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Guidelines For Riparian Forest Restoration in Utah

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Abstract

In Utah, and much of the Intermountain West, riparian forests make up a small percentage of the landscape but provide disproportionately large ecological functions and societal values. Since the early 1800s, Utah's riparian forests have experienced shifts in natural disturbance regimes, changes in flow regimes and water tables, changes in vegetation composition and structure, introduction of exotic plant and animal species, and land use conversion. Today, managers need science-based guidance to assess ecological integrity, detect causes of degradation, and select appropriate methods for restoration of ecosystem processes and functions as well as the structure and composition of riparian forests. In this document, we provide a step-by-step process for making decisions about riparian forest restoration. These steps include (1) identification of forest vegetation types and hydrogeomorphic valley types, (2) identification of symptoms of degraded ecological integrity, (3) determination of stressors causing degradation, (4) selection of the appropriate management response(s) based on the symptoms and stressors present, and (5) selection of appropriate methods for collecting baseline data and monitoring management results. This process will assist managers in improving the ecological integrity and resilience in the face of current and future stressors.

Keywords: *riparian, forest, disturbance regimes, restoration, resilience, water quality, vegetation types, species diversity, invasive species, beaver, watershed condition*

Cover: Narrowleaf cottonwood riparian forest on the Manti-La Sal National Forest in southern Utah, elevation 6,460 feet. USDA Forest Service photo by Dorothy Wallace-Senft.

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Utah Forest Restoration Working Group

The Utah Forest Restoration Working Group (UFRWG) is a collaborative partnership of agencies and stakeholders working together on a consensus basis to address forest management issues in Utah in a forward-looking, constructive manner. Current member organizations include Federal and State resource management agencies, county governments, nonprofit conservation groups, outdoor sportspersons' groups, industry associations, and professional societies.

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Executive Summary

Riparian areas are among the most biologically diverse, productive, and threatened habitats in the western United States. We define riparian forests as ecosystems that occur along perennial, intermittent, or ephemeral streams currently or historically supporting native trees at least 5 meters (16 feet) tall at maturity. Though riparian forests are estimated to occupy less than 2 percent of the landscape in Utah (Gilbert et al. 2016), they provide disproportionately large ecological functions and societal values. This document provides land managers with information useful for managing and restoring riparian forests.

Chapters 1 and 2 provide an overview of the variety, conditions, trends, and community types of riparian forests in Utah, along with data sources for locating more in-depth and local information. Eighteen frequently observed symptoms that indicate a particular riparian forest is impaired or degraded are described in Chapter 3, including those exhibited by the riparian trees, associated vegetation, the adjacent stream channel, and water quality and quantity. Seventeen stressors that can negatively affect riparian forests are also described in Chapter 3 and matched in a decision matrix (table 3.1) with the specific symptoms that may result. Chapter 4 focuses on potential actions that a land manager may initiate. Management options are offered at the intersection of a particular symptom and stressor in the decision matrix (table 3.1). Overviews of options include references to more detailed planning and design information, along with a description of conditions under which taking no action may be the preferred solution. Chapter 5 offers qualitative and quantitative methods for initial assessment and future monitoring of riparian forest conditions, along with links to published sources that offer step-by-step directions for each method. The methods differ in the technical expertise, time, and precision required.

A land manager may wish to address only certain symptoms and stressors, and therefore consider only particular management options and methods of measuring riparian forest restoration success. It is ultimately up to land managers and stakeholders to determine the most appropriate restoration action(s) for their situation and management goals. This is a working document for use in riparian forests in Utah and elsewhere in the Intermountain West.

Scope and Purpose

The purpose of this document is to provide recommendations for riparian forest restoration in Utah. We present these recommendations as a working document for use in riparian forests in Utah and elsewhere in the Intermountain West.

This document was prepared by a subcommittee of the Utah Forest Restoration Working Group, a multiagency collaborative partnership that requested the development of riparian forest restoration guidelines. The authors have synthesized many information sources to create an interactive tool that resource managers can apply to a variety of riparian sites.

We define **riparian areas** as ecosystems that occur along **perennial**, **intermittent**, or **ephemeral streams** (terms in boldface are further defined in the Glossary starting on p. **153**). While we recognize that riparian areas, including riparian forests, may also occur around the edges of lakes, ponds, springs, bogs, or meadows, this document focuses on **riparian forests** that are adjacent to flowing water. We define riparian forests as riparian areas currently or historically supporting native trees at least 5 meters (16 feet) tall at maturity. A tree is a woody plant with one to few main stems and a more-or-less definite crown (FGDC 2008; Oswalt et al. 2019). The minimum height of 5 meters is consistent with U.S. Department of Agriculture, Forest Service (hereafter, Forest Service) technical definitions used to distinguish forests from other **vegetation types** (Oswalt et al. 2019).

