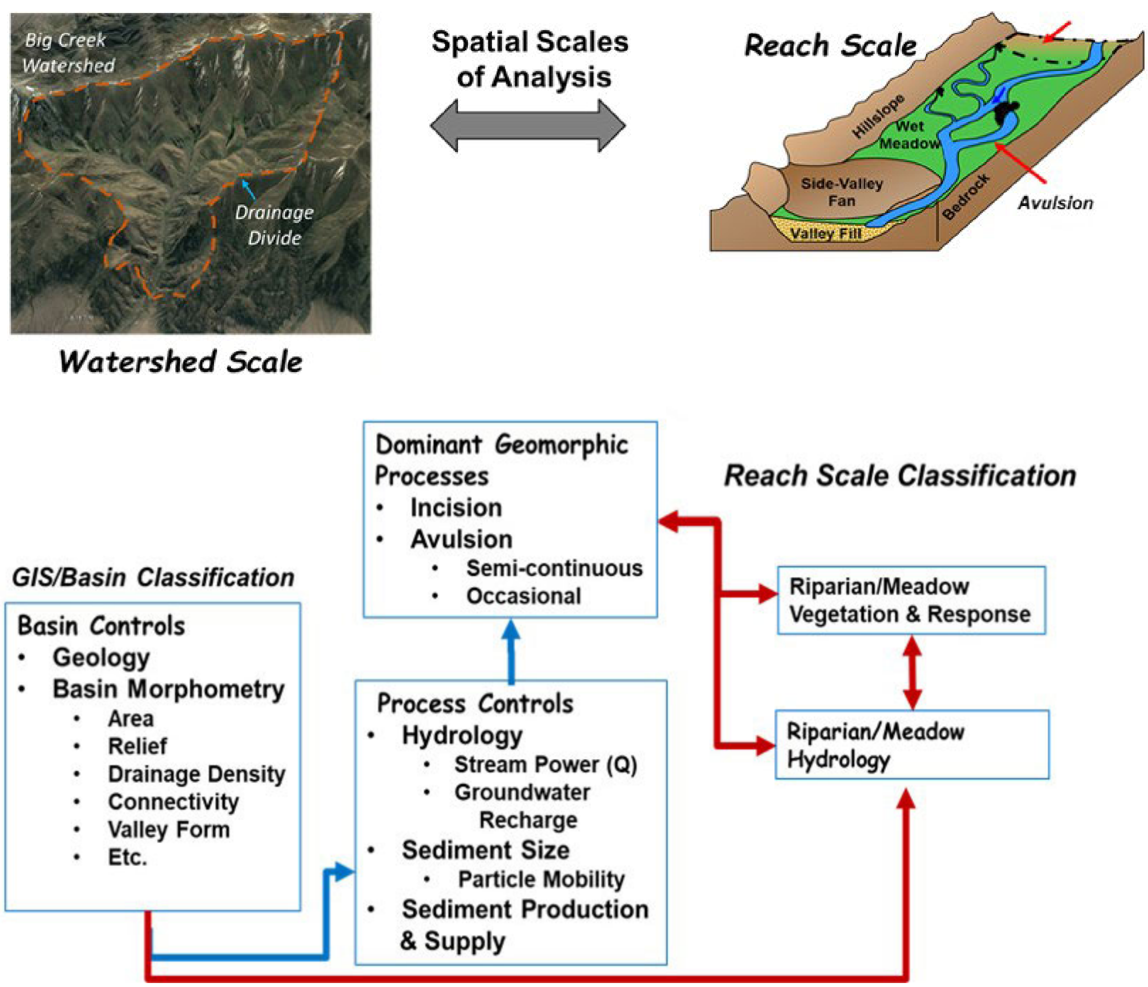


Figure 8—Geomorphic processes and controls operating along a stream reach. These processes depend on discharge, sediment size, and sediment supply, which in turn are controlled by the watershed characteristics upstream of the reach, including morphometry, vegetation type and abundance, and underlying geology. Defining the potential responses of a stream reach to both natural and anthropogenic disturbance requires a hierarchical approach in which a watershed's fundamental characteristics can be related to its hydrologic and sedimentologic regime and smaller-scale (reach) geomorphic processes.

What Is Watershed Morphometry?

Watershed morphometry describes the dimensions, shape, and relief of a watershed and the extent and arrangement of its drainage network. An analysis of watershed morphometry, including that of the Great Basin, uses several common variables.

How Is Watershed Morphometry Related to Watershed Hydrology and Sediment Yield?

The quantity and rate of runoff and sediment transport from hillslopes to the watershed mouth are dependent, in part, on the watershed's morphometry (Gardiner 1990; Patton 1988; Patton and Baker 1976; Ritter et al. 2011). These relations are so prevalent and significant that the U.S. Geological Survey created a software package (National Streamflow Statistics program) that provides the algorithms for States and regions to predict flood frequencies and magnitudes within ungauged watersheds. In upland watersheds, the most important parameter in controlling runoff is watershed area, followed by other parameters such as drainage density, watershed relief, and watershed shape. Given the influence of watershed morphometry on watershed hydrologic and sedimentologic regime, an understanding of watershed morphometry provides insights into the relative magnitude of flood flows and, to a lesser degree, sediment yields associated with a specific watershed. For example, watersheds with high sensitivity often are characterized by relatively high peak discharges and stream powers (i.e., the product of discharge and slope) capable of transporting the available sediments through the channel to the mouth of the watershed. High peak discharges are characteristic of watersheds with a relatively high drainage density, a high ruggedness number, an equant shape (described by the circularity and form ratios), and a high relief and relief ratio. Elevation is also important because, in general, watersheds with a greater percentage of their basin at high elevations have relatively high mean annual precipitation.

What Is Hydrologic Connectivity?

The influence of watershed morphometry on runoff and sediment transport is complicated in upland watersheds of the Great Basin by the extent to which the drainage network is connected hydrologically. Connectivity refers to the degree to which water and sediment can be transferred from one part of the drainage network to another downstream section through a distinct channel (Miller et al. 2012) (fig. 9). Water and sediment can move freely and quickly along connected reaches, but flows along disconnected reaches can disperse and infiltrate, resulting in deposition. Connectivity influences both stream flows and sediment availability along axial channels because the water and sediment produced in a disconnected subbasin are likely to infiltrate along an unincised reach, promoting sediment deposition. The degree of disconnected basin area within a watershed can be determined by identifying and mapping segments of the valley or drainage network that lack a stream channel (e.g., unincised side-valley alluvial fans, fig. 9) from aerial images or Google Earth, then measuring the upstream watershed area of the disconnected subbasins. In general, the higher the percentage of disconnected watershed area, the less flashy and dynamic the watershed, and the higher the resilience. The sensitivity of these watersheds is more likely to be altered if the disconnected reaches become connected by channel incision (e.g., during a significant flood).

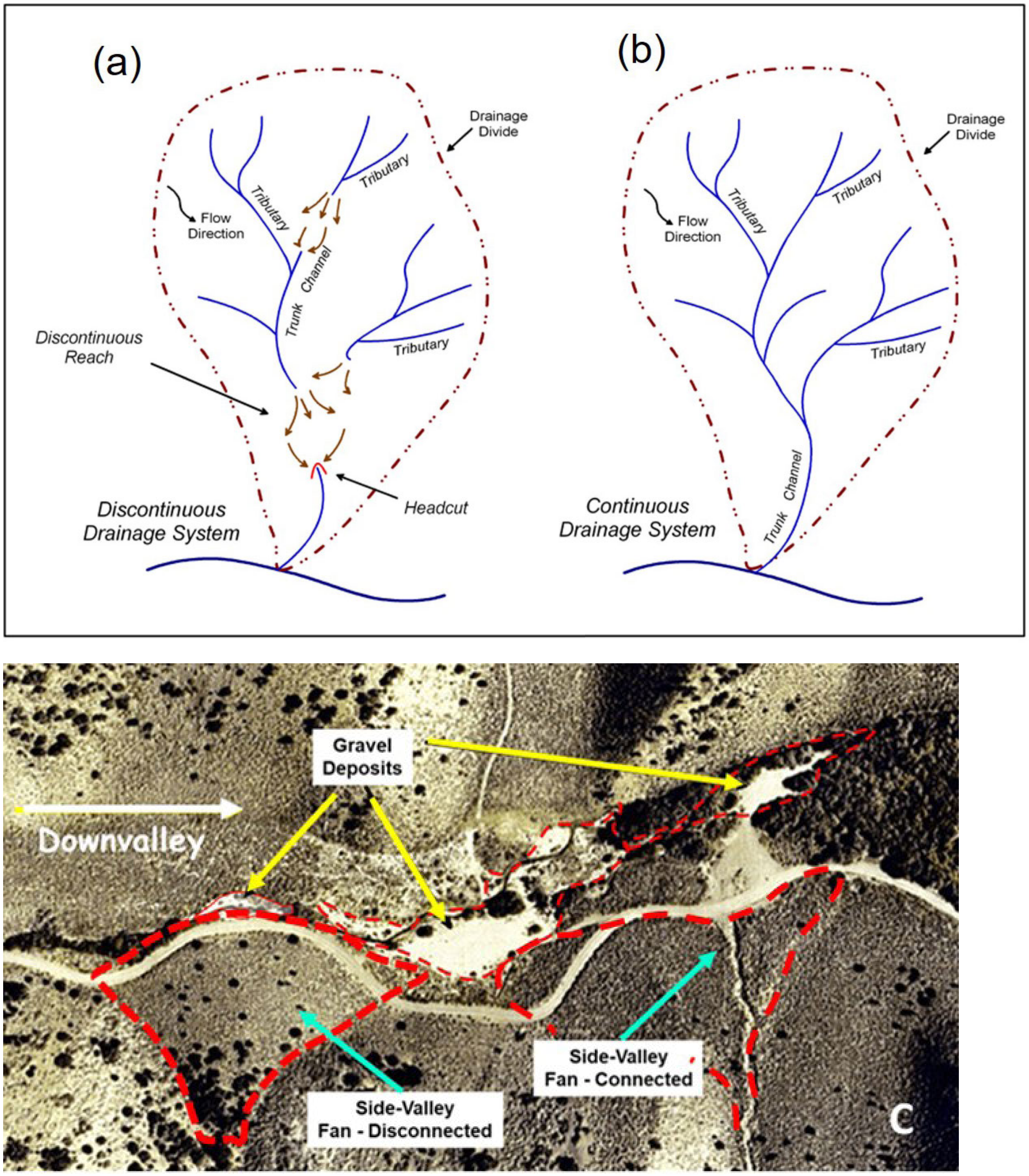


Figure 9—Schematic of discontinuous and continuous drainage systems. In many upland watersheds of the Great Basin, runoff from parts of the watershed is disconnected from the axial drainage and no surface channel exists (a) (Chambers and Miller 2011a; Miller et al. 2012). Many other drainage networks are fully connected hydrologically (b), allowing for the continuous flow of water and sediment through a surface channel to the watershed's mouth. Disconnected reaches are often associated with unentrenched side-valley alluvial fans (c) or unincised wet meadow complexes. The degree to which a drainage network is connected or disconnected significantly influences surface runoff, groundwater recharge, and the influx of sediment to that axial channel. Alluvial fans are outlined by thick red dashed line. Overbank gravels are associated with avulsions and deposited by the axial channel. The image in (c) is from Kingston Canyon, central Nevada. (Image from Google Earth.)

Connectivity commonly is related to the lithology of the underlying bedrock. Higher connectivity is associated with fine-grained sedimentary rocks (e.g., shales) and volcanic rocks that yield high rates of runoff (Miller et al. 2012). Low levels of connectivity (percentage of total basin) are most frequently associated with metamorphic assemblages and sedimentary rocks that are extensively fractured (e.g., carbonates).

How Does Geology Affect Watershed Processes?

Bedrock geology is a primary determinant of a watershed's hydrologic regime in that it dictates the relative amount of infiltration versus runoff, given its hydraulic conductivity (permeability) and the hydraulic conductivity of the surface materials that are produced by weathering processes. A watershed's underlying geology also controls the size and quantity of sediment that is produced by weathering processes on hillslopes, which is a critical determinant of axial channel processes and process rates. Of importance is the availability of hillslope sediment that can be mobilized by the watershed's runoff. In areas characterized by relatively minor variations in weathering rates, sediment size and availability primarily are controlled by the lithology, degree of fracturing, and, for sedimentary or metasedimentary strata, thickness of the stratigraphic beds (layers). Within a given mountain range or ecological region, for example, specific bedrock units often generate a relatively consistent amount of sediment of a given size. Thus, geology can provide important insights into sediment supply and mobility. However, over larger areas (e.g., the northern Great Basin), similar types of bedrock (e.g., volcanic flows or tuffs) can produce a wide range of sediment sizes of varying amounts. Insights into the size and quantity of sediment generated by weathering processes at the watershed scale often can be obtained by examining the nature of the hillslopes. Watersheds consisting of rugged hillslopes composed of exposed bedrock are often characterized by large-sized but low quantities of channel bed sediments, resulting in lower sensitivities to disturbance. Conversely, relatively smooth, vegetated hillslopes that lack significant bedrock exposures are associated with larger amounts of finer-grained sediments (Miller et al. 2012) (fig. 10). These sediments may be mobilized, for example, during floods or after a wildfire, resulting in higher basin sensitivities.

Complicating the relationship between geology and sediment characteristics is the input of sediment to the channel from relict landforms and features that were created under very different weathering regimes. Glacial moraines, glacial outwash terraces (fig. 11), and large talus cones are examples of relicts that have sediments which differ significantly from those produced by the more recent weathering of the underlying bedrock. Glacial features may provide either fine or coarse sediment to the channel. It is important to determine what type of sediments, if any, make up these types of relict features and what they are contributing to the channel. In general, the larger the material, the lower the basin's overall sensitivity and the higher its resilience.

Figure 10—Smooth hillslope covered by fine, mobile sediment (a, b, c) in contrast with rugged hillslopes composed of bedrock with limited mobile sediment (d, e, f). Debris and mobilized fine sediment on hillslopes (b, c) are transported to side-valley fans adjacent to the valley floor via debris flows. Large colluvial boulders compose this hillslope and are largely immobile (f). Photos taken by the authors and used with their permission.

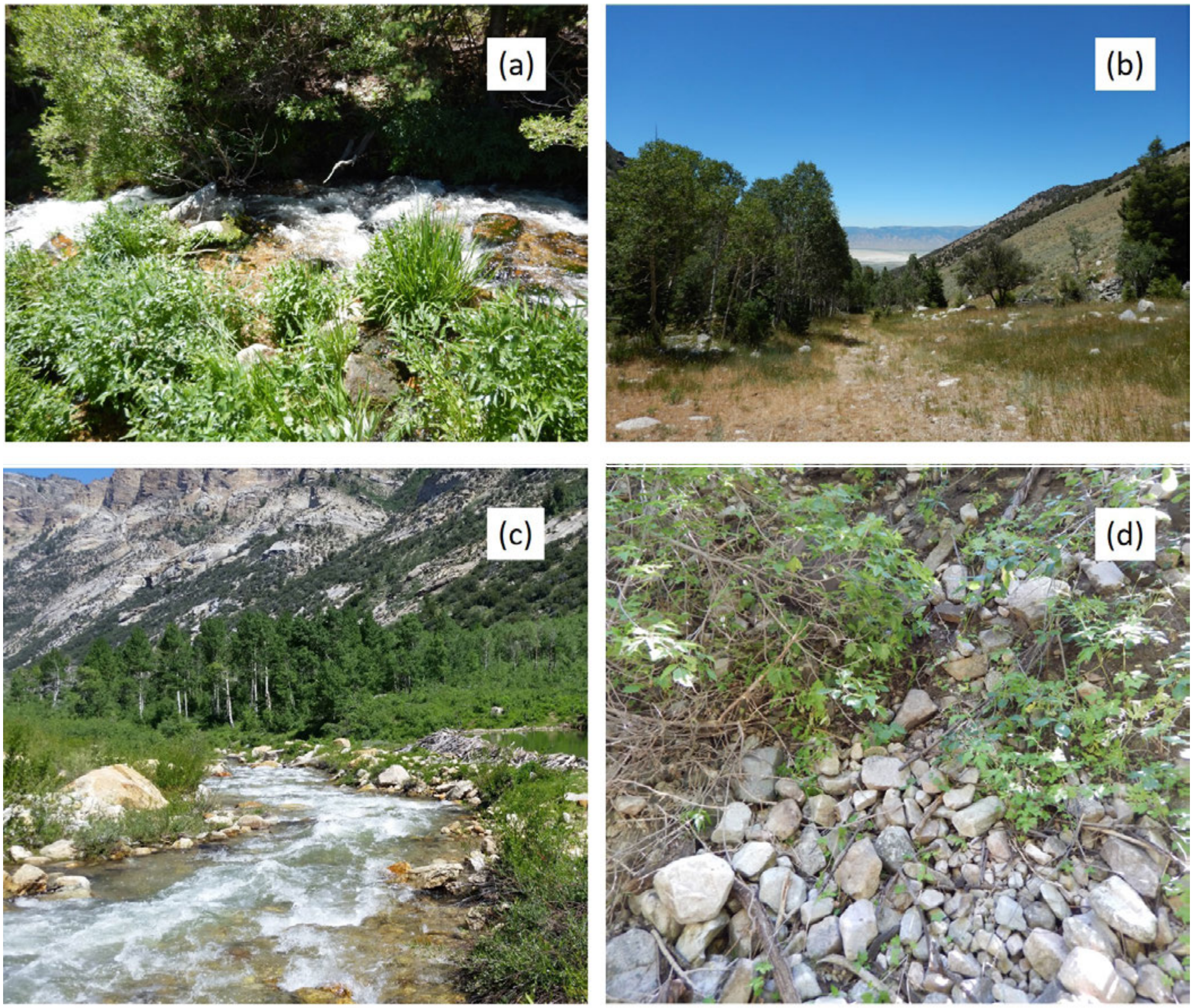


Figure 11—Channels with large clasts and boulders (a, b) that are derived from relict geomorphic features, such as glacial moraines or outwash terraces (c). The large clasts in these features are often eroded and armor the channel bed upon entering the channel, thereby limiting changes in channel form (c, d). Photos taken by the authors and used with their permission.

How Does Hillslope Vegetation Affect Watershed Processes?

The type and amount of vegetation on hillslopes affect soil water storage and erosional processes, and thus the quantity of water and sediment that is delivered to stream channels (text box). On a regional basis, temperature and precipitation regimes and soil types are the primary influences on cover and biomass of vegetation. On a more local scale, vegetation cover and biomass generally increase with increases in precipitation over elevation gradients, and are also affected by soil characteristics, slope, and aspect. Thus, hillslope vegetation interacts with watershed geology, which strongly influences soil type and watershed morphometry to affect water and sediment delivery.

The Effects of Vegetation on Soil Water Storage and Erosional Processes (based on Marston 2010).

The type, cover, and biomass of vegetation affect water and sediment supply through both physical and ecophysiological processes:

- Leaves and litter intercept raindrops and can dissipate erosive energy.
- Roots bind soil aggregates and can decrease piping, surface erosion, and shallow mass movement.
- Vegetation structure and patterning influence overland flows and thus the amount and type of surface erosion.
- Transpiration by plants can decrease soil water, potentially reducing mass movement.
- Development of organic matter in soils due to decomposition of plant matter can increase infiltration and percolation, and thus soil water storage.

The type, cover, and biomass of hillslope vegetation are affected by a variety of disturbances to the uplands including wildfires, livestock grazing, vegetation treatments such as pinyon and juniper removal, conversion of sagebrush ecosystems to introduced grasses, trails and roads, and climate change. Consequently, the relative effect of hillslope vegetation on water storage and erosional processes at any point in time is strongly affected by disturbance—the type of disturbance, the time since disturbance, and the relative resilience of the vegetation to the disturbance.

How Do Watershed Morphometry and Geology Affect Riparian Vegetation Types?

Several watershed properties, including bedrock geology, area, length, relief, and ruggedness, are important predictors of riparian vegetation types (Baker 1989; Engelhardt et al. 2012). As noted previously, bedrock geology is related to infiltration and runoff rates via the hydraulic conductivity of surface and subsurface materials, and influences the grain size and erodibility of materials on the hillslopes and in the channel. Watershed size, relief, and shape are related to flood discharge and time to peak flow. To evaluate relationships among watershed geomorphic characteristics and vegetation extent and composition in the Great Basin, 18 watersheds with different geology and morphology were studied with high-resolution imagery and geospatial analyses (Engelhardt et al. 2012). The major findings were:

- **Riparian forest vegetation** extent and composition were best predicted by a high hypsometric integral, indicating greater landmass at higher elevations within the watershed. Other important predictors were high relief ratio, ruggedness, and proportion of volcanic and intrusive rocks. Such watersheds effectively capture and retain snow, producing higher snowmelt discharge in spring and early summer. Spring floods are especially important for the regeneration of *Populus* and *Salix* spp. (Scott et al. 1996). *Populus tremuloides* and several riparian conifers are facultative riparian species associated with greater water availability and cooler temperatures at higher elevations

(Weixelman et al. 1996). Scientific and common names of plants mentioned in this report are listed in Appendix 7, table A.7.1 for riparian ecosystems and Appendix 9, table A.9.1 for meadow ecosystems.

- **Riparian shrub vegetation** extent and composition were best predicted by stream power and watershed relief. Reproduction of native woody species such as *Betula occidentalis* and *Salix* spp. often depends on flooding to create the bare surfaces required for seedling establishment (Karrenberg et al. 2002; Scott et al. 1996). In addition, these species have traits that allow them to survive scouring floods, including high bending stability of shoots and roots and the ability to resprout when uprooted or damaged by flood water (Karrenberg et al. 2002; Naiman et al. 2005).
- **Riparian meadow complexes** are dependent on groundwater and reach their greatest extent where geomorphic conditions promote fine sediment deposition and elevated water tables (Lord et al. 2011). In the Great Basin, riparian meadows were associated with large watersheds that had low ruggedness, low gradients, and a high percentage of alluvium (Engelhardt et al. 2012). The wet and mesic meadow types were strongly associated with a higher percentage of carbonate and metasedimentary rocks within the watershed. These rock types promote infiltration and maintenance of high groundwater levels, and weather to produce smaller sediment particle sizes compared to intrusive igneous rocks (Sable and Wohl 2006). Fine-grained sediments of lower hydraulic conductivity favor higher water tables and thus enable persistence of wet and mesic meadow vegetation (Loheide et al. 2009; Lord et al. 2011; Lowry and Loheide 2010). These watersheds were also characterized by less topographic relief, which facilitates longer water and sediment retention times. Finally, side-valley alluvial fans are common and important geomorphic features of these watersheds that can constrain flow and result in sediment deposition upstream of the fans (Miller et al. 2001). In areas where elevated water tables occur above the alluvial fans, meadow ecosystems are common (Chambers et al. 2004b; Jewett et al. 2004). Although the locations of meadows are determined by groundwater conditions, meadows are strongly influenced by changes in streams because streams can exert strong control over local, shallow water table levels.

What Are the Basin Morphologic Types?

It is not possible to predict the processes and process rates that occur along the riparian corridor solely on the basis of watershed morphometry and bedrock geology because of variations in connectivity and the relationships between geology and a basin's hydrologic and sedimentologic regimes. However, studies specific to the Great Basin have identified an alternative, watershed-scale, geomorphic approach that provides important and consistent insights into watershed dynamics and sensitivity to disturbance. In this approach, watersheds are classified according to their general relief, valley width, and frequency and size of side-valley alluvial fans. These parameters are indicators of how dynamic a watershed has been over thousands of years and is likely to be at the present time.

There are three major basin types (fig.12). Type A basins have steep slopes, high channel gradients, and high relief and are likely to generate high runoff. The lack of side-valley fans in these basins suggests that they have not produced much sediment over geologic time. Type A1 and Type A2 basins are differentiated largely by the size of the sediment produced and its mobility. In Type A1 basins, any sediment produced is readily transported; in Type A2 basins, large bed material within the channels results in little sediment transport. While Type A1 basins are characterized by frequent avulsion and anabranching channels, Type A2 basins are characterized by relatively immobile channel beds. Type B basins are characterized by side-valley alluvial fans. Basins with large fans have, at some point during the Holocene, generated sediments that were transported off the hillslopes to the mouth of the tributary. These fans often result in a stepped-valley profile with sediment deposition and lower gradient channels upstream of the fan, and steeper gradient channels and sediment transport downstream of the fan. Channel characteristics depend on position relative to the fan. Channels upstream of the fans with deeper sediment have the potential for incision, whereas those downstream have the potential for sediment transport and avulsion at some point downstream. Type C basins are characterized by broad, low-relief, and low-gradient valley floors, and often have relatively deep alluvium in the valley bottoms. Unincised reaches are either devoid of channels or have shallow depressions of flowing water on a relatively flat valley floor. Incised reaches often have pronounced knickpoints and can form gully systems with trenches incised to 5 to 10 m below the valley floor and measuring kilometers in length. Most gully systems exhibit well-defined downstream changes in channel form. Classifying watersheds into one of three basin types provides insights into how the basin may respond to changes in environmental conditions (climate and land use or land cover). It also provides insights into the types of riparian vegetation that the watershed is likely to support.

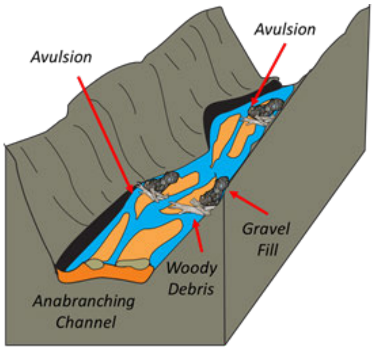
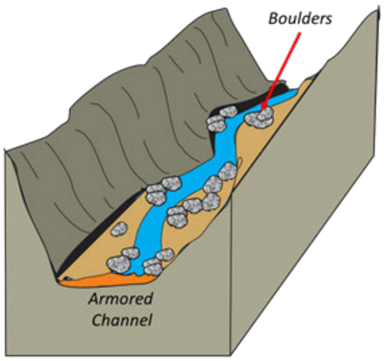
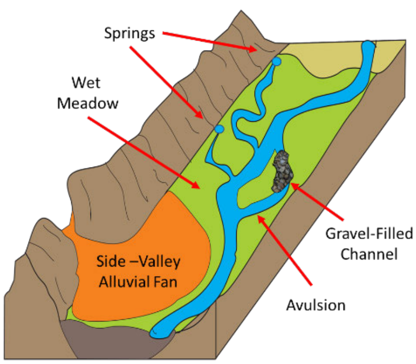
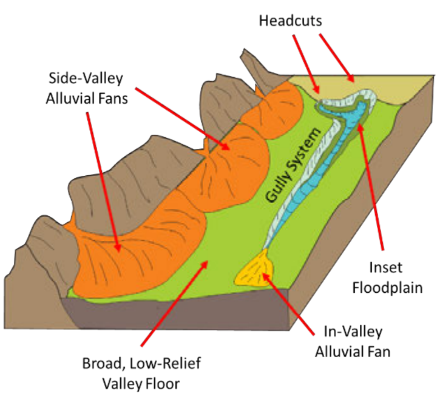
Basin Type	Common Traits	Characteristics
Type A1		• Steep slopes, narrow valley floors, high channel gradients, and high relief • Readily transported, coarse sediment, lack side-valley fans • Local deposition producing channel avulsions • Anabranching channels
Type A2		• Steep slopes, narrow valley floors that typically lack side-valley fans • Large bed material and low sediment transport • Avulsion and incision are rare • Relatively immobile channels • Often associated with glaciated basins, or resistant bedrock with local colluvial sediments
Type B		• Large side-valley alluvial fans and wet meadow complex • Stepped longitudinal profile across toe of fan • Sediments periodically mobilized during extreme events, resulting in incision • Rare avulsions upstream of fan • Variable channel characteristics
Type C		• Broad, low-relief and low gradient valley floors • Deep alluvial fill in valley underlying valley floor • Fans may occur but have little influence on channel form • Unincised reaches have shallow or no channels • Incised reaches possess discontinuous inset floodplains and terraces • Gully systems, once formed, terminate upstream in headcuts • Often possess large wet meadow complexes

Figure 12—Schematic of morphometric differences in the three defined basin types. Variations in basin types provide important insights into watershed dynamics. For example, side-valley alluvial fans require the long-term generation and mobilization of hillslope sediments.

Component 2—Geomorphic Characteristics of Stream Channels and Stream Reaches

The type of fluvial geomorphic processes and the rate at which they function vary not only among watersheds, but also along the drainage network. Within upland watersheds of the Great Basin, detailed analyses have shown that channel responses to disturbance are dominated by two distinct types of processes: channel incision and channel avulsion. Variations in the type, magnitude, and rate of these processes create differences in geomorphic sensitivity and ecological resilience between watersheds and along a watershed's stream reaches.

What Is Channel Incision?

Incision is the downward erosion of the channel bed. Channel incision can be defined as the depth from the valley floor to the surface of the lowest inset terrace within the trench or the channel bed. Incision occurs when the driving forces dictated by discharge exceed the energy required to transport the available sediment and the resisting forces determined by the strength of the underlying materials (Beechie et al. 2008; Harvey and Watson 1986). Incision is generally initiated by (1) a change in base level of the channel bed (elevation below which erosion cannot occur); (2) an alteration in the relationships among runoff, sediment size, and sediment supply; or (3) a reduction in the stabilizing capacity of vegetation. These alterations may be induced by such factors as changes in land use or land cover, climate, or the type and abundance of upland or riparian vegetation (table 1).

What Are the Impacts of Incision?

Channel incision generally leads to bank instability, an increase in downstream sediment transport, and an alteration in channel morphology. In many areas, including upland watersheds in the Great Basin, alterations in channel form occur through a three-stage evolutionary sequence, although the specifics of the sequence can vary from place to place. The stages are cutting of a narrow channel (i.e., incision), channel widening (i.e., lateral erosion), and channel migration (i.e., additional lateral erosion) that may result in the development of an inset floodplain (fig. 13) (Schumm et al. 1984; Simon and Hupp 1987). An additional impact is lowering of the local water table, a process that often has profound effects on riparian plant communities, including those associated with meadows (Chambers and Miller 2011b; Chambers et al. 2004a,b; Lord et al. 2011).

Table 1—Summary of potential disturbances that may cause channel incision (after Miller and Orbock Miller 2007).

Type of Change	Potential Effects
Changes in climate	• Alterations in the frequency, intensity, and duration of precipitation • Changes in storm characteristics • Temperature changes • Vegetation changes
Changes to drainage basin	• Deforestation or afforestation and other vegetation changes • Wildfire, intentional burning • Land-use changes, such as agriculture, urbanization, and road construction • Livestock grazing
Changes to drainage network	• Development of irrigation networks, drainage ditches, and storm drains
Tectonic activity	• Uplift or fault development
Channel changes	• Channel straightening and meander cut-off • Sediment removal by gravel mining • Sediment additions • Invasion by nonnative vegetation • Bank protection and stabilization • Dredging • Embankments • Diversions of flow • Dam construction • Weirs • Return flows • Bridge crossings • Culverts • Restoration and other channel improvements

What Factors Control the Rates of Channel Incision?

Within channels prone to incision, those with more stream power (stronger flows) and finer, more mobile bed sediments are most likely to exhibit high rates of deep channel incision (Schumm 1999). Stream power is positively related to the product of discharge and slope; thus, channels characterized by higher gradients and more runoff have higher stream powers. Stream powers can be exceptionally high during large floods. For example, the record-setting high flows that occurred throughout the Great Basin in 1983 and 1984 resulted in rapid, deep incision in many upland watersheds. Incision also is strongly dictated by the size of the channel bed and bank materials; the larger the size, the less likely that rapid channel incision will occur. In many areas, the size of the channel bed sediment reflects not only the current weathering, erosion, and transport of sediment from upland areas to the channel, but also the introduction of large clasts (boulders) produced by glaciation or mass wasting processes (fig. 11). Factors that can reduce incision rates locally include bedrock outcrops, the roots of riparian vegetation, and the introduction of large woody debris.

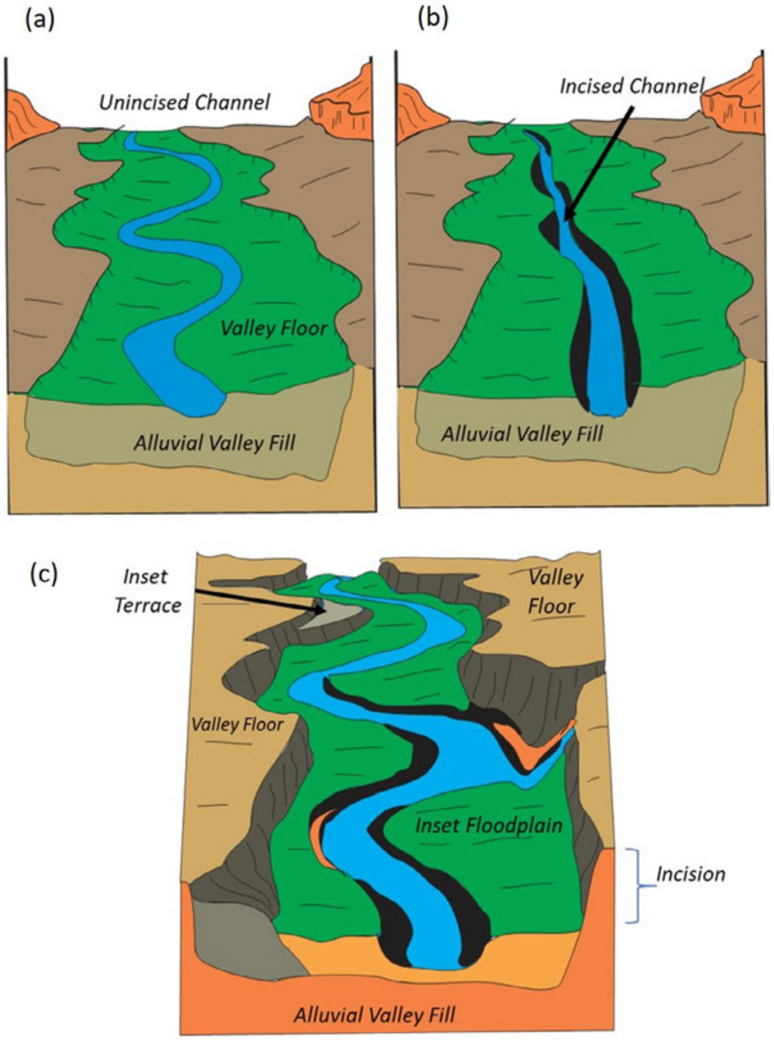


Figure 13—Commonly observed channel evolutionary sequence. Downcutting of the channel creates an incised channel or trench (a), which subsequently is enlarged through channel migration and bank erosion (b). During migration, inset floodplains and terraces are often created (c). (Figure modified from Wells et al. 1987.)

What Watershed Characteristics Lead to Incision in Upland Watersheds in the Great Basin?

Paleoecological studies in central Nevada show a shift from relatively cool and wet to warm and dry conditions about 2,600 years before present (YBP) that appears to have decreased the extent of woodlands and increased the dominance of shrubs (Wigand and Rhode 2002; Wigand et al. 1995). Regionally, this shift occurred slightly later (~2,000 YBP) (Tausch et al. 2004). The drier and warmer conditions led to significant sediment deposition on side-valley alluvial fans and within the axial valleys that continued throughout central Nevada until about 1,900 YBP. This deposition probably ceased in response to a reduction in mobile fine-grained sediment on the hillslopes and a change in hillslope hydrology. Since about 1,900 YBP, upland watersheds throughout the central Great Basin, and presumably other parts of the northern Great Basin, have been characterized by periods of channel or valley incision, separated by periods of stability (Miller et al. 2001). The current sensitivity of upland watersheds to incision is very likely due to a general lack of runoff that can transport the available hillslope sediment to the drainage network. In many locations, limited upland sediment transport is associated with limited quantities of fine-grained hillslope sediments. In either case, the inability to mobilize hillslope sediments leads to sediment-deficient (starved) channels that are prone to incision (Miller et al. 2001, 2004). These climatically driven reductions in sediment loads may be exacerbated by anthropogenic features, such as reservoirs, that trap and store sediment moving along the axial channel (Kondolf et al. 2014). In combination, these controlling factors produce variations in the magnitude and rates of incision both between watersheds and along reaches of a given watershed.

What Factors Control Spatial Variations in Incision?

As noted earlier, spatial variations in incision (i.e., whether incision has occurred or is occurring and to what degree at a given location) are ultimately dictated by watershed-scale parameters, which control the watershed's runoff and sediment size and supply, and by local parameters. Local factors, such as bedrock outcrops and vegetation, may either inhibit or promote incision. Incision is promoted by high flows, small particle sizes, and reduced sediment loads (fig. 2). Any factor that promotes runoff to the drainage network, or that decreases the size and influx of hillslope sediment, promotes incision. Incision can also be initiated by changes in channel form that alter channel gradients or flow competence and capacity.

Two types of spatial variation are common within upland watersheds. The first is related to the process of headward (i.e., upstream) migration of knickpoints. In many instances, incision initially occurs downstream in areas of higher runoff and smaller particle size and migrates upstream, in the form of a headcut. In these watersheds, depth of incision can be significant (i.e., greater than meters) downstream, but limited or nonexistent upstream (Miller et al. 2011a). The second is related to downstream morphologic changes in valley width and gradient along a given drainage, particularly where the valley fill is composed of fine-grained sediments, such as within meadow complexes. In these watersheds, incision and upstream headcut migration are associated with relatively narrow valleys and steeper gradients, which in combination confine flood flows and enhance stream powers. Wider and less steep valley reaches within these watersheds are often characterized by deposition of sediment eroded from the narrower, steeper upstream valley reaches.