The term "**restoration**" can mean different things to different people, with definitions spanning broad to narrow applications. Here, riparian forest restoration will refer primarily to active or passive management that improves the ecological integrity and **resilience** of riparian forest where it is currently or was historically present, and where environmental conditions are suitable for long-term persistence. Although the guidelines focus on riparian forests, they may be useful for riparian area restoration in general.

We anticipate that managers of public and private riparian forest lands will be able to use the strategies outlined herein as a road map to identify, design, and implement projects to restore riparian forests and monitor results. We recommend that managers follow a multistep process, namely: (1) assess the condition of the riparian forest of interest; (2) identify **symptoms** of potentially problematic conditions; (3) determine the **stressors** that contribute to identified symptoms; (4) implement appropriate monitoring to establish **baseline conditions**; (5) select and implement appropriate **management option**(s) to eliminate or mitigate stressors (or both) in order to improve forest conditions; (6) monitor to measure changes against restoration objectives; and (7) if necessary, adapt using steps 1 through 6. It is ultimately the land managers' decision to choose the most appropriate restoration action(s) for their situation and management goals. Public land managers work with stakeholders, partners, and policymakers to collect the best information available to inform sustainable actions within forested riparian areas.

This guide is organized as follows: Chapter 1 summarizes the benefits of riparian forests and the types of riparian forests in Utah. Chapter 2 describes the extent and conditions of riparian forests in Utah. Chapter 3 explains how to assess the symptoms and stressors affecting a particular riparian area. Chapter 4 presents management options for addressing particular symptoms and stressors. Chapter 5 discusses selection of postrestoration monitoring methods and provides sources for commonly used assessment and monitoring methods.

How to Use This Document

Guidelines for Riparian Forest Restoration in Utah is intended to be used as a reference and procedural guide for identifying, describing, diagnosing, managing, and treating riparian forest ecosystems. It assists users with initially obtaining the most current information and technology for stewardship and project planning in riparian forests. It can serve as a useful handbook for any decision maker, whether a public land manager or a private landowner.

Chapter 1 includes information about the variety of riparian forest plant communities in Utah and their arrangement on the landscape. Chapter 2 presents a statewide overview of current conditions and expected trends, introducing some of the most common impairments seen on Utah's riparian forests. Chapters 1 and 2 can be used to help assess the potential of the riparian forest in question and determine restoration goals.

Chapters 3 and 4 of this guide are organized around a decision matrix (table 3.1) that allows the user of this guide to choose observed symptoms, identify probable stressors that are causing them, and develop recommendations for specific management options (treatments) to consider. Chapter 3 lists and describes easily observable indicators of reduced ecological integrity (symptoms), and the factors (i.e., stressors) that may have caused, or may still be causing, the symptoms. Chapter 4 contains descriptions of management options, with caveats and references to more detailed information. Because many of the topics covered are interconnected, readers may notice some repetition within and between Chapters 3 and 4.

Chapter 5 contains information and resources for monitoring riparian conditions and restoration effectiveness. Tables 5.1 and 5.2 provide direct links to resources for detailed descriptions of monitoring methods. Managers who intend to implement a restoration project may benefit from consulting this section to aid in establishing baseline conditions before implementing the management options in Chapter 4.

Appendixes A, B, C, and D provide additional information on the functional groups of riparian indicator species, plant names, plant identification resources, and a field for or checklist for assessing a riparian forest, respectively.

Chapter 1: Importance of Forested Riparian Ecosystems

Riparian forests provide both ecological and societal benefits. Not all riparian forests provide every benefit outlined in this chapter. For example, monocultures of tamarisk and Russian olive can be considered riparian forest but do not offer all the benefit described here.

Ecological Benefits of Riparian Forests

The focus on the ecological importance of riparian forests in Utah is best couched within the ecological benefits of riparian systems throughout the western United States and indeed worldwide. Riparian ecosystems are among the most biologically diverse, productive, and threatened habitats in the American Southwest (Hultine et al. 2010; Johnson and Jones 1977; Johnson et al. 1985; Knopf et al. 1988; Poff et al. 2012; Stromberg 1993; Webb and Leake 2006). In the Intermountain West, riparian areas are estimated to be less than 2 percent of the total land area (Gilbert et al. 2016. Nevertheless, the functions and values of riparian ecosystems are disproportionate to their relatively small area, particularly in the semiarid regions of North America (Patten 1998).

Riparian forest communities play an instrumental role in the **geomorphic** and **hydrologic processes** of Utah's stream and river systems. Riparian vegetation protects and stabilizes streambanks, reduces **erosion**, and slows and spreads overbank flow and out-of-bank flood waters while trapping **sediment** that can initiate soil development (Baker 2002; Dosskey et al. 2010; Tabacchi et al. 2000). As a result, these forested and thickly vegetated areas contribute to continuous development of streambanks and **floodplains**. Slowing and spreading out of flood waters increases infiltration into the soil, recharges **groundwater**, and extends the duration of the **runoff** period (Tabacchi et al. 2000; Wissmar and Swanson 1990). Intact riparian forests make riparian systems resilient and better able to withstand **disturbances**, such as floods, than riparian areas with depleted or shallow-rooted vegetation.

Riparian areas, including riparian forests, support highly productive and diverse plant communities, which are a transitional link between terrestrial upland and aquatic ecosystems (Osborne and Kovacic 1993). Riparian habitats in Utah support plant and wildlife species not found in upland habitats (Kauffman et al. 2001; Naiman and Decamps 1997; Sabo et al. 2005). Riparian ecosystems are also important movement corridors for larger mammal species such as deer, mountain lions, and bears, as well as aquatic species such as native cutthroat trout, and native nongame fish. Utah's Division of Wildlife Resources notes the importance of riparian forest corridors in its statewide initiative to identify, preserve, and enhance essential movement corridors for terrestrial and aquatic wildlife species in the state (UDWR 2020). Riparian forests also provide migratory, breeding, and foraging habitat for birds, bats, and insects (e.g., butterflies, dragonflies) within otherwise dry and inhospitable environments (Fremier et al. 2015). Riparian forests benefit both aquatic and terrestrial ecosystems by providing woody food and dam construction material for beavers. Beaver dams slow flow velocity and create ponds, which may expand aquatic and riparian habitat.

Riparian forests also enhance aquatic habitat structure, **water quality**, and food webs. They enhance fish habitat by providing critical underbank cover, which fish use as hiding and resting zones (Leonard et al. 1992). Their shade prevents solar warming of streams, which thus maintains lower water temperatures and concomitantly higher dissolved oxygen, and their overhanging canopies facilitate increased insect drop to streams (i.e., when insects fall from streamside vegetation directly into the water column) (Baxter et al. 2005; FISRWG 1998; Leonard et al. 1992; Nakano and Murakami 2001). In addition to insects, riparian vegetation provides other high-quality inputs of organic matter (e.g., leaves, fruits), an important basis for aquatic food webs. As riparian trees die or lose limbs, **woody debris** enters the waterway, providing structure that contributes to important instream fish habitat (Angermeier and Karr 1984; FISRWG 1998).

Perhaps most importantly, healthy and functioning riparian forests provide critical climate refugia and ecosystem resilience in the face of increasing drought and rising temperatures associated with changing climate across the West. Because riparian areas span elevational and latitudinal gradients that species are likely to follow as areas of climatic suitability shift, these natural corridors are important landscape features to conserve for both short-term and long-term climate adaptation (Krosby et al. 2018).

Historical Perspective on Utah Riparian Forests

Riparian areas in Utah and the forests found there have been important to both Indigenous peoples and immigrant settlers. The ecological services that riparian forests provide make them natural magnets for human habitation, with the presence of water being an obvious primary attraction. Historically, the diversity of plant and animal species within riparian corridors created important hunting and gathering opportunities, and the shade and humidity found in riparian forests provided more pleasant microclimates in particular seasons. Because of their scarcity across the landscape relative to upland areas, riparian forests were of uniquely high value to Indigenous people, and they continue to be intensively used and sometimes highly contested areas in present-day Utah.

River corridors are recognized as critical ecosystems for humans, as illustrated by the Fremont people cultivating maize along creeks and streams where water could be easily diverted to fields (Spangler 2019). Evidence from the Archaic Period (8000–400 B C.) shows human habitation along major river corridors. Among the inhabitants were Zuni people, whose ancestors were Archaic hunter-gatherers, followed by the Paiute and Ute cultures. However, because riparian areas are characterized by frequent flooding and channel movement, artifacts and structures commonly found in floodplains tended to be removed over centuries of dynamic river movement. Human structures and modifications in riparian areas are simply less likely to have persisted than those in upland areas.

The first major European influence on riparian systems in Utah came in the form of beaver trapping. It is estimated that 60 million to 400 million beavers were active in North America prior to European immigration. Extensive beaver removal began on the East Coast in the early 17th century, and by 1800, trappers were exploring the West to locate and trap remaining beaver populations. By 1900, beavers were almost extinct in North America (Naiman et al. 1988). Many attributes of stream ecosystems were lost before stream research had begun, but retrospective research has indicated that the loss of dam-building beavers' impoundment of water resulted in increased flood magnitudes and frequencies, decreased baseflows, channelized stream networks, and reduced overland flow (Fouty 2018).