What Factors Control Incision in Meadow Ecosystems?

As with other reaches of the drainage network, the ultimate propensity for a meadow to incise is dependent on the relationships among stream power, sediment size, and sediment load. However, many meadows are located in Type B basins upstream of large side-valley fans that promote the deposition of fine-grained sediments and constrict the downstream flow of groundwater. These side-valley alluvial fans, particularly those associated with debris flows, often have large boulders that cannot be easily transported by the watershed's generated runoff. As the toes of these fans erode (truncate), the larger clasts armor the channel bed. Only during rare, extreme events can this armor break and cause channel incision. The result is the development of a convexity (or step) in the longitudinal profile of the channel and valley floor (fig. 14). These steps represent zones of continued slow incision and instability that serve as local base-level controls and govern the amount of upstream incision.

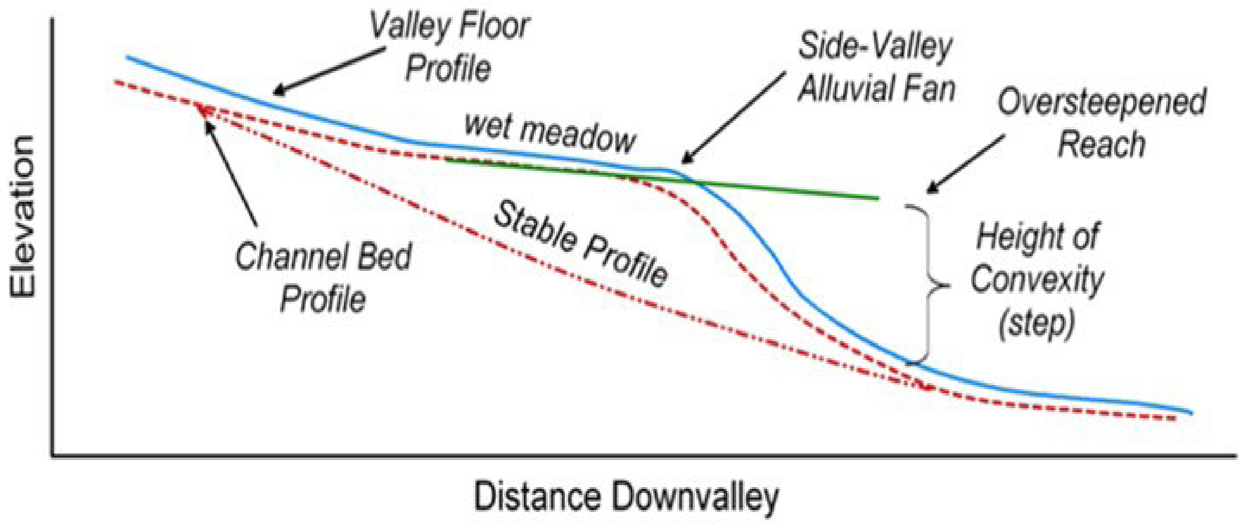


Figure 14—The longitudinal profile of a large side-valley alluvial fan. The profile of large side-valley alluvial fans commonly has a step-like feature in which the valley floor downstream of the fan is several meters in elevation below the valley floor upstream of the fan (Miller et al. 2011b). This convexity represents a long-term zone of instability that exists until the step is removed (red dashed line). The convexity is produced by the continued but slow erosion of the fan deposits, which releases large clasts (boulders) from the valley fill and results in channel armoring. This armor severely limits the rate of channel incision because it cannot be broken except during rare, high-magnitude events. The convexity acts as a local base-level control that governs the amount of erosion that occurs upstream. Reducing the erosion along this reach is likely to limit incision immediately upstream.

When meadows are located in Type C basins that are characterized by relatively wide, low-gradient valley floors and fine-grained valley fill, incision is often induced by the concentration of surface runoff by either natural or anthropogenic features (e.g., cattle trails, berms, drainage ditches, culverts) (fig. 15). Once incision is initiated in meadows with fine-grained fill, headcuts typically form, and their upstream migration is enhanced by groundwater-sapping processes as groundwater flow converges toward the developing trench.

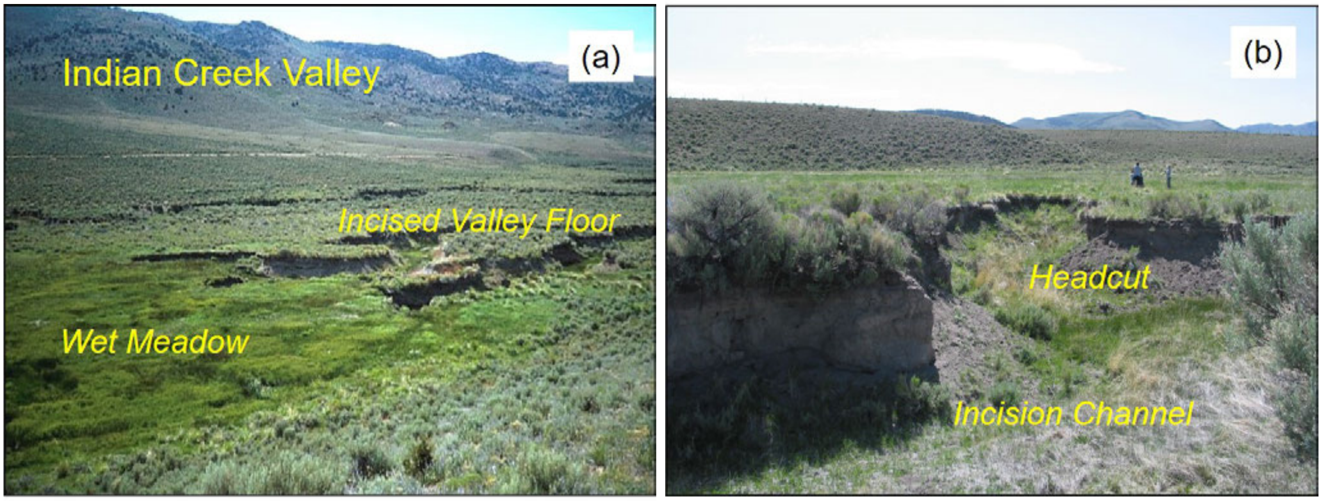


Figure 15—Progressive incision in the Type C basin in Indian Valley, central Nevada. Channel incision leads to lowered water tables and changes in the meadow vegetation (a). Headcut migration is the cause of the incision and is often enhanced by groundwater sapping as groundwater converges on the entrenched zone (b). Photographs taken by the authors and used with their permission.

What Is Channel Avulsion?

Channel avulsion is the rapid abandonment of part of a river channel and the abrupt formation of a new channel in a different location on the valley floor. It is generally caused by in-channel deposition (aggradation) of sediment along a relatively low-gradient reach of the drainage network, a process that forces water onto the adjacent floodplain surface. The displaced water then cuts a new channel into the valley floor that merges both downstream and upstream with the pre-avulsion channel system, creating a channel pattern called anabranching (fig. 16). There is some debate as to whether anabranching channels represent equilibrium or disequilibrium forms (Jansen and Nanson 2004; Jerolmack and Mohrig 2007). In the northern Great Basin, the pattern appears to have been operative for millennia in some areas, allowing for the nearly complete reworking of the valley fill. As such, these processes represent a long-term mechanism of dealing with changes in the prevailing hydrologic and sedimentologic regime.

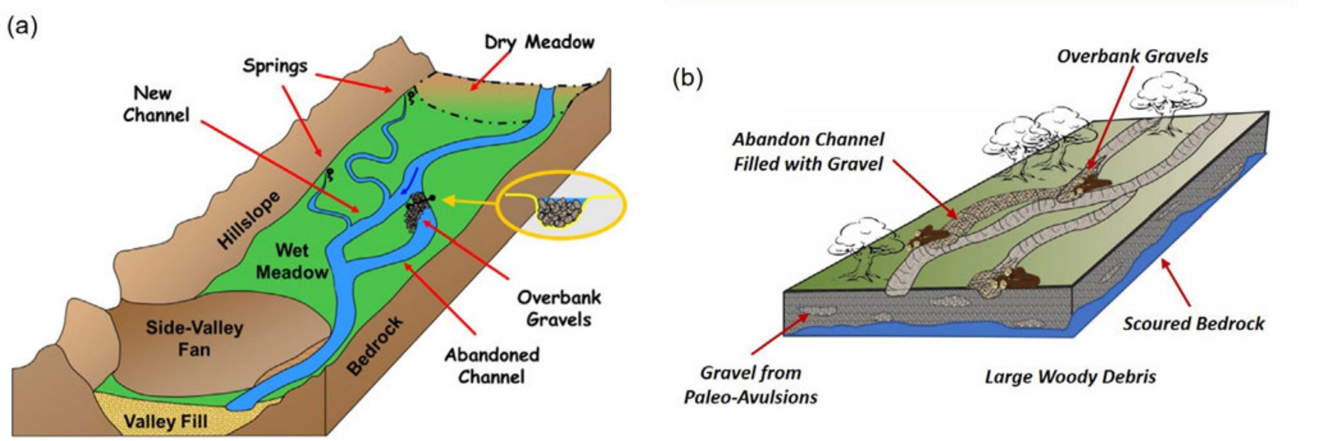


Figure 16—The two general forms of channel avulsion that occur within the Great Basin. Relatively rare avulsions (a) occur upstream of large side-valley alluvial fans where decreases in channel gradients allow for localized deposition of coarse sediment within the channel. Upon channel filling, sediments are often deposited over the valley floor, forming gravel bars. These types of avulsions are associated with the abrupt influx of sediment to the axial drainage system. More widely distributed avulsions are often associated with Type A1 basins, characterized by large quantities of highly mobile bed sediments (b). In these basins the channel is highly dynamic and characterized by anabranching.

What Conditions Promote Channel Avulsion?

Anabranching channels occur locally along upland streams in the Great Basin. They are characterized by a multithread pattern in which channels flow around relatively stable, vegetated islands composed of floodplain deposits (Nanson and Knighton 1996) (fig. 16). The channel pattern is produced by channel avulsion that is initiated by the localized deposition of sediment on the channel bed. When sediments partially or entirely fill the channel reach, water is forced onto the valley floor. Once on the valley floor, the water either flows into an existing spring channel or depression, which is enlarged, or cuts a new channel before flowing downstream into the original axial channel. Avulsion, then, involves both aggradation and incision that are spatially separated and linked to specific channels within the reach. It is fostered by abundant, mobile sediment, a flood-prone hydrologic regime, a downstream reduction in channel gradient, and relatively stable banks that limit bank erosion and allow for localized channel aggradation (Miller 1991; Nanson and Knighton 1996).

In the Great Basin, the frequency at which avulsions occur varies significantly among watersheds, primarily as a function of sediment supply, size, and discharge. In Type A1 basins, which are characterized by significant runoff, narrow, steep valleys, and large quantities of mobile sediment, avulsions occur during nearly every overbank flood event. Aggradation is often triggered by the accumulation of sediment upstream of large-woody debris dams or other obstructions to flow. The channels are highly dynamic, and the valley floor is continually reworked (fig. 16b). In Type B basins, avulsions occur much less frequently (several decades between events) and are often found upstream of large-side valley alluvial fans characterized by relatively low-channel or valley gradients (fig. 16a). The occurrence of avulsions at these sites is generally associated with the rare but rapid influx of sediment from breached beaver dams, landslides, debris flows, or other sources that is locally redeposited upstream of the fans as a result of a reduction in valley gradients. Avulsions at these sites often coincide with major runoff events, such as the floods in 1983 and 1984. Avulsions in basin types that are not significantly influenced by side-valley alluvial fans, including most Type C basins, are extremely rare or do not occur because one or more of the factors that promote avulsion is missing.

What Are the Impacts of Avulsion?

The impacts of avulsion vary with the type and frequency at which they occur. The frequent occurrence of avulsions in Type A1 basins leads to the continual erosion and reworking of the valley floor. In these basins, avulsions are so frequent that their occurrence produces little change in the longer-term morphology of the riparian corridor. In contrast, avulsions in Type B basins (upstream of side-valley fans and within meadows) can significantly affect the existing riparian ecosystem by (1) depositing coarse-grained sediments within the channel and on the valley floor or meadow; (2) eroding or incising existing or new channels, creating an anabranching pattern that reduces the area of the adjacent meadow complex; and (3) lowering water tables as incision occurs along the new channel, thereby impacting the local plant community. Where recovery of the riparian corridor or meadow complex following these events occurs, it can take decades, depending on the rates of channel incision and the local groundwater flow conditions. In some places avulsion can result in permanent changes in channels (e.g., a large increase in channel width or thick deposit of coarse sediment), a decrease in water retention capacity, and a loss of riparian and meadow vegetation.

Component 3—Vegetation Characteristics of Stream Reaches

The composition and extent of the riparian vegetation are strongly influenced by the dominant geomorphic characteristics of a stream reach, including (1) the stream gradient and channel and bank substrate characteristics and (2) the types of fluvial landforms that are present. The adaptations of the riparian species to flooding, substrates, and water table regimes reflect the geomorphic characteristics of the stream reach. In turn, the types of riparian species that characterize a stream reach can affect fluvial geomorphic processes and resilience of the riparian ecosystem to disturbances, such as incision and avulsion.

A diversity of riparian vegetation types occur in the Great Basin. The dominant vegetation types included in this report are in Appendix 3.

What Are the Relationships of Water Table Regimes, Substrate Characteristics, and Stream Channels to Riparian and Meadow Vegetation?

A primary control on the extent and composition of riparian vegetation is water availability as influenced by water table regimes and substrate characteristics. All riparian species are adapted to a specific range of water availability and can be assigned a riparian or wetland status rating (table 2). Soil texture affects water availability and rooting, and thus species composition. Information on how soil characteristics are associated with riparian species composition in the Great Basin is provided in Weixelman et al. (1996).

Table 2—Riparian and wetland indicator status ratings based on the ecological descriptions in Lichvar and Minkin (2008).

Indicator Status	Abbreviation	Ecological Description
Obligate	OBL	Almost always is a hydrophyte, rarely in uplands.
Facultative Wetland	FACW	Usually is a hydrophyte but occasionally found in uplands.
Facultative	FAC	Commonly occurs as either a hydrophyte or nonhydrophyte.
Facultative Upland	FACU	Occasionally is a hydrophyte but usually occurs in uplands.
Upland	UPL	Rarely is a hydrophyte, almost always in uplands.

The relationships between water table depth and riparian species in the Great Basin have been determined for riparian vegetation associated with (1) losing stream reaches and (2) meadow ecosystems with elevated water tables due to downstream geomorphic constraints, such as zones of elevated bedrock beneath the valley alluvium, seeps, or springs and the necessary substrate characteristics to maintain elevated water tables. Depth to water table, as governed by stream terrace and floodplain height, channel and bank particle size, and stream slope are related to vegetation type in losing stream reaches (table 3). Riparian vegetation is stratified according to the height of the stream terraces and floodplain above the average height of the water surface within the stream channel during low flows (Hupp and Osterkamp 1985, 1996; Stromberg et al. 1996, 2010) (table 3). Thus, assigning a riparian or wetland indicator rating to the species on the inset terraces and floodplain provides information on water availability from either the stream or groundwater for each geomorphic position along the stream reach.

Table 3—Geomorphic characteristics associated with common vegetation types adjacent to losing streams with constrained water tables in the central Great Basin (from Chambers et al. 2004b).

Vegetation Type	Terrace/ Floodplain Height (M)	Channel Particle D_{50} (Mm)	Bank Particles <2 Mm (%)	Channel Slope (%) (M/M)
Artemisia tridentata/ *Leymus cinereus* or *Poa secunda*	1.85 ± 0.19	39.2 ± 4.4	60.5 ± 5.6	0.035 ± 0.006
Prunus virginiana/*Rosa woodsii*	1.77 ± 0.40	59.7 ± 5.3	26.4 ± 6.4	0.054 ± 0.014
Dense *Rosa woodsii*	1.56 ± 0.18	48.9 ± 3.4	50.7 ± 5.7	0.041 ± 0.007
Betula occidentalis/mesic meadow	1.04 ± 0.40	65.4 ± 3.0	35.0 ± 11.4	0.048 ± 0.008
Mesic meadow	0.87 ± 0.16	25.5 ± 6.4	60.9 ± 7.5	0.034 ± 0.008
Salix spp./mesic forb	0.73 ± 0.11	55.3 ± 3.1	2.8 ± 6.3	0.047 ± 0.006
Salix spp./mesic meadow	0.49 ± 0.05	51.7 ± 5.5	60.8 ± 7.7	0.034 ± 0.009
Carex nebrascensis meadow	0.38 ± 0.06	15.3 ± 5.0	77.6 ± 6.0	0.018 ± 0.006

Each meadow vegetation type is characterized by a range in the depth to the water table and can be identified by a set of indicator species (fig. 17). These species occur in association with meadow complexes as well as relatively low-gradient streams with banks and terraces that have relatively small soil particle sizes. The variability in depth to water table that a species or meadow vegetation type can tolerate increases as the depth to the water table increases (fig. 17) (Castelli et al. 2000). A loss of vigor or increase in mortality within a particular meadow vegetation type can indicate a drop in the water table or an increase in the variability of depth to water table (Chambers et al. 2011b; Lord et al. 2011). Factors causing a drop in the water table include stream incision, soil compaction by livestock grazing, and climate change.

The relationship of a meadow to stream and spring channels determines the potential for geomorphic processes, such as stream incision and avulsion, to influence the meadow (Lord et al. 2011). Meadows can occur (1) where springs result in elevated water tables and there is no connection with the stream channel—usually at the valley margins; (2) in valley bottoms in association with stream systems, but in the absence of alluvial fans; and (3) in valley bottoms in association with stream systems and upstream of alluvial fans. Meadow vegetation can also occur as stringers or narrow bands along losing stream channels. For the purposes of assessment, these stringer meadows are treated as riparian vegetation.

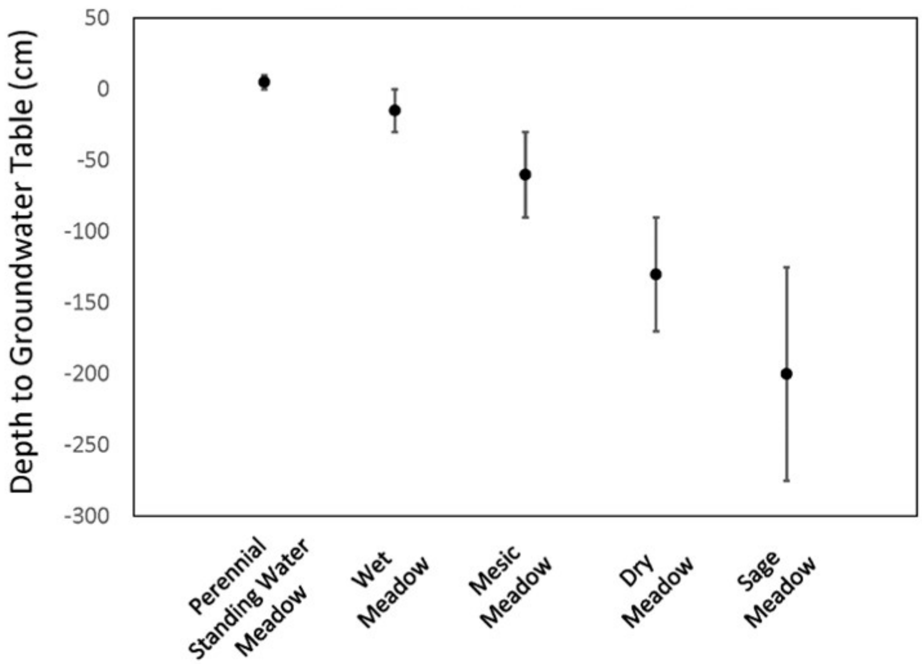


Figure 17—Meadow vegetation type as a function of depth to water table. Meadow vegetation types are closely related to water table depth (Chambers et al. 2004b). As depth to water table increases, the variability in the water table increases and meadow vegetation types are characterized by species adapted to drier conditions.

The hydrologic complexity (i.e., variation in water table depths) within a meadow is indicated by the patchiness of the different meadow types. For example, a large meadow upstream of an alluvial fan may have a high degree of complexity, as indicated by several different meadow vegetation types, that vary in relation to differences in depth to the water table (fig. 18). Hydrologic and thus vegetation complexity often are caused by high variation in sediment types underlying a meadow; this condition is common upstream of alluvial fans where sediments range from fine silts and clays to coarse gravels (Lord et al. 2011).

In meadows where stream incision is occurring, groundwater can flow more rapidly from the meadow soils into the stream, lowering the water table adjacent to the stream. The drop in the water table is reflected in drier meadow vegetation types and, in some cases, expansion of woody vegetation or nonnative invasive species adjacent to the stream channel (fig. 19).

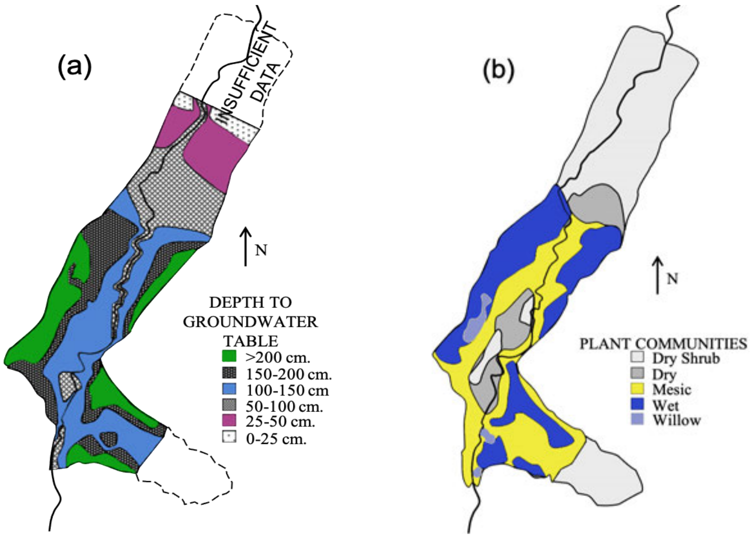


Figure 18—Depth to water table and distribution of dominant vegetation community types in Kingston Canyon, central Nevada. Patterns of depth to the water table (a) are closely related to meadow vegetation types (b) and the degree of shrub encroachment in meadow ecosystems (Lord et al. 2011).

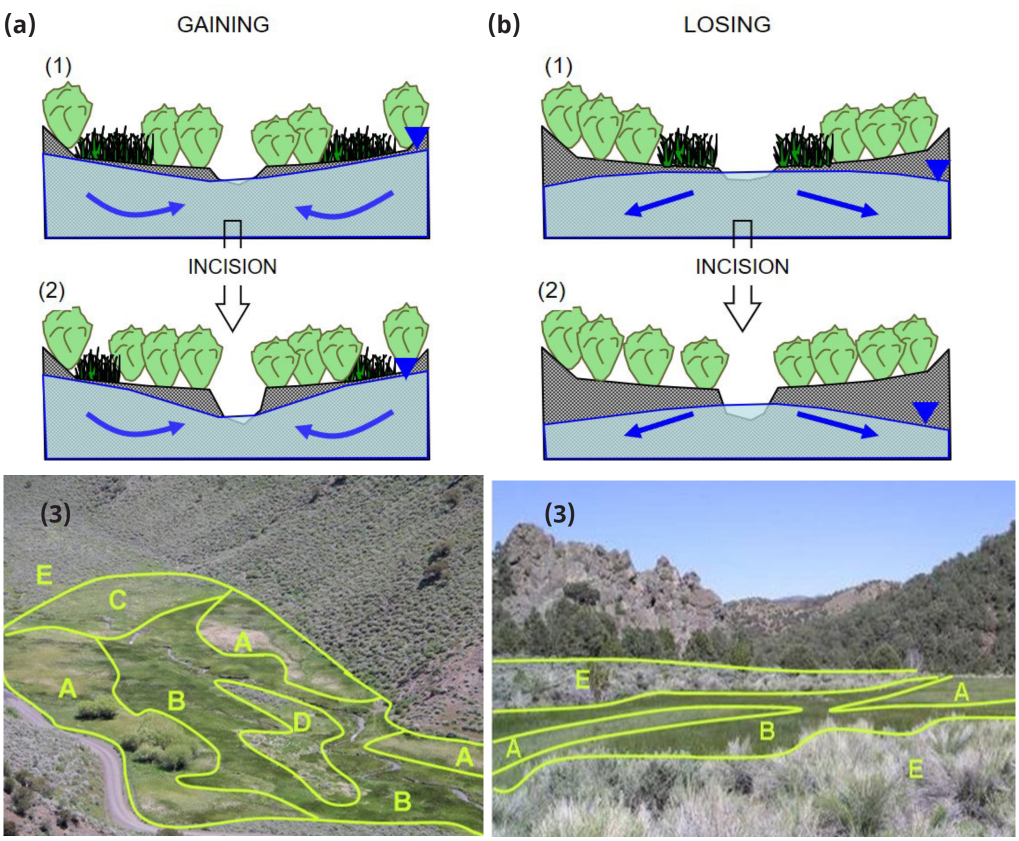


Figure 19—Schematic showing the different effects of incision on meadows for gaining versus losing stream reaches. In a gaining reach (a), incision typically results in a small, localized decrease in the water table, but in a losing reach (b) incision can result in a large decrease in the water table (Lord et al. 2011). Meadow types reflect the stream type: a3 is a meadow complex with wet and mesic types at valley margins; b3 is a stringer meadow associated with a losing stream where saturated soils are constrained to the area immediately adjacent to the channel. Meadow types in a3 are A = wet, B = mesic, C = dry, D = mesic to dry, and E = sage.

What Are the Relationships of Riparian Vegetation to Flood Regimes?

Many riparian plant species depend on flooding and sediment deposition to enable establishment. These species typically have greater tolerance to inundation or scouring. Examples of woody species dependent on flooding and sediment deposition are cottonwoods (*Populus* spp.) and willows (*Salix* spp.), but many early- and mid-seral herbaceous species and nonnative invasive species also can establish on newly exposed surfaces. The time since the most recent flood and the magnitude of the flood are reflected in the successional status of the species on the affected landforms (table 4). Anthropogenic disturbances such as inappropriate livestock grazing or recreational use can result in a shift in successional classes from late to mid to low, or just low.

Table 4—The successional status rating classes for individual plants as assigned by Burton et al. (2011; see pp. 137–143 for more detail, including references).

Class	Symbol	Definition
Early seral	E	All annual and short-lived (living less than 5 years) perennial plants that tend to be replaced by plants that live longer. All noxious weeds and shallow-rooted perennial species that tend to be tolerant of grazing and other uses are classified as early seral.
Mid-seral	M	Perennial plants, mostly forbs, that are not shade-tolerant and tend to have fibrous root systems. These plants are usually replaced in a riparian community by long-lived plants.
Late seral	L	Plants that usually exist in the most stable riparian plant communities. They tend to stabilize stream banks and develop extensive root systems.

Depending on the reach characteristics and magnitude of the flood disturbance, riparian vegetation can stabilize stream banks and lower-elevation terraces, and thus mitigate flood effects. The relative ability of riparian vegetation to stabilize stream banks depends on the root strength and rooting depth of the riparian vegetation on stream banks. The ability of plant species and communities to stabilize stream banks can be compared by assigning a relative bank stability rating to individual species based on their rooting characteristics (table 5).

Table 5—Relative rating of a species' ability to stabilize stream banks based on general rooting characteristics assigned by Burton et al. (2011). Numerical values conform to Winward (2000).

Life Form	Stability Rating
Forbs	
Taproot or most roots shallow (<15 cm)	Low
Fibrous roots, usually up to 30 cm	Medium
Rhizomatous roots, little indication of extensive fibrous roots	Medium
Rhizomatous roots, with extensive fibrous roots	High

Life Form	Stability Rating
Graminoids	
Annual, biennial, and short-lived perennials	Low
Stoloniferous, caespitose, tufted, or short slender rhizomatous perennials (<1 m tall)	Low
Slender or thin creeping rhizomes	Medium
Long, stout, well-developed creeping rhizomes	High

Life Form	Stability Rating
Woody species	
Taprooted species	Low
Short shrubs (<1 m tall) with shallow root systems	Low
Shallow to moderate root systems	Medium
Rhizomatous root system, generally shallow (<31 cm)	Medium
Root crown with spreading roots	High
Widespread root systems	High

What Characterizes the Vegetation of Reaches Dominated by Avulsions?

Avulsion dominated stream channels with abundant, mobile sediment and a flood-prone hydrologic regime (common in Type A1 basins) are characterized by disturbance-adapted riparian species. In channels with frequent avulsions and continuous reworking of the valley floor, plant traits include high bending stability and the ability to resprout when damaged by movement of channel bed sediments. Examples of species with these traits are *Betula occidentalis*, *Salix* spp., *Alnus* spp., and, to a lesser degree, *Prunus virginiana*.

What Characterizes the Vegetation of Stream Reaches with Immobile Channel Beds?

Along channels where incision is limited by immobile bedrock and avulsions are rare (e.g., Type A2 basins), the dominant riparian vegetation is characterized by an overstory of woody species, such as *Populus tremuloides*, *Betula occidentalis*, *Alnus incana*, *Cornus sericea*, and *Salix* spp. (Chambers et al. 2004b; Engelhardt et al. 2012, 2015).

Accumulation of fine sediments and a relatively stable channel can support a diverse understory of sedges, grasses, and forbs.

What Characterizes the Vegetation of Stream Reaches Influenced by Side-Valley Alluvial Fans?

In Type B basins dominated by side-valley alluvial fans, the stepped valley topography is reflected in the vegetation along the riparian corridor. Meadow complexes often are associated with elevated water tables and fine sediments located upstream of side-valley alluvial fans (fig. 20). For example, water table depths ranging from 5 to 30 cm usually are characterized by species such as *Carex nebrascensis, Deschampsia cespitosa*, and *Stellaria* spp. In contrast, meadows with water table depths ranging from 90 to 170 cm exhibit more variability in depth to water table, and usually are characterized by species such as *Elymus trachycaulus, Muhlenbergia richardsonis*, and *Achillea millefolium*.

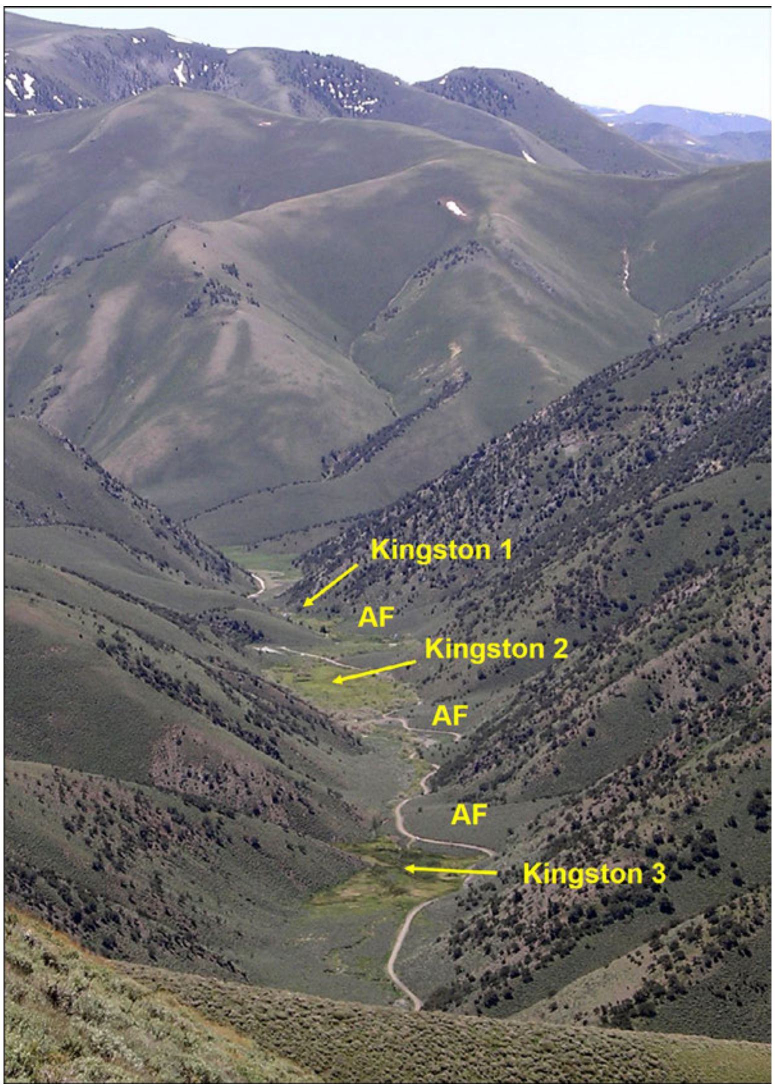


Figure 20—Alluvial fans (AF) in Kingston Canyon, central Nevada. Meadow complexes are often associated with alluvial fans. (Photo from Lord et al. 2011.)

Stream systems associated with meadow complexes usually are closely connected to the groundwater system and may be either gaining or losing (fig. 19). Upstream of alluvial fans and meadow complexes, streams often are losing water and are disconnected or weakly connected to the groundwater system. Vegetation in the valley bottom typically grades into *Artemisia tridentata* ssp. and other shrub species. Downstream of alluvial fans, stream power and sediment size usually increase and streams are again losing. Vegetation associated with these downstream reaches is characterized by woody species such as *Populus* spp. and *Salix* spp. Rushes, sedges, grasses, and forbs occur in the understory with the species composition depending on elevation, stream power, sediment size, and groundwater availability (Chambers et al. 2004b; Weixelman et al. 1996).

What Characterizes the Vegetation of Incision Dominated Stream Reaches?

Along stream reaches where incision is the dominant process (Type B or Type C basins), vegetation often is stratified in relation to the elevation of the terraces and floodplain as previously described (table 3). In systems with low to moderate stream gradients and finer- textured substrates, grasses, sedges, and forbs typical of meadow vegetation can establish on lower terraces (<1.0 m above the channel bed) and contribute to bank stabilization. *Salix* spp. often occur on low- and mid-elevation terraces along systems with moderate to high stream gradients and coarser-textured substrates. The understory composition depends on water availability and substrate characteristics. The floodplain can be characterized by a mix of riparian shrubs such as *Cornus sericea* or *Prunus virginiana* and a diversity of understory grasses and forbs, or *Artemisia tridentata* and species typical of dry meadows, depending on the depth to the water table. Areas with high levels of anthropogenic disturbance can have a high percentage of nonnative invasive species.

Component 4—Effects of Natural and Human-Caused Disturbances and Stressors

Natural and human-caused disturbances are superimposed on the dominant geomorphic processes and characteristic vegetation within the riparian corridor. These disturbances can affect geomorphic processes or riparian vegetation composition and extent, or both. Watershed-scale data are available for mapping the primary disturbances in the Great Basin (Appendix 2, table A.2.1).

What Are the Effects of Natural Disturbances and Stressors?

In the Great Basin, the primary driver of stream and riparian ecosystem change is high-flow events (i.e., floods) resulting from high levels of precipitation with significant runoff. Other disturbances and stressors, such as those resulting from wildfires or beaver activity, influence the effects of these high-flow events on stream channels and riparian vegetation.

- **Wildfire.** Wildfire removes hillslope vegetation, which can decrease soil water storage and increase surface runoff and erosion. Large amounts of sediment can be delivered to the stream channels, affecting geomorphic processes. Resulting changes in riparian vegetation composition and extent may affect water quality and temperature (Dwire and Kaufman 2003).

- **Beaver.** Beaver dams can create a series of impoundments in streams that alter geomorphic and hydrologic processes as well as streamside and floodplain vegetation. These changes can have positive effects on riparian extent and habitat for some species (see review in Pilliod et al. 2017; Fesenmyer et al. 2018). In some systems, the dams can persist for decades to centuries (Lanman et al. 2012). In other systems (e.g., certain hydrogeomorphic contexts or where vegetation health or availability is insufficient), the dams can erode during high flows, resulting in a combination of stream incision and deposition (J. Miller and J. Chambers, personal observations, 2018 and 2019; Munger and Lingo 2003). Abandoned ponds may result in low water quality in low-flow systems (J. Miller and J. Chambers, personal observations, 2018 and 2019). Recent research in the Great Basin suggests that beaver dams have more-positive effects on riparian extent in systems characterized by wider valleys (Lingo 2013; Munger and Lingo 2003), higher elevations with higher precipitation, higher stream flows, and lower stream gradients (Fesenmyer et al. 2018). Conversely, beaver dams have more-negative effects in narrow valleys with high stream gradients and lower stream flows (Lingo 2013; J. Miller and J. Chambers, personal observations, 2018 and 2019).
- **Climate change.** Previous research on riparian areas in the Great Basin showed that changes in climate during the Holocene caused changes in vegetation types, soil erosion and sedimentation rates, flood frequencies, and stream incision rates (Miller et al. 2004; Tausch et al. 2004). Ongoing and future climate change may have cascading, complex impacts on streams, groundwater, and riparian ecosystems.

What Are the Effects of Human-caused Disturbances?

A wide variety of anthropogenic disturbances affect stream systems and riparian ecosystems (Downs and Gregory 1995) in the Great Basin. Disturbances that affect geomorphic processes usually affect the riparian vegetation. The more common disturbances are listed next.