Later immigrants found riparian areas to be essential components of the landscape and tended to concentrate their settlements and activities there, utilizing water for household needs, livestock, and eventually farming. In the 1850s, Mormon exploration parties from Salt Lake City considered abundant water a vital component for potential new settlement areas. Maps of modern-day Utah illustrate that human communities were established along waterways or lakes and that much of the private land in Utah occurs at the lowest elevations and along streams and rivers. Parley P. Pratt, while on an 1850 expedition to southern Utah, noted the use of irrigation ditches by Indigenous people living along the Santa Clara River, in the area known today as Washington County. Irrigation ditches were among the first public improvements created in Utah. The development of canal systems was integral to the success of the new colonies. Communal labor organized by the leadership of the Church of Jesus Christ of Latter-day Saints constructed these canal systems (Fuller 1994).

Euro-Americans who settled Utah used trees found in riparian areas for building materials, fuel, and fodder, or cleared them to make way for farming. Riparian forests were modified not only by diversions of natural streamflows into irrigation systems, but also by impoundments created to store water throughout the year, which often inundated riparian areas. The first irrigation reservoir in the United States was purportedly Newton Dam, constructed in Cache County, Utah, in 1871 (Arrington and Anderson 1971).

Today, even though Utah is predominantly a public lands State (only about 30 percent of the State is privately owned), riparian areas are disproportionately privately owned. This is a legacy of both the pattern of settlement and the Homestead Act of 1862, which allowed Federal land to be privatized through settlement and being "improved upon" (i.e., typically if a cabin was built). Given that a family could homestead no more than 160 acres, the obvious strategy was to focus on the most useful and arable land, which generally occurred along waterways. The combination of historical settlement patterns, private property rights, and the doctrine of prior appropriation of water rights means that control of riparian forests is often distributed across a relatively large number of individual landowners.

Societal Benefits of Healthy Riparian Areas

Properly functioning riparian forests in Utah and associated understory vegetation provide several ecosystem services important to human populations. These include the following:

- Adequate water quality for both aquatic life and downstream human users. Foliage, roots, and soil microbes filter water; assimilate, store, and t ansform nutrients; immobilize harmful chemicals (Dosskey et al. 2010; Schultz et al. 2009); and minimize **bank erosion** (Tabacchi et al. 2000), which may help reduce **sedimentation** of water supply systems. Moreover, shade of riparian trees prevents solar warming and thus moderates stream temperatures, thereby maintaining high oxygen levels; the Utah Division of Water Quality monitors both of these factors as key measures of water quality.
- Enhanced water supply. Increased water holding capacity, as well as stable stream channels and banks, results in a higher water table. An elevated **water table** can extend the runoff period and increase baseflow (Tabacchi et al. 2000; Wissmar and Swanson 1990), thus improving reliability of water delivered to human users downstream, particularly during times of drought (Schultz et al. 2009; Tabacchi et al. 2000). In addition, a higher water table also benefits agricultural users in adjacent areas, in that a higher water table means less water is required to water crops.
- Modulation or buffering of severe **natural disturbances**. For example, vigorous and healthy riparian vegetation can reduce the magnitude and velocity of floods (Simon and Collison 2002). Healthy, native riparian vegetation is often less flammable than adjacent upland vegetation and can play a role in reducing the spread of wildfire in forests, woodlands, shrublands, and grasslands (Dwire and Kauffman 2003).
- Recreational and spiritual values including intrinsic, aesthetic, and scenic benefits. Though recreational activities can have negative impacts, camping, hiking, river running, hunting, and fishing are considered enjoyable activities in Utah and across the western United States (Poff et al. 2012)

Riparian Forests in Utah

Riparian forests in Utah are highly diverse, from the low elevation ecosystems in the Colorado Plateau (fig. 1.1) to high elevation communities in the Uinta Mountains. They can be described with three increasing levels of detail: zones, dominance types, and community types. Decision makers and managers are urged to be aware of zones, dominance types, and community types when assessing riparian forest systems of interest for symptoms of impairment and for identifying potential stressors (Chapter 3), because the management options for effective restoration of those systems (Chapter 4) can in part depend on the vegetation types of the assessment reach.

Figure 1.1—Fremont cottonwood riparian forest along the Escalante River, south of Boulder, Utah, elevation 5,200 feet. USDA Forest Service photo by David Tart.

Zones are groupings of dominance types with similar distributions along environmental gradients. Dominance types are based on the most abundant overstory tree species. Community types are defined by understory shrubs and herbs in addition to the overstory trees. They can be defined and described only through the collection and analysis of field data from a variety of sites representing the diversity of communities that occur on the landscapes sampled (Padgett et al. 1989). We next describe Utah's riparian forests using this tiered system starting with zones, followed by dominance types, and then community types.