- **Roads in the valley bottoms and stream crossings.** Roads can alter the shape and pattern of the stream system, and consequently the response of the stream to high-flow events. Roads in the floodplain can cause the stream to flow onto the road surface during high flows, resulting in more-concentrated stream flows, higher stream power, and increased risk of incision. In addition, poorly designed road crossings can concentrate flows and cause scour of the channel around the road crossing. Channel incision caused by roads has the potential to move rapidly both upstream and downstream. Road culverts that are installed such that the bottom of the culvert is below the previously existing natural stream bed often induce headcuts and subsequent incision above the culvert. Roads and culverts also can lead to scouring below the culvert, which may or may not lead to more extensive impacts farther downstream.

- **Surface water manipulation or diversion.** Rerouting of stream channels or diverting water from springs or stream channels with either ditches or flood irrigation can dewater riparian and meadow vegetation. It can also result in the development of headcuts and formation of gullies during high-flow events. Permanently diverting water away from the stream or meadow ecosystem (e.g., with a ditch, pipeline, spring box, or other form of dewatering) can dewater riparian and meadow vegetation and decrease their extent.
- **Groundwater extraction.** Water extractions via wells can dewater riparian and meadow vegetation, result in nonnative species invasions, and degrade species' habitats.
- **Improper livestock grazing.** Improper timing, duration, or intensity of livestock grazing has well-documented effects on stream systems and riparian and meadow vegetation (Belsky et al. 1999; Beschta et al. 2013; Kaufman and Krueger 1984; Trimble and Mendel 1995). The effects of improper grazing may include (1) soil compaction, decreased infiltration, and increased runoff; (2) a decrease in riparian species with high wetland indicator status and an increase in species with low successional status and nonnative invasive species; (3) decreases in stream bank stability and increases in bank erosion; and (4) changes in stream channel pattern and process.
- **Wild horses.** Wild horses have well-documented effects on streams and riparian vegetation, particularly when numbers are above Appropriate Management Levels or when the animals concentrate in riparian areas or on meadow complexes at levels above carrying capacity (Beever and Aldridge 2011; Griffin et al. 2019). Under these conditions, the effects are similar to those of improper livestock grazing.
- **Recreational activities.** Recreational activities and their effects, such as developed and undeveloped campgrounds and trails, can result in surface disturbance, soil compaction, and decreased infiltration. They can impact stream bank stability and stream channels and the extent and composition of riparian vegetation.
- **Human developments (housing).** Development of land for housing and commercial enterprises generally increases the area of impervious cover, which can increase runoff while restricting sediment inputs to the channel. In combination, these alterations often lead to channel widening, incision, and other geomorphic responses that degrade riparian vegetation, water quality, and habitat for aquatic species.
- **Mining activity.** Mining operations, particularly historical mining activities, can alter local groundwater flow systems. Many historical operations generated waste or tailings piles enriched in sulfide minerals, toxic trace metals, or other chemical pollutants. These waste materials may produce acid mine drainage or be eroded and transported to local streams, where their introduction often degrades water quality, riparian vegetation, and habitat for aquatic species (Macklin et al. 2006).

Geomorphic Sensitivity and Ecological Resilience Categories and Management Implications

A categorization of the sensitivity and resilience of Great Basin watersheds has been developed based on our understanding of watershed, stream channel, and vegetation characteristics. Initially, four distinct categories of sensitivity and resilience were defined for Great Basin watersheds by Germanoski and Miller (2004) and Miller et al. (2011a): (1) flood dominated, (2) fan dominated, (3) deeply incised, and (4) pseudostable. More recent work defined a fifth category, armored watersheds. These watersheds differ according to the magnitude and rate of channel response to disturbance.

The dominant short-term processes, potential for geomorphic and vegetation changes, and long-term geomorphic sensitivity to geomorphic change are summarized in table 6. This summary also provides information on the ecological resilience and management implications for each of the five types. An overview of the five categories and the management implications is provided next. Additional information on management implications is in Chambers and Miller (2011a) and Chambers et al. (2004a).

Flood Dominated Watersheds

These watersheds are found exclusively in Type A1 basins (fig. 12) and are characterized by large quantities of highly mobile sediment. High-magnitude floods result in frequent and extensive avulsion and widespread reworking of the valley floor (fig. 16b). The channel is geomorphologically unstable over the short term. Natural or anthropogenic disturbances within the watershed are unlikely to alter the predominant geomorphic processes or channel or valley form within the watershed over decades. When high-magnitude floods mobilize large quantities of sediment, they are subsequently redeposited, often upstream of woody debris, filling short reaches of the channel and causing avulsion. The vegetation within flood dominated watersheds is adapted to the frequent movement of channel bed sediments, and thus the riparian ecosystem is resilient to all but the most extreme disturbances. The dynamic nature of these systems makes restoration difficult and requires the placement of roads and other structures well above valley bottoms.

Table 6—Watershed sensitivity and resilience types categorized by basin type, dominant processes and potential for change, geomorphic sensitivity, and ecological resilience. The primary management implications are provided for each watershed type.

Watershed type and basin type	Dominant short-term processes and potential for geomorphic and vegetation change	Long-term (decadal) geomorphic sensitivity to disturbance		Ecological resilience to disturbance	Restoration and management implications
		Incision	***Avulsion***	***Incision or avulsion, or both***	
Flood dominated Type A1	• Highly dynamic • Frequent; avulsions and associated incision continuously rework valley floor and change channel form • Short-term sensitivity is very high • Riparian vegetation is typically adapted to the dynamic conditions	Low to moderate (Incision associated with avulsions)	Low to moderate (Avulsions and valley floor reworking continues, but processes and form remain the same)	Moderate to high	• Valley floor is highly unstable and likely to remain so for decades • Roads and infrastructure should be located off the valley floor • Maintaining bridges and road crossings may be difficult • Low potential for channel stabilization or restoration following disturbance
Armored Type A2	• Channel change by incision is common, but rate is limited by immobile bedrock or large clasts • Avulsions typically are absent due to lack of mobile sediments • Woody vegetation types dominate, with meadow types in understory	Low	Low	Moderate to high	• Disturbances are unlikely to have a significant effect on these systems • Excellent potential for stream restoration
Fan dominated Type B	• Slow but continuous incision produces inset terraces, knickpoints, and lowered groundwater tables • Rare, localized avulsions occur upstream of side-valley fans • Meadow types occur upstream of fans; woody types downstream of fans • Progressive incision can result in lowering of water tables and changes in plant species composition	Low to moderate	Low to moderate	Moderate to high	• Relatively slow rates of incision often allow for significant restoration potential, including of meadows upstream of side-valley fans that act as base-level controls • Upland disturbance has potential to influence runoff-recharge relations that may influence groundwater hydrology • Management and restoration strategies focused on stabilizing channels adjacent to fans can limit incision

Table 6 continued.

Watershed type and basin type	Dominant short-term processes and potential for geomorphic and vegetation change	Long-term (decadal) geomorphic sensitivity to disturbance		Ecological resilience to disturbance	Restoration and management implications
		Incision	***Avulsion***	***Incision or avulsion, or both***	
Deeply incised Type B or C	• Deeply incised channels that may be locally stable with inset floodplains • Prone to rapid, renewed incision that lowers groundwater levels, reduces riparian corridor extent, and alters riparian species composition • Avulsions are rare due to rapid incision • Plant species composition depends on stream gradient, water table depth, and sediment size	Moderate to high	Low	Low to moderate	• Channels prone to renewed incision given additional upland or channel disturbances • Channels, riparian ecosystems, and wet meadows likely to be difficult to restore due to significantly lowered water tables and unstable and widening trench walls • Restoration potential depends on stream gradient, local groundwater conditions, and sediment size
Pseudostable Type C	• Stable channels with potential to undergo rapid, deep incision; systems likely to remain unstable for decades • Woody vegetation types dominate, with meadow types in understory and occasional meadows • Avulsions rare • Incision lowers groundwater levels, reduces riparian corridor extent, and alters riparian species composition	Moderate to very high	Low to moderate	Low	• Channels and riparian ecosystems prone to extreme change • Potential upland and channel disturbance should be minimized with aggressive management strategies • Very low potential for restoration of destabilized systems

Armored Watersheds

These watersheds are most commonly associated with Type A2 basins, although some occur in Type B basins (fig. 12). Incision and lateral channel migration are limited by large bed and bank sediments that can be entrained only during exceptionally large events. Many of these watersheds in both basin types were glaciated, and the large debris is derived from glacial moraines or outwash deposits (fig. 11). In other cases, the material represents coarse colluvial sediments or outcrops of resistant bedrock. Regardless of the source of the coarse debris, the channel position is fixed locally, limiting channel dynamics and resulting in low sensitivity. In general, the riparian vegetation in armored watersheds is characterized by woody species in the overstory and sedges, grasses, and forbs in the understory. Riparian ecosystems have relatively high resilience due to relatively immobile channels. However, their resilience is reduced by land uses such as improper livestock grazing, high recreational use, and mining. These watersheds have high potential for stream and riparian ecosystem restoration.

Fan Dominated Watersheds

These watersheds are associated with Type B basins characterized by large side-valley alluvial fans (fig. 12). The fans act as local base-level controls that influence the magnitude and rate of channel incision. Channels upstream of the fans have relatively shallow gradients and often have undergone slow but continuous channel incision. Channel avulsions related to a periodic influx of mobile sediment to the channel also can occur upstream of large side-valley fans (fig. 16). At and immediately below the fans, coarse debris supplied to the channel by the fan usually results in channel bed armoring and inhibits erosion, thereby maintaining the stepped-valley profile caused by the fans (fig. 14). Relatively limited depths and rates of channel incision in the watershed overall indicate that fan dominated watersheds have low to moderate sensitivity with respect to both incision and avulsion (table 6).

As described earlier, meadow vegetation types often occur upstream of fans, while woody types occur downstream. Relatively minor changes in riparian and meadow ecosystems often occur in response to channel incision, indicating moderate to high resilience with respect to incision and avulsion over time. However, these changes can be cumulative, especially in watersheds that are relatively steep, have multiple road crossings, or have beaver dams that fail during high-flow events. Riparian ecosystems, including meadows, generally exhibit relatively high management and restoration potential, depending on local groundwater conditions (Chambers and Miller 2011b; Chambers et al. 2004a,b; Lord et al. 2011; Miller et al. 2011b; Wright and Chambers 2002). Where stepped-valley profiles occur, management and restoration strategies should focus on stabilizing channel reaches adjacent to the side-valley fans and thus limiting further incision. One approach is to armor these reaches with large rock.

Deeply Incised Watersheds

These watersheds are typically associated with Type B and Type C basins with relatively fine-grained and mobile sediment, and can easily be eroded by surface or groundwater flows (figs. 12, 15). Incision of the alluvial valley fill can be extensive (fig. 21), often reaching 5 to 10 m in depth. Where side-valley fans are present, preexisting topographic steps in the longitudinal profile of the axial channel have been removed during incision. In many watersheds, incision is concentrated in the lower to mid-reaches of the watershed; headwater reaches have yet to be incised or have discontinuous gulley systems. Within Type B basins, incision can result in multiple extensive and well-preserved terraces of varying age along the riparian corridor. These terraces demonstrate the episodic nature of the incision process, which is associated with large runoff events.

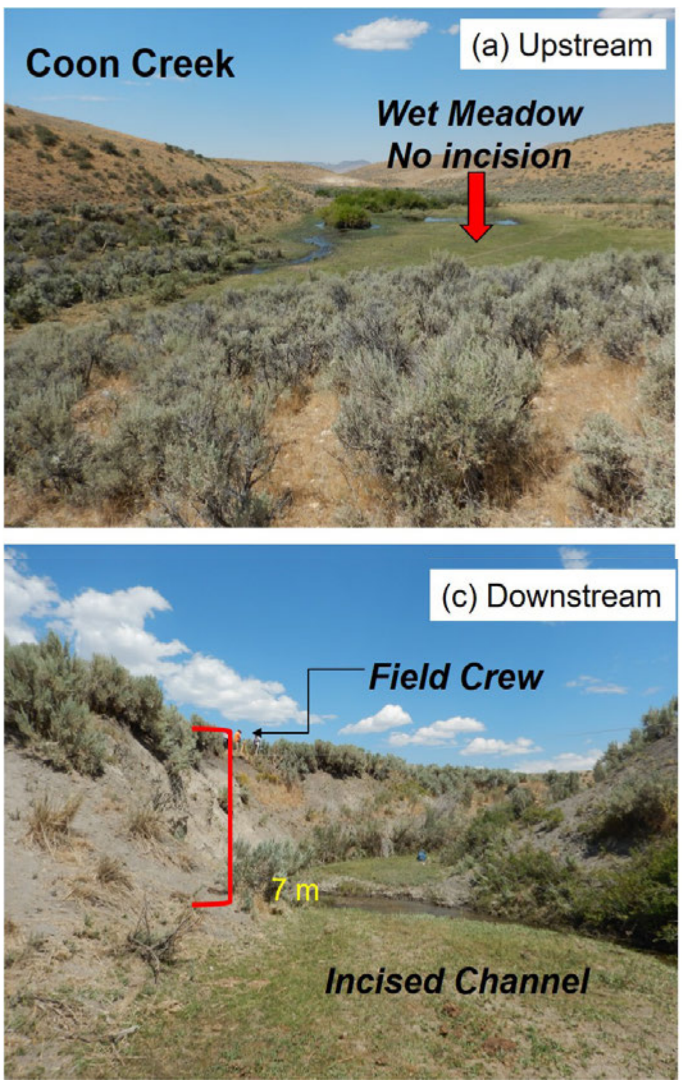


Figure 21—Deeply incised Type C basin in the Independence Range, Nevada. The photographs show the spatial variation in the degree of incision in an upstream reach (a), mid-watershed reach containing an upstream migrating headcut (b), and downstream reach containing inset floodplain deposits (c). The fine-grained nature of the valley fill deposits allows rapid incision and formation of nearly vertical trench walls. Photos taken by the authors and used with their permission.

Resilience of riparian ecosystems typically is low to moderate. Where incision has occurred, it has led to a significant lowering of the water table, a decrease in the extent of the floodplain and riparian or meadow vegetation, and, depending on groundwater flow conditions, a significant change in vegetation composition. The development of well-organized channel bed features (e.g., pool-riffle sequences) and vegetation on the lowest terrace suggest that both the channels and water tables, particularly along downstream reaches, are relatively stable. The predominant changes in channel form occur via bank failure associated with lateral channel migration during high flows.

Management activities that promote the concentration of flows, such as roads in the valley bottoms and cattle trails, should be avoided in watersheds with a propensity for deep incision. Once incision has occurred, the potential to restore the system to conditions prior to incision is extremely limited. Restoration of unincised reaches depends on stream gradient, local groundwater conditions, and sediment size.

Pseudostable Watersheds

These watersheds primarily are associated with Type B basins but may also occur in Type C basins. Their characteristics, including loose, sandy, and highly permeable valley fill and abundant, fine-grained hillslope sediments, result in rapid and catastrophic changes in channel and valley form in response to disturbances (fig. 22). Some of these basins have already incised in response to disturbance, while others are currently stable but prone to rapid incision.

Two well-documented examples of incised watersheds are Crow Creek, which responded to a wildfire in 1983 (Germanoski and Miller 1995), and Marshall Canyon (Germanoski et al. 2001; Miller et al. 2011a), which incised catastrophically during and after a heavy rainstorm in spring 1998. The latter resulted in development of a trench that was 7 to 10 m wide and 6 m deep a few months later, and the trench terminated upstream in three amphitheater-like headcuts (fig. 22). Incision was due in part to groundwater flow into the stream. These watersheds often can be recognized by the loose, highly permeable, coarse sand- to granule-sized sediment that characterizes the valley fill.

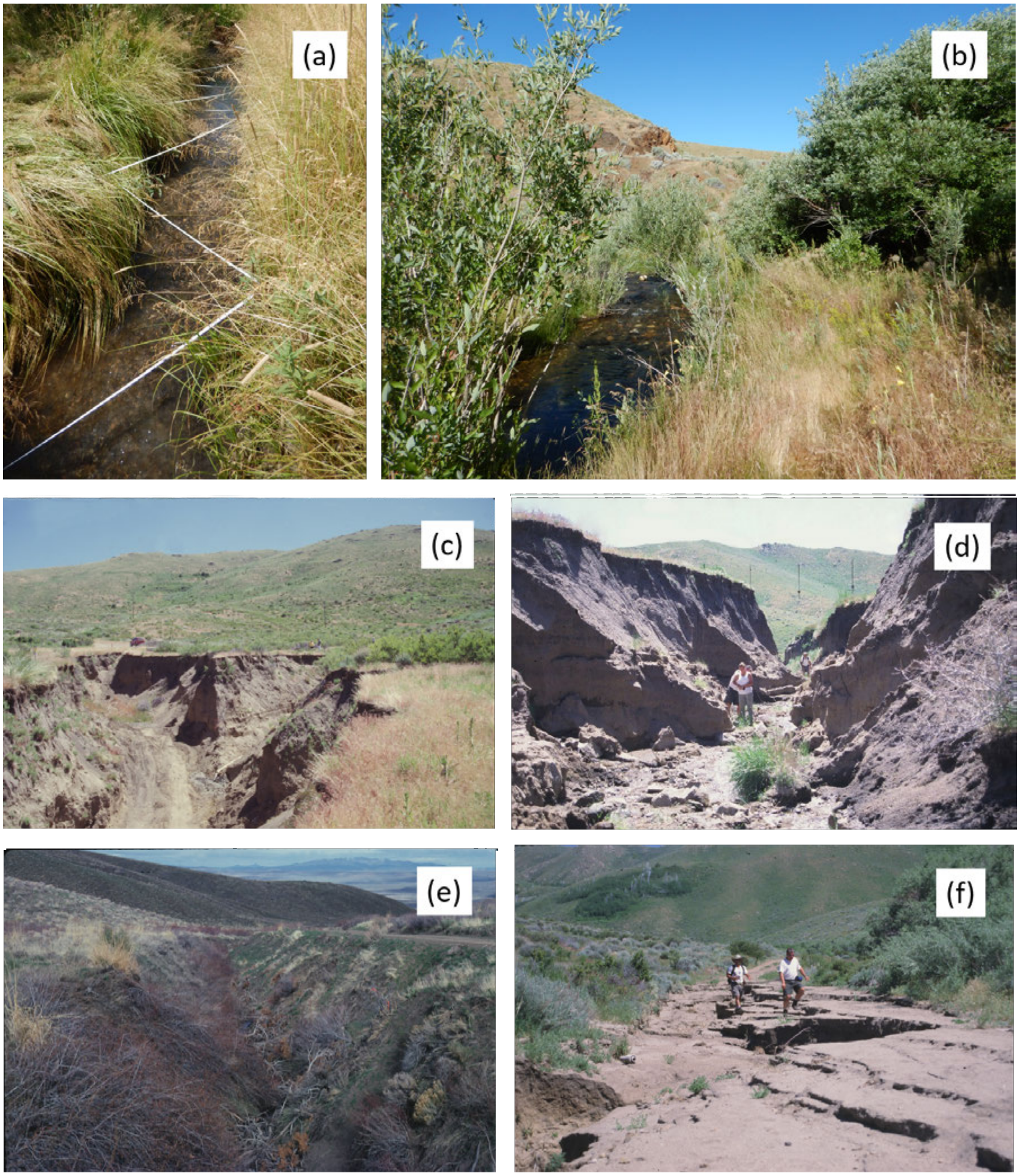


Figure 22—Response of a pseudostable watershed to a high-flow event. In pseudostable watersheds, stream systems are characterized by relatively small, abundant sediments within the channel and abundant, fine-grained sediment on the hillslopes (a, b), and have the potential for large responses to disturbances. Catastrophic incision of the valley floor occurred in this type of stream in Marshall Canyon, central Nevada (c, d). The eroded sediment was transported downstream through the reach (e) and redeposited along the valley floor over a 3-month period (f). The valley fill was composed of highly permeable, coarse-sand and granular-sized sediments that possessed little cohesion and were easily eroded. Photos taken by the authors and used with their permission.

Other pseudostable watersheds are characterized by past debris flow activity, which left boulder levees on hillslopes and large debris flow deposits in side-valley fans and along valley floors (figs. 23, 24). Such responses were observed after a wildfire in the Lexington Creek watershed. Introduction and transport of large quantities of sediment generated by large debris flows led to downstream aggradation and reincision of the channel system, which had devastating effects on the riparian ecosystems. Lexington Creek and other similar watersheds (e.g., Muncy Creek) have stratigraphic records of past debris flow activity that indicate their dynamic nature.

Because incision usually results in a lowering of water tables and a decrease in the extent of the riparian corridor, ecological resilience of these reaches to incision is moderate to low. Channels within these watersheds may be difficult to stabilize and manage because of a tendency to incise, often catastrophically, or to exhibit widespread debris flow activity after disturbances. The potential to restore riparian ecosystems and meadow complexes depends strongly on substrate characteristics and local groundwater flow patterns. Prevention of large-scale disturbance is key to maintaining ecological integrity in these watersheds.

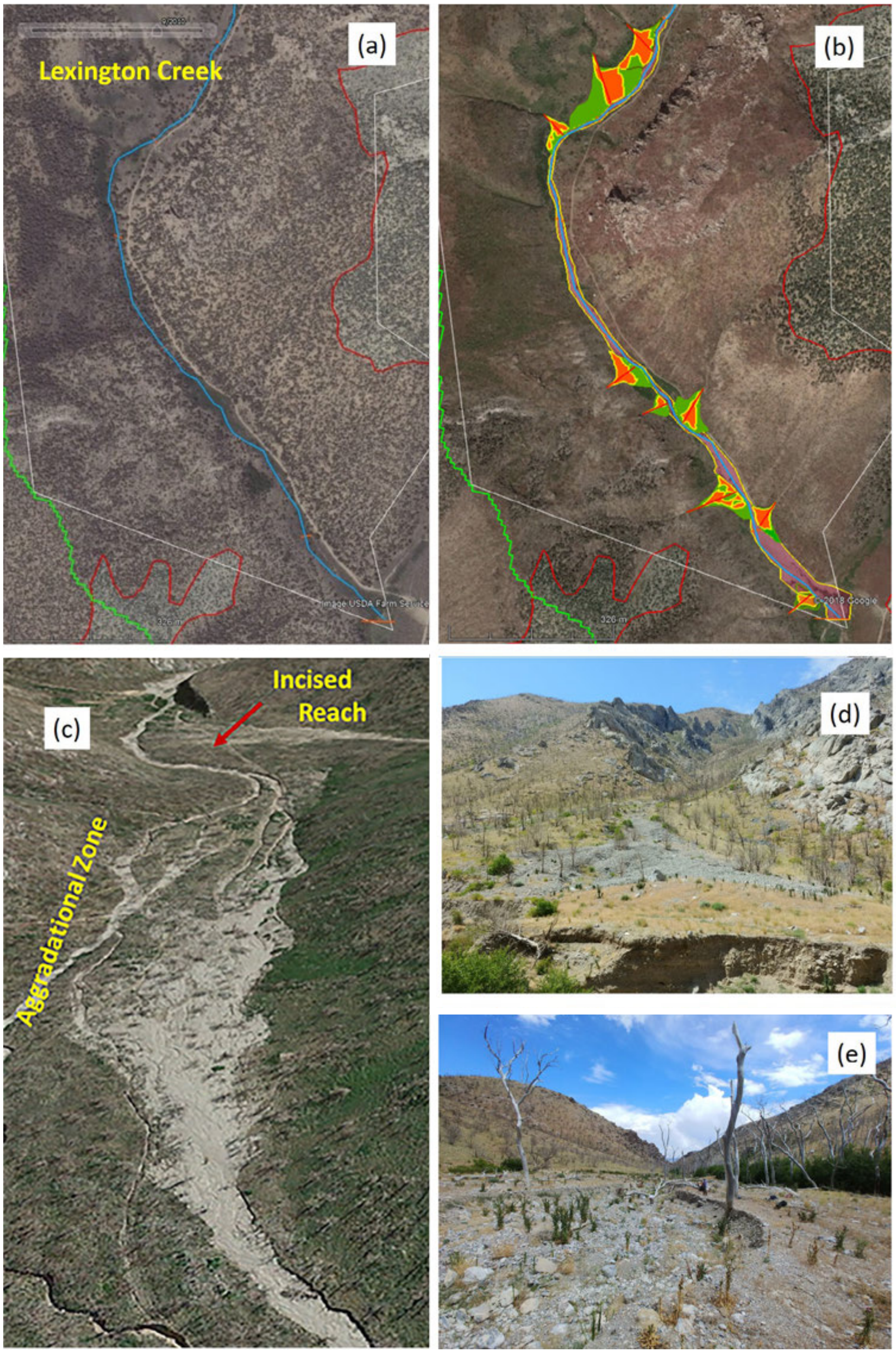


Figure 23—Lexington Creek watershed prior to a wildfire in 2013 (a) and the locations of debris flow deposits on side-valley alluvial fans (red) and within the axial drainage (green) following the fire (b). High spatial variations in channel bed aggradation occurred following the fire (c). Sediment was derived primarily from the debris flows (d) and resulted in a large aggradation zone (c, e). Images a, b, and c from Google Earth obtained October 21, 2019; photos d and e taken by the authors and used with their permission.

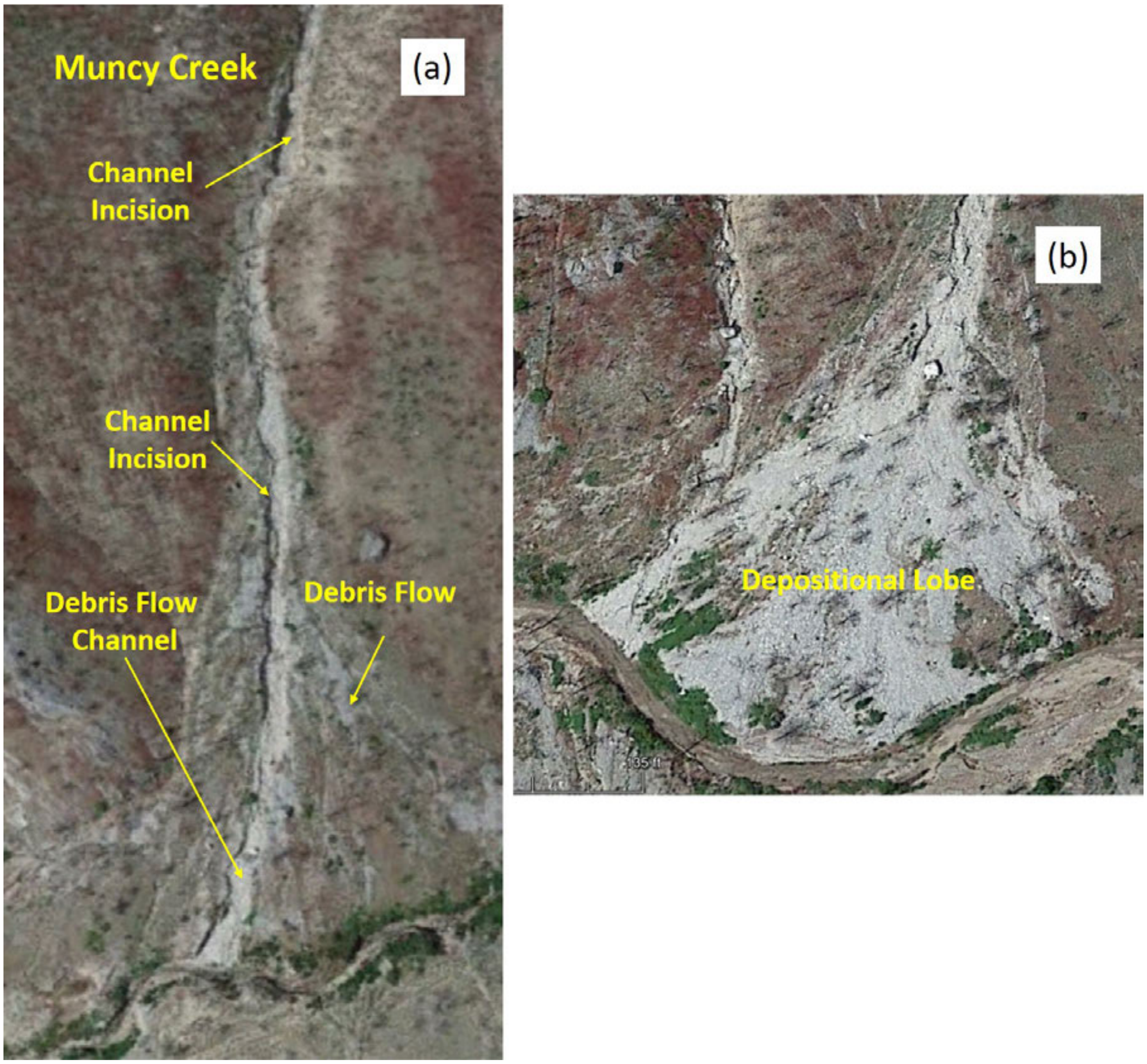


Figure 24—Aerial photos of debris flows (a), and depositional lobe along the axial channel (b) in Muncy Creek watershed after a wildfire. Images from Google Earth obtained October 21, 2019.

Part II. Assessment Protocol

This assessment protocol is designed to provide an understanding of reach- and watershed-scale sensitivity of stream systems, resilience of riparian ecosystems, and general ecological integrity of upland watersheds of the Great Basin. The assessment protocol (table 7) consists of five primary tasks that are conducted in three phases:

- **Phase I—Preliminary Work (completed in the office)**
  (1) Collection of information on watershed characteristics and historical responses to disturbance and determination of the basin type (A1, A2, B, C)

  (2) Selection of reach-scale field sites based on an evaluation of the distinct watershed segments (reach types) within the watershed

- **Phase II—Field Data Collection**
  (3) Collection of reach-scale geomorphic, riparian vegetation, and disturbance data

  (4) Collection of data on the meadow complexes that occur within the watersheds, including geomorphic setting, meadow geomorphic and hydrologic processes, meadow vegetation, and disturbance data

- **Phase III—Interpretation (completed in office)**
  (5) Determination of the watershed sensitivity and resilience type and evaluation of ecological integrity

A system for storing the collected data should be developed for all assessments. A Microsoft Excel® sample database created to store data for the Nevada Wetland Rapid Assessment provides an example and is available at the Nevada Division of Natural Heritage website: https://heritage.nv.gov/.

In addition to the assessment protocol, Part II provides examples of the different sensitivity and resilience types and their diagnostic characteristics along with management implications.

The website contains the primary elements of Part II of this report and it is available. at: https://experience.arcgis.com/experience/49f171f01aed451d8bbebb5558638a6c. The website provides the necessary information and data forms to complete the assessment.

Table 7—Key to the five tasks in the assessment protocol, the available data, and the data forms. The first column is the data collected; the second is the data source and relevant appendix.

Phase I. Preliminary Work (completed in office)

1. Collect watershed characteristics and historical response data • Basin type(s) (A1, A2, B, C) • Dominant riparian and meadow vegetation types • Mean annual precipitation • Watershed area • Basin connectivity • Past debris flow activity • Influence of side-valley alluvial fans • Past and present disturbances (wildfires, roads, dams and diversions) • Species at-risk	See Appendix 4—Data Form and Information for Assessing Watershed Characteristics and Distinct Watershed Segments in the Office Derived from photo interpretation of National Agriculture Imagery Program (NAIP) and Google Earth imagery, and the Great Basin Watershed Database (Appendix 2) Also see geospatial vegetation change data and Desert Research Institute's Wetland Analysis Toolbar
2. Determine distinct watershed segments and select reach-scale study sites • Extent and distribution of distinct watershed segments (dominant stream reach types) within basin types • Locations and types and meadows	See Appendix 4—Data Form and Information for Assessing Watershed Characteristics and Distinct Watershed Segments in the Office Derived from photo interpretation of NAIP and Google Earth imagery, and 1:24,000 topographic maps

Phase II. Field Data Collection

3. Collect and analyze reach-scale sensitivity and resilience data ***Reach-scale geomorphic data*** • Channel character and form • Sediment size, mobility, and availability • Evidence of incision • Evidence of avulsion	See Appendix 6—Data Form and Information for Assessing Stream Geomorphic Characteristics in the Field Based on collection of data for the dominant reach types in the high, middle and lower elevation zones within the watershed
Reach-scale vegetation data • Riparian vegetation type and extent • Riparian indicator species on each stream geomorphic surface • Vegetation vigor and mortality • Wetland indicator status • Successional and bank stability class • Nonnative invasive species	See Appendix 7—Data Form and Information for Assessing Riparian Vegetation in the Field Based on collection of data for the dominant reach types in the high-, middle-, and lower elevation zones within the watershedReach-scale vegetation data

Table 7 continued.

Reach-scale disturbance data • Roads in the valley bottoms, stream crossings and culverts, and road captures • Campsites • Human developments • Mining activity • Surface water manipulation or diversion • Groundwater extraction • Beaver activity • Prescribed fire or wildfire • Livestock effects • Wild horse effects	See Appendix 8—Data Form and Information for Assessing Disturbance in the Field Based on collection of data for the dominant reach types in the high-, middle-, and lower elevation zones within the watershed
4. Collect and analyze meadow sensitivity and resilience data • Meadow-wide geomorphic, hydrologic, and vegetation data • Meadow size and geomorphic position • Stream and groundwater influences • Meadow complexity and vegetation patterns • Meadow hydrologic type • Meadow vegetation types and indicator meadow species • Vegetation vigor and mortality • Wetland indicator status • Successional and bank stability class • Nonnative invasive species	See Appendix 9—Data Form and Information for Assessing Meadow Complexes in the Field Based on collection of data for each selected meadow

Phase III. Interpretation (completed in office)

5. Determine the watershed sensitivity and resilience type and evaluate its ecological integrity ***Watershed sensitivity and resilience type*** • Watershed characteristics • Geomorphic and riparian vegetation characteristics • Sensitivity to incision and avulsion • Ecological resilience to disturbance • Restoration and management implications	Appendix 10—Score Sheet for Categorizing Watershed Sensitivity and Resilience and Scoring Values Derived from office and field data See table 6 for description of watershed sensitivity and resilience types
Meadow sensitivity and resilience • Watershed type • Meadow hydrologic type • Sensitivity to incision and avulsion • Ecological resilience to disturbance • Restoration and management implications	See Appendix 9—Data Form and Information for Assessing Meadow Complexes in the Field, and Appendix 10—Score Sheet for Categorizing Watershed Sensitivity and Resilience and Scoring Values Derived from office and field data
Relative ecological integrity of watershed • Geomorphic characteristics • Vegetation characteristics • Response to anthropogenic and other disturbances	See Appendix 11—Score Sheet for Rating Ecological Integrity and Description of the Rating Variables Derived from office and field data

Phase I—Preliminary Work (office)

Task 1—Collect Watershed Characteristic and Historical Response Data

In the office, watershed characteristics known to influence watershed responses to natural and human-caused disturbances and indicators of past responses to those disturbances are evaluated. The information and data form for assessing the watershed characteristics are in Appendix 4.

Data and observational information are obtained primarily from the Great Basin Watershed Database (Board et al. 2020; Dilts et al. 2020) and 1:24,000 scale topographic maps and aerial photographs available from the National Agricultural Imagery Program (NAIP), or imagery from Google Earth.

The Great Basin Watershed Database contains a wide range of watershed-scale data for nearly 1,500 montane watersheds with perennial stream channels in the Great Basin (Appendix 2). The data are available at: https://doi.org/10.2737/RDS-2020-0059. In addition, the data can be loaded directly in ArcGIS Pro or ArcGIS Desktop as streaming data at https://usfs.maps.arcgis.com/home/item.html?id=29f4c16030c8498698ce090acb8767be. A description of the data available is in Appendix 2, table A.2.1, and the information needed to access and use the database is in Appendix 2, exhibit A.2.1 as well as Board et al. 2020.

The database includes:

- Watershed precipitation, morphometric, and geologic information;
- Geospatial data on nonriparian, herbaceous, and woody riparian vegetation within the riparian corridor (extent and composition) for the southern and central Great Basin regions (Knight 2019);
- Geospatial data on major disturbances (wildfire, roads, dams and diversions); and
- Geospatial data on species distributions or habitat probability models of species at-risk in the Great Basin.

The watershed characteristics used in this assessment are discussed next and are identified in bold. Other watershed characteristics that may contribute to more detailed assessments are also discussed but are not in bold.

The office assessment begins by determining the **basin type (A1, A2, B, C)** for the focal watershed from aerial photographs and Google Earth Imagery (fig. 12; Appendix 4, exhibit A.4.1). Basin type provides important insights into runoff, sediment generation, and sediment size. It categorizes the watershed based on watershed relief, average stream and hillslope gradients, side-valley fan influence, and valley width, all of which influence runoff and sediment regimes. Basin type also provides insights into the resistance of the underlying bedrock and the amount of sediment generated over geologic timescales. For example, wider valley floors and increases in frequency and size of side-valley alluvial fans are associated with less-resistant bedrock and production of larger quantities of mobile sediment.

Dominant riparian vegetation types and presence of meadow complexes are also identified from aerial photographs and Google Earth Imagery (Appendix 3, exhibit A.3.1). Riparian and meadow vegetation types within a watershed are closely related to the dominant geomorphic processes, such as runoff and sediment regimes. For example, Type A1 basins, which are characterized primarily by flood dominated watersheds, are adapted to frequent movement of channel bed sediments, and are typically composed of species adapted to frequent avulsions and reworking of the valley floor, such as *Betula occidentalis, Salix* spp., and *Alnus* spp. Type B basins, which are characterized by large side-valley alluvial fans and a stepped-valley profile, often support meadow complexes upstream of the fans.