Riparian Forest Zones

We divide riparian forests in Utah into three approximate elevation zones based on the dominant tree species: Conifer-Aspen forests at high elevations, Cool Deciduous forests at middle elevations, and Warm Deciduous forests at low elevations. The elevation ranges of the zones vary with latitude (fig. 1.2). The zones overlap in elevation due to variation in cold air drainage and valley types, and shading and cooler temperatures in deep narrow canyons. The elevational overlap between zones, particularly for the Cool and Warm Deciduous zones, is more pronounced in southern Utah (i.e., less than 37.5° N latitude; figs. 1.2, 1.3), which is characterized by numerous deep narrow canyons often surrounded by bedrock surfaces. In addition to shading, these canyons often receive runoff water from adjacent bedrock areas

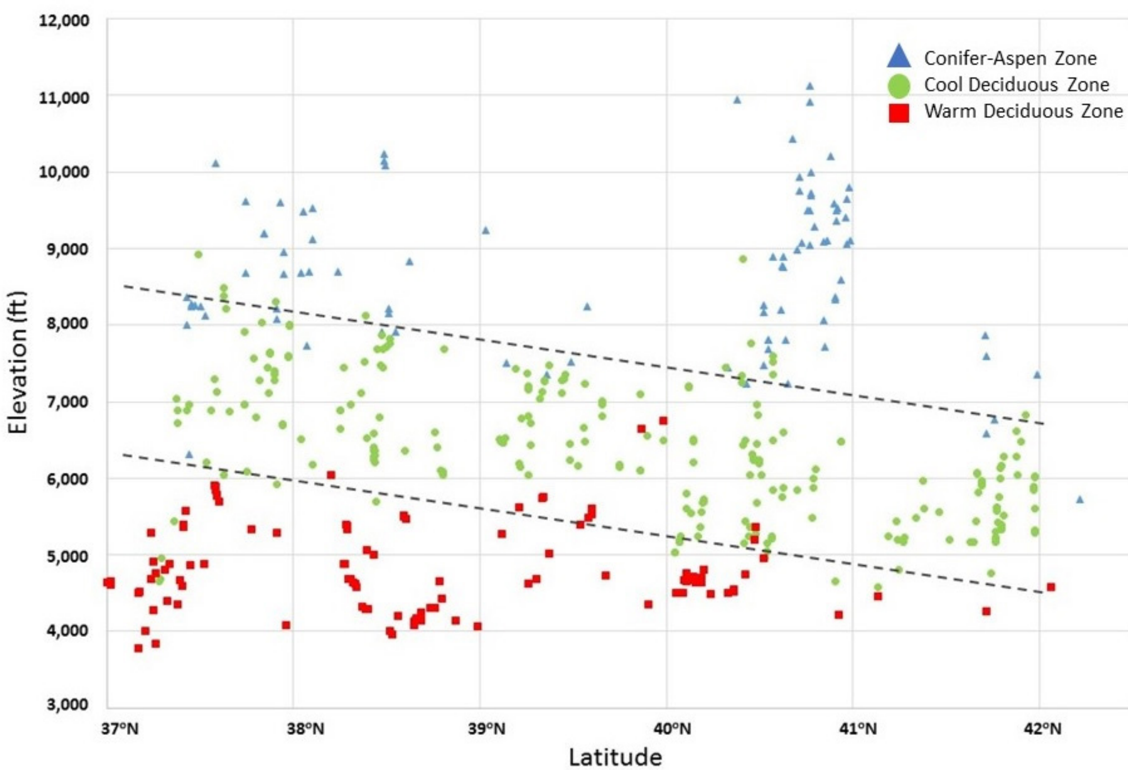

Figure 1.2—Relationship of elevation to latitude for Riparian Forest Zones in Utah (developed by David Tart, USDA Forest Service). For reference, 37° N is the Arizona border and 42° N is the Idaho border. Dashed lines separate the three zones.