Watershed characteristics related to runoff are used to assess the likelihood of a watershed generating high discharges and stream powers (see discussion in Ritter et al. 2011) and are available in the Great Basin Watershed Database (Appendix 2). **Mean annual precipitation** and **watershed area** are particularly useful in evaluating runoff and sediment mobility because increases in both precipitation and basin area generally lead to an increase in peak flows (Appendix 4, exhibit A.4.1). Watershed geology may also be useful as volcanic rocks (i.e., basalts, andesite, rhyolitic flows, and tuffs) tend to be more resistant and generate significant runoff. In contrast, fractured carbonates, metasediments, and felsic igneous rocks produce lower peak flows for a given basin area.

Percent basin connectivity between reaches is an important control on reach and watershed hydrology that is evaluated from aerial photographs and Google Earth Imagery (Appendix 4, exhibit A.4.1). In the Great Basin, few areas have dense tree canopies, and disconnected reaches can be identified on aerial imagery by lack of a distinct channel on valley floors or side-valley alluvial fans (fig. 9). Such unchannelized reaches typically occur on large alluvial fans or near the mouth of large tributaries characterized by wide, low-gradient valley floors with thick alluvial deposits. The degree of connectivity can be characterized as the percentage of the total watershed area that is disconnected from the axial channel (Appendix 4, exhibit A.4.1). Higher percentage connectivity (or lower percentage disconnection) tends to result in greater peak flows (Miller et al. 2011b).

Historical geomorphic and vegetation responses to disturbance provide important insights into channel and watershed sensitivity and resilience. Significant changes in response to past disturbances are generally associated with stream reaches and watersheds with high sensitivity and low resilience. An initial analysis of both hillslope and channel responses can be obtained from aerial imagery, such as NAIP or Google Earth. Use of the historical image option on Google Earth is particularly helpful for assessing vegetation, geomorphic, and channel responses to disturbance, but generally is limited to about 1984 onward. The channels and hillslopes within an area can be examined quickly and compared from different perspectives and at different resolutions to evaluate change over time. Changes in geomorphic features such as debris flows, depositional lobes on fans or the valley floor, channel incision, changes in channel form and position, and changes in riparian vegetation can be identified for specific time intervals. Changes in nonriparian, herbaceous, and woody riparian vegetation within the riparian corridor (extent and composition), and thus hydrologic regimes, can be evaluated with DRI's Wetland Analysis Toolbar. These changes can then be linked to events and other disturbances such as wildfires, floods, and roads and should be included in the notes.

Debris flows are a strong indicator of hillslope movement and are assessed with aerial imagery (Appendix 4, exhibit A.4.1). Debris flows are typically activated during major runoff events and are particularly common after disturbances to the watershed that remove vegetation from the hillslopes, such as wildfires or vegetation treatments (figs. 23, 24). Debris flows on the hillslopes can deliver large amounts of sediment to the axial channel and cause channel aggradation or reworking. They are composed of excavated (scoured) channels devoid of sediments on steep hillslopes, which generally flow onto side-valley fans. They also can be recognized by coarse, fan-shaped deposits and linear levees (often consisting of large boulders) on side-valley fans (figs. 23d, 24b). Basins of higher sensitivity to disturbance and with greater probabilities of debris flows tend to be associated with smooth hillslopes that have an abundance of fine-grained, mobile sediment, particularly in hillslope hollows (figs. 10a,b,c). In contrast, basins with less sensitivity tend to be associated with widespread bedrock outcrops (figs. 10d,e,f) and relatively limited upland sediment supplies.

Fan influence refers to the effects of side-valley alluvial fans on the morphology and processes of the axial stream channel; its assessment requires both office and field data (Appendix 4, exhibit A.4.1, and Appendix 6, exhibit A.6.1). Side-valley alluvial fans influence the longitudinal profile of the axial channel within the watershed and can create topographic steps that act as local base-level controls (fig. 14). Depending on sediment characteristics and flow regimes, these steps also can influence sediment deposition, groundwater availability, and riparian vegetation types. For example, meadow complexes often occur upstream of alluvial fans on the "step," while woody riparian vegetation occurs downstream on the oversteepened reach (figs. 14, 20).

Information on disturbances within the watersheds, such as **wildfires, road density, and dams and diversions**, can be obtained from the Great Basin Watershed Database (Appendix 2). The proportion of a watershed that has burned, severity of the burn, and time since the burn can provide important insights into hillslope and channel response to subsequent precipitation and high-flow events. Similarly, the road density in the stream corridor may be linked to road captures by the stream and stream incision. In addition, dams and diversions can significantly impact current ecological conditions or ecological integrity.

The potential of a watershed or particular reach type to support **species at-risk** can be evaluated from species distributions or habitat probabilities in the Great Basin Watershed Database (Appendix 2). When information from this evaluation is coupled with information on sensitivity and resilience to disturbance, important insights can be gained on the suitability of a watershed or particular reach type for habitat conservation or restoration activities.

Task 2—Select Reach-scale Field Sites

The extent and distribution of distinct watershed segments are determined to help guide selection of stream reaches for field analysis. Aerial imagery combined with 1:24,000 scale topographic maps is used to document and map variations in channel and valley conditions along the drainage network (Appendix 4, figs. A.4.1, A.4.2, A.4.3). The data collected are recorded on form A.4.1 (Appendix 4) and described in Appendix 4, exhibit A.4.1. Specific parameters used to identify distinct watershed segments along the axial drainage network within a watershed include composition of the valley fill (e.g., colluvium, alluvium, bedrock), existence of a well-defined and integrated channel (i.e., channelized vs. unchannelized reaches), depth of incision, channel pattern (i.e., meandering, braided, anabranching), presence of stable beaver dams, number and size of side-valley alluvial fans, occurrence of wet meadow complexes, vegetation types, and valley width and gradient (Appendix 4, figs. A.4.1, A.4.2, A.4.3). The resulting watershed segments consist of relatively homogeneous geologic materials, valley morphometric characteristics, landforms, and riparian vegetation, and thus contain similar types of stream reaches. The number and characteristics of these segments differ among watersheds.

Stream reaches for field data collection are selected from the dominant watershed segments at high, mid-, and low elevations within the watersheds. In most watersheds, three stream reaches are selected for field data collection—one from the dominant watershed segment at each elevation. Stream reaches are shorter segments of the drainage network with homogeneous channel and valley floor characteristics, including landforms (e.g., terraces, floodplains), channel bed features (e.g., pools or riffles, step or pools, bars, knickpoints), and sediment sizes.

Reaches higher and lower in the watershed are characterized, even if the dominant watershed segment type at a particular elevation does not make up a large part of the watershed. This step is taken because ongoing processes in watershed segments at different elevations have the potential to influence stream reaches higher or lower in the watershed. For example, channel incision and headcut migration often take decades to complete. The occurrence of a downstream headcut often indicates that an upstream reach will incise in the future if the headcut is not addressed through management or otherwise halted by a resistant feature (e.g., bedrock).

In watersheds that include more than one distinct basin type (A1, A2, B, C), it will be necessary to identify the dominant watershed segments in each basin type within the watershed and to select representative stream reaches for analyses from the dominant watershed segments. In addition, in watersheds consisting of a wide range of watershed segment types that vary spatially in complex patterns, analysis of additional reaches will be necessary to characterize the sensitivity and resilience of the watershed. The key is to ensure that the predominant geomorphic processes and vegetation types that occur within the watershed are documented during the field work.

Phase II—Field Data Collection

Task 3—Collect and Analyze Reach-scale Sensitivity and Resilience Data

Rapid assessments of the selected stream reaches are used to provide information on the long-term (i.e., decadal) sensitivity and resilience to disturbance as indicated by the dominant short-term processes and the potential for geomorphic and vegetation change. The assessments also provide information on the effects of natural and anthropogenic disturbances on current ecological conditions or ecological integrity of the stream reach.

Specific geomorphic, vegetation, and disturbance data collected in the field are used to complete the assessments (table 7). The data forms and all necessary information for completing the forms are in Appendix 6 (geomorphic), Appendix 7 (riparian vegetation), and Appendix 8 (disturbance). An equipment list is provided in Appendix 5. The stream reaches selected for collection of field data should be long enough to include all valley, channel, and channel bed features along the representative watershed segment. Stream reaches 30 m in length are usually sufficient to characterize the channel geomorphology and vegetation of the distinct watershed segments. To characterize the effects of disturbances in the watershed, adjacent upstream and downstream reaches are evaluated in addition to the sample reach.

The geomorphic assessment provides insights into the types and rates of dominant geomorphic processes that characterize the stream reach. The assessment involves collecting information that describes the current cross-sectional morphology of the valley (including the channel) and the longitudinal profile of the stream channel. Information also is collected on the materials making up the channel bed, banks, and valley fill, sediment mobility, and availability of mobile bed sediments, which are stored in channel bars. And features are assessed that are indicative of the magnitude and rate of channel incision (e.g., knickpoints, headcuts, terraces), occurrence and amount of channel avulsion (e.g., filled or unfilled paleochannels), and the extent and mechanisms of bank erosion.

The vegetation assessment provides information on the response of the riparian vegetation to recent or ongoing disturbances affecting water tables, such as channel incision or avulsion, and other disturbances, such as inappropriate livestock grazing or excessive use by wild horses. Information is collected on apparent decreases in the extent of the riparian area due to factors such as stream incision and the degree to which the riparian vegetation occurs in a postincision trench. In addition, the relative cover, vigor, mortality, and wetland indicator rating of the dominant indicator species (Appendix 7, table A.7.1) that occur on the different stream geomorphic positions (valley floor, terraces, floodplain) are assessed and then summarized for the stream reach as a whole.

The disturbance assessment is designed to provide information on any negative effects of human-caused disturbance on stream channels and riparian ecosystems. Information is collected on the presence of each disturbance, its location (in the sample reach, upstream, downstream), and the component(s) affected by the disturbance (stream channel, stream bank, riparian or meadow vegetation). The relative effects of the disturbance are recorded to determine whether the disturbance is having no or a minor negative effect or a clear negative effect, or has significantly altered stream geomorphic processes or the riparian vegetation.

Task 4—Collect and Analyze Meadow Sensitivity and Resilience Data

Meadow assessments are conducted in basin types with meadow complexes and where individual meadows are considered a significant resource. The assessment provides information on the sensitivity and resilience of the meadow complex to both natural and anthropogenic disturbance. In addition to the geomorphic and disturbance data described earlier, data are collected on the geomorphic and hydrologic characteristics and vegetation of the sampled meadow. The data forms and necessary information for completing the forms are in Appendix 6 (geomorphic assessment), Appendix 8 (disturbance assessment), and Appendix 9 (meadow assessment) (table 7). Meadow assessments are conducted for as many as four meadows that represent the dominant meadow types and their responses to disturbance within the watershed. The geomorphic assessment is conducted for a representative stream reach within the meadow. The disturbance assessment characterizes the effects of disturbances within the meadow and in adjacent stream reaches upstream and downstream of the meadow. The assessments of meadow geomorphic and hydrologic characteristics and meadow vegetation encompass the entire meadow.

The meadow assessment provides information on the geomorphic, hydrologic, and meadow vegetation responses to disturbances that alter water tables, such as channel incision or avulsion, as well as human-caused disturbances such as inappropriate livestock grazing. Information is collected first on the geomorphic and hydrologic characteristics of the meadow, including its geomorphic position, groundwater sources and springs, relationship to the stream, complexity, and evidence of incision. This information is used to determine the meadow hydrologic type: its hydrogeologic setting, hydrology, and connections to the stream (Appendix 9, fig. A.9.3). Information is then collected on the relative cover, vigor, mortality, and wetland indicator rating of the dominant indicator meadow species that occur within the different meadow types (standing water, wet, mesic, dry, and shrub) (Appendix 9, table A.9.1) and summarized for the entire meadow complex.

Phase III—Interpretation (office)

Task 5—Determine the Watershed Sensitivity and Resilience Type, Evaluate Sensitivity to Incision and Avulsion, and Determine Ecological Integrity

Five sensitivity and resilience categories have been defined for the Great Basin watersheds: flood dominated, armored, fan dominated, deeply incised, and pseudostable (table 6). The Phase I (office) and Phase II (field) assessments provide the information needed to evaluate the relative sensitivity to stream incision and avulsion and determine the sensitivity and resilience category of the focal watershed or basin types within the watershed. The assessments also provide the information needed to evaluate the ecological integrity of the focal watershed or basin types within the watershed.

A score sheet for assessing watershed sensitivity and resilience is in Appendix 10 (form A.10.1). Control and response variables are used to evaluate relative sensitivity and resilience. The control variables are those that have been shown to influence watershed responses to disturbance: general watershed characteristics that describe the watershed's hydrology and geomorphology and information on the size, availability, and mobility of the sediments within the watershed. The response variables are those that provide evidence of the rate, magnitude, and timing of contemporary and historical channel incision and evidence of the existence and frequency of channel avulsions. The general watershed characteristics are obtained from the data collected in the office (Appendix 4, form A.4.1). Information on sediment size and availability, and stream channel incision and avulsion, is obtained from the geomorphic and vegetation data collected in the field (Appendix 6, form A.6.1 and Appendix 7, form A.7.1).

Incision and avulsion sensitivity indices are calculated from the control and response variables to score watershed sensitivity and resilience (see Appendix 10). The indices are calculated as follows:

$$\text{Incision Sensitivity Index} = (\Sigma \text{ of control variables}/10) \times \Sigma \text{ of subtotal evidence of incision}$$

$$\text{Avulsion Sensitivity Index} = (\Sigma \text{ of control variables}/10) \times \Sigma \text{ of subtotal evidence of avulsion}$$

Potential runoff and potential to transport available sediment by the generated runoff increase as the values for the control variables increase. Therefore, larger values of the indices indicate higher potential for incision and avulsion. The subtotals of the evidence for incision and avulsion provide insights into the magnitude and frequency with which these processes occurred in the past.

The incision and avulsion sensitivity indices calculated for the individual reaches represent the distinct watershed segments that were identified in Task 2. These indices can be calculated for the entire watershed or the basin types within the watershed based on the percentages of the distinct watershed segments within the watershed or basin type.

The watershed sensitivity and resilience type is determined by comparing the incision and sensitivity indices calculated from the office and field data in form A.10.1 to the typical values for these indices found in Appendix 10 (table A.10.1). For the incision and avulsion indices, the watershed sensitivity and resilience type can be determined for distinct watershed segments, basin types within the watershed, or the entire watershed. Where a single distinct watershed segment makes up most of the watershed or basin type, a single sensitivity and resilience type may be an adequate descriptor of potential response to disturbance. However, where watersheds or basin types are composed of two or more distinct watershed segments with potentially different sensitivity and resilience, it may be necessary to consider the sensitivity and resilience type of each segment to determine effective management strategies.

The challenges associated with determining the different watershed sensitivity and resilience types vary by type (table 6). In some cases, deciding on the watershed type is straightforward. For example, diagnostic traits of **Flood dominated (Type A1 basin)** watersheds are anabranching channel patterns caused by the frequent occurrence of avulsion, high-magnitude flooding, and large supplies of mobile sediment (Appendix 12, fig. A.12.1). These watersheds tend to be characterized by riparian species adapted to abrasion. **Armored (Type A2 basin)** watersheds often are characterized by basin morphometric properties similar to flood dominated basins but have large bed and bank sediments that cannot be moved by the available stream flows except during exceptionally large floods (Appendix 12, figs. A.12.2, A.12.3). These types of watersheds tend to have woody vegetation types with meadow-type vegetation in the understory. **Fan dominated (Type B basin)** watersheds are characterized by large side-valley fans, many of which are associated with a stepped longitudinal profile and meadow complexes (Appendix 12, fig. A.12.4).

The primary characteristic of **Deeply incised (Type B or C basin)** watersheds is that the channel has undergone significant incision (often exceeding 4–5 m) (Appendix 12, figs. A.12.5, A.12.6). Where side-valley alluvial fans are present, steps in the longitudinal profile have been removed and the channel profile has a more uniform, U-shaped form. Many deeply incised reaches terminate upstream in large, almost vertical headcuts that connect the channel bed to the valley floor (fig. 21b). Where wet meadows are present, they have been significantly degraded by drops in the water table in lower parts of the watershed, and, in some cases, have been replaced by drier vegetation. The channel bed and valley fill sediments in most of these basins are composed of easily eroded, fine-grained sediments.

The sensitivity and resilience of **Pseudostable (Type B or C basin)** watersheds are the most difficult to classify. These basins have the potential to undergo rapid, catastrophic incision or valley aggradation and, once destabilized, tend to remain in that condition for decades (fig. 22; Appendix 12, fig. A.12.7). They are often characterized by loose, highly permeable, fine-grained valley fill and abundant hillslope materials that are easily mobilized if the watershed is disturbed. Vegetation typically is characterized by woody vegetation types with meadow-type vegetation in the understory, and occasionally meadow-type vegetation with no woody types present. The most easily recognized examples are associated with wildfires that led to debris flows, valley aggradation, and channel incision impacting nearly the entire valley floor (fig. 23). In other cases, the debris flows are limited, but the channel has responded by means of deep and extensive incision, which may be amplified by groundwater sapping. These types of pseudostable basins often resemble deeply incised basins with riparian vegetation located primarily in the incised trench, but can be differentiated by (1) significant channel or valley fill deposits (e.g., debris flow deposits) that were created following the disturbance but were later re-incised, and (2) out-of-phase erosional and depositional processes in which zones of ongoing erosion are separated upstream and downstream by zones of deposition.

Meadow sensitivity and resilience takes into account the watershed sensitivity and resilience type but also considers the meadow hydrologic type. Meadows should be evaluated individually because of the unique geomorphic and hydrologic conditions required for their formation and because of inherently high sensitivity. In these groundwater-dependent ecosystems, even a small shift in the hydrology (due to climate, stream changes, or land use) may result in significant changes in meadow hydrology and vegetation. Meadows typically are associated with **Fan dominated (Type B basin) and Deeply incised (Type B or C basin)** watersheds (see table 6). The incision and avulsion sensitivity indices from the Score Sheet for Assessing Watershed Sensitivity and Resilience in Appendix 10 (form A.10.1) provide important information about the influence of the stream on past degradation of the meadow and the potential for future degradation. The meadow hydrologic type (Appendix 9, fig. A.9.3) provides additional information on the hydrogeologic setting, hydrology, and stream connections of the meadow that can be used to develop effective management approaches.

Ecological integrity can vary significantly among watersheds and is an important factor to consider when evaluating riparian ecosystem and meadow condition. An understanding of the factors affecting ecological integrity can be obtained from office and field assessments of the types of natural disturbances, such as recent wildfires, and anthropogenic disturbances such as road networks, dams, and diversions, and their relative effects. The response to these disturbances can be obtained for each sampled reach from the field geomorphic, vegetation, and disturbance assessments. A score sheet for assessing ecological integrity and a description of the rating variables is in Appendix 11 (form A.11.1). For additional information on the relationships of ecological resilience and ecological integrity, see the section in Part I, “What Is Ecological Integrity and How Is It Related to Ecological Resilience?”

The summary information on the different sensitivity and resilience watershed types—their dominant short-term processes and potential for geomorphic and vegetation changes, as well as their long-term geomorphic sensitivity to geomorphic change—provides insights into their ecological resilience and the management considerations for each of the five types. Additional information on the sensitivity and resilience types is provided in the section “Geomorphic Sensitivity and Ecological Resilience Categories and Management Implications” in Part I. Specific examples of the different watershed types, their diagnostic indicators, and observed ecological integrity are in Appendix 12, “Examples of the Different Watershed Types, Their Diagnostic Indicators, and Observed Ecological Integrity.”

More details on the factors to consider when developing management approaches are provided in prior publications. For riparian ecosystems, the factors to consider are described in Chambers et al. (2004a). For meadow complexes, these factors are in Chambers et al. (2004a, 2011b) and Lord et al. (2011).

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Appendix 1—Definitions of Terms

This appendix defines the terms used in Part I, "Sensitivity and Resilience Concepts, Components, and Categories," and Part II, "Assessment Protocol."

Alluvial fan is a cone-shaped accumulation of unconsolidated sediment deposited by streams at the base of a mountain range or hillslope. Fans often contain sediments deposited by hyperconcentrated flows (high sediment concentrations) and debris flows.

Bank stability rating provides information on the relative ability of riparian vegetation to stabilize stream banks and is assigned based on the root strength and rooting depth of the riparian vegetation on the stream bank (Burton et al. 2011; Swanson 2016).

Basin morphometry describes the dimensions, shape, and relief of a drainage basin and the extent and arrangement of its drainage network.

Basin type is defined as that part of a watershed that is characterized by homogeneous morphologic traits, landforms, and processes. A basin type may include all of the watershed, or only part of the watershed if landscape morphology, landforms, and processes vary spatially within the watershed.

Channel avulsion is the rapid abandonment of part of a river channel and the abrupt formation of a new channel in a different location on the valley floor. It generally is caused by in-channel deposition (aggradation) of sediment along a relatively low-gradient reach of the drainage network, a process that forces water onto the adjacent floodplain surface. The displaced water then cuts a new channel into the valley floor that merges both downstream and upstream with the pre-avulsion channel system, creating a channel pattern called anabranching.

Channel incision is the downward erosion of the channel bed. Channel incision can be defined as the depth from the valley floor to the surface of the lowest inset terrace within the trench, or the channel bed if no inset is present. Channel incision generally leads to bank instability, an increase in downstream sediment transport, and an alteration in channel morphology.

Channel stability is a function of the amount of change in channel conditions (e.g., width, depth, slope) over timeframes ranging from an event to a few years.

Channel types:

- ***Single-thread channel*** system is a type of drainage network composed of a single, continuous channel.
- ***Multithread channel*** system is a type of drainage network composed of multiple channels that diverge and merge along the valley floor.
- ***Meandering channels*** are a type of single-thread channel characterized by a series of sinuous curves that swing from side to side across the floodplain. Typically defined as having a sinuosity (ratio of distance along center of channel to distance straight down valley) of greater than 1.5.

- ***Straight channels*** are a type of single-thread channel characterized by relatively straight channel banks. However, the thalweg (deepest part of the flow) may meander within the straight banks. The sinuosity of straight channels is less than 1.5.
- ***Braided channels*** are a type of multithread channel pattern in which the channels flow around accumulations of coarse sediment (bars) deposited by the channel network. The islands of sediment are typically unvegetated and highly dynamic or unstable, and may migrate downstream through time.
- ***Anabranching channels*** are characterized by a multithread pattern in which multiple channels flow around relatively stable, vegetated islands composed of floodplain deposits.

Clast refers to a fragment of rock broken off from other rocks (including bedrock) by physical or chemical weathering (or both). Clast size influences sediment transport whether in suspension or as bed load; therefore, the clast size of sedimentary deposits influences the tendency for incision or avulsion.

Disturbance-adapted species in riparian ecosystems have greater tolerance to inundation or scouring during high flows than other riparian species.

Drainage basin is synonymous with watershed, and is the area that drains precipitation, mainly by a stream or river and its associated tributaries, to a common outlet along the axial channel or valley.

Ecological integrity is defined as the structure, composition, and function of an ecosystem within the bounds of natural or historical disturbance regimes, and the ability of an ecosystem to support and maintain a full suite of organisms with species composition, diversity, and function comparable to similar systems in an undisturbed state (Bushman et al. 2019; Lemly et al. 2016). It describes the current ecological conditions of riparian and meadow ecosystems based on abiotic and biotic indicators of composition, structure, and function.

Ecological resilience describes the amount of change needed to shift an ecosystem from one set of processes and structures to a different set of processes and structures, or the amount of disturbance that a system can withstand before it shifts into a new regime or alternative stable state (Holling 1973). In the applied sciences, ecological resilience also is used as a measure of the capacity of an ecosystem to regain its fundamental structure, processes, and functioning (or remain largely unchanged) despite stresses, disturbances, or nonnative invasive species (Chambers et al. 2014; Seidl et al. 2016).

Equilibrium of geomorphic systems refers to a balance between a set of driving forces that promote change (climate, gravity, tectonics) in the Earth's surface and a set of resisting forces (governed by the resistance of the Earth's materials) to undergo change. Types of equilibrium have been defined on the basis of the timeframe under consideration. Here, the primary concern is with dynamic or graded-time equilibrium, which represents the changes in channel form around a mean condition over years to centuries.

Fan step is an abrupt upstream increase in channel bed elevation as a stream traverses the toe of a side-valley alluvial fan.

Gaining stream reaches receive water from groundwater through the stream bed. In some environments, the stream always gains water from groundwater, resulting in perennial stream flow. In other environments, flow direction varies along the stream; some reaches receive groundwater and other reaches lose flow to groundwater. Furthermore, the flow direction between groundwater and stream water can change seasonally or over very short timeframes as a result of individual runoff events that cause rapid fluctuations in stream levels (Winter et al. 1998). Most streams in meadow complexes are gaining.

Geomorphic processes are actions (e.g., erosion or deposition) that occur when an alteration in a driving force induces a change in the Earth's surface. The response in the morphology of the surface (stream or river channel) represents the proportional change that occurs and is characterized in terms of the type, magnitude, and rate of change.

Geomorphic sensitivity describes the capacity of the geomorphic system to absorb change and remain in a state of dynamic equilibrium over a period of years. It is a function of the likelihood that a given change in the controls of the system will produce a "sensible, recognizable, and persistent response" in the stream system and riparian corridor (Brunsden and Thornes 1979).

Groundwater is all water below the ground surface, including water in the saturated and unsaturated zones.

Headcut is the identifiable point of active erosion where a break in grade occurs from a lower to a higher elevation. An active headcut migrates in an upstream direction and commonly is associated with gully systems in previously unincised alluvial valleys.

Hydrologic connectivity refers to the degree to which water and sediment can be transferred from one part of the drainage network to another downstream section through a distinct channel. For streams and rivers, the balance is often viewed in terms of the water or discharge that is available to erode and transport sediment, and the size and amount of sediment that is available for transport by the available flow.

Indicator species are plant species that can be used to infer environmental conditions, such as water table regimes or disturbance regimes in riparian and meadow ecosystems.

Knickpoints are abrupt, vertical, or near-vertical breaks in channel slope that are a direct indicator of ongoing channel incision.

Losing stream reaches lose water to groundwater by seepage through the stream bed. Losing streams can be connected to the groundwater system by a continuous saturated zone or disconnected from the groundwater system by an unsaturated zone. Stream reaches can vary between gaining and losing with distance, or temporally with seasonal changes or during runoff events. Most streams in the Great Basin are losing.

Meadow complexes are areas with two or more meadow vegetation types, each of which is characterized by different depths to the water table.

Meadow types are characterized by a range in the depth to water table and can be identified by a distinct set of indicator plant species.

Perennial stream systems flow continuously throughout the year. They generally are fed in part by springs or groundwater where the water table intersects the channel bed. Groundwater supplies the baseflow for perennial streams during dry periods, but flow is also supplemented by stormwater runoff and snowmelt (Nadeau 2011).

Riparian pertains to the bank of a body of flowing water: the land adjacent to a river or stream that is, at least periodically, influenced by flooding. Riparian sometimes is used to indicate the banks of lakes and ponds subject to periodic inundation by wave action or flooding.

Reference states exhibit the ecological potential and historical range of variability of the ecological types.

Stream power is a measure of a stream's ability to erode and transport sediment and is equal to the product of stream gradient and discharge.

Stream reaches are segments of the drainage network (watershed segment) possessing homogeneous channel (width, depth, gradient, planimetric configuration, pattern) and channel bed features (e.g., pools and riffles, step and pools, bars, knickpoints) as well as valley floor landforms (e.g., terraces, floodplains).

Stringer meadows are narrow riparian areas along stream channels that consist of meadow vegetation types. These meadows are narrow because they are topographically confined or adjacent to a losing stream with limited saturated soils adjacent to the channel. Only one or two meadow types may occur and the types may have little complexity.

Successional status is a description of the occurrence and persistence of plant species over time after disturbance based on longevity, life form, shade tolerance, and rooting characteristics. Ecological status rating classes for individual plants are assigned by Burton et al. (2011). Succession rating classes are early, mid-, and late seral (see Part I, table 4). Anthropogenic disturbances such as inappropriate livestock grazing or recreational use also influence successional classes and can cause shifts in successional classes from mid- or late seral to early seral.

Terraces form when streams cut downward into the underlying bedrock or valley fill, leaving discontinuous remnants of older floodplain surfaces as step-like benches along the sides of the valley. Terraces can be thought of as abandoned floodplains.

Thalweg is the line that connects the lowest or deepest points along the stream bed.

Thresholds are defined as the limits to equilibrium. When a threshold is crossed in a geomorphic system, the stream will respond by acquiring a new morphologic state as described by its width, depth, slope, pattern (straight, meandering, braided, or anabranching), and planimetric configuration (e.g., sinuosity, meander wavelength). When a threshold is crossed in a riparian or meadow ecosystem, the system transitions to a new ecological state as reflected by its vegetation composition and structure and its ecological function.

Uplands are topographically elevated lands that are not influenced by a consistent source of surface water or groundwater and, therefore, do not support **wetland** vegetation or hydric soil development as would a wetland or **riparian** area.

Watershed is synonymous with drainage basin, and is the area that drains precipitation, mainly by a stream or river and its associated tributaries, to a common outlet along the axial channel or valley.

Watershed segments contain one or more stream reaches and are characterized by similar valley materials (e.g., bedrock, colluvium, alluvium), valley morphologic characteristics (e.g., width, gradient, relief), landform types (e.g., terraces and alluvial fans), and processes.

Wetland indicator status (WIS) is a categorization of plant species based on the likelihood of their occurrence in wetlands or uplands (Lichvar and Minkin 2008). See Part I, table 3.

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Appendix 2—Information on the Watershed-Scale Data Available in the Great Basin Watershed Database and Its Use

This appendix provides the descriptions and data sources of the watershed characteristics in the database for the Great Basin geographic regions (table A.2.1). It also provides information on how to access the data (exhibit A.2.1).

Table A.2.1—The characteristics, units, descriptions, and data sources for the topographic, climatic, geologic, hydrologic, vegetation, disturbance, and species data in the Great Basin Watershed Database (Dilts et al. 2020). The data are available at: https://doi.org/10.2737/RDS-2020-0059. The data can also be downloaded directly in ArcGIS Pro, ArcGIS Desktop, or QGIS at: https://www.arcgis.com/home/item.html?id=29f4c16030c8498698ce090acb8767be. Use of ArcGIS to access the data is described in exhibit A.2.1 and a general characterization of the watersheds is in Board et al. (2020).

Characteristic	Units	Description	Source
Topography			
Watershed area	m^2	Total watershed area	Engelhardt (2009); National Elevation Dataset (USGS 2017)
Mean elevation	m	Mean elevation of the watershed	National Elevation Dataset (USGS 2017)
Ruggedness	—	(Maximum elevation – minimum elevation) × drainage density	Engelhardt (2009); National Elevation Dataset (USGS 2017)
Watershed length	m	Length of the watershed along the main channel	Engelhardt (2009); National Elevation Dataset (USGS 2017)
Relief ratio	—	(Maximum elevation – minimum elevation)/watershed length	Engelhardt (2009); National Elevation Dataset (USGS 2017)
Relative stream power	m^2	Estimate of stream power from watershed area × relief ratio	Engelhardt (2009); National Elevation Dataset (USGS 2017)
Drainage density	km/km^2	Total stream length/watershed area	Engelhardt (2009); National Elevation Dataset (USGS 2017)
Hypsometric integral	%	Percentage area under a dimensionless curve produced as the ratio of h/H and a/A, where h = elevation, H = watershed relief, a = planimetric area above h, and A = planimetric watershed area	Engelhardt (2009); National Elevation Dataset (USGS 2017)
Percent valley bottom	%	Percentage of the watershed mapped as valley bottom based on a 15-m height above nearest drainage	Knight (2019); National Elevation Dataset (USGS 2017); Nobre et al. (2011)
Percent tablelands	%	Percentage of the watershed with slope of less than 5° outside of valley bottoms	National Elevation Dataset (USGS 2017)
Local vector ruggedness	radians/m	Average terrain ruggedness based on the methodology of Sappington et al. (2007) with modifications in which the underlying smooth topography is removed	National Elevation Dataset (USGS 2017); Sappington et al. (2007)
Climate			
Annual precipitation	mm	30-year mean annual precipitation	Daly et al. (1994); PRISM Climate Group (2017)

Table A.2.1 continued.

Characteristic	Units	Description	Source
Monsoonality	%	Proportion of precipitation that falls during monsoon season: 30-year mean July to September precipitation/annual precipitation	PRISM Climate Group (2017); Romme et al. (2009)
Snow fraction	%	Proportion of precipitation that is snow: 30-year mean snow precipitation/annual precipitation	Dilts et al. (2015); PRISM Climate Group (2017)
Geology			
Percent carbonate	%	Proportion of watershed area with carbonate bedrock	Horton (2017)
Percent sedimentary	%	Proportion of watershed area with sedimentary bedrock	Horton (2017)
Percent intrusive igneous	%	Proportion of watershed area with intrusive bedrock	Horton (2017)
Percent volcanic	%	Proportion of watershed area with volcanic bedrock	Horton (2017)
Hydrology			
Percent perennial	%	Perennial stream length/total stream length	National Hydrography Dataset Plus (USGS 2012)
Perennial stream connectivity	count	Number of unique perennial stream segments within the watershed	National Hydrography Dataset Plus (USGS 2012)
Average perennial length	m	Average length of perennial stream segments within the watershed	National Hydrography Dataset Plus (USGS 2012)
Vegetation			
Annual herbaceous cover	%	Watershed mean of pixel percent cover of provisional herbaceous vegetation	Xian et al. (2015)
Tree cover	%	Watershed mean of pixel percent tree canopy cover	Homer et al. (2015)
Shrub cover	%	Watershed mean of pixel percent shrub cover	Xian et al. (2015)
Disturbance			
Percent burned	%	Cumulative proportional area of watershed burned between 1984 and 2017	Eidenshink et al. (2007); USGS (2000, 2005)
Road density	km/km^2	Density of roads within the watershed	U.S. Census Bureau (2017)
Percent private land	%	Percentage of private land within the watershed	BLM (2015)
Number of dams/ diversions	count	Count of the number of dams and diversions within the watershed	National Hydrography Dataset Plus (USGS 2012)

Table A.2.1 continued.

Characteristic	Units	Description	Source
Species			
Mammals			
Mule deer	APOC	Average probability of occurrence of mule deer (*Odocoileus hemionus*)	Cushman et al. (2016)
Pronghorn	APOC	Average probability of occurrence of pronghorn (*Antilocapra americana*)	Cushman et al. (2016)
Pygmy rabbit	APOC	Average probability of occurrence of pygmy rabbit (*Brachylagus idahoensis*)	Cushman et al. (2016)
Birds			
Brewer's sparrow	APOC	Average probability of occurrence of Brewer's sparrow (*Spizella brewer*)	Cushman et al. (2016)
Gray flycatcher	APOC	Average probability of occurrence of gray flycatcher (*Empidonax wrightii*)	Cushman et al. (2016)
Greater sage-grouse	APOC	Average probability of occurrence (APOC) of Greater sage-grouse (*Centrocercus urophasianus*)	Coates et al. (2016); Doherty et al. (2011)
Juniper titmouse	APOC	Average probability of occurrence of juniper titmouse (*Baeolophus ridgwayi*)	Cushman et al. (2016)
Pinyon jay	APOC	Average probability of occurrence of pinyon jay (*Gymnorhinus cyanocephalus*)	Cushman et al. (2016)
Sage sparrow	APOC	Average probability of occurrence of sage sparrow (*Artemisiospiza nevadensis*)	Cushman et al. (2016)
Vesper sparrow	APOC	Average probability of occurrence of vesper sparrow (*Poocetes gramineus*)	Cushman et al. (2016)
Fish			
Native cutthroat trout	m	Length of stream suitable for native cutthroat trouts, including Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*) in the watershed	Isaak et al. (2017)
Insects			
Monarch butterfly	APOC	Average probability of occurrence of breeding monarch butterflies (*Danaus plexippus*) (not including tropical milkweed)	Dilts et al. (2019)

Exhibit A.2.1—Accessing the Great Basin Watershed Data.

A prior report, Characterizing Ecoregions and Montane Perennial Watersheds of the Great Basin, described development of the Great Basin Watershed Database and summarized information on the characteristics of the focal regions and watersheds within the regions (Board et al. 2020). The report also described access and use of the database, and that information is repeated here to facilitate use of the database in the assessment. The data available in the Great Basin Watershed Database are listed in table A.2.1. The database is available as an ArcGIS feature layer at https://usfs.maps.arcgis.com/home/item.html?id=29f4c16030c8498698ce090acb8767be and as a streaming web service described below. The feature layer includes the drawing properties when the file is added into ArcMap or ArcGIS Pro software and an associated metadata files in .xml format. Additionally, metadata are available in .docx format and include descriptions of attribute fields and data sources from which the values were derived.

The streaming web service file format can be obtained in ArcMap, ArcGIS Pro, or opensource QGIS software, and symbols for attributes have already been delineated. The streaming web services can also be viewed with ESRI's built-in web viewer on ArcGIS online, which provides access to users outside the geographic information systems (GIS) community.