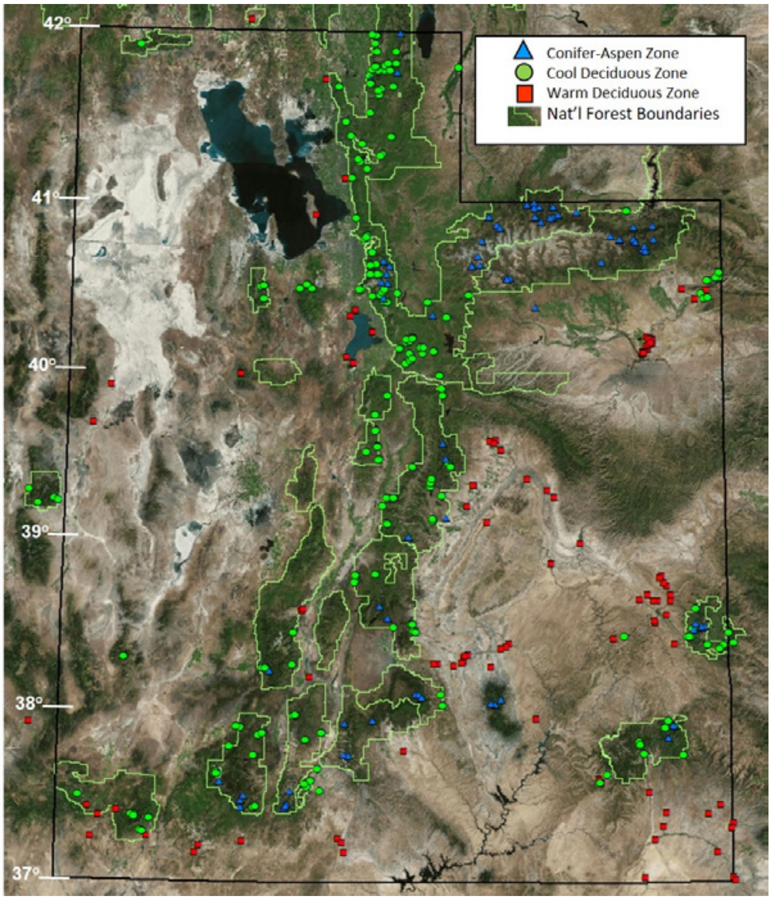

Figure 1.3—Geographic distribution of vegetation plots representing riparian forest zones in Utah.

The data points depicted in figures 1.2 and 1.3 are mostly from vegetation classification or mapping projects on national forests, national parks and monuments, and one national wildlife refuge. Additional plots and observations are from the LANDFIRE national vegetation and fuels mapping project, a repeat photography project (Kay 2015), rangeland monitoring conducted by the Dixie National Forest and the Utah Division of Wildlife Resources, and observations collected by the Utah Forest Restoration Working Group (table 1.1).

The Conifer-Aspen forest zone appears to have higher species density (number of species per unit area) of native plant species than the Cool and Warm Deciduous zones (table 1.2), likely reflecting cooler and more moist growing conditions as well as less intensive land use. It also has a lower density of introduced species, probably because more exotic species are adapted to low elevation sites and human land use has been less intensive and continuous in steep mountain valleys. (Mountain meadows have also experienced more intensive use but are not discussed in this guide.)

Table 1.1—Vegetation Data Shown in Figures 1.2 and 1.3.

Type of Vegetation Data	No. of Plots
Forest Service vegetation classification [1]	172
National Park Service vegetation classification [2]	45
National Wildlife Refuge vegetation classification [3]	20
Forest Service vegetation mapping [4]	119
LANDFIRE vegetation mapping [5]	34
Photo points [6]	5
Rangeland vegetation monitoring [7]	54
Utah Forest Restoration Working Group Observations	13
Total	**467**

[1]Mauk & Henderson, 1984; Mueggler, 1988; Padgett, et al., 1989; Pfister, 1972; Youngblood & Mauk, 1985; Youngblood, et al., 1985
[2]Clark, et al., 2009; Cogan, et al., 2004, 2012; Coles, et al., 2008a,b; 2009a,b; Tendick, et al. 2011a,b, 2012, 2017
[3]Von Loh, et al., 2002
[4]USDA Forest Service, 2016; USDA Forest Service, 2017; USDA Forest Service, 2018
[5]https://www.landfire.gov
[6]Kay, 2015, Google Earth
[7]Payne et al. 2015; Smith et al. 2020

Table 1.2—Species Density of Native and Exotic Plants[1].

Riparian Forest Zone	Number of Plots 400 m^2	500 m^2	Mean Number of Native Species per 400 m^2 ± Standard Deviation	Mean Number of Exotic Species per 400 m^2 ± Standard Deviation
Conifer-Aspen	5	21	26.5 ± 9.6	0.5 ± 0.7
Cool Deciduous	26	2	11.8 ± 5.7	1.6 ± 1.7
Warm Deciduous	42	—	11.3 ± 6.4	3.3 ± 1.6

[1]Plots are either 400 or 500 m^2 in area and all plants present were identified p ecisely enough to determine whether they were native or introduced species. The number of species on each 500 m^2 plot was adjusted to 400 m^2 by multiplying by 0.8 (i.e. 400/500) before calculating the means and standard deviations reported here.

These differences in native species density are expected to correspond to differences in ecological resilience, at least between the Conifer-Aspen zone and the Cool and Warm Deciduous zones. In altered riparian forests, the more native species present on a site, the more likely there will be some that can respond favorably to natural disturbances and begin the recovery process (Enqvist et al. 2003; Leslie and McCabe 2013; Walker et al. 1997).