To access the data within ArcMap in the Catalog window click on "GIS servers," followed by "add GIS Server," and enter https://services1.arcgis.com/gGHDlz6USftL5Pau/arcgis/rest/services/GB_Montane_DB/FeatureServer. Scroll down to the feature services named "GB_Montane_DB"; feature datasets other than "GB_Montane_DB" are not related to this project. Unfortunately, ArcMap does not provide options for filtering feature services within an institutional ArcGIS Online account.

The streaming web services can also be accessed in open-source QGIS. Open QGIS, go to "Layers," click on "Add Layer," and click on "Add ArcGIS Feature Server Layer." Next, type in a name for your new feature server and copy in https://services1.arcgis.com/gGHDlz6USftL5Pau/arcgis/rest/services/GB_Montane_DB/FeatureServer.

ArcGIS Online provides several visualization options for non-GIS users. To launch the mapviewer, enter https://usfs.maps.arcgis.com/apps/mapviewer/index.html?layers=29f4c16030c8498698ce090acb8767be into the address bar of your web browser. All the layers will be available. Regions, and mountain ranges have simple attributes. The layers Longest Stream, Streams and Valley Bottom also have simple attributes and are not visible unless the user zooms in to an appropriate extent, watershed or below. Pour Point, Furthest Head, Heads are not visible unless turned on by the user. The watersheds layer has the full suite of attributes and will probably be the most interesting to viewers. Watersheds display with a default symbolization based on the ecoregion they occupy.

Users may change colors and symbol size on the basis of attributes within the table. Click the "change style" button (which has a square, circle, and triangle). Ensure that the Watersheds layer is selected. Choose one or more attributes by clicking the "+ Field" button and selecting the attribute of interest. Next, select one of the drawing styles. "Counts and amounts (color)" allows the watershed polygons to be colored based on a single quantitative attribute such as average elevation, watershed relief, or drainage density. “Counts and amounts (size)” will depict each watershed with a point symbol in which the size represents the quantity. Both symbol types provide interactive tools that allow the user to customize the color ramps and symbol sizes.

A third useful symbol encompasses two quantities. Select the two attributes that you wish to display (e.g., precipitation and average elevation). This will render a bivariate map that allows users to explore relations between two variables (fig. A.2.1). In this example, watersheds with both high precipitation and high elevation are scattered throughout the area but are more common in both Eastern and Central Nevada. Watersheds with low precipitation and low elevation are primarily in the western part of the area particularly in the Lava Plains region. Watersheds with high precipitation but low elevation are in a band in the Northern part of the area. Users who have a free ArcGIS Online account can also overlay their own data on the database.

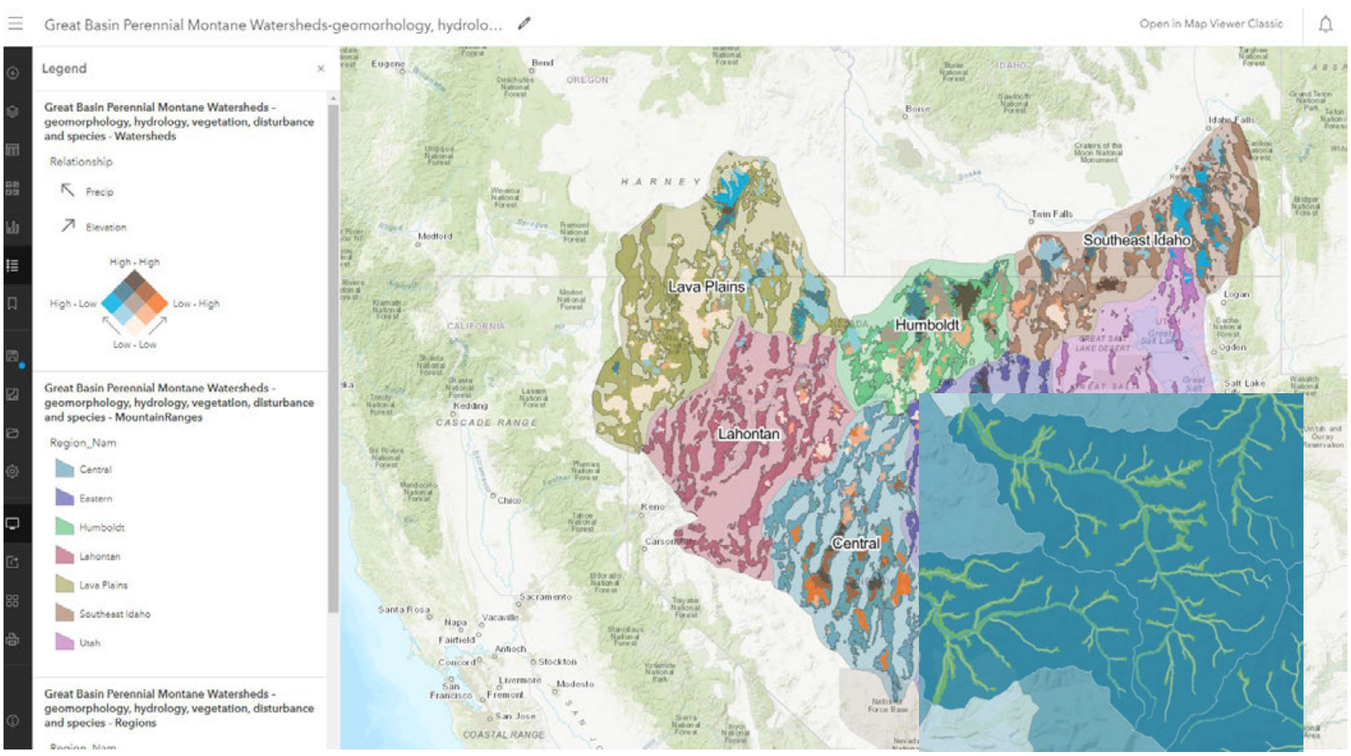

Figure A.2.1—Illustration of the type of visualization available in ArcGIS Online for the “Great Basin Perennial Montane Watersheds – geomorphology, hydrology, vegetation, disturbance and species”. ArcGIS Online can be launched from the viewer’s browser by typing in https://usfs.maps.arcgis.com/apps/mapviewer/index.html?layers=29f4c16030c8498698ce090acb8767be. The map shows the seven regions overlaid with the perennial montane watersheds. The inset shows the stream and valley bottom of a watershed. Instructions for using the tool are in text.

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Appendix 3—General Descriptions of the Dominant Riparian and Meadow Ecosystem Types Addressed in This Report

This appendix provides descriptions of the dominant riparian and meadow vegetation types covered in this report (exhibit A.3.1) based on Castelli et al. (2000), Comer et al. (2003), Lemly et al. (2016), Lord et al. (2011), and Weixelman et al. (1996, 1999). Detailed vegetation classifications are available for riparian ecosystems and meadow complexes in the central Great Basin (Manning and Padget 1995; Weixelman et al. 1996) and the eastern Sierra Nevada (Weixelman et al. 1999). More complete lists of scientific and common names are in Appendix 7, table A.7.1 for riparian plants, and Appendix 9, table A.9.1 for meadow plants.

Exhibit A.3.1—Descriptions of Montane Riparian and Meadow Ecosystems in the Great Basin.

Montane Riparian Ecosystems

- **Subalpine-Montane Conifer**. This vegetation type occurs on stream terraces or trough-shaped floodplains. Common tree species at higher elevations with colder soils include *Pinus flexilis, Abies concolor, Abies lasiocarpa, Picea engelmannii*, and *Pseudotsuga menziesii*. *Pinus ponderosa* and *Juniperus scopulorum* can occur at more moderate elevations with warmer soils. *Pinus flexilis* occurs in the central part of the Great Basin, but most of these types are more common in the eastern portion of the Great Basin. Common shrubs are *Cornus sericea, Rosa woodsia, Prunus virginiana*, and *Salix* spp. A wide variety of herbaceous species occur on these sites, with graminoids being more common on sites with finer textured soils and shallower depths to field capacity, and forbs occurring more often on sites with a higher proportion of cobbles and greater depths to field capacity.
- **Subalpine-Montane Populus tremuloides**. This vegetation type commonly occurs on trough floodplains but is also found on stream terraces and toe slopes. Soils are relatively cold. On sites with relatively shallow depth to field capacity (27 ± 27 cm in the eastern Sierra Nevada), graminoids occur in the understory and *Salix* spp. and *Alnus* spp. may be present. On sites where depth to field capacity is greater (53 ± 53 cm in the eastern Sierra Nevada) shrub species include *Salix* spp., *Alnus incana, Ribes* spp., and *Symphoricarpos* spp. Understory species can include *Osmorhiza* spp., *Thalictrum* spp., *Mertensia* spp., *Geranium* spp., *Ligusticum grayi, Aquilegia formosa, Aconitum columbianum, Poa wheeleri, Bromus marginatus*, and *Elymus* spp.
- **Subalpine-Montane Cold Willow**. This vegetation type typically occurs on trough floodplains or trough stream terraces but also occurs on gravelbars. These sites occur at higher elevations in areas with steeper valley slopes (2.5–8 percent). Soils are sandy, and depth to field capacity is close to the soil surface (about 10–50 cm). The dominant willow species are *Salix boothii, Salix lutea* × *Salix boothii, Salix lucida* ssp. *lasiandra*, and *Salix geyeriana*. Sites with fewer cobbles where field capacity is close to the soil surface tend to

have understories dominated by graminoids. Sites with a higher percentage of cobbles in the soil layers and greater depths to field capacity tend to have understories dominated by forbs.

- **Montane *Betula occidentalis***. This vegetation type typically occurs on stream terraces or trough-shaped floodplains that tend to be found in canyon constrictions. Average soil temperatures tend to be warmer but exhibit a broad range. Soils typically have a high proportion of coarse fragments (gravels, cobbles, and boulders). Sites usually have a dense overstory of *Betula occidentalis*.
- **Lower Montane Warm Willow**. This vegetation type typically occurs on gravel bars but is also found on trough-shaped floodplains, stream terraces, and incised landforms (Riverine hydrogeomorphic [HGM] class). These sites tend to be found at lower elevations with gentler valley slopes (1–5 percent). Sites are associated with gravel-bed streams, and depth to field capacity is relatively close to the surface (approximately 80 cm). Warm willow species dominate (*Salix exigua, S. lutea, S. lemmoni*, or *S. lasiolepis*). On very warm sites, exotic shrub species may include *Tamarix* spp. and *Elaeagnus angustifolia*. Sites with finer textured soils where field capacity is close to the soil surface tend to have understories dominated by graminoids; those with coarser textured soils and a high percentage of cobbles in the soil layers tend to have understories dominated by forbs. This system may occur on slopes, on lakeshores, or around ponds where the vegetation is associated with groundwater discharge or a subsurface connection to lake or pond water, and may experience overland flow but no channel formation (Slope, Lacustrine, or Depressional HGM classes). It is also typically found in backwater channels and other perennially wet but less scoured sites, such as floodplain swales and irrigation ditches.
- **Lower Montane Cottonwood**. This vegetation type is most commonly found on stream terraces but also occurs on trough-shaped floodplains. Soils are relatively warm. Usually no more than 15 percent cobbles are found in any one soil horizon. Cottonwoods, either *Populus fremontii, Populus balsamifera ssp. trichocarpa,* or *Populus angustifolia*, are overstory species. Understory shrubs may include *Salix* spp., *Prunus* spp., *Rhus trilobata, Cornus* spp., or *Artemisia* spp. Understory grasses and forbs may include *Achnatherum* spp., *Elymus* spp., *Leymus* spp., *Bromus carinatus, Bromus marginatus, Poa fendleriana, Lupinus* spp., *Geranium* spp., *Osmorhiza* spp., *Maianthemum* spp., *Aquilegia formosa, Thalictrum* spp., and *Aconitum columbianum*. This system can also occur on lakeshores or around ponds where the vegetation is associated with groundwater discharge or a subsurface connection to lake or pond water, and may experience overland flow but no channel formation (Slope, Lacustrine, or Depressional HGM classes).
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- **Lower Montane *Artemisia tridentata* ssp. *tridentata***. This vegetation type occurs along trough-shaped drainage ways and floodplains, stream terraces, and toe slopes. This type may also occur in associations with incised or avulsed landforms. Soil temperatures are relatively warm. In systems that are not incised, field capacity is typically within a meter of the surface, but in incised systems field capacity is often greater than 1 m. Coarse fragments (gravels, cobbles, boulders) are typically less than 60 percent by volume for unincised systems but can be greater than 60 percent for incised systems. The graminoids *Achnatherum* spp., *Leymus cinereus*, *Leymus triticoides*, or *Poa secunda* ssp. *juncifolia* are the most common grasses on unincised sites. After incision, *Poa secunda* ssp. *secunda*, *Elymus elymoides*, and *Bromus tectorum* can be the most common grasses. This type may also occur at relatively high elevations in association with *Artemisia tridentata* ssp. *vaseyana*.

Meadow Complexes

Herbaceous wetlands are associated with a relatively high water table (ranges from 0 cm to about 300 cm depth to water table) and typically lack prolonged standing water. These herbaceous wetlands occur in association with seeps, springs, or montane streams, and are located in geomorphic positions that allow the accumulation of fine-textured sediments. Sites may be dominated by natural groundwater inputs with fairly stable hydrology. Sites may exhibit groundwater sapping, lowered water tables, and changes in vegetation composition when located adjacent to incising (downcutting) streams. Sites may also be controlled by artificial overland flow (surface or subsurface irrigation runoff or return flow) or artificial groundwater seepage (including from leaky irrigation ditches). Sites may be small or very large. These sites may be intentionally managed for hay production or may be the result of unintentional return flows, runoff, or seepage. Vegetation is dominated by native or nonnative herbaceous species; graminoids (grasses, sedges, rushes) typically have the highest cover. Species composition may be dominated by nonnative hay grasses. Patches of emergent marsh vegetation and standing water are less than 0.1 ha in size and not the predominant vegetation. The meadow ecosystems in the Great Basin are described next.

- **Montane Meadow**. This vegetation type is found in herbaceous wetlands associated with a high water table or overland flow. Sites are typically associated with snowmelt or elevated groundwater. Sites associated with the Flats or Slope HGM classes are rarely subject to high-disturbance events such as flooding. Those associated with a stream channel are more tightly connected to overbank flooding from the stream channel (Riverine HGM class) and may be affected by avulsion or incision, or both. Sites vary in size; montane meadow vegetation may occur on stream terraces with elevated water tables. Vegetation is dominated by herbaceous species; graminoids typically have the highest area cover. The plant community types in the

- following list are associated with different groundwater levels and are indicated by species with different physiological tolerances for depth to water table (Castelli et al. 2000; Chambers et al. 2004; Lord et al. 2011).
    - ***Meadows with perennial standing water:*** Depth to water table is +10 to 0 cm. Characteristic species include *Carex aquatilis, Carex utriculata, Scirpus microcarpus*, and *Senecio hydrophilus*.
    - ***Wet meadow:*** Depth to water table is 5 to 30 cm. Characteristic species include *Carex nebrascensis, Deschampsia elongata*, and *Deschampsia cespitosa*.
    - ***Mesic meadow:*** Depth to water table is 30 to 90 cm. Characteristic species include *Carex microptera, Carex praegracilis, Poa secunda* ssp. *juncifolia, Juncus arcticus* ssp. *littoralis*, and *Deschampsia cespitosa. Poa pratensis* is common; it is an indicator of historical heavy grazing and may not reflect the current grazing regime.
    - ***Dry meadow:*** Depth to water table is 90 to 170 cm. Characteristic species include *Leymus triticoides, Elymus trachycaulus, Poa secunda* ssp. *juncifolia*, and *Muhlenbergia richardsonis. Poa pratensis* is common; it is an indicator of historical heavy grazing and may not reflect the current grazing regime.
    - ***Dry shrub meadow:*** Depth to water table is 125 to 275 cm. Characteristic species include *Artemisia tridentata* ssp., *Carex douglassi,* and *Leymus cinereus*.
- **Irrigated Wet Meadow.** This vegetation type is found in large herbaceous wetlands associated with a high water table that is controlled by artificial overland flow (irrigation). Sites typically lack prolonged standing water, but may have standing water early in the season if water levels are very high. Vegetation is dominated by native or nonnative herbaceous species; graminoids have the highest cover. Species composition may be dominated by nonnative hay grasses such as *Poa* spp., *Alopecurus* spp., *Phleum pratense*, and *Bromus inermis* spp. *inermis*. There can be patches of emergent marsh vegetation and standing water less than 0.1 ha; these are not the predominant vegetation.

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Appendix 4—Data Form and Information for Assessing Watershed Characteristics and Distinct Watershed Segments in the Office

This appendix provides data form A.4.1 and the information (exhibit A.4.1) needed to assess the overall watershed characteristics, past and present disturbances, and species at-risk within the focal watershed. It also includes the information needed to determine the distinct watershed segments within the watershed and identify potential stream reaches and meadows for field analyses.

The information on watershed characteristics and past and present disturbances is used in the assessments of watershed sensitivity and resilience (Appendix 10) and watershed integrity (Appendix 11).

The form can be downloaded at https://experience.arcgis.com/experience/49f171f01aed451d8bbebb5558638a6c.

Form A.4.1–WATERSHED CHARACTERISTIC AND DISTINCT WATERSHED SEGMENT DATA	
Date:	Recorder:
Mountain Range:	Watershed Name:
Database Code from the Great Basin watershed database:	
Watershed Characteristics	
Basin Type(s) (see figure 12 in Part I): ☐ A1 ☐ A2 ☐ B ☐ C	
Dominant Riparian Vegetation Types (see Appendix 3, exhibit A.3.1):	
Meadows (see Appendix 3, exhibit A.3.1): number: ________ **types:**	
Mean Annual Precipitation (mm):	
Watershed Area (km^2):	
Basin Connectivity: ☐ 1 = <80% ☐ 2 = 80-90% ☐ 3 = 90-95% ☐ 4 = >95%	
Past Debris Flow Activity (# of flows): ☐ 0 = 0-10 ☐ 1 = 10-20 ☐ 2 = 20-40 ☐ 3 = >40	
Past Debris Flow Activity (location in watershed): ☐ lower ☐ mid ☐ upper	
Fan Influence: number: % of valley width covered:	
Fan Influence Summary: ☐ 0 = basin wide ☐ 1 = regional ☐ 2 = localized ☐ 3 = none	
Large-Scale Disturbances	
Wildfires: ☐ yes ☐ no date(s) of wildfires: % watershed burned:	
Road Density:	
Dams and Diversions (# and type):	
Other (e.g., mining, houses, etc.):	
Wildfires: ☐ yes ☐ no date(s) of wildfires: % watershed burned:	
Road Density:	
Dams and Diversions (# and type):	
Other (e.g., mining, houses, etc.):	
Species At-Risk	
Record average probability of occurrence (APOC) or meters of stream (m)	
Species #1:	
Species #2:	
Species #3:	
Species #4:	
Species #5:	
Distinct Watershed Segments	
Determine distinct watershed segments for each basin type within the watershed. See examples in figures A.4.1, A.4.2, A.4.3.	
Distinct Watershed Segments (#): Basin Type 1 ____________ Basin Type 2 ____________	
Watershed Length (m):	
Length of Each Watershed Segment in Basin Type 1 (m): 1______ 2______ 3______ 4______	
Length of Each Watershed Segment in Basin Type 2 (m): 1______ 2______ 3______ 4______	
Percentage of Each Watershed Segment in Basin Type 1 (%): 1 ______ 2 ______ 3 ______ 4______	
Percentage of Each Watershed Segment in Basin Type 2 (%): 1 ______ 2 ______ 3 ______ 4______	
Notes:	

Exhibit A.4.1—Descriptions of the Variables Used to Assess (in the office) the Watershed Characteristics and Distinct Watershed Segments.

Watershed Characteristics

- **Basin Type(s):** The basin types and their characteristics are illustrated in Part I, fig. 12 in this report. Basin types can be subjectively determined from a combination of aerial photographs (e.g., found on Google Earth) and topographic maps on the basis of five parameters: valley width, the number of side-valley alluvial fans, the percentage of the valley width covered by side-valley fans, basin relief, and hillslope gradients. Type A basins have narrow valley floors that are often less than 100 m wide and devoid of broad, low-relief alluvial surfaces (surfaces underlain by river sediments); have few, small side-valley alluvial fans; and exhibit high gradient hillslopes associated with high basin relief. Type A1 basins are characterized by large quantities of highly mobile sediment, and high-magnitude floods result in frequent and extensive avulsion and widespread reworking of the valley floor. In Type A2 basins, incision and lateral channel migration are limited by large bed and bank sediments that can be entrained only during exceptionally large flood events. In contrast, Type B basins have relatively wide (>100 m) valley floors with low-relief alluvial surfaces; numerous, large side-valley fans that often extend at least halfway across the valley floor; and moderate hillslope gradients and basin relief. Type C basins have much wider valley floors than the other two types and contain extensive low-relief alluvial surfaces (often measured in 100s of meters). Large side-valley fans may be present, but because of high valley widths, the fans tend not to extend more than halfway across the valley floor (although exceptions exist). Relief and hillslope gradients are significantly lower than in the other basin types.
- **Dominant Riparian Vegetation:** The dominant vegetation types are described in Appendix 3, exhibit A.3.1. Vegetation types are determined from aerial imagery, such as the National Agricultural Imagery Program (NAIP) or Google Earth. It may be necessary to verify the vegetation types during the field visits.
- **Meadow Types:** The dominant meadow types are also described in Appendix 3, exhibit A.3.1. Identification of meadows at this stage ensures that both riparian stream reaches and meadows are included in the field sampling. It may be necessary to verify the meadow types during the field visits.
- **Mean Annual Precipitation (mm) and Watershed Area (km^2):** Data on these watershed characteristics are in the Great Basin Watershed Database (Appendix 2, table A.2.1). They can be accessed in ArcGIS Pro or ArcGIS Desktop at https://www.arcgis.com/home/item.html?id=29f4c16030c8498698ce090acb8767be. A description of how to use ArcGIS to access the data is in Appendix 2, exhibit A.2.1.

- **Basin Connectivity (%):** Data on basin connectivity are obtained directly from aerial imagery, such as NAIP or Google Earth. Disconnected reaches are characterized by lack of a distinct channel and occur most often on large alluvial fans and at the mouth of large tributaries with wide, low-gradient valley floors and thick alluvial deposits (Part I, fig. 9). Connectivity is calculated as the percentage of the total watershed area that is disconnected from the axial channel. It can be determined from aerial photographs by (1) identifying all tributary reaches along the drainage network that lack a channel and therefore have basin areas that are not physically linked to the axial stream by a channel, (2) measuring the watershed area upstream of the disconnected stream reach, and (3) summing the total area of disconnected channel and subtracting it from the total basin area. The percentage of basin connectivity is recorded as: 1 = <80 percent, 2 = 80–90 percent, 3 = 90–95 percent, 4 = >95 percent.
- **Past Debris Flow Activity (# of past debris flows):** Data on debris flows are obtained directly from aerial imagery, such as NAIP or Google Earth. Debris flows are typically activated during major runoff events and are particularly common following disturbances to the watershed that remove vegetation from the hillslopes, such as wildfires or vegetation treatments. The response of the axial system to disturbance is often linked to the occurrence of debris flows on hillslopes because they deliver large quantities of sediment to the valley floor and channel system and result in extensive channel aggradation or reworking (or both). The occurrence of debris flows depends on the climate, soil and sediment characteristics, hillslope gradients, plant successional processes within the watershed, and other variables. Past debris flows can be recognized on aerial photographs by the occurrence of (1) excavated (scoured) channels devoid of sediments on steep hillslopes which generally flow onto side-valley fans and (2) coarse, fan-shape deposits and linear levees (often consisting of large boulders) on side-valley fans (Part II, figs. 23b, 24a,b). The number of debris flows within the watershed is recorded as: 0 = 0–10; 1 = 10–20; 2 = 20–40; 3 = >40. In addition to the number of debris flows that have occurred, their distribution within the watershed should be recorded as lower, mid, or upper.
- **Fan Influence:** Fan influence refers to the effects of side-valley alluvial fans on the morphology and processes of the axial stream channel. Of primary interest is the spatial extent to which side-valley fans influence the longitudinal profile of the axial channel within the watershed, and whether one or more fans have created topographic steps that act as local base-level controls. Determination of fan influence requires both office and field data. In the office, aerial photographs can be used to determine whether side-valley fans are present and extend across most of the valley floor. If they do, then the number of fans and percentage of the valley floor covered are recorded.

The overall fan influence is recorded as basin-wide (numerous step-forming fans throughout basin), regional (numerous step-forming fans located in specific parts of the basin), localized (few to common step-forming fans restricted to localized reaches of the valley floor), or none. If fans occur within a watershed, field observations are required to determine whether the fans have affected the longitudinal profile of the axial channel by creating reaches downstream of the fan that are significantly lower than upstream reaches (i.e., topographic steps exist) (Part I, fig. 14).

Large-scale Disturbance and Species At-Risk

- Data on large-scale disturbances and species at-risk within the watersheds are in the Great Basin Watershed Database (Appendix 2, table A.2.1). They can be accessed in ArcGIS Pro or ArcGIS Desktop at https://www.arcgis.com/home/item.html?id=29f4c16030c8498698ce090acb8767be. A description of how to use ArcGIS to access the data is in Appendix 2, exhibit A.2.1. Detection of disturbances in the database or on aerial photos and topographic maps provides information on the responses of individual reaches to disturbance and is factored into management plans. Occurrence of species at-risk provides information needed to prioritize watersheds for study and for conservation and restoration actions.

Distinct Watershed Segments

- **Distinct Watershed Segments (#):** The distribution of the distinct watershed segments is identified for each basin type within the watershed using aerial imagery, such as NAIP or Google Earth, combined with 1:24,000 scale topographic maps. Distinct watershed segments consist of relatively homogeneous geological materials, valley morphometric characteristics, landforms, and riparian vegetation, and thus contain similar types of stream reaches. The parameters used to identify distinct watershed segments along the axial drainage network within a watershed include the type of valley fill (e.g., colluvium, alluvium, bedrock), existence of a well-defined and integrated channel (i.e., channelized vs. unchannelized reaches), depth of incision, channel pattern (i.e., meandering, braided, anabranching), presence of stable beaver dams, number and size of side-valley alluvial fans, occurrence of meadow complexes, vegetation types, and valley width and gradient. Aerial photos illustrating the geomorphic features of distinct watershed segments in different basin types are in figures A.4.1, A.4.2, and A.4.3. The distinct watershed segments represent the dominant stream reach types and are used to select potential stream reaches in the higher, mid-, and lower elevational zones within the watersheds for field analyses. They are also used to identify potential meadows for field analyses in those watersheds where they occur.

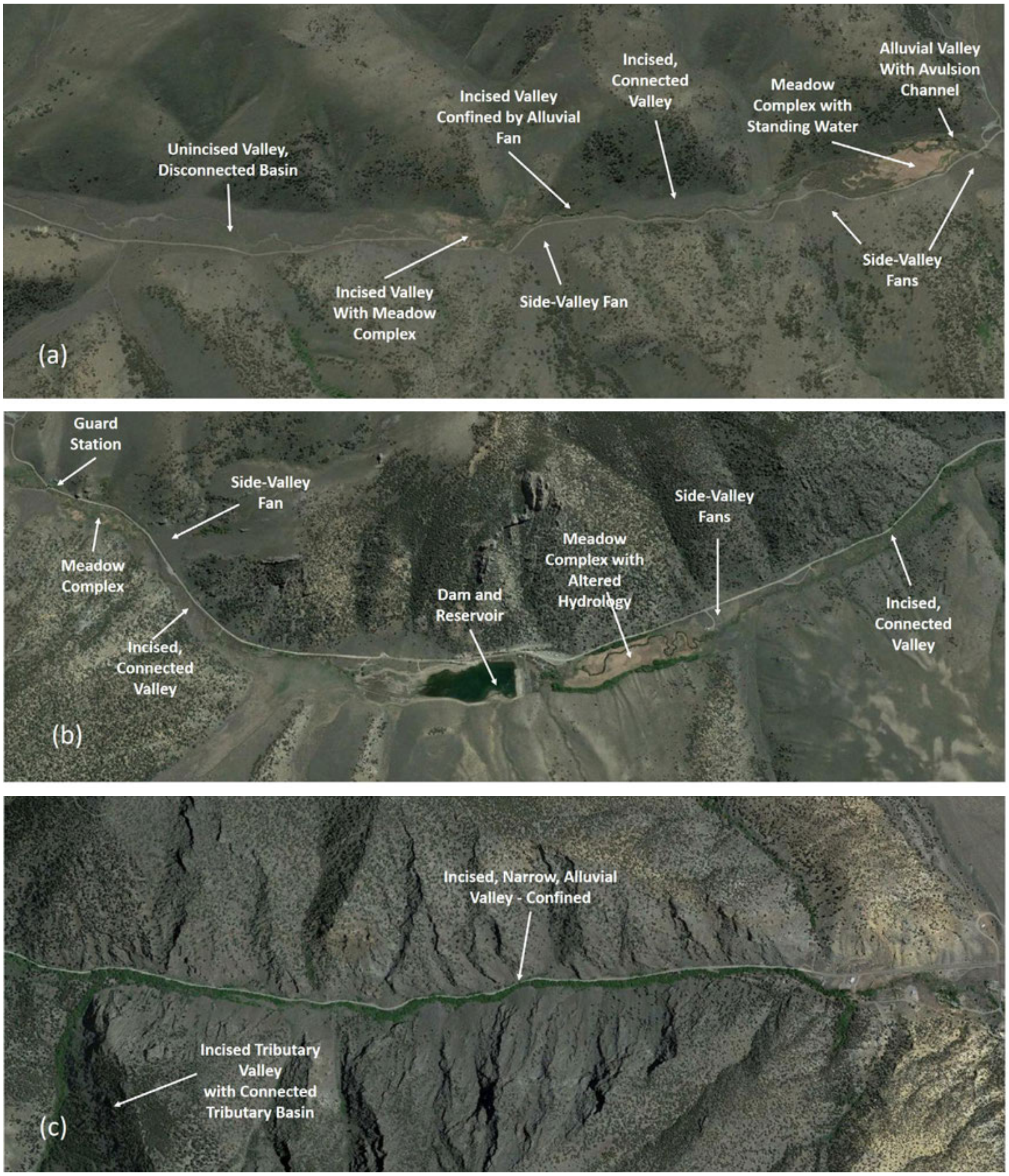

Figure A.4.1—Aerial photographs illustrating the geomorphic features of the elevational zones within Kingston Canyon, central Nevada. Higher elevations in Kingston Canyon are strongly influenced by side-valley alluvial fans and are categorized as Type B basins (a). A variety of different valley morphologic conditions exist and connectivity is moderate. In this elevational zone, logical sample sites include a representative stream reach in the incised, connected valley; the meadow complex in the incised valley; and, depending on assessment objectives, the meadow complex with standing water. The mid-elevation in Kingston Canyon (b) is also a Type B basin and has significant human influence. In this zone logical sample sites are a representative stream reach in the incised, connected alluvial valley and the meadow complexes. The meadow complex with altered hydrology due to the dam and reservoir may have altered ecological integrity. In contrast to the higher and middle portions of the watershed, the lower part of Kingston Canyon (c) is a Type A1 basin located in a narrow, bedrock-controlled valley and characterized largely by an incised alluvial channel. The lower basin is highly connected. Sampling one representative stream reach is sufficient for the lower elevation portion of the watershed. Images from Google Earth obtained December 2, 2020.

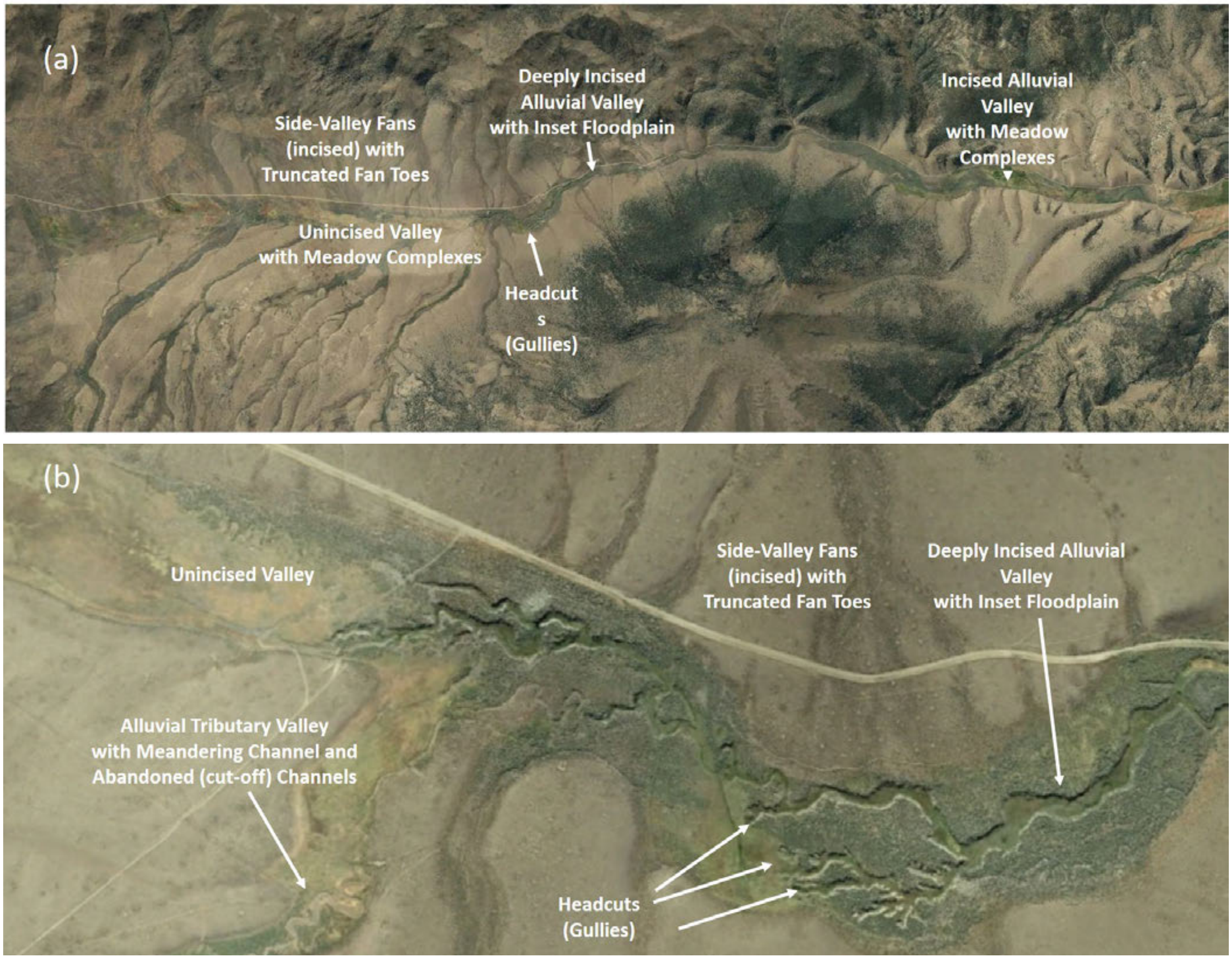

Figure A.4.2—Aerial photographs illustrating the geomorphic features in Indian Valley, central Nevada. (a) Indian Valley is a Type C basin characterized by low-gradient, wide, alluvial valleys and incised side-valley fans that have been truncated. (b) A gully system is developing within the valley through migration of headcuts. Indian Valley is an area of conservation concern because it supports a population of Columbia spotted frog, which was a candidate species for listing under the Endangered Species Act (ESA 1973) from 1993 to late 2015. Logical sample sites within Indian Valley include the unincised valley with meadow complexes, the gully system, and representative reaches in the deeply incised alluvial valley with an inset floodplain and the incised valley with an inset flood plain. Images from Google Earth obtained December 2, 2020.

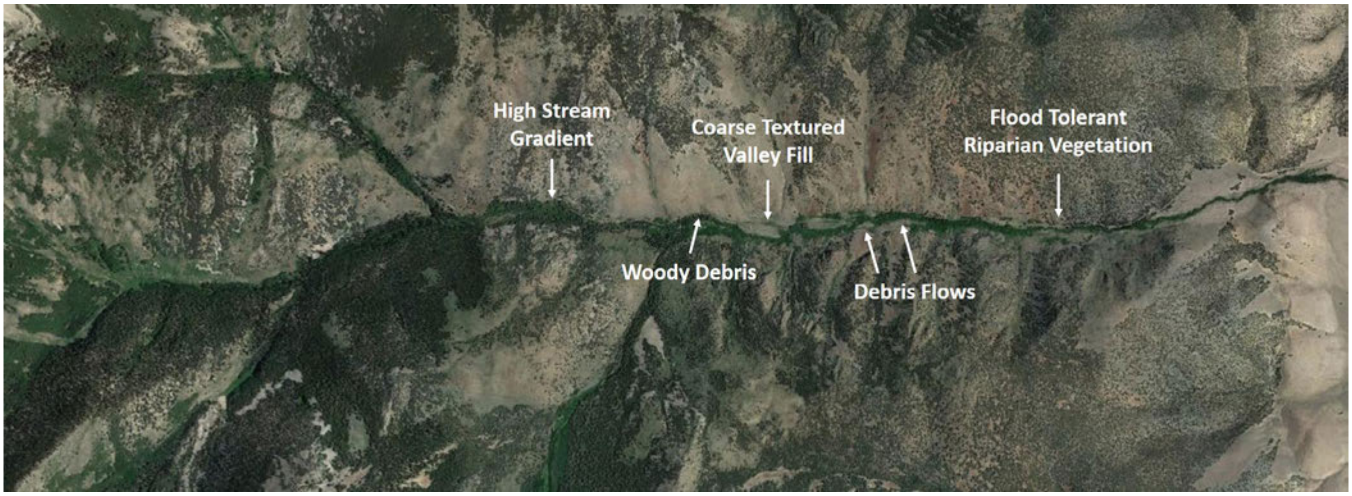

Fig. A.4.3—Aerial photograph illustrating the geomorphic features in McCoy Creek, eastern Nevada. McCoy Creek is a Type A1 basin characterized by steep slopes and a relatively narrow valley floor. The channel is characterized by coarse sediment and woody debris and there is evidence of channel avulsion. Geomorphic characteristics are relatively consistent throughout this small watershed, and sample locations are selected at high, mid-, and low elevations within the watershed. Image from Google Earth obtained December 2, 2020.

- **Watershed Length/Length of Each Basin Type within the Watershed (m):** The length of the watershed can be obtained by using the ruler tool in Google Earth, the distance measure tool in Google Maps, or the measure tool in ArcGIS. The length of the watershed includes the distance from the first appearance of a well-defined stream channel in the upper watershed to where the stream flows out of the canyon and onto the alluvial fan in the lower watershed.
- **Length of Each Watershed Segment (m):** The lengths of the distinct watershed segments can be obtained by using the ruler tool in Google Earth, the distance measure tool in Google Maps, or the measure tool in ArcGIS.
- **Percentage of Each Watershed Segment (%):** The percentage of each distinct watershed segment within the watershed is calculated by dividing the length of the distinct watershed segment by the length of the watershed. Similarly, the percentage of each distinct watershed segment within a basin type is calculated by dividing the length of the distinct watershed segment by the length of the basin type.

Reference

Endangered Species Act of 1973 [ESA]; 16 U.S.C. 1531-1536, 1538-1540. Available at https://www.gpo.gov/fdsys/pkg/USCODE-2012-title16/html/USCODE-2012-title16-chap35-sec1531.htm [Accessed 2021 February 5].

Appendix 5—Equipment

Following is a list of equipment and other gear needed for collecting field data.

Basic Equipment

- Two 50-m measuring tapes
- One 100-m measuring tape
- One 3-m hand measuring tape
- Range survey pins for anchoring tapes
- One stadia rod
- Two clinometers or a laser level
- Flagging
- Clipboards
- Pencils, pencil lead, permanent markers
- Field journals
- Filebox for data sheets

Sampling Protocol and Data Sheets

- Sampling protocols and data sheets for geomorphic, riparian vegetation, disturbance, and meadow data assessments

Maps and Aerial Images

- Topographic maps for navigation to study watershed
- Aerial images with dominant reach types in the upper, middle, and lower parts of the watershed delineated

Global Positioning System (GPS)

- Recreational-grade GPS
- Extra batteries and charger

Camera and Accessories

- Digital camera and extra data card, batteries, and battery charger
- White board and markers to label photographs with date, watershed, watershed database code, and position in watershed

Species Lists

- Great Basin riparian and meadow species (Appendix 7, table A.7.1 and Appendix 9, table A.9.1)
- Regional floras and vegetation keys
- Small rulers and hand lenses for plant identification
- Plastic bags for collecting plants
- Plant presses

Appendix 6—Data Form and Information for Assessing Stream Geomorphic Characteristics in the Field

This appendix provides data form A.6.1 and the information (exhibit A.6.1) needed to assess the stream geomorphic characteristics. The geomorphic data are collected along the same stream reach as the riparian vegetation and disturbance data. These data are also collected when meadow complexes are sampled.

Use form A.6.1 to record the geomorphic data. Use one form for each stream reach or meadow complex. At each sampled stream reach or meadow complex, record identifying information on the data form: date, observer, watershed name, the watershed code in the Great Basin watershed database, location within the watershed (e.g., high, mid, low), and the reach length of the observations (typically 30 m). Use a GPS to record the Universal Transverse Mercator (UTM) coordinates and elevation where the stream cross-sectional profile is drawn for the sampled reach.

A complete description of the variables recorded and the specific measurements or scores used to describe each variable are in exhibit A.6.1. The assessment involves collecting information on the current cross-sectional morphology of the valley (including the channel) and the longitudinal profile of the stream channel. Collect information on the materials that make up the channel bed, banks, and valley fill, and the sediment mobility and availability of bed sediments. In addition, obtain information on features that are indicative of the magnitude and rate of channel incision (e.g., knickpoints, headcuts, terraces), occurrence and amount of channel avulsion (e.g., filled or unfilled paleochannels), and the extent and mechanisms of bank erosion. Collect stream cross-section and bed material distribution data where more detailed data are desired.

Draw a cross-sectional profile for each sampled reach at a representative location within the reach. An illustration of a cross-sectional profile of a stream channel is in figure A.6.1. Use this drawing to identify the geomorphic positions used to sample riparian vegetation as described in the riparian vegetation data form (Appendix 7, form A.7.1).

The data collected in the geomorphic assessment are used in the score sheets for assessing watershed sensitivity and resilience in Appendix 10 and for rating ecological integrity in Appendix 11.

The form can be downloaded at https://experience.arcgis.com/experience/49f171f01aed451d8bbebb5558638a6c.

Form A.6.1–GEOMORPHIC DATA Date: Observer:

Watershed Name: Database Code:

UTM Zone: Elevation (m):

UTMs: Northing Easting

Location in Basin: ☐ Low ☐ Mid ☐ High Reach Length of Observations (m):

Definitions of terms and methods for the variables collected are in Appendix 6, exhibit A.6.1.
Use consistent units for all measurements.

Channel Character and Form

Flow Type: ☐ Perennial ☐ Ephemeral

Flow/Water Width (m): ________________ **Flow Depth (m):** __________________

Bankfull Channel Width (m): _____________ **Bankfull Channel Depth (m):** ________________

Channel Slope: distance (m): _____________ clinometer height (m): __________________

stadia height (m): _________ slope: ________________

Sediment Size and Mobility

Bed Particle Size: approx. D_{50}: ___________ approx. max. (avg. 10 largest): ___________

Bank/Valley Fill Sediment Size (%): _____ gravel/boulders _____mixed gravel/fines _____fines (<2 mm)

Bed Clast Immobility (% of channel bed): ☐ >75% ☐ 50-75% ☐ 10-50% ☐ <10%

Pebble Count Taken: ☐ yes ☐ no

Cross-section Taken: ☐ yes ☐ no

Sediment Availability

Bar Frequency (# per reach in channel): ☐ none ☐ few (1-2) ☐ common (3-4) ☐ many (>4)

Bar Extent (% of channel bed): ☐ none to 10% ☐ 10-20% ☐ 20-30% ☐ >30%

Gravel Bars on Valley Floor (# per reach): ☐ none ☐ few (1-2) ☐ common (3-4) ☐ many (>4)

Evidence of Incision within the study reach

Fan Steps at the Reach: ☐ yes ☐ no If yes, range in height(s) (m): _________

Knickpoints (# per reach): ☐ none ☐ few (1-2) ☐ common (3-4) ☐ many (>4)

Knickpoint Height (cm): ☐ none ☐ 0-25 cm ☐ 25-50 cm ☐ > 50 cm

Knickpoint Composition: ☐ bedrock ☐ boulders ☐ unconsol. sediment (gravel/silt/clay) ☐ roots

Inset Terraces (#): ☐ none ☐ 1 ☐ 2 ☐ 3 ☐ >/=4

Incision Depth (m): ☐ none ☐ 0-1 m ☐ 1-2 m ☐ >2 m

Bedrock Outcrops (% of channel bed): ☐ none ☐ localized (<25%) ☐ extensive(>25%)

Headcuts (# per reach): ☐ none ☐ few (1-2) ☐ common (3-4) ☐ many (>4)

Headcut Height (m): ☐ no headcuts ☐ 0-1 m ☐ 1-2 m ☐ >2 m

Evidence of Avulsion and Avulsion Channels within the study reach

Anabranching Channels (# per reach): ☐ none ☐ few (1-2) ☐ common (3-4) ☐ many (>4)

Gravel Filled Channels (# per reach): ☐ none ☐ few (1-2) ☐ common (3-4) ☐ many (>4)

Gravel Aggradation/Debris Dams (# per reach): ☐ none ☐ few (1-2) ☐ common (3-4) ☐ many (>4)

Form A.6.1–GEOMORPHIC DATA	Date:	Observer:
Watershed Name:	Database Code:	
UTM Zone:	Elevation:	
UTMs: Northing	Easting	
Location in Basin: ☐ Low ☐ Mid ☐ High	Reach Length of Observations:	

Sketch of Stream Cross-sectional Profile: See Appendix 6, figure A.6.1 for an example sketch of a cross-sectional profile. Include all topographic features as well as bars, bank characteristics, and other features of geomorphic significance. Include the vertical and horizontal scale. Where sampled reaches are near fan steps, headcuts, or other significant geomorphic features, also include a longitudinal sketch. See Part I, figure 14 for an example of a longitudinal profile illustrating a fan step downstream of a meadow.

Exhibit A.6.1—Descriptions of the Variables Used to Assess Stream Reach Geomorphic Characteristics in the Field.

- **Reach Length of Observations:** A stream reach is defined as a segment of the drainage network with homogeneous channel and valley floor characteristics, including landforms (e.g., terraces, floodplains), channel bed features (e.g., pools and riffles, step and pools, bars, knickpoints), and sediment sizes. In the field, select sample reaches from the dominant watershed segments in the lower, middle, and higher portions of the watershed, which have been identified in the office. The sample reach should be representative of the most common reach type within the dominant watershed segment. It should be long enough to include all valley, channel, and channel bed features that exist within the reach type. A typical study reach length is 30 m.
- **Channel Character and Form**
  - ***Flow Type:*** Describes the temporal variations in flow within the channel. Perennial flow refers to flow that is present within the reach throughout the year. Ephemeral flow exhibits distinct periods of flow and dry conditions within the stream reach during the year.
  - ***Flow or Water Width and Flow Depth:*** The width of the water at the water's surface, and the maximum depth of the water in the channel.
  - ***Bankfull:*** The water level at which water is at the top of the stream bank and any further increase in water level would cause the water to "spill over" and inundate the adjacent terrace or floodplain. The bankfull channel is defined based on several parameters including: (1) the break in slope between the channel banks and the floodplain, defined as the first flat-lying, low-relief surface above the channel bed whose sediments are deposited by the modern channel; (2) the elevation of the highest depositional feature within the channel (e.g., point bar, alternate bar, or central bar), where well-defined floodplains are absent; and (3) changes in the particle-size distribution and vegetation along the channel perimeter resulting from a change in the frequency of inundation and depositional processes.
  - ***Bankfull Channel Width and Depth:*** Bankfull channel width is the width of the channel at the bankfull water stage. Bankfull depth is the maximum depth of the channel measured from the bankfull stage to the thalweg (deepest part of the channel).
  - ***Channel Slope:*** Gradient (rise/run) of the channel measured along the thalweg of the stream. To calculate percent slope, divide the elevation change (stadia or level height – clinometer height) by the distance measured. Multiply the resulting number by 100 to obtain the percentage slope.

- **Sediment Size and Mobility:** Particle size and mobility influence the ease with which the channel bed can be eroded and incised by flood flows. The variables used to evaluate sediment size and mobility (see following list) can be estimated. Alternatively, pebble counts can be taken. Methods for collecting and analyzing particle size are in Bunte and Abt (2001).
    - ***Bed Particle Size:*** Particle size D_{50} is defined based on the intermediate diameters of at least 50 particles (clasts) randomly collected from the channel bed. The approximate maximum particle size is the average intermediate diameter of the 10 largest particles (clasts) in the sample reach.
    - ***Bank Sediment Size (%):*** Describes the percentage of the bank deposits consisting of gravel and boulders, mixed gravels and fines, and fines (<2 mm). In many cases, the channel banks will be composed of multiple alluvial stratigraphic units possessing sediments of varying size. Where multiple units are present, the percentage of each particle-size range should be assessed by considering all of the units collectively.
    - ***Bed Clast Immobility (% of channel bed):*** Describes the approximate percentage of clasts on the channel bed that have not been transported by floods occurring at least once every 5 to 10 years. Indicators of immobility include the degree to which clasts are coated by biofilms (algae), particle imbrication (the stacking of clasts at an oblique angle in the channel bed), and sediment sources (e.g., glacial moraines, talus cones).
- **Sediment Availability:** Describes the amount of mobile sediment that is stored within the channel and that can be entrained and transported during low to moderate flood events. Large amounts of sediment are required for channel avulsions, whereas limited sediment relative to the available discharge leads to channel incision. Sediment availability is determined from three parameters:
    - ***Bar Frequency (# per reach):*** Bars represent accumulations of sediment within the channel. The number of bars describes the occurrence of in-channel bars composed of mobile bed materials within the channel in the sample reach. Record bar number per reach as: none; few (1–2); common (3–4); or many (>4).
    - ***Bar Extent (% of channel bed):*** Describes the percentage of the channel bed composed of in-channel bars in the sample reach (e.g., point bars, alternate bars, glides). Record bar extent within the channel bed as: 0–10%; 10–20%; 20–30%; or >30%.
    - ***Gravel Bars on Valley Floor (# per reach):*** Gravel accumulations on the valley floor are an indicator of the movement of large amounts of sediment during overbank floods. In some cases, these deposits are associated with channel aggradation (filling), which may or may not be associated with

channel avulsion initiated by a localized aggradational event. Record number of gravel bars per reach as: none; few (1–2); common (3–4); or many (>4).

- **Evidence of Channel Incision:** The degree and rate to which the channel has or is currently incising provides insights into its future response. Following are descriptions of channel features and characteristics that provide evidence of incision, and the procedures to measure and record them.
  - ***Fan Steps:*** Large side-valley alluvial fans that traverse the majority of the valley floor often produce "steps" or abrupt changes in the longitudinal profile of the channel bed (Part I, fig. 14). Where these occur, they should be noted, and estimate the approximate height of the elevation change across the fan by using a clinometer.
  - ***Knickpoints (# per reach):*** Knickpoints, defined as abrupt, vertical or almost vertical breaks in channel slope over a distance of a few meters, are a direct indicator of ongoing channel incision. Record number of knickpoints as: none; few (1–2 per reach); common (3–4); or many (>4).
  - ***Knickpoint Height (cm):*** Knickpoint height is measured as the maximum distance from the top of the knickpoint to the channel bed at the foot of the knickpoint. Knickpoint height depends, in part, on the composition of the materials in which the knickpoint is formed. Cohesive or resistant materials (or both) tend to form higher knickpoints. However, the type of channel materials is also an indicator of the magnitude to which channel incision is likely to occur. Knickpoint height is recorded as the average height of the knickpoints at the sample reach. Record knickpoint height as: no knickpoints; 0–25 cm; 25–50 cm high; or >50 cm high.
  - ***Knickpoint Composition:*** Refers to the predominant type of material(s) with which the knickpoint is constructed. Common materials include bedrock, boulders, unconsolidated sediments (gravel, silt and clay), and roots.
  - ***Inset Terraces (#):*** Terraces are formed during channel incision. The number of terraces within a valley is an indicator of the number of incision events that have occurred and may help approximate the length of time over which incision has occurred and the rate and timing of incision. Inset terraces indicate a period of lateral erosion and deposition (of an inset floodplain) prior to subsequent incision. Multiple incision events may occur before the development of an inset floodplain, precluding the presence of an indicative inset terrace. Additionally, lateral erosion after an incision event may remove evidence of one or more inset terraces. In the Great Basin, inset terraces of differing age often correspond to high-magnitude flood events that are capable of eroding channel bed sediments and are occupied by differing vegetation communities. Evidence of a given

inset terrace may exist on one or both sides of a channel. Consider surfaces of similar height above the thalweg on both sides of a channel as parts of the same inset terrace. Record the number of inset terraces as: none; few (1); common (2–3 per reach); or many (>4).

- ***Incision Depth (m):*** The depth of incision, or depth of the incised trench, is a measure of depth of channel incision below the valley floor. Incision depth is measured as the distance from the valley floor to the top of the inset floodplain, if a floodplain is present. If no floodplain is present, then it is the distance from the valley floor to the highest point on the channel bed. Deep, highly incised channels are typically associated with fine-grained channel bed and bank materials, and large-scale headcuts or knickpoints. Record incision depth as: none; 0–1 m; 1–2 m; or >2 m.
- ***Bedrock Outcrops or Exposures (% of channel bed):*** Describes the presence of bedrock within the channel bed or banks (or both). The rate and depth of incision can be reduced along some reaches by the occurrence of resistant bedrock outcrops. Where present, the percentage of the channel bed consisting of bedrock should be recorded. Record bedrock as: none; localized (<25% of channel bed); or extensive (>25% of channel bed).
- ***Headcuts (# per reach):*** Headcuts are similar to knickpoints but are commonly associated with gully systems that are developed in previously unincised alluvial valleys devoid of an existing channel (see Part I, figures 15, 21). They often represent a significant potential change in valley conditions by means of channel incision. Record number of headcuts as: none; few (1–2 per reach); common (3–4); or many (>4).
- ***Headcut Height (m):*** Headcut height is the maximum height of the headcut as measured from the incised channel bed to the valley floor. Record headcut height as: none; 0–1 m; 1–2 m; or >2 m.

- **Evidence of Avulsions and Avulsion Channels:** Avulsions indicate the abrupt change in channel position from one location to another on the valley floor. Several indicators of occurrence and frequency of avulsion are used to rate geomorphic sensitivity to this process:
  - ***Anabranching Channels (# per reach):*** Anabranching channels are typically formed by channel avulsion and are usually associated with relatively unstable channels characterized by local channel aggradation. Record the number of anabranching channels per reach as: none; few (1–2 per reach); common (2–4); or many (>4).
  - ***Gravel-filled Channels (# per reach):*** Gravel-filled channels are segments of "old" channel reaches that have been filled with gravel and no longer transmit water. The gravel fill found in most paleo-channels are found near the surface of the valley floor. While not all gravel-filled channels are associated with channel avulsions, they are the primary evidence of

avulsions, and can be found at most sites where avulsion has occurred in the Great Basin. Record the number of gravel-filled channels in the reach as: none; few (1–2); common (2–4); or many (>4).

- ***Gravel Aggradation/Debris Dams (# per reach):*** Accumulation (aggradation) of gravel behind piles of wood debris or woody riparian species is common in many Type A1 basins. Avulsions are often associated with these gravel accumulations, and they result in partial blockage of the channel, particularly during the input of sediment from debris flows, landslides, or upstream valley incision (or combination thereof). Record the number of gravel aggradation or debris dams per reach as: none; few (1); common (2–4); or many (>4).

Reference

Bunte, K.; Abt, S.R. 2001. Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics and streambed monitoring. Gen. Tech. Rep. RMRS-GTR-74. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 428 p.

Appendix 7—Data Form and Information for Assessing Riparian Vegetation in the Field

This appendix provides data form A.7.1 and the information (exhibit A.7.1) needed for collecting the riparian vegetation data. The riparian vegetation data are collected along the same stream reach as the geomorphic and disturbance data.

Use form A.7.1 to collect data on the riparian vegetation. Use one form for each sampled stream reach. At each sampled reach, record identifying information on the data form. This information includes the date, observer, watershed name, the watershed code in the Great Basin Watershed Database, location within the watershed (e.g., high, mid, low), and the reach length of the observations (typically 30 m). Use a GPS to record the UTM coordinates and elevation where the stream cross-sectional profile is drawn for the sampled reach.

Descriptions of the variables recorded and the specific measurements or scores used to describe each variable are in exhibit A.7.1. A list of the dominant riparian species in Great Basin riparian ecosystems and their wetland indicator status, successional status, and bank stability index are in exhibit A.7.1. The vegetation assessment involves collecting information on any apparent decrease in the extent of the riparian area and the degree to which the riparian vegetation occurs in a post incision trench. Collect data on the relative cover, vigor, mortality, wetland indicator status, successional status, and bank stability rating of the dominant riparian indicator species are collected for each geomorphic position (valley floor, inset terraces, floodplain). These data provide information on the responses of the riparian vegetation to recent or ongoing disturbances affecting groundwater tables, such as channel incision or avulsion, as well as other disturbances, such as inappropriate livestock grazing.

The riparian vegetation data collected during the field assessment are summarized for each geomorphic position and for the overall sampled reach as described in the data form and in exhibit A.7.1. The data for the overall reach are included in the score sheets for assessing watershed sensitivity and resilience in Appendix 10 and for rating ecological integrity in Appendix 11. The interpretation of the data and combined scores is discussed in Part II, Task 5 of this report.

The form can be downloaded at
https://experience.arcgis.com/experience/49f171f01aed451d8bbebb5558638a6c.

Form A.7.1–RIPARIAN VEGETATION DATA	Date: Observer:
Watershed Name:	Database Code:
UTM Zone:	Elevation (m):
UTMs: Northing	Easting
Location in Basin: ☐Low ☐Mid ☐High	Reach Length of Observation (m):

Vegetation type (check dominant one): ☐Subalpine-montane conifer (SC) ☐ *Populus tremuloides* (PT)
☐ Cold willow (CW) ☐ *Betula occidentalis* (BA) ☐Warm willow (WW) ☐ Cottonwood (CT) ☐ *Artemisia* (AR)
☐ Other: ______________________________
The dominant riparian vegetation types are in Appendix 3, table A.3.1.

Decrease in riparian area extent due to incision or drying (check one): ☐ none ☐ low (1-10%)
☐ moderate (10-30%) ☐ high (>30%)

Riparian plants only in incised trench (check one): ☐0 = none ☐1 = little ☐2 = common ☐3 = widespread

Record data for six stream geomorphic positions: FP (flood plain), T1 (terrace 1), T2 (terrace 2), T3 (terrace 3), VF (valley floor). See Appendix 6, figure A.6.1 for an illustration of the locations of the floodplain, inset terraces, and valley floor. Make sure the positions coincide with the stream cross-sectional profile sketch on the geomorphic data form (fig. A.6.1). Note that not all positions will occur in every sampled stream reach.

Dominant indicator species and aerial cover (%): record as trace < 1 (trace); 1-5; 5-25; 25-50; 50-75; 75-100.
Vigor and mortality of each species: record as high (H), moderate (M), or low (L) as described in Appendix 7, exhibit A.7.1.
Wetland Indicator Status (WIS), successional status (Succ), and bank stability (Stab) of each species: record the values for each species from the riparian species list as described in Appendix 7, table A.7.1.
Nativity of the species: record as yes (Y) or no (N) as described in the riparian species list (table A.7.1).

Record the following data for the geomorphic position summaries:
Cover: estimate and record the average vegetation cover for the entire geomorphic position.
Vigor and Mortality: record value most indicative of response to disturbance for the geomorphic position as described in Appendix 7, exhibit A.7.1.
WIS, Succ, and Stab: record most common value for the geomorphic position.
Native: record total number of nonnative species at the geomorphic position.

Position	Dominant Indicator Species	Cover (%)	Vigor H/M/L	Mort H/M/L	WIS O/F/FW /FU/U	Succ E/M/L	Stab H/M/L	Native Y/N
FP								
FP								
FP								
FP								
FP								
FP								
Stream Bank Summary								
T1								
T1								
T1								
T1								
T1								
T1								
Terrace 1 Summary								

Form A.7.1–RIPARIAN VEGETATION DATA		Date: Observer:
Watershed Name:		Database Code:
UTM Zone:		Elevation (m):
UTMs: Northing		Easting
Location in Basin: ☐Low ☐Mid ☐High		Reach Length of Observation (m):

Position	**Dominant Indicator Species**	**Cover (%)**	**Vigor H/M/L**	**Mort H/M/L**	**WIS O/F/FW /FU/U**	**Succ E/M/L**	**Stab H/M/L**	**Native Y/N**
T2								
T2								
T2								
T2								
T2								
T2								
Terrace 2 Summary								
T3								
T3								
T3								
T3								
T3								
T3								
Terrace 3 Summary								
VF								
VF								
VF								
VF								
VF								
VF								
Valley Floor Summary								

Record the following data for the reach summary:
Cover: estimate and record the average vegetation cover for the entire sample reach.
Vigor and mortality: record value indicative of reach response to disturbance as described in exhibit A.7.1. **WIS, Succ, and Stab:** record value indicative of reach disturbance response as described in exhibit A.7.1. **Native:** record total number of nonnative species observed for all positions.

Reach Summary							

List the Indicator Species for the reach:

Notes:

Exhibit A.7.1—Descriptions of the Variables Used to Assess the Riparian Vegetation in the Field.

- **Riparian Vegetation Type:** The dominant riparian vegetation types are in Appendix 3, exhibit A.3.1. Circle or list the dominant type on the form.
- **Riparian Area Extent:** Channel incision typically results in a drop in the water table and, frequently, a decline in extent of the riparian area. Record decrease in riparian area extent as: none (little evidence of a decrease in the size of the riparian area due to channel incision in the reach); low (some channel incision has occurred and there is evidence of a decrease in riparian extent of 1–10%); moderate (10–30%) (channel incision has resulted in a decrease of riparian area extent by as much as 30% in the reach); or high (incision has resulted in a decrease of riparian area extent greater than 30% in the reach).
- **Riparian Plants in Trench:** Following stream incision, riparian vegetation may occur only in the incised trench. Circle yes or no to indicate whether or not the riparian plants occur only in the incised trench.
- **Dominant Indicator Species:** Indicator riparian species are those that provide information on water availability for a given geomorphic position, where water availability is determined by depth to groundwater and substrate characteristics. Identify and record the dominant indicator species for each geomorphic position by walking the entire extent of the sample stream reach. No additional information is needed for the geomorphic position summary. For the reach summary, list the species that are most indicative of the reach response to stream incision or avulsion. In the notes section, note whether the dominant indicator species also reflect anthropogenic disturbances such as livestock grazing.
- **Aerial Cover:** The cover of riparian vegetation provides valuable information on response to disturbance. For each geomorphic position, estimate and record the average aerial cover (%) of each dominant indicator species as: <1 (trace); 1–5; 5–25; 25–50; 50–75; or 75–100. For the geomorphic position summary, estimate and record the average vegetation cover for the geomorphic position as a whole. For the reach summary, estimate and record the average vegetation cover for the entire sample reach.
- **Vegetation Vigor:** Provides information on potential effects of decreases in water tables, insects, disease, weather extremes, or other disturbances, such as inappropriate grazing or recreational overuse. Reduced vigor is indicated by low height, production (leaf area or leader growth), or root growth and signs of stress, such as chlorosis or yellowing. For each geomorphic position, record the vigor of each dominant indicator species as high (later successional herbaceous and woody species are vigorous), moderate (later successional herbaceous and woody species are less vigorous than appropriate), or low

(vigor of later successional herbaceous and woody species is low). For the geomorphic position and reach summaries, record the value that is most indicative of the reach response to disturbance. In the notes section, note the apparent cause of any loss in vigor.

- **Vegetation Mortality:** Increased mortality is indicated by patches of dying or dead herbaceous or woody species (or both). Mature willows with good vigor often have dead stems and this should not be interpreted as a sign of increased mortality. For each geomorphic position, record the mortality of each dominant indicator species as high (later successional herbaceous and woody species show no evidence of increased mortality), moderate (later successional herbaceous and woody species show evidence of increased mortality), or low (mortality of later successional herbaceous and woody species is high). For the geomorphic position and reach summaries, record the value that is most indicative of the reach response to disturbance. In the notes section, note the apparent cause of any increase in mortality.
- **Riparian or Wetland Indicator Status (WIS):** Descriptions of the wetland indicator status values are in Part I, table 2; the indicator status values for the riparian species are in Appendix table A.7.1. Indicator status provides general insights into flow regimes, groundwater dynamics, and the responses of the riparian vegetation within the stream reach. For each geomorphic position, record the WIS value of each dominant indicator species from table A.7.1. For the geomorphic position summary, record the most common value. For the reach summary, record WIS as high (wetland obligate, facultative wetland, and facultative upland species are found on appropriate geomorphic positions), moderate (greater number of facultative upland and upland species than appropriate), or low (many more facultative upland and upland species than appropriate).
- **Successional Status:** Descriptions of the successional status values are in Part I, table 4; the successional status values for the riparian species are in table A.7.1. Successional status ratings for individual plants provide information on responses of the riparian ecosystems to past and present disturbance (Part I, table 4). Record the successional status value for each dominant indicator species from table A.7.1. For the geomorphic position summary, record the most common value. For the reach summary, record the average successional status as high (a large number or cover of late-seral species with few mid- and early-seral species), moderate (a reduced number or cover of late-seral species and an increase in mid- and early-seral species), or low (very low numbers or cover of late-seral species and dominance by mid- and early-seral species). In the notes section, note the apparent cause of any reduction in successional status.

- **Bank Stability Rating:** The bank stability ratings are based on Part I, table 5 and values for the riparian species are in table A.7.1. Most perennial streams require 70 to 90 percent stabilizing cover (vegetation, large or anchored rock, anchored wood) to buffer the erosive force of water (Burton et al. 2011; Winward 2000). Root strength and rooting depth of the riparian vegetation on stream banks contribute to overall stream bank stability. Record the bank stability rating for each dominant indicator species from table A.7.1. For the geomorphic position summary, record the most common value. For the reach summary, record the bank stability rating as high (a large proportion or cover of species with high stability ratings), moderate (a large proportion or cover of species with a medium stability rating), or low (a high proportion or cover of species with a low stability rating). In the notes section, note the apparent cause of any loss of bank stability.
- **Nativity:** Species designations as nonnative-invasive or noxious weed are in table A.7.1. Record all nonnative-invasive species and noxious weeds as nonnative. For the geomorphic position summaries, record the total number of nonnative species on the geomorphic position. For the reach summary, record the total number of nonnative species for the entire reach.

Table A.7.1—Scientific and common names (NRCS 2020) of the dominant riparian species in Great Basin riparian ecosystems (based on Swanson 2016), with additional information to be used to complete the riparian vegetation data form (form A.7.1) Wetland indicator status: OBL = obligate; FAC = facultative; FACW = facultative wetland; FACU = facultative upland; UPL = upland (Lichvar and Minkin 2008). Successional status: E = early seral; M = mid-seral; L = late seral. Bank stability index: L = low stability; M = moderate stability; H = high stability (Burton et al. 2011; Swanson 2016). *Nonnative-invasive; **noxious weed.

Species	Symbol	Common name	Wetland indicator status (WIS)	Successional status (Succ)	Stability index (Stab)
Shrubs and trees					
Acer glabrum	ACGL	Rocky Mountain maple	FAC	M	M
Acer negundo	ACNE2	boxelder	FACW	L	H
Alnus incana	ALIN2	mountain alder	FACW	L	H
Artemisia tridentata ssp. *tridentata*	ARTRT	basin big sagebrush	—	E	L
Baccharis salicifolia	BASA4	willow baccharis (mule-fat)	FAC	L	H
Betula occidentalis	BEOC2	water birch	FACW	L	H
Chrysothamnus viscidiflorus	CHVI8	yellow rabbitbrush	—	E	L
Cornus sericea	COSE16	red osier dogwood	—	L	H
Crataegus douglasii	CRDO2	black hawthorn	FAC	M	M
*Elaeagnus angustifolia***	ELAN	Russian olive	FAC	E	M
Ericameria nauseosa	ERNA10	rubber rabbitbrush	—	E	L
Ledum glandulosum	LEGL	trapper's tea (western Labrador tea)	—	M	M
Lonicera involucrata	LOIN5	black twinberry	FAC	M	M
Populus acuminata	POAC5	lance leaf cottonwood	—	L	H
Populus angustifolia	POAN3	narrowleaf cottonwood	—	L	H
Populus balsamifera ssp. *trichocarpa*	POBAT	black cottonwood	FAC	L	H
Populus fremontii	POFR2	Fremont cottonwood	—	L	H
Populus tremuloides	POTR5	quaking aspen	FACU	L	H
Prunus virginiana	PRVI	chokecherry	—	L	H
Ribes aureum	RIAU	goldern currant	FAC	E	M
Ribes hudsonianum	RIHU	northern black currant	FACW	M	M
Ribes inerme	RIIN2	whitestem gooseberry	FAC	E	M
Rosa woodsii	ROWO	Wood's rose	FACU	E	M
Salix boothii	SABO2	Booth's willow	FACW	E	M

Species	Symbol	Common name	Wetland indicator status (WIS)	Successional status (Succ)	Stability index (Stab)
Salix drummondiana	SADR	Drummond's willow	FACW	E	M
Salix eastwoodiae	SAEA	mountain willow	—	E	M
Salix exigua	SAEX	narrowleaf willow	FACW	E	M
Salix geyeriana	SAGE2	Geyer's willow	OBL	L	H
Salix lasiolepis	SALA6	arroyo willow	FACW	E	M
Salix lemmonii	SALE	Lemmon's willow	FACW	E	M
Salix lucida	SALU	shining (Pacific/whiplash) willow	—	E	M
Salix lutea	SALU2	yellow willow	OBL	L	H
Salix orestera	SAOR	Sierra willow	FACW	E	M
Symphoricarpos spp.	SYMPH	snowberry	—	M	M
*Tamarix ramosissima***	TARA	saltcedar	—	E	H
Forbs			—		
Aconitum columbianum	ACCO4	Columbian monkshood	—	L	M
Angelica kingii	ANKI	King's angelica	FACW	M	M
Aquilegia formosa	AQFO	western columbine	FAC	L	L
Argentina anserina	ARAN7	silverweed cinquefoil	OBL	E	L
Arnica spp.	ARNIC	arnica	—	M	M
Artemisia cana	ARCA13	silver sagebrush	FACU	M	L
Caltha leptosepala	CALE4	white marsh marigold	OBL	E	M
Camassia quamash	CAQU2	common camas	FACW	M	M
*Cardaria draba***	CADR	whitetop	—	E	L
*Carduus nutans***	CANU4	nodding plumeless thistle	FACU	E	L
Chamerion angustifolium	CHAN9	fireweed	—	M	L
Cicuta douglasii	CIDO	western water hemlock	OBL	M	M
*Cirsium arvense***	CIAR4	Canada thistle	FACU	E	L
*Conium maculatum***	COMA2	poison hemlock	FACW	E	L
Dodecatheon spp.	DODEC	shootingstar	—	E	L
Epilobium glaberrimum	EPGL	glaucus willowherb	FACW	M	L
Erigeron spp.	ERIGE2	fleabain	FACW	L	M
Geranium viscosissimum	GEVI2	sticky geranium	—	E	M
Geum macrophyllum	GEMA4	largeleaf avens	FACW	E	L

Species	Symbol	Common name	Wetland indicator status (WIS)	Successional status (Succ)	Stability index (Stab)
Heracleum maximum	HEMA80	cow parsnip	FACW	L	M
Iris missouriensis	IRMI	Rocky Mountain iris	FACW	M	L
Iva axillaris	IVAX	poverty weed	FAC	E	L
Kalmia microphylla	KAMI	bog laurel	OBL	M	M
*Lepidium latifolium***	LELA2	broadleaved pepperweed	FAC	E	L
Maianthemum racemosum	MARA7	feathery false lily of the valley	FAC	L	L
Mentha arvensis	MEAR4	wild mint	FACW	M	L
Mertensia ciliata	MECI3	streamside bluebells	FACW	M	M
Mimulus primuloides	MIPR	primrose monkeyflower	FACW	M	L
*Nasturtium officinale**	NAOF	watercress	OBL	E	L
Pedicularis groenlandica	PEGR2	elephant head lousewort	OBL	L	L
*Plantago major**	PLMA2	common plantain	FAC	E	L
Polygonum bistortoides	POBI6	American bistort	—	M	L
Argentina anserina	ARAN7	silverweed cinquefoil	OBL	E	L
Potentilla gracilis	POGR9	slender cinquefoil	FAC	E	L
Ranunculus cymbalaria	RACY	alkali buttercup	—	M	L
Rudbeckia occidentalis	RUOC2	coneflower/blackhead	FAC	E	L
*Rumex crispus**	RUCR	curly dock	FAC	E	L
Rumex paucifolius	RUPA6	alpine sheep sorrel	FAC	E	L
Saxifraga odontoloma	SAOD2	brook saxifrage	—	M	L
Sphenosciadium capitellatum	SPCA5	woolyhead parsnip	FACW	E	L
Taraxacum officinale	TAOF	common dandelion	FACU	E	L
Thalictrum fendleri	THFE	Fendler's meadowrue	FAC	E	L
Urtica dioica	URDI	stinging nettle	FAC	M	L
Veratrum californicum	VECA2	California false hellebore	FACW	M	H
Veronica americana	VEAM2	American speedwell	OBL	M	M
Viola palustris	VIPA4	marsh violet	FACW	M	L
Grasses					
Agrostis exarata	AGEX	spike bentgrass	—	E	L
Agrostis scabra	AGSC5	rough bentgrass	—	E	L
*Agrostis stolonifera**	AGST2	creeping bentgrass	—	E	L

Species	Symbol	Common name	Wetland indicator status (WIS)	Successional status (Succ)	Stability index (Stab)
Alopecurus aequalis	ALAE	short-awned foxtail	OBL	E	L
*Bromus tectorum***	BRTE	cheatgrass	—	E	L
Calamagrostis canadensis	CACA4	blue-joint reedgrass	FACW	L	H
Calamagrostis stricta	CAST36	slimstem reedgrass	FACW	L	H
Catabrosa aquatica	CAAQ3	water whorlgrass	—	E	L
Deschampsia cespitosa	DECE	tufted hairgrass	—	L	M
Distichlis spicata	DISP	inland saltgrass	FAC	M	M
Leymus triticoides	ELTR3	beardless wildrye	FAC	E	M
Festuca rubra	FERU2	red fescue	FAC	M	M
Glyceria grandis	GLGR	American mannagrass	OBL	L	H
Glyceria striata	GLST	fowl mannagrass	OBL	L	M
Hordeum brachyantherum	HOBR2	meadow barley	FACW	E	L
Hordeum jubatum	HOJU	foxtail barley	FAC	E	L
Leymus cinereus	LECI4	basin wildrye	FAC	M	M
Muhlenbergia richardsonis	MURI	mat muhly	FAC	M	L
Phalaris arundinacea	PHAR3	reed canarygrass	—	E	M
Phleum alpinum	PHAL2	alpine timothy	FAC	E	L
*Phragmites australis**	PHAU7	common reedgrass	FACW	L	H
Poa pratensis	POPR	Kentucky bluegrass	FAC	E	L
Poa secunda	POSE	Sandberg bluegrass (rush bluegrass)	FACU	E	L
*Polypogon monspeliensis**	POMO5	annual rabbitsfoot grass	FACW	E	L
Grasslike					
Carex aquatilis	CAAQ	water sedge	OBL	L	H
Carex athrostachya	CAAT3	slenderbeak sedge	FACW	L	H
Carex aurea	CAAU3	golden sedge	OBL	L	L
Carex canescens	CACA11	gray sedge	OBL	M	L
Carex disperma	CADI6	softleaf sedge	OBL	L	M
Carex douglasii	CADO2	Douglas' sedge	FAC	M	L
Carex lenticularis	CALE8	tufted sedge	OBL	L	M
Carex microptera	CAMI7	small-winged sedge	FAC	M	M
Carex nebrascensis	CANE2	Nebraska sedge	OBL	L	H

Species	Symbol	Common name	Wetland indicator status (WIS)	Successional status (Succ)	Stability index (Stab)
Carex pellita	CAPE42	wooly sedge	OBL	L	H
Carex praegracilis	CAPR5	cluster field sedge	FACW	L	H
Carex scopulorum	CASC12	mountain sedge	FACW	L	H
Carex simulata	CASI2	short-beaked sedge	OBL	L	H
Carex spp.	CAREXRH	rhizomatous sedge	—	L	H
Carex utriculata	CAUT	Northwest Territory sedge	OBL	L	H
Carex vesicaria	CAVE6	blister sedge	OBL	L	H
Eleocharis palustris	ELPA3	common spikerush	OBL	E	M
Eleocharis quinqueflora	ELQU2	fewflower spikerush	OBL	M	M
Equisetum arvense	EQAR	field horsetail	FAC	M	M
Equisetum hyemale	EQHY	scouringrush horsetail	FACW	M	M
Equisetum laevigatum	EQLA	smooth horsetail	FACW	E	L
Juncus arcticus	JUAR2	mountain (Baltic) rush	—	L	H
Juncus bufonius	JUBU	toad rush	FACW	E	L
Juncus ensifolius	JUEN	swordleaf rush	FACW	E	L
Juncus longistylis	JULO	longstyle rush	FACW	E	L
Juncus nevadensis	JUNE	Sierra rush	FACW	L	M
Juncus orthophyllus	JUOR	straightleaf rush	FACW	M	L
Juncus tenuis	JUTE	poverty rush	FACW	E	L
Schoenoplectus acutus	SCAC3	hardstem bulrush	OBL	L	M
Schoenoplectus pungens	SCPU10	threesquare bulrush	OBL	L	M
Schoenoplectus tabernaemontani	SCTA2	softstem bulrush	OBL	L	M
Scirpus microcarpus	SCMI2	panicled (small fruited) bulrush	OBL	L	M
Scirpus nevadensis	SCNE	Nevada bulrush	OBL	L	M
Triglochin maritima (or *palustris)*	TRMA20	arrowgrass	—	E	M
Typha latifolia	TYLA	broadleaf cattail	OBL	M	H

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Appendix 8—Data Form and Information for Assessing Disturbance in the Field

This appendix provides data form A.8.1 and the information needed for the disturbance assessment. Use form A.8.1 to collect disturbance data for assessments of both riparian and meadow ecosystems. Use one data form for each reach. At each sampled stream reach, record identifying information on the form: the date, observer, watershed name, the watershed code in the Great Basin Watershed Database, location within the watershed (e.g., high, mid, low), and the reach length of the observations (typically 30 m). Use a GPS to record the UTM coordinates and elevation where the stream cross-section is drawn for the sampled reach.