Species composition for the three riparian zones of Utah is compared in table 1.3. We listed species that occur on at least 20 percent of the plots (i.e., with a constancy of at least 20 percent) or that average at least 5 percent cover in one or more zones. Results are based on 294 plots with complete species lists from the sources in table 1.1. These species include the most common and abundant species within each zone as a whole.

Table 1.3—Most Common and Abundant Plant Species by Riparian Forest Zone.

	Conifer-Aspen Zone 91 plots		Cool Deciduous Zone 143 plots		Warm Deciduous Zone 60 plots	
Species Name[1]	Constancy[2]	Cover[3]	Constancy	Cover	Constancy	Cover
Trees:						
Engelmann spruce	**52**	**14**	5[4]	tr	—	—
subalpine fir	**39**	**9**	5	1	—	—
lodgepole pine	**36**	**13**	—	—	—	—
quaking aspen	**28**	**7**	6	tr	—	—
blue spruce	**22**	**9**	4	tr	—	—
thinleaf alder	**16**	**9**	**18**	**9**	—	—
narrowleaf cottonwood	7	1	**50**	**24**	—	—
boxelder	—	—	**40**	**15**	18	2
water birch	7	1	**37**	**19**	10	1
Rocky Mountain juniper	1	tr	**20**	**1**	7	tr
Fremont cottonwood	—	—	4	tr	**70**	**22**
#tamarisk	—	—	1	tr	**42**	**7**
#Russian olive	—	—	—	—	**18**	**5**
Shrubs:						
shrubby cinquefoil	**28**	**2**	—	—	—	—
common juniper	**25**	**1**	5	tr	—	—
grouse whortleberry	**22**	**2**	—	—	—	—
twinberry honeysuckle	**21**	**1**	4	tr	—	—
redosier dogwood	11	2	**39**	**14**	2	tr
Woods' rose	10	tr	**30**	**4**	7	tr
mountain snowberry	14	tr	**22**	**1**	2	tr
western white clematis	1	tr	**21**	**1**	10	1
narrowleaf willow	2	tr	13	2	**30**	**6**
skunkbush sumac	—	—	18	4	**30**	**2**
rubber rabbitbrush	1	tr	6	tr	**23**	**1**
Graminoids:						
spike trisetum	**37**	**1**	—	—	—	—
bluejoint reedgrass	**35**	**9**	1	tr	—	—
tufted hairgrass	**27**	**3**	1	tr	—	—
smallwing sedge	**22**	**1**	5	tr	—	—
fringed brome	**21**	**1**	3	tr	—	—

Table 1.3 cont.

Species Name[1]	Conifer-Aspen Zone 91 plots Constancy[2]	Cover[3]	Cool Deciduous Zone 143 plots Constancy	Cover	Warm Deciduous Zone 60 plots Constancy	Cover
#Kentucky bluegrass	29	3	**55**	**15**	23	2
#cheatgrass	—	—	16	2	**53**	**3**
mountain rush	9	tr	6	tr	**25**	**1**
Forbs:						
common yarrow	**53**	**1**	19	tr	—	—
Virginia strawberry	**34**	**1**	1	tr	—	—
bluntseed sweetroot	**26**	**1**	1	tr	—	—
Fendler's meadow-rue	**26**	**1**	4	tr	—	—
Richardson's geranium	**25**	**1**	11	1	—	—
subalpine fleaban	**25**	**1**	—	—	—	—
sticky geranium	**23**	**1**	5	tr	—	—
tall fringed bluebells	**21**	**1**	1	tr	—	—
#common dandelion	**41**	**4**	**35**	**1**	5	0
field horsetail	**38**	**12**	**27**	**5**	7	0
starry false lily of the valley	**29**	**2**	**46**	**5**	7	0
#sweetclover	—	—	6	tr	**32**	**2**
#broadleaved pepperweed	—	—	1	tr	**23**	**1**

[1]# indicates nonnative species.
[2]Constancy is the percentage of plots in which a species occurs. It indicates how common a species is within a zone.
[3]Cover is the average cover of a species calculated across all plots in the zone, including the plots where it is absent. tr=trace, less than 0.5 percent cover.
[4]Bold data indicates a species is common within a zone (and facilitates comparison of important species across zones), whereas non-bolded data indicates a species is uncommon.
[5]Number of Samples by Plot Area —

Zone	Area (m^2) 500	400	375	300	200	100	50	Total
Conifer-Aspen	27	7	1	—	—	—	56	91
Cool Deciduous	4	35	—	1	—	—	103	143
Warm Deciduous	—	48	—	1	1	7	3	60

We would have preferred to calculate constancy for a set of plots with the same area as sample area influences the number of species encountered. However, the datasets available for Utah riparian forests use plots ranging from 50 to 500 m^2 (500–5,400 ft^2) in area. Even with this caveat, table 1.3 provides a reasonable comparison of the three zones.