Common disturbances in the Great Basin are described in the section “What Are the Effects of Human-caused Disturbances?” in Part I of this report. Record disturbances that are not in the list provided, as well as those present in the sample reach and adjacent upstream and downstream reaches. Any negative effects of the disturbance on the stream channel, stream bank, or riparian vegetation of the sample reach are then recorded. Record the effects of the disturbance as none (no negative effect); low (the disturbance is having a minor negative effect on the stream channel, stream banks, or vegetation); moderate (the disturbance is having a clear negative effect on geomorphic processes or riparian vegetation); or high (the disturbance has significantly altered geomorphic processes or the riparian vegetation in a negative way).

The disturbance data collected in the field are summarized for the sampled stream reaches in the ecological integrity form in Appendix 11. Combining summaries of disturbance data with those for the geomorphic and vegetation data can provide a clear picture of the type and magnitude of disturbances and, thus, the types of management actions needed to improve the ecological conditions or integrity of the stream reach.

The form can be downloaded at https://experience.arcgis.com/experience/49f171f01aed451d8bbebb5558638a6c.

Form A.8.1– DISTURBANCE DATA	Date:	Observer:
Watershed Name:	Database Code:	
UTM Zone:	Elevation (m):	
UTMs: Northing	Easting	
Location in Basin: ☐Low ☐Mid ☐High	Reach Length of Observations (m):	
Camera ID and Nos.		

Yes/No: enter **Y** if the disturbance is present in the sample reach or in adjacent upstream and downstream reaches and **N** if it is not.
Location of disturbance: record as sample reach/meadow (**SR/SM**), upstream (**UPS**), or downstream (**DST**).
Component(s) affected by disturbance: record as stream channel (**SC**), stream bank (**SB**), and/or riparian/meadow vegetation (**RV/MV**).
Negative effects of disturbance on sample reach: record as none (**N**), low (**L**), moderate (**M**), or high (**H**).

Other: list other disturbances affecting the stream reach, their location, and their relative effect.

Disturbance Type	Yes / No	Location	Component	Effect
Road in the valley bottom				
Road channel in-stream crossings				
Culverts				
Road captures (stream diverted onto road)				
Developed campsites				
Undeveloped campsites				
Human developments (houses/cabins)				
Mining activity on hillslopes (☐historical, ☐ active)				
Mining activity in valley bottom (☐historical, ☐ active)				
Surface water manipulation (ditches, spring boxes, etc.)				
Groundwater extraction (wells)				
Water diversion (dams/canals)				
Inactive beaver dams (erosion, low water quality, etc.)				
Active beaver dams (appropriate channel location, continued maintenance, redundant structures, etc.)				
Wildfire - Fire name/ date if known:				
Prescribed fire				
Livestock effects on vegetation (☐sheep, ☐cattle)				
Livestock effects on bank and channel				
Wild horse effects on vegetation				
Wild horse effects on bank and channel				
Other disturbances:				

Notes:

Appendix 9—Data Forms and Information for Assessing Meadow Complexes in the Field

This appendix provides data form A.9.1 and the information (exhibit A.9.1) needed for collecting the meadow geomorphic and hydrologic data. Also included are data form A.9.2 and information (exhibit A.9.2) for collecting the meadow vegetation data. The geomorphic data described in Appendix 6 and disturbance data described in Appendix 8 also are collected for each meadow. The geomorphic assessment is conducted for a representative reach within the meadow and should reflect the conditions observed for the meadow as a whole. The disturbance assessment characterizes the effects of disturbances in adjacent stream reaches upstream and downstream of the meadow. The sensitivity and resilience of meadow complexes within a watershed are evaluated for up to four meadows that represent the dominant meadow types and their responses to disturbance within a focal watershed.

At each sampled stream reach, record identifying information on forms A.9.1 and A.9.2: the date, observer, watershed name, the watershed code in the Great Basin watershed database, meadow name, location within the watershed (e.g., high, mid, low). Use a GPS to record the UTM coordinates and elevation where the stream cross-section is drawn for the sampled reach.

An explanation of the variables recorded in the geomorphic and hydrologic assessment is in exhibit A.9.1. Geomorphic and hydrologic data are collected on the geomorphic position of the meadow, groundwater sources and springs, relationship of the stream to the meadow, meadow complexity and hydrologic traits, and evidence of incision. Illustrations and descriptions of meadow hydrologic types—their hydrologic setting, hydrology, and connection of the stream to the meadow vegetation—are in figure A.9.3.

An overview of the meadow vegetation types is in Appendix 3, exhibit A.3.1, and the dominant species within each type are in table A.9.1. Determine the meadow vegetation types and their relative abundances within the meadow complex by walking through the meadow and estimating the percentage of each vegetation type. Aerial photos of the meadow can be used to delineate the different meadow types and help estimate their percentages.

The meadow vegetation is assessed by walking through each meadow type, recording the dominant indicator species within the type, and estimating the percentage cover of the species as indicated in form A.9.2. Species vigor, mortality, successional status, and bank stability status are recorded as described in exhibit A.9.2. Successional status and bank stability status for the dominant Great Basin meadow species are in table A.9.1.

The information collected for each meadow vegetation type on the relative cover, vigor, and mortality of the dominant or indicator species increases understanding of the response of the meadow vegetation to recent or ongoing disturbances affecting water availability. The information on the relative cover, successional status, and bank stability rating provides insights into the longer-term responses of the meadow vegetation to a variety of different disturbances.

The watershed characteristics, stream geomorphic, and meadow vegetation data can be used to evaluate the incision and avulsion sensitivity of individual meadows as described in Appendix 10. In addition, the watershed characteristics, meadow vegetation and disturbance data can be used to rate meadow ecological integrity as described in Appendix 11.

The forms can be downloaded at https://experience.arcgis.com/experience/49f171f01aed451d8bbebb5558638a6c.

Form A.9.1–MEADOW GEOMORPHIC & HYDROLOGIC DATA	Date: Observer:
Watershed Name:	Database Code:
Meadow Name:	
UTM Zone:	Elevation (m):
Coordinates (UTMs): Northing	Easting
Location in Watershed: ☐Low ☐Mid ☐High	

Definitions of terms and methods of data collection are in Appendix 9, exhibit A.9.1 and illustrations of meadow hydrologic types are in Appendix 9, figure A.9.3. Definitions of the meadow vegetation types are in Appendix 3, exhibit A.3.1 and the species contained within each meadow vegetation type are in Appendix 9, table A.9.1.

Meadow Size

Length parallel to valley (m): __________ Approximate area (ha): _________

Length perpendicular to valley (m): __________

Geomorphic Position (check 1, 2, or 3)

(1) Large meadow upstream of an alluvial fan or bedrock constriction

(2) Large meadow in the valley bottom with no alluvial fan or bedrock constriction present

(3) Spring-fed meadow on part of valley floor with no stream contact

Groundwater Sources and Springs

Groundwater source is down valley; meadow gradually becomes wetter down valley: ☐no ☐yes

Springs located along edge of valley floor (#): ☐none ☐1-3 ☐4-6 ☐>6

Springs not located along edge of valley floor (#): ☐none ☐1-3 ☐4-6 ☐>6

Stream Connection to Meadow (check 1, 2, 3, or 4):

☐(1) Stream bisects meadow ☐(2) Stream on one side of meadow ☐(3) Stream in valley but doesn't contact meadow ☐(4) No stream in same part of valley as meadow

Stream and Groundwater Influence on Meadow Hydrology (check 1, 2, 3, or 4)

☐(1) Gaining stream – drier meadow vegetation types near stream ☐(2) Losing stream – wetter meadow vegetation types near stream ☐(3) No obvious pattern ☐(4) Stream does not bisect meadow

Meadow Complexity (circle 1, 2, or 3)

☐(1) Simple ☐(2) Moderate ☐(3) Complex

Vegetation/incision Patterns Perpendicular to Stream (check 1, 2, 3, or 4)

☐(1) No change in vegetation type crossing stream ☐(2) Minor shift from wetter to drier vegetation types adjacent to stream ☐(3) Major shift from wetter to drier vegetation types adjacent to stream ☐(4) N/A

Meadow Hydrologic Type (check 1, 2, 3, 4, 5, or 6)

Use answers above and information in Appendix 9, figure A.9.3 to determine type.

☐(1) Simple, not degraded by stream ☐(2) Simple, minimally degraded by stream ☐(3) Simple, degraded by stream ☐(4) Complex, minimally degraded by stream ☐(5) Complex, degraded by stream

☐(6) Other (describe): ____

Notes:

	Page 2
Form A.9.1–MEADOW GEOMORPHIC & HYDROLOGIC DATA	Date: Observer:
Watershed Name:	Database Code:
Meadow Name:	
UTM Zone:	Elevation:
Coordinates (UTMs): Northing	Easting
Location in Watershed: ☐Low ☐Mid ☐High	
Meadow Drawing: A map of the meadow is drawn in the field that includes the stream, meadow types, relation of stream to meadow vegetation types, and locations of springs in the meadow. The scale is shown. Ideally, an aerial photograph of the meadow is used to illustrate these features (see Appendix 9, figures A.9.1, A.9.2). Alternatively, a sketch of the meadow can be drawn by hand.	

Exhibit A.9.1—Descriptions of the Geomorphic and Hydrologic Data Needed to Complete the Data Form for the Meadow Assessment (Form A.9.1).

- **Meadow Size:** The ecological importance and potential for impacts by natural and human-caused disturbance are often related to a meadow's size. To estimate meadow area, the approximate dimensions of the meadow are estimated from aerial imagery by positioning a best-fit rectangle or oval over the meadow (see figure A.9.1). The area is calculated by multiplying width by length for a rectangle shape, or by multiplying half of the width by half of the length by pi for an oval shape.

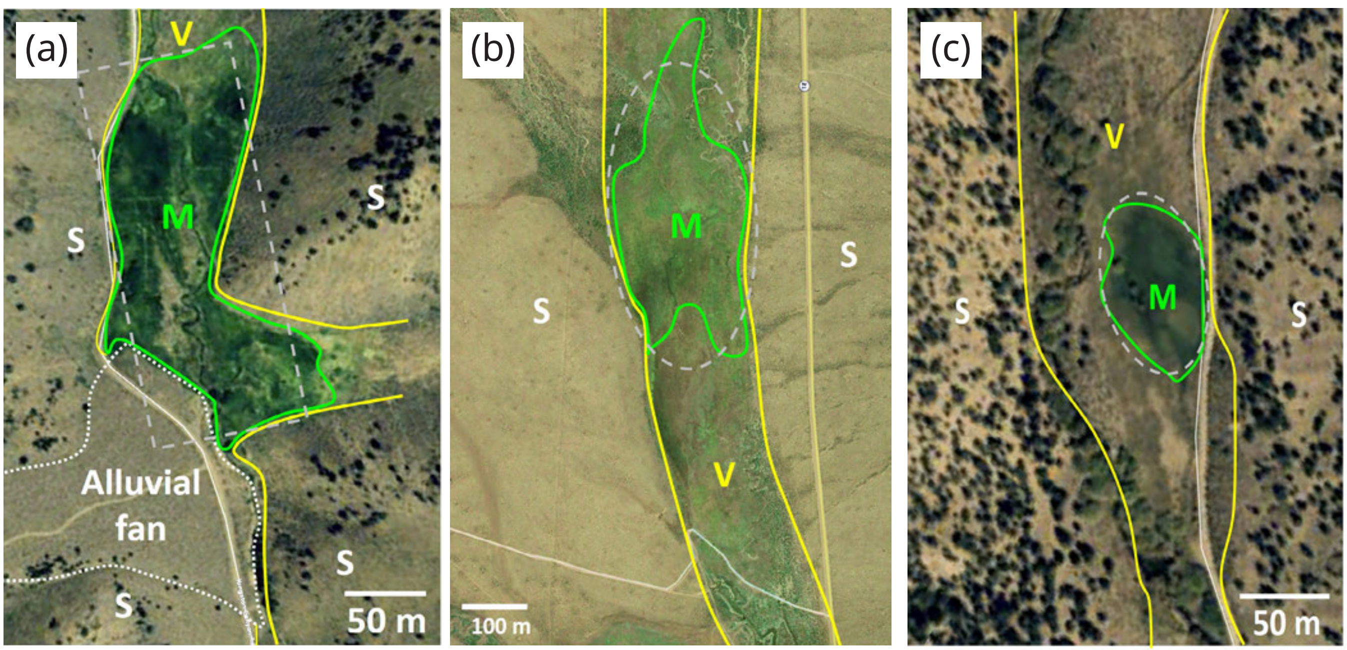


Figure A.9.1—Illustration of the outlines of meadows on aerial photographs. Images depict the three most common geomorphic settings of meadows in the Great Basin: large meadow upstream of an alluvial fan (a), large meadow in the valley bottom with no alluvial fan present (b), and spring-fed meadow on part of valley floor with no stream contact (c). Meadow dimensions are estimated using aerial imagery by positioning a best-fit rectangle (a) or oval (b, c) over the meadow (illustrated by dashed gray lines). The area is calculated by multiplying width by length for a rectangle shape, or by multiplying half of the width by half of the length by pi for an oval shape. The photographs show the meadow (M), valley (V), side-slope (S), north arrow, and scale. In photograph (a) the alluvial fan is also shown. Downstream is at the bottom of each photo. Image from Google Earth, obtained October 2020.

- **Geomorphic Position:** The geomorphic setting of a meadow has a strong influence on its hydrology and connection to the stream and meadow vegetation types. The most common geomorphic settings in the Great Basin are: (1) large meadow upstream of an alluvial fan; (2) large meadow in the valley bottom with no alluvial fan present; and (3) spring-fed meadow on part of valley floor with no stream contact. The annotated aerial images in figure A.9.1 show the three settings.

- **Groundwater Sources and Springs:** Observations about springs (abundance and location) and general vegetation patterns can be used to infer groundwater sources for meadows and hydrogeologic conditions. An abundance of springs located at valley side margins or within the valley floor is likely to reflect a localized groundwater discharge area, whereas their absence may indicate that the primary source of groundwater is through upstream valley- floor sediments. Areas with springs, especially on valley floors, are indicative of artesian conditions that form where fine-grained, confining sediment layers cap coarser-grained sediments. Breaching of the confining layer, whether by backhoe or stream incision, may cause significant changes in the groundwater and, therefore, vegetation. To locate springs, walk throughout the meadow, especially in areas of wet or mesic vegetation. Note the number of springs along the edges of the valley floor and in middle of the valley floor and draw their locations on the map (fig. A.9.2).

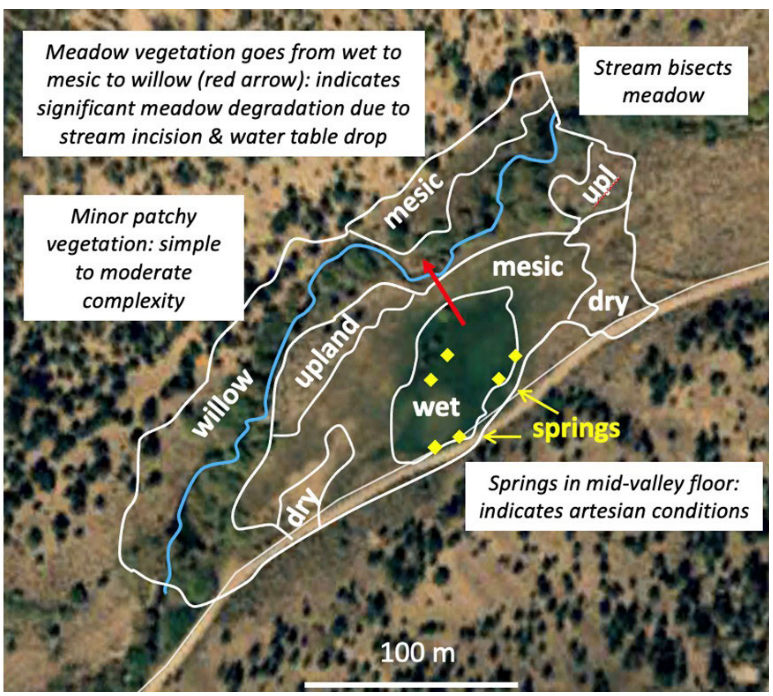
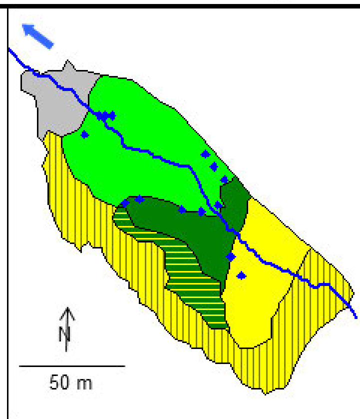
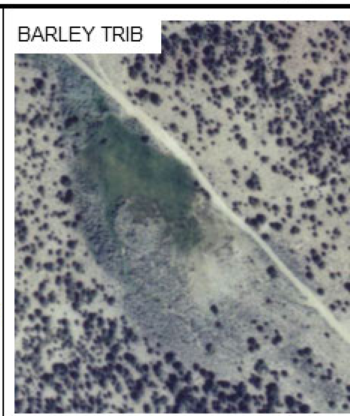
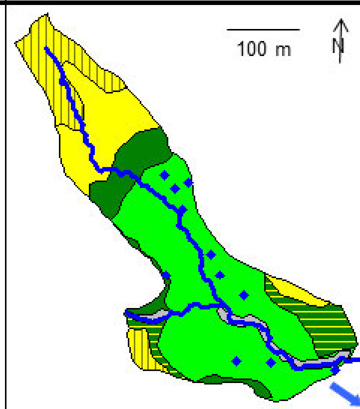
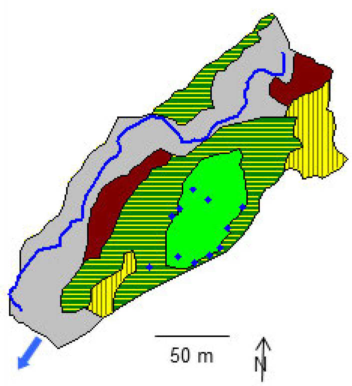


Figure A.9.2—Illustration of use of an aerial photograph of the sample meadow to map the locations of the stream, springs, and meadow types, and the relationship of the stream to meadow vegetation types; upl = upland. The scale should always be included.

- **Stream Connection to Meadow:** The relationship of a stream to a meadow is important because changes in stream channels (e.g., incision, avulsion, migration) can influence meadow hydrology and vegetation. One of four possible relationships is recorded: (1) stream bisects meadow; (2) stream is on one side of meadow; (3) stream is in valley but doesn't contact meadow; and (4) no stream in same part of valley as meadow.
- **Stream and Groundwater Influence on Meadow:** Hydrologic traits of meadows, such as the source of groundwater and groundwater flow directions can be assessed from vegetation patterns. For example, areas where groundwater flow is toward a stream (i.e., the stream is gaining) will have wetter vegetation types at the valley margins and drier types adjacent to the stream. In contrast, a losing stream will have wetter vegetation types adjacent to the stream. To assess whether groundwater flow in a meadow is toward a stream (gaining) or away from a stream (losing), observe the overall relationship of the groundwater-dependent vegetation from the valley side to the stream. Do not include inset stream terraces in the assessment as they do not typically reflect the same groundwater relationships as the meadow overall.
- **Meadow Complexity:** Describes the degree to which meadow vegetation types are contiguous (simple) or patchy (complex). Patchiness of vegetation types reflects underlying complexity in the hydrologic and geologic conditions. Use the following descriptions and figures of the distribution of plant types to select the complexity type that best matches the conditions within the meadow. See figure A.9.3 for additional descriptions, figures, and photographs of the meadow hydrologic types.
    - In simple meadows, meadow vegetation types are mostly contiguous. This pattern reflects systematic shifts in the depth to the groundwater table over the meadow and low lateral variability of underlying sediments. Because of this simplicity, declines in groundwater tables and shifts in vegetation types due to stream incision have higher predictability.
    - In complex meadows, meadow vegetation types occur in patches throughout the meadow. This pattern reflects high variability in depth to groundwater table and underlying sediments; some plant patches may be isolated because of dissection by past stream incision. In this setting, declines in the groundwater table and shifts in vegetation due to stream incision are difficult to predict, and may include major change with little incision. Complex meadows are common upstream of alluvial fans.
    - Moderate meadows have intermediate complexity.
- **Vegetation Patterns Perpendicular to Stream:** Assessment of impacts of stream incision on the meadow groundwater table and meadow vegetation types can be made by observing meadow vegetation type patterns associated

with streams that bisect or adjoin a meadow. Stream incision causes a lowering of the groundwater table. The magnitude of the drop and the consequent shift in vegetation types is a function of the amount of incision, direction of groundwater flow, sediment permeability, and meadow vegetation types. If meadow vegetation type shows no change on either side of a stream, it typically indicates that any incision that has occurred did not cause enough of a decline in the groundwater table to cause a shift in meadow vegetation type, such as where wet meadow vegetation occurs adjacent to both sides of the stream. A meadow with moderate degradation by stream incision may show a shift in meadow type from wet to mesic or dry. In a meadow significantly degraded by incision, willows or upland vegetation may be adjacent to the stream channel. Assess the overall impact of stream incision by observing plant patterns adjacent to the stream. Do not include inset stream terraces in the assessment as they do not typically reflect the same groundwater relationships as the meadow overall. Select the incision category that best matches the distribution of plant types. See figure A.9.3 for additional descriptions, illustrations, and photographs of the meadow plant types.

- **Meadow Hydrologic Type:** Use the answers in form A.9.1 and the information presented in figure A.9.3 to determine the meadow hydrologic type. These types are: (1) simple, not degraded by stream (fig. A.9.3a); (2) simple, minimally degraded by stream (fig. A.9.3b); (3) simple, degraded by stream (fig. A.9.3c); (4) complex, minimally degraded by stream (fig. A.9.3d); (5) complex, degraded by stream (fig. A.9.3e); or (6) other.

Meadow Traits	Meadow Plant Map	Meadow Aerial Photograph
A. Simple, Not Degraded by Stream <u>Hydrogeologic Setting</u> • bedrock constriction • continuous geologic units <u>Hydrology</u> • GW source is down-valley • springs common in low permeability sediment layer <u>Stream Connections</u> • gaining • incision has little effect on GW and vegetation patterns		
B. Simple, Minimally Degraded by Stream <u>Hydrogeologic Setting</u> • bedrock constriction • continuous geologic units <u>Hydrology</u> • GW source is down and side-valley • springs common in low-permeability sediment layer • perched GW table down-meadow <u>Stream Connections</u> • gaining some; perched some • >1 m of incision has little effect on GW and vegetation patterns		
C. Simple, Degraded by Stream <u>Hydrogeologic Setting</u> • downstream valley constriction and alluvial fan <u>Hydrology</u> • GW source is center and down-valley • artesian conditions and springs common <u>Stream Connections</u> • gaining • incision has likely breached confined aquifer and affected riparian GW and vegetation patterns		

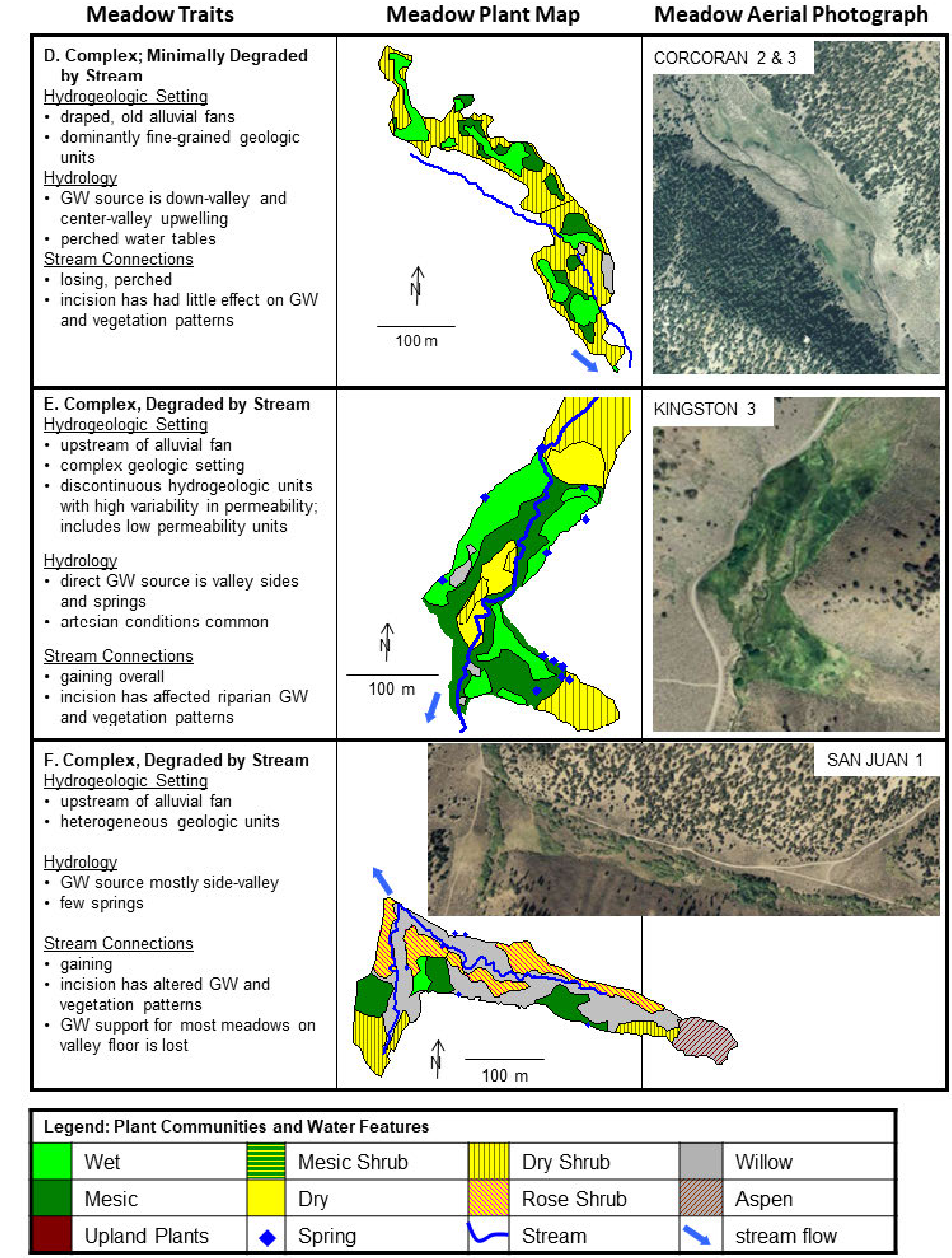


Figure A.9.3—Hydrologic characteristics, maps of plant communities, and aerial photographs for six meadow hydrologic types in the Great Basin (Lord et al. 2011). The information in this figure is used to complete the meadow geomorphic and hydrologic data form (form A.9.1). The left column describes key hydrologic characteristics and the current relationship of the stream to meadow hydrology and vegetation patterns. The middle and right columns show maps of the plant communities and aerial photographs of the setting. The aerial photographs are from meadows in central Nevada. GW = groundwater. Image from Google Earth, obtained October 2020.

Form A.9.2–MEADOW VEGETATION DATA	Date: Observer:
Watershed Name:	Database Code:
UTM Zone:	Elevation (m):
UTMs: Northing	Easting
Location in Basin: ☐Low ☐Mid ☐High	

Record the relative aerial cover of the meadow complex by meadow type (%):
Standing Water (SW) _______ Wet Meadow ______ Mesic Meadow ______ Dry Meadow ______
Shrub Meadow ______
The meadow types are described in Appendix 3, exhibit A.3.1, and their characteristic species are in Appendix 9, table A.9.1.

Record the following data for each meadow type that occurs in the meadow complex:
Dominant indicator species and aerial cover (%): record as trace < 1 (trace); 1-5; 5-25; 25-50; 50-75; 75-100.
Vigor and mortality of each species: record as high (H), moderate (M), or low (L) as described in Appendix 9, exhibit A.9.2.
Record Wetland Indicator Status (WIS), successional status (Succ), and bank stability (Stab) of each species: record values for each species from the meadow species list as described in Appendix 9, table A.9.1.
Nativity of the species: record as yes (Y) or no (N) as indicated in the meadow species list (table A.9.1).

Record the following data for the meadow type summaries:
Cover: estimate and record average vegetation cover for the entire meadow type.
Vigor and Mortality: record value most indicative of response to disturbance for the meadow type as described in Appendix 9, exhibit A.9.2.
WIS, Succ, and Stab: record most common values for the meadow type.
Native: record total number of nonnative species for the meadow type.

Meadow Type	Dominant Indicator Species	Cover (%)	Vigor H/M/L	Mort H/M/L	WIS O/F/FW /FU/U	Succ E/M/L	Stab H/M/L	Native Y/N
SW								
SW								
SW								
SW								
SW								
SW								
Standing Water Meadow Summary								
Wet								
Wet								
Wet								
Wet								
Wet								
Wet								
Wet Meadow Summary								

Form A.9.2–MEADOW VEGETATION DATA		Date:			Observer:			
Watershed Name:		Database Code:						
UTM Zone:		Elevation (m):						
UTMs: Northing		Easting						
Location in Basin: ☐Low ☐Mid ☐High								
Meadow Type	**Dominant Indicator Species**	**Cover (%)**	**Vigor H/M/L**	**Mort H/M/L**	**WIS O/F/FW /FU/U**	**Succ E/M/L**	**Stab H/M/L**	**Native Y/N**
Mesic								
Mesic								
Mesic								
Mesic								
Mesic								
Mesic								
Mesic Meadow Summary								
Dry								
Dry								
Dry								
Dry								
Dry								
Dry								
Dry Meadow Summary								
Shrub								
Shrub								
Shrub								
Shrub								
Shrub								
Shrub								
Shrub Meadow Summary								

Record the following data for the meadow summary:
Cover: estimate and record the average graminoid and forb vegetation cover for the entire meadow.
Vigor and mortality: record the value that is most indicative of the meadow response to disturbance as described in Appendix 9, exhibit A.9.2.
WIS, Succ, and Stab: record value most indicative of reach disturbance response as described in Appendix 9, exhibit A.9.2.
Native: record total number of nonnative species for the entire meadow.

Meadow Summary Values							
Indicator Species:							

Notes:

Exhibit A.9.2—Descriptions of the Variables Used to Assess the Meadow Vegetation in the Field.

- **Cover of Each Meadow Type (%):** The meadow types are described in Appendix 3, exhibit A.3.1, and their dominant indicator species are in table A.9.1. The percentage cover of each meadow type is estimated in the field or from aerial imagery. This estimate can be made from the drawing of the meadow in form A.9.1.
- **Dominant Indicator Species:** The indicator species for each meadow type are listed in table A.9.1. Meadow indicator species provide information on water availability for a particular meadow type, where water availability is determined primarily by depth to the water table. For each meadow type, record the native meadow species that indicate water availability over the duration of the growing season. No additional information is needed for the meadow type summary. For the overall meadow summary, record the species that are most indicative of the meadow's response to stream incision or avulsion. In the notes section, note whether the dominant indicator species also reflect anthropogenic disturbances such as livestock grazing.
- **Cover:** The cover of meadow vegetation provides information on response to disturbance. For each meadow type, record the average cover (%) for each dominant indicator species as <1 (trace); 1–5; 5–25; 25–50; 50–75; or 75–100. For the meadow type summary, estimate and record the average cover for the meadow vegetation type as a whole. For the meadow summary, estimate and record the total vegetation cover for the entire meadow.
- **Vegetation Vigor:** Provides information on insects, disease, weather extremes, potential decreases in water tables, or other disturbances such as inappropriate grazing or recreational overuse. Reduced vigor is indicated by low height, low production (leaf area or leader growth), or signs of stress, such as chlorosis or yellowing. For each meadow type, record the vigor of each dominant indicator species as high (later successional herbaceous and woody species are vigorous), moderate (later successional herbaceous and woody species are less vigorous than appropriate), or low (vigor of later successional herbaceous and woody species is low). For the meadow type summaries and the overall meadow summary, record the value that is most indicative of the meadow's response to disturbance. In the notes section, note the apparent cause of any loss in vigor.
- **Vegetation Mortality:** Increased mortality is indicated by patches of dying or dead herbaceous or woody (or both) species. Mature Salix trees with good vigor often have dead stems, which should not be interpreted as a sign of increased mortality. For each meadow type, record the mortality of each dominant indicator species as high (later successional herbaceous and woody species show no evidence of increased mortality), moderate (later successional

herbaceous and woody species show evidence of increased mortality), or low (mortality of later successional herbaceous and woody species is high). For the meadow type summaries and the overall meadow summary, record the value that is most indicative of the meadow's response to disturbance. In the notes section, note the apparent cause of any increases in mortality.

- **Riparian or Wetland Indicator Status (WIS):** Descriptions of the wetland indicator status values are in Part I, table 2 and the indicator status values for the meadow species are in table A.9.1. Indicator status provides general insights into flow regimes, groundwater dynamics, and the responses of the vegetation within the meadow. For each meadow type, record the WIS value of each dominant indicator species from table A.9.1. For the meadow type summaries, record the most common values for the type. For the overall meadow summary, record WIS as high (wetland obligate, facultative wetland, and facultative upland species are found in appropriate locations and numbers within the meadow), moderate (greater number of facultative upland and upland species than appropriate) or low (many more facultative upland and upland species than appropriate).
- **Successional Status:** Descriptions of the successional status values are in Part I, table 4, and the successional status values for the meadow species are in table A.9.1. Successional status ratings for individual plants provide information on the riparian ecosystems past and present responses to disturbance (table 4). Record the successional status value for each dominant indicator species from table A.9.1. For the meadow type summaries, record the most common value for the type. For the overall meadow summary, record the average successional status as high (a large number or cover of late seral species with few mid- and early seral species), moderate (a reduced number or cover of late seral species and increase in mid- and early seral species), or low (very low numbers or cover of late seral species, and dominance by mid- and early seral species). In the notes section, note the apparent cause of any reduction in successional status.
- **Bank Stability Rating:** The bank stability ratings are based on Part I, table 5, and values for the meadow species are in table A.9.1. Most perennial streams require 70 to 90 percent stabilizing cover (vegetation, large or anchored rock, anchored wood) to buffer the erosive force of water (Burton et al. 2011; Winward 2000). Root strength and rooting depth of meadow vegetation contribute to overall stability. Record the bank stability rating for each dominant indicator species from table A.9.1. For the meadow type summaries, record the most common value for the type. For the overall meadow summary, record the bank stability rating as high (a large proportion or cover of species with high stability ratings), moderate (a large proportion or cover of species

with a medium stability rating), or low (a high proportion or cover of species with a low stability rating). In the notes section, note the apparent cause of any loss of bank stability.

- **Nativity:** Species designations as nonnative-invasive or noxious weed are in Appendix 7, table A.7.1 and in table A.9.1. Record all nonnative-invasive species and noxious weeds as nonnative. For the geomorphic position summaries, record the total number of nonnative species on the geomorphic position. For the overall meadow summary, record the total number of nonnative species for the entire meadow.

Table A.9.1—Scientific and common names (NRCS 2020) of the dominant plant species, grouped by meadow type, in Great Basin meadow complexes, with additional information to be used to complete the meadow vegetation data form (form A.9.2). Wetland indicator status: OBL = obligate; FAC = facultative; FACW = facultative wetland; FACU = facultative upland; UPL = upland (Lichvar and Minkin 2008). Successional status: E = early seral; M = mid-seral; L = late seral. Bank stability index: L = low stability; M = moderate stability; H = high stability (Burton et al. 2011; Swanson 2016). *Nonnative-invasive.

Species	Symbol	Common name	Wetland indicator status (WIS)	Successional status (Succ)	Stability rating (Stab)
Standing Water Meadow					
Depth to water table: +10 to 0 cm					
Grasslike					
Carex aquatilis	CAAQ	water sedge	OBL	L	H
Carex utriculata	CAUT	Northwest Territory sedge	OBL	L	H
Scirpus microcarpus	SCMI2	panicled bulrush	OBL	L	H
Associated shrubs					
Salix geyeriana	SAGE2	Geyer willow	OBL	L	H
Salix wolfii	SAWO	Wolf's willow	OBL	L	H
Forbs					
Mimulus guttatus	MIGU	seep monkeyflower	OBL	M	L
Nasturtium officinale	NAOF	water cress	OBL	M	L
Veronica americana	VEAM2	American speedwell	OBL	M	L
Disturbance indicators					
Eleocharis quinqueflora	ELQU2	few flower spikerush		E	L
Senecio hydrophilus	SEHY2	water ragwort	OBL	E	L
Wet Meadow					
Depth to water table: 0 to 30 cm					
Grasslike					
Carex nebrascensis	CANE2	Nebraska sedge	OBL	L	H
Carex praegracilis	CAPR5	clustered field sedge	FACW	L	H
Carex scopulorum	CASC12	mountain sedge	FACW	L	H
Carex utriculata	CAUT	Northwest Territory sedge	OBL	L	H
Juncus longistylis	JULO	longstyle rush	FACW	L	M
Juncus nevadensis	JUNE	Sierra rush	FACW	L	M
Grasses					
Deschampsia elongata	DEEL	slender hairgrass	FACW	L	L

Table A.9.1 continued

Species	Symbol	Common name	Wetland indicator status (WIS)	Successional status (Succ)	Stability rating (Stab)
Glyceria striata	GLST	fowl mannagrass	OBL	L	M
Forbs					
Caltha leptosepala	CALE4	white marsh marigold	OBL	M	M
Epilobium ciliatum	EPCI	fringed willowherb	FACW	M	L
Mimulus guttatus	MIGU	seep monkeyflower	OBL	M	L
Mimulus primuloides	MIPR	primrose monkeyflower	FACW	M	L
Veronica americana	VEAM2	American speedwell	OBL	M	M
Associated shrubs					
Salix boothii	SABO2	Booth's willow	FACW	L	H
Salix exigua	SAEX	narrowleaf willow	FACW	L	H
Salix geyeriana	SAGE2	Geyer willow	OBL	L	H
Salix lasiolepis	SALA6	arroyo willow	FACW	L	H
Salix lemmonii	SALE	Lemmon's willow	FACW	L	H
Salix lutea	SALU2	yellow willow	OBL	L	H
Disturbance indicators					
Agrostis stolonifera	AGST2	creeping bentgrass	FACW	E	L
Alopecurus spp.	ALOPE	foxtail		E	L
Geum macrophyllum	GEMA4	largeleaf avens	FACW	E	L
Equisetum spp.	EQUIS	horsetail		E	M
Juncus ensifolius	JUEN	swordleaf rush	FACW	E	L
Thermopsis spp.	THERM	goldenbanner		E	L
Mesic Meadow ***Depth to water table: 30 to 90 cm***					
Grasslike					
Carex athrostachya	CAAT3	slenderbeak sedge	FACW	L	M
Carex microptera	CAMI7	smallwing sedge	FAC	M	M
Carex praegracilis	CAPR5	clustered field sedge	FACW	L	H
Juncus arcticus ssp. *littoralis*	JUARL	mountain rush (Baltic rush)		L	H
Grasses					
Elymus trachycaulus	ELTR7	slender wheatgrass	FACU	E	L
Deschampsia cespitosa	DECE	tufted hairgrass		M	L

Species	Symbol	Common name	Wetland indicator status (WIS)	Successional status (Succ)	Stability rating (Stab)
Poa pratensis	POPR	Kentucky bluegrass	FAC	E	L
Poa secunda ssp. *juncifolia*	PONE3	Nevada bluegrass		E	L
Forbs					
Achillea millefolium	ACMI2	common yarrow		E	L
Potentilla gracilis	POGR9	slender cinquefoil	FAC	E	L
Stellaria longipes	STLO2	longstalk starwort	FACW	M	M
Symphyotrichum spathulatum var. *spathulatum*	SYSPS	western mountain aster		E	L
Trifolium monanthum	TRMO2	mountain carpet clover	FAC		
Trifolium wormskioldii	TRWO	cows clover	FACW	M	L
Associated shrubs					
Ribes aureum	RIAU	golden currant	FAC	E	M
Ribes inerme	RIIN2	whitestem gooseberry	FAC	E	M
Salix boothii	SABO2	Booth's willow	FACW	L	H
Salix exigua	SAEX	narrowleaf willow	FACW	L	H
Salix geyeriana	SAGE2	Geyer willow	OBL	L	H
Salix lasiolepis	SALA6	arroyo willow	FACW	L	H
Salix lucida	SALU	shining willow	OBL	L	H
Salix lutea	SALU2	yellow willow	OBL	L	H
Disturbance indicators					
*Agrostis stolonifera**	AGST2	creeping bentgrass		E	L
Alopecurus spp.	ALOPE	foxtail		E	L
Carduus nutans	CANU4	nodding plumeless thistle	FACU	E	L
Bromus inermis	BRNI2	smooth brome	FACU	E	L
Cirsium arvense	CIAR4	Canada thistle	FACU	E	L
Erigeron divergens	ERDI4	spreading fleabane		E	L
Hordeum brachyantherum	HOBR2	meadow barley	FACW	E	L
Iris missouriensis	IRMI	Rocky Mountain iris	FACW	M	M
Poa bulbosa	POBU	bulbous bluegrass	FACW	E	L
Rosa woodsii	ROWO	Woods' rose	FACU	E	M
Juncus arcticus ssp. *littoralis*	JUARL	mountain rush (Baltic rush)		L	H

Table A.9.1 continued

Species	Symbol	Common name	Wetland indicator status (WIS)	Successional status (Succ)	Stability rating (Stab)
Rumex spp.	RUMEX	dock		E	L
Taraxacum officinale	TAOF	common dandelion	FACU	E	L
Urtica dioica	URDI	stinging nettle	FAC	E	L
Viola nephrophylla	VINE	northern bog violet	FACW	M	L
Dry Meadow ***Depth to water table: 90 to 170 cm***					
Grasslike					
Carex douglasii	CADO2	Douglas' sedge	FAC	M	L
Grasses					
Leymus triticoides	LETR5	beardless wildrye	FAC	E	L
Muhlenbergia richardsonis	MURI	mat muhly	FAC	L	H
Pascopyrum smithii	PASM	western wheatgrass	FAC	M	M
Poa secunda ssp. *juncifolia*	PONE3	Nevada bluegrass		E	L
Forbs					
Achillea millefolium	ACMI2	common yarrow		E	L
Erigeron divergens	ERDI4	spreading fleabane		E	L
Penstemon rydbergii	PERY	Rydberg's penstemon	FACU	M	L
Associated shrubs					
Ribes aureum	RIAU	golden currant	FAC	E	M
Disturbance indicators					
Bromus inermis	BRNI2	smooth brome	FACU	E	L
*Bromus tectorum**	BRTE	cheatgrass		E	L
*Cardaria draba**	CADR	whitetop		E	M
Carduus nutans	CANU4	nodding plumeless thistle	FACU	E	L
Cirsium arvense	CIAR4	Canada thistle	FACU	E	L
Cirsium scariosum	CISC2	meadow thistle	FAC	E	L
Elymus lanceolatus	ELLA3	thickspike wheatgrass	UPL	E	L
Poa bulbosa	POBU	bulbous bluegrass	FACW	E	L
Iris missouriensis	IRMI	Rocky Mountain iris	FACW	M	M
*Iva axillaris**	IVAX	povertyweed	FAC	E	L
*Lepidium latifolium**	LELA2	broadleaved pepperweed	FAC	E	M

Species	Symbol	Common name	Wetland indicator status (WIS)	Successional status (Succ)	Stability rating (Stab)
Taraxacum officinale	TAOF	common dandelion	FACU	E	L
Rosa woodsii	ROWO	Woods' rose	FACU	E	M
Urtica dioica	URDI	stinging nettle	FAC	E	L
Shrub Meadow ***Depth to water table: 125 to 275 cm***					
Grasslike					
Carex douglasii	CADO2	Douglas' sedge	FAC	M	L
Juncus arcticus ssp. *littoralis*	JUARL	mountain rush (Baltic Rush)		L	H
Grasses					
Elymus lanceolatus	ELLA3	thickspike wheatgrass	UPL	E	L
Leymus cinereus	LECI4	basin wildrye	FAC	M	M
Leymus triticoides	LETR5	beardless wildrye	FAC	E	L
Muhlenbergia richardsonis	MURI	mat muhly	FAC	L	H
Pascopyrum smithii	PASM	western wheatgrass	FAC	M	M
Poa pratensis	POPR	Kentucky bluegrass	FAC	E	L
Poa secunda	POSE	Sandberg bluegrass (rush bluegrass)	FACU	E	L
*Thinopyrum intermedium**	THIN6	intermediate wheatgrass		M	L
Forbs					
Achillea millefolium	ACMI2	common yarrow		E	L
Allium bisceptrum	ALBI2	twincrest onion		M	L
Astragalus lentiginosus	ASLE8	freckled milkvetch	UPL		
Cryptantha flavoculata	CRFL6	roughseed cryptantha		M	L
Erigeron divergens	ERDI4	spreading fleabane		E	L
Lupinus argenteus	LUAR3	silvery lupine		M	L
Penstemon rydbergii	PERY	Rydberg's penstemon	FACU	M	L
Associated shrubs					
Artemisia tridentata ssp. *tridentata*	ARTRT	basin big sagebrush		E	L
Artemisia tridentata ssp. *vaseyana*	ARTRV	mountain big sagebrush		E	L
Chrysothamnus viscidiflorus	CHVI8	yellow rabbitbrush		E	L
Ribes aureum	RIAU	golden currant	FAC	E	M
Symphoricarpos oreophilus	SYOR2	mountain snowberry		M	M

Table A.9.1 continued

Species	Symbol	Common name	Wetland indicator status (WIS)	Successional status (Succ)	Stability rating (Stab)
Disturbance indicators					
*Bromus tectorum**	BRTE	cheatgrass		E	L
*Cardaria draba**	CADR	whitetop		E	M
Carduus nutans	CANU4	nodding plumeless thistle	FACU	E	L
Cirsium arvense	CIAR4	Canada thistle	FACU	E	L
Poa bulbosa	POBU	bulbous bluegrass	FACW	E	L
Iris missouriensis	IRMI	Rocky Mountain iris	FACW	M	M
Ericameria nauseosa	ERNA10	rubber rabbitbrush		E	L
*Iva axillaris**	IVAX	poverty weed	FAC	E	L
Taraxacum officinale	TAOF	common dandelion	FACU	E	L
Rosa woodsii	ROWO	Woods' rose	FACU	E	M
Urtica dioica	URDI	stinging nettle	FAC	E	L

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Appendix 10—Score Sheet for Categorizing Watershed Sensitivity and Resilience and Scoring Values

This appendix provides data form A.10.1 and the information needed to determine the relative sensitivity and resilience category of the focal watershed. Record identifying information for the watershed on the data form: the date, observer, watershed name, and the watershed code in the Great Basin Watershed Database.

The scores recorded on the form are obtained from the general watershed characteristic data form (Appendix 4, form A.4.1), the geomorphic data form (Appendix 6, form A.6.1), and the riparian vegetation data form (Appendix 7, form A.7.1). Enter one score for the watershed characteristics that were determined in the office, and one score for each stream reach that was sampled in the field. Record the scores as: 1 = high, 2 = mid, 3 = low, or 4 = additional.

The factors controlling watershed sensitivity and resilience are those that have been shown to influence watershed responses to disturbance. These include certain watershed characteristics, stream channel sediment size and availability, and the dominant riparian vegetation type. To obtain the control values for each reach, (1) sum the values for the watershed characteristics, (2) sum the values for sediment size and availability for each reach, and (3) add together the two sums for each reach.

The response values are those that provide evidence of incision and evidence of avulsion. Sum the values for evidence of incision and avulsion to provide subtotals for each reach. Then calculate simple indices to help evaluate sensitivity to incision and avulsion, as follows:

Incision Sensitivity Index = (Σ of controlling factors/10) × Σ of subtotal evidence of incision

Avulsion Sensitivity Index = (Σ of controlling factors/10) × Σ of subtotal evidence of avulsion

As the values for the controlling factors increase, potential runoff and potential to transport available sediment by the generated runoff increase. Thus, larger values indicate a higher potential for incision and avulsion. The subtotal of the evidence for incision and avulsion provides insights into the magnitude and frequency with which these processes occurred in the past. The controlling factors are divided by 10 to limit the effects of the controlling factors on the observations of past incision or avulsion within the watershed.

The incision and avulsion sensitivity indices determined for the individual reaches represent distinct watershed segments within the watershed. These indices can be calculated for the entire watershed or the basin types within the watershed based on the percentages of the distinct watershed segments that each sampled reach represents. The data needed for these calculations are in form A.4.1.

Typical scoring values of watershed characteristics, sediment availability and size, evidence of incision, and evidence of avulsions and avulsion channels for each watershed sensitivity and resilience category are in table A.10.1. The values provided are those most commonly observed (median) for the watershed sensitivity and resilience category, with the possible range of values in parentheses. To determine the watershed sensitivity and resilience category, compare the incision and sensitivity indices calculated in form A.10.1 to those in table A.10. Information on incision and avulsion sensitivity and the sensitivity and resilience category for the basin types and watershed as a whole is used to inform conservation and restoration strategies within the watershed (Part I, table 6).

The form can be downloaded at https://experience.arcgis.com/experience/49f171f01aed451d8bbebb5558638a6c.

Form A.10.1–Score Sheet for Watershed Sensitivity and Resilience Date:

Observer:	Database Code:
Watershed Name:	Basin Type(s) (A1, A2, B, C):

Vegetation Type(s) (check): ☐Subalpine-montane conifer (SC); ☐ *Populus tremuloides* (PT); ☐Cold willow (CW); ☐ *Betula occidentalis* (BA); ☐ Warm willow (WW); ☐ Cottonwood (CT); ☐ *Artemisia* (AR); ☐Meadow (MD)

General Watershed Characteristics – *Form A.4.1*					
Mean Annual Precip (mm)	1 = <350, 2 = 350-475, 3 = 475-600, 4 = >600				
Watershed Area (km^2)	1 = <10, 2 = <10-25, 3 = 25-50, 4 = >50				
Basin Connectivity (%)	1 = <80, 2 = 80-90, 3 = 90-95, 4 = >95				
Past Debris Flows (# of flows)	0 = 0-10, 1 = 10-20, 2 = 20-40, 3 = >40				
Fan Influence	0 = basin wide, 1 = regional, 2 = localized, 3 = none				
Watershed characteristics sum					
Geomorphic and Riparian Vegetation Characteristics – *Forms A.6.1 and A.7.1*					
	Reach 1 = high, 2 = mid, 3 = low, 4 = additional (mark choice(s)) Leave Reach 4 blank if not sampled.	**1**	**2**	**3**	**4**
Sediment Size and Availability					
Bank/Valley Sediment Size	1 = gravel/boulders, 2 = mixed coarse/fines, 3 = fines				
Bed Clast Immobility (% of bed)	1 = >75%, 2 = 50-75%, 3 = 10-50%, 4 = <10%				
Dominant Vegetation	1 = woody species, 2 = mixed woody/grasses/forbs, 3 = grasses/forbs				
Bar Frequency (#)	0 = none, 1 = few (1-2), 2 = common (3-4), 3 = many (>4)				
Bar Extent (% of bed)	0 = none to 10%, 1 = 10-20%, 2 = 20-30%, 3 = >30%				
Gravel Bars on Valley Floor	0 = none, 1 = few (1-2), 2 = common (3-4), 3 = many (>4)				
Sediment size and availability sum for each reach					
Control subtotal (watershed characteristics + sediment size & availability) for each reach					
Evidence of Incision					
Knickpoints (#)	0 = none, 1 = few (1-2), 2 = common (3-4), 4= many (>4)				
Knickpoint Height (cm)	0 = none, 1 = 0-25 cm, 2 = 25-50 cm, 3 = >50 cm				
Insert Terraces (#)	0 = none, 1 = few (1), 2 = common (2-3), 3 = many (>4)				
Incision Depth (m)	0 = none, 1 = 0-1 m, 2= 1-2 m, 3 = >2 m				
Bedrock Outcrops (% of bed)	0 = extensive, 1 = localized, 2 = none				
Headcut Height (m)	0 = none, 1 = 0-1 m, 2 = 1-2 m, 3 = >2 m				
Reduced Riparian Extent	0 = none, 1 = 1-10%; 2 = 10-30%, 3 = >30%				
Riparian Plants Only in Trench	0 = none, 1 = little, 2 = common, 3 = widespread				
Incision evidence subtotal for each reach					
Evidence of Avulsion					
Anabranching Channels	0 = none, 1 = few, 2 = common, 3 = many				
Gravel Filled Channels	0 = none, 1 = few, 3 = common, 3 = many				
Gravel Aggradation/Debris Dams	0 = none, 1 = few, 2 = common, 3 = many				
Abrasion-adapted Plants	0 = none, 1 = few, 2= common, 3 = many				
Avulsion evidence subtotal for each reach					
Reach Incision Sensitivity Index: (subtotal of controls/10) × subtotal of incision					
Reach Avulsion Sensitivity Index: (subtotal of controls/10) × subtotal of avulsion evidence					

Average of All Reaches within Basin Type: Incision Sensitivity = ________
Avulsion Sensitivity = ________
(Based on percentage of the watershed or basin type that each stream reach represents)

Table A.10.1—Typical scores for watershed, stream channel, and riparian ecosystem characteristics for the five watershed sensitivity/resilience types. Values are those most commonly observed for each type with the possible range of values in parentheses.

	General Watershed Characteristics				
	Flood dominated A1	**Armored A2 B (rare)**	**Fan dominated B**	**Deeply incised B or C**	**Pseudostable B or C**
Parameters					
Mean Annual Precipitation	2 (1-3)	2 (2-3)	3 (3-3)	2 (2-3)	3 (2-3)
Basin Type	2	1 (1 or 3)	3	3 (3-4)	3 (2-3)
Basin Area	3 (2-3)	2 (1-4)	3 (2-3)	4 (2-4)	2 (1-3)
Basin Connectivity	3	3 (1-3)	1 (1-2)	3	3 (2-3)
Past Debris Flow Activity	0	3 (1-3)	0 (0-1)	1 (0-1)	0 (0-4)
Fan Influence	1	2 (1-2)	1 (1-4)	2 (2-3)	2 (1-3)

	Geomorphic and Riparian Vegetation Characteristics				
	Flood dominated A1	**Armored A2 B (rare)**	**Fan dominated B**	**Deeply incised B or C**	**Pseudostable B or C**
Sediment Size and Availability					
Bank/Valley Sediment Size	2	1	2 (2-3)	3	3
Bar Frequency	3 (2-3)	1 (0-2)	2 (1-3)	2 (0-3)	2 (0-3)
Bar Extent	3 (2-3)	1 (1-2)	2 (1-3)	2 (1-3)	2 (0-3)
Bed Clast Immobility	4	1 (1-2)	3	4 (3-4)	4
Gravel Bars on Valley Floor	2	0 (0-1)	1 (0-1)	0	0 (0-2)
Vegetation Relation to Sediment	1(1-2)	1 (1-2)	2 (1-3)	2 (2-3)	2 (2-3)
Control Subtotals	***21-27***	***11-26***	***17-28***	***19-31***	***16-34***
Evidence of Incision					
Knickpoints	2	1	2 (1-2)	2 (1-3)	2 (0-3)
Knickpoint Height	2	1	2	2 (1-3)	0 (0-3)
Inset Terraces	1	1 (0-1)	1 (0-2)	2 (0-3)	1 (0-2)
Incision Depth	0	1 (1-2)	2	2	1 (0-3)
Bedrock Outcrops	1	0 (0-2)	2	2	2 (0-2)
Headcut Height	0	0	0	0 (0-3)	1 (0-3)
Reduced Riparian Extent	0	1 (0-2)	1 (0-2)	1 (0-3)	1 (1-3)
Riparian Plants Only in Trench	1 (1-2)	0	2 (2-3)	3 (3-4)	2 (2-4)
Incision Evidence Subtotal	***8-9***	***4-11***	***10-19***	***11-26***	***4-26***
Evidence of Avulsion					
Anabranching Channels	3	0	1 (0-1)	0	0 (0-1)
Gravel Filled Channels	3	0	1 (0-1)	0	0 (0-1)
Gravel Aggradation/Debris Dams	3	0	1 (0-1)	0	0 (0-1)
Abrasion Adapted Plants	3 (2-3)	1 (1-2)	1 (1-2)	1(1-3)	1 (0-3)
Avulsion Evidence Subtotal	***11-12***	***1-2***	***1-5***	***1-3***	***0-6***
Incision Sensitivity Index	20 (17-24)	11 (4-29)	29 (17-53)	42 (21-81)	29 (6-88)
Avulsion Sensitivity Index	30 (23-32)	2 (1-5)	9 (2-14)	3 (2-9)	2 (0-20)

Appendix 11—Score Sheet for Rating Ecological Integrity and Description of the Rating Variables

This appendix provides data form A.11.1 and the information needed to determine the ecological integrity of the focal watershed. The watershed and vegetation characteristics and other data needed to complete form A.11.1 are described in exhibit A.11.1.

Record identifying information for the watershed on form A.11.1: the date, observer, mountain range, watershed name, and the watershed code in the Great Basin Watershed Database. Then use the general watershed characteristics determined in the office (Appendix 4, form A.4.1) and the data in the score sheet for assessing watershed sensitivity and resilience (Appendix 10, form A.10.1) to complete the assessment of general geomorphic characteristics. Use the reach summaries from the riparian vegetation data collected in the field (Appendix 7, form A.7.1) to complete the assessment of general vegetation characteristics. The scores for the disturbance assessment are derived from the reach-scale disturbance data collected within the watershed (Appendix 8, form A.8.1).

Ecological integrity can be evaluated for the individual sampled reaches and the entire watershed. High scores for a particular category (geomorphic, vegetation, disturbances) indicate reduced ecological resilience and low ecological integrity.

The form can be downloaded at
https://experience.arcgis.com/experience/49f171f01aed451d8bbebb5558638a6c.

A.11.1–WATERSHED ECOLOGICAL INTEGRITY		Date:			
Observer:		Database Code:			
Mountain Range:		Watershed Name:			
Watershed Type (A1, A2, B, C)**:**					
Watershed Sensitivity and Resilience Type (forms A.10.1 and A.10.2)**:** ______________________________ (Flood dominated, Armored, Fan dominated, Deeply incised, Pseudostable)					
Ratings: High scores for a category (geomorphic, vegetation, disturbances) indicate reduced ecological resilience and low ecological integrity. These can be evaluated at both the reach and watershed scale.					
	Reach 1 = high, 2 = mid, 3 = low, 4 = additional (mark choice(s)) Leave Reach 4 blank if not sampled.	**REACH**			
		1	**2**	**3**	**4**
Parameter	**Scores**	**Score**			
General Geomorphic Characteristics – *Forms A.4.1 and A.10.1*					
Debris Flow Activity	0 = none, 2 = slight, 3 = moderate, 4 = large				
Active or Recent Channel Incision	0 = none, 2 = local, 3 = moderate, 4 = widespread				
Recent Avulsions Preventing Stabilization	0 = none, 2 = local, 3 = moderate, 4 = widespread				
Sum of Geomorphic Characteristics for each reach					
General Vegetation Characteristics – *Form A.7.1*					
Decrease in Riparian Area Extent	0 = none, 2 = low, 3 = moderate, 4 = high				
Vegetation Vigor	1 = high, 2 = moderate, 3 = low				
Vegetation Mortality	1 = high, 2 = moderate, 3 = low				
Wetland Indicator Status	1 = high, 2 = moderate, 3 = low				
Successional Class	1 = high, 2 = moderate, 3 = low				
Bank Stability Class	1 = high, 2 = moderate, 3 = low				
Nonnative Invasive Species	1 = none to few, 2 = common, 3= widespread				
Sum of Vegetation Characteristics for each reach					
Response to Anthropogenic and Other Disturbances – *Form A.8.1*					
Roads and Road Crossings	0 = none, 2 = low, 3 = moderate, 4 = high				
Recreational Activities	0 = none, 2 = low, 3 = moderate, 4 = high				
Development (housing)	0 = none, 2 = low, 3 = moderate, 4 = high				
Development (mining)	0 = none, 2 = low, 3 = moderate, 4 = high				
Surface Water Manipulation	0 = none, 2 = low, 3 = moderate, 4 = high				
Groundwater Extraction	0 = none, 2 = low, 3 = moderate, 4 = high				
Water Diversion (dams/canals)	0 = none, 2 = low, 3 = moderate, 4 = high				
Beaver Dams (incision, etc.)	0 = none, 2 = low, 3 = moderate, 4 = high				
Fire Effects	0 = none, 2 = low, 3 = moderate, 4 = high				
Livestock Grazing	0 = none, 2 = low, 3 = moderate, 4 = high				
Wild Horse Effects	0 = none, 2 = low, 3 = moderate, 4 = high				
Other:	0 = none, 2 = low, 3 = moderate, 4 = high				
Other:	0 = none, 2 = low, 3 = moderate, 4 = high				
Sum of Disturbance Response for each reach					

Exhibit A.11.1—Descriptions of the Data Used to Assess Watershed Ecological Integrity Assessment.

General Geomorphic Characteristics

- **Debris Flow Activity:** Use the watershed score for past debris flow activity (number of flows) in form A.4.1 to assign the scores for debris flow activity. Enter the watershed score for each reach as: 0 = none (0–10); 2 = slight (10–20); 3 = moderate (20–40); or 4 = large (>40).
- **Active or Recent Channel Incision:** Use the subtotals for incision evidence for the sampled reaches and incision sensitivity index in form A.10.1 to assign the scores for active or recent channel incision. Enter the scores as: 0 (none) = no evidence of recent channel incision affecting channel processes and riparian ecosystems; 2 (local) = channel incision is localized and is affecting only a few areas within the watershed; 3 (moderate) = channel incision is fairly widespread within the watershed, 4 (widespread) = channel incision is progressive and affects the ecological integrity of most of the watershed.
- **Recent Avulsions Preventing Stabilization:** Use the subtotals for the avulsion evidence for the sampled reaches and avulsion sensitivity index in form A.10.1 to assign the scores for active or recent channel incision. Enter the scores as: 0 (none) = no evidence of recent channel avulsion affecting channel processes and riparian ecosystems; 2 (local) = avulsion is localized and is affecting the ecological integrity of only a few areas within the watershed; 3 (moderate) = avulsion is fairly widespread within the watershed and is affecting ecological integrity; or 4 (widespread) = channel avulsion occurs throughout the watershed and is significantly affecting ecological integrity.

General Vegetation Characteristics

- **Riparian Area Extent, Vegetation Vigor and Mortality, Wetland Indicator Status, Successional Status, and Bank Stability Status:** These data are collected during the riparian vegetation assessment and are described in Appendix 7, exhibit A.7.1. Data on riparian area extent are from the first section of form A.7.1; data on wetland indicator status, successional status, bank stability status, vegetation vigor, and vegetation mortality are from the reach summaries in form A.7.1.
- **Nonnative Invasive Species:** Nonnative invasive species are typically an indicator of anthropogenic disturbance at some point in time. The information entered on this form is derived from the reach summaries for the riparian vegetation data in form A.7.1. Assign the scores as follows: 1 = none to few nonnative invasive species occur and cover of these species is very low; 2 = several nonnative invasive species occur and cover of these species is low to moderate; or 3 = a large number of nonnative invasive species are present and cover of these species is moderate to high.

Response to Anthropogenic and Other Disturbances

The primary natural and anthropogenic disturbances affecting stream systems and riparian and meadow vegetation are described in Part I. The scores are based on the watershed-scale (form A.4.1) and reach-scale disturbance data collected within the watershed (form A.8.1). Assign scores for all disturbances as follows: 0 = no negative effect; 2 = low if the disturbance is having a minor negative effect on the stream channel, stream banks, or vegetation; 3 = moderate if it is having a clear negative effect on geomorphic processes or riparian vegetation; or 4 = high if the disturbance has significantly altered geomorphic processes or the riparian vegetation in a negative way.

The form can be downloaded at https://experience.arcgis.com/experience/49f171f01aed451d8bbebb5558638a6c.

Appendix 12—Examples of the Different Watershed Types, Their Diagnostic Indicators, and Observed Ecological Integrity

This appendix provides illustrations of the different watershed types and their characteristics (figs. A.12.1–A.12.7) based on field observations in the Great Basin geographic regions. The watershed sensitivity and resilience category and basin type (A1, A2, B, C) are given, the diagnostic indicators are provided, and the observed ecological integrity is discussed.

Figure A.12.1—A flood dominated watershed (Type A1 basin) in North Willow Creek, Utah. (Photos taken by the authors and used with their permission.)

Diagnostic Indicators

Upper reach: A fairly stable, single-channel system with relatively low flows and large clasts. The stream is losing with riparian obligate trees and shrubs in the overstory and mesic meadow vegetation adjacent to channel.

Middle and lower reaches: An anabranching (multichannel) pattern with numerous filled or partially filled paleochannels that cover most of the valley floor. Dominant characteristics are abundant mobile sediment and a flood-prone regime indicated by overbank flows. Vegetation is dominated by riparian shrubs and trees adapted to flooding and abrasion. There is sediment aggradation upstream of large woody debris.

Ecological integrity: The upper and middle reaches have road crossings in nearby reaches and have moderate ecological integrity. The lower reach is adjacent to a road that impinges on the stream and has lower ecological integrity.

Armored Watershed

Figure A.12.2—A general example of an armored watershed (Type B basin). (Photos taken by the authors and used with their permission.)

Diagnostic Indicators

Upper and middle reaches: Many channels possess large clasts and boulders eroded from a glaciofluvial terrace. Channel incision is limited. The channel bed exhibits few low-height knickpoints formed by boulders; the boulders are covered by biofilm indicating limited sediment transport; there is very little bank erosion; and sediment supply is low as indicated by a limited number of bars. Vegetation typically is characterized by woody riparian vegetation types with herbaceous vegetation adjacent to the stream.

Figure A.12.3—An armored watershed (Type B basin) in Cassia Creek, Idaho. (Photos taken by the authors and used with their permission.)

Diagnostic Indicators

Upper, middle, and lower reaches: Shallow channels characterized by limited bank erosion, rare knickpoints, and limited, localized incision. There are no terrace features; bed materials consist of large gravel and boulders covered in biofilms (algae), indicating limited transport; gravel bars are rare, indicating sediment supply is limited; and there are no overbank gravels or flood debris. Vegetation is characterized by woody riparian types with meadow types in the understory and adjacent to the stream.

Ecological integrity: Relatively high due to channel stability and few current anthropogenic disturbances. Roads and road crossings impinge on the stream in some locations; livestock grazing does not appear to be affecting the vegetation.

Fan Dominated Watershed

Figure A.12.4—A fan dominated watershed (Type B basin) in Upper Kingston Canyon, Nevada. (Photos taken by the authors and used with their permission.)

Diagnostic Indicators

Upper and middle reaches: Upper Kingston Canyon is a different basin type than the lower canyon. The valley is characterized by large side-valley alluvial fans that extend across the valley floor and have been truncated. The longitudinal profile of the valley and channel bed are characterized by stepped morphology. Localized gravel deposits associated with rare avulsion events occur both upstream and downstream of fans, and localized inset terraces extend upstream of the fan and terminate farther upstream in migrating headcuts. Meadow complexes upstream of fans are drained by relatively minor, but long-term, channel incision that is controlled by the erosion of large materials in the channel bed at the base of the fan.

Ecological integrity: Ecological integrity is moderate to high. Ongoing incision is resulting in drying of the meadow near the channel and encroachment of upland species. Livestock grazing is not having an influence currently.

Figure A.12.5—A deeply incised watershed (Type C basin) in Shoshone Creek, Idaho. (Photos taken by the authors and used with their permission.)

Diagnostic Indicators

Upper reach: A fairly stable channel characterized by fine sediments intermixed with large clasts and relatively low flows. The stream is losing and has riparian obligate trees and shrubs in the overstory and wet to mesic meadow vegetation adjacent to channel.

Middle and lower reaches: An incising channel that is characterized by fine sediments and has a channel bed that is below the valley floor. Spring flows are relatively high. Vegetation is dominated by meadow types intermixed with willows adjacent to the channel and upland trees and shrubs on the floodplain.

Ecological integrity: The upper reach has high ecological integrity. The middle and lower reaches are adjusting to past floods (1980s) that removed beaver dams and resulted in significant erosion near the dams and downstream.

Deeply Incised Watershed

Figure A.12.6—A deeply incised watershed (Type C basin) in Coon Creek, Nevada. (Photos taken by the authors and used with their permission.)

Diagnostic Indicators

Upper reach: A shallow, discontinuous channel on the valley floor characterized by fine, mobile sediment and small knickpoints. Sediment supply is limited as indicated by bars. Wet to mesic meadow vegetation occurs adjacent to the channel and upland shrubs are on the floodplain.

Middle reach: A deep V-shaped channel formed in fine-grained cohesive sediments that terminates upstream in a headcut. Headcut migration is indicated by recent bank failures. Fine sediments result in almost vertical bank walls and limited sediment availability is indicated by few bars or bed sediments. Vegetation is dominated by meadow vegetation types and nonnative invasive species adjacent to channel and upland shrubs on the floodplain.

Lower reach: A deeply incised channel (>7 m) with a stable inset floodplain at the bottom of the trench. The channel walls consist of fine-grained, cohesive, stratified sediments of varying age and bank failures are common on outside channel bends. Large meadow complexes have been drained and mesic and dry meadow vegetation is currently in the trench.

Ecological integrity: The upper reach has low ecological integrity due to a large knickpoint (2 m) in a lower reach and improper cattle grazing. The middle and lower reaches have low ecological integrity due to incision and active geomorphic and vegetation change. The stream banks, stream channel, and riparian vegetation are also impacted by improper cattle grazing.

Figure A.12.7—A pseudostable watershed (Type B basin) in Muncy Creek, Nevada. (Photos taken by the authors and used with their permission.)

Diagnostic Indicators

Upper, middle, and lower reaches: Abundant, mobile sediment on the hillslope was mobilized by debris flows following wildfire. Debris flows characterized by levees and deposition occur on side-valley fans, and the axial valley is characterized by widespread channel and valley floor aggradation. Aggraded reaches are separated by deep incision that followed localized channel aggradation. The side-valley fans have historical debris-flow deposits indicating past erosion events. The stream reaches are losing and woody riparian vegetation is reestablishing.

Ecological integrity: The riparian corridor has relatively low ecological integrity due largely to instability of the stream channel and low abundance of riparian vegetation.

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