The distributions of most of the shrubs, graminoids, and forbs listed in table 1.3 correspond to the distributions of the tree species used to define the zones. These species can be used to further define or cha acterize the riparian forest zones. A few species are common or abundant in both the Conifer-Aspen and Cool Deciduous zones. Thinleaf alder has a very wide elevation range and occurs in the upper elevations of both the Cool Deciduous and Conifer-Aspen zones. Kentucky bluegrass is common across all three zones, but it occurs twice as often in the Cool Deciduous zone and is much more abundant there than in the other two zones.

Table 1.3 lists the 45 most common and abundant plant species in Utah's riparian forests but does not portray the full species diversity within those forests. The 294-plot dataset includes 639 species, reflecting the wide variety in composition of riparian forest plant communities in Utah. Few species are common throughout a zone, but many are common in one to a few plant communities within a zone.

The Conifer-Aspen Zone

This zone is defined by the dominance of subalpine fir, Engelmann spruce, blue spruce, aspen, or lodgepole pine, or a combination thereof (fig. 1.4, table 1.3). Thinleaf alder communities are also common in this zone. The lower elevational limit for this zone ranges from about 6,700 feet near the Idaho border (42° N) to 8,300 feet at 37.5° N latitude just north of the Arizona border. South of 38° N latitude, this zone overlaps the Cool Deciduous zone in deep shaded canyons and at the foot of north-facing slopes, occurring as low as 6,300 feet. This zone occurs predominantly on National Forest System lands in Utah (fig. 1.3)

Figure 1.4—Conifer-Aspen riparian forest zone: Engelmann spruce and arrowleaf ragwort community type along Geyser Creek, near Geyser Pass in the La Sal Mountains in Utah, elevation 10,230 feet. USDA Forest Service photo by David Tart.

Common understory species in Conifer-Aspen zone riparian forests include bluejoint reedgrass, horsetail, tufted hairgrass, arrowleaf ragwort, red baneberry, shrubby cinquefoil, Columbian monkshood, claspleaf twistedstalk, and blue wildrye (Padgett et al. 1989). Kentucky bluegrass, common dandelion, longstalk clover, or mountain rush, or a combination thereof, is abundant in degraded stands. This zone has the greatest number of native species and the fewest exotic species (table 1.2) though exotic plant species were present on 63 percent of the plots in this zone.

Adjacent riparian shrublands are often dominated by planeleaf and Booth's, Geyer's, Drummond's, or Wolf's willow as well as mountain silver sagebrush and shrubby cinquefoil. Water sedge and Northwest Territory sedge meadows are also common in this zone.

The Cool Deciduous Zone

This zone is defined by the dominance of narrowleaf cottonwood, water birch, or boxelder, or a combination thereof (fig. 1.5, table 1.3). Bigtooth maple and thinleaf alder communities are also common. White fir, Douglas-fir, ponderosa pine, Rocky Mountai juniper, Gambel oak, and (nonnative) crack willow also occur in this zone. Its elevation range varies from 4,400 to 6,700 feet near the Idaho border (42º N), and from 6,100 to 8,300 feet at 37.5º N latitude (fig. 1.1). South of 38º N latitude, the elevation of this zone overlaps with the Warm Deciduous zone in deep shaded canyons and at the foot of north-facing slopes, occurring as low as 4,700 feet. This zone also occurs mostly on National Forest System lands (fig. 1.2)

Figure 1.5—Cool Deciduous riparian forest zone: narrowleaf cottonwood and skunkbush sumac community within a floodplain in Ferron Canyon, Manti-La Sal National Forest in Utah, elevation 6,460 feet. USDA Forest Service photo by Dorothy Wallace-Senft.

Common forest understory species in this zone include redosier dogwood, skunkbush sumac, horsetail, Wood's rose, and narrowleaf willow (Padgett et al. 1989). Cheatgrass, Kentucky bluegrass, and rubber rabbitbrush are abundant in disturbed areas (table 1.3). This zone supports fewer native species and more exotic species than the Conifer-Aspen zone (table 1.2). Exotic plant species were present on 82 percent of the plots in this zone.

Adjacent riparian shrublands are often dominated by redosier dogwood, Booth's willow, narrowleaf willow, or yellow willow. Herbaceous communities include Northwest Territory sedge, Nebraska sedge, and mountain (Baltic) rush meadows.

The Warm Deciduous Zone

This zone is defined by the dominance of Fremont cottonwood, Rio Grande cottonwood, lanceleaf cottonwood, Goodding's willow, velvet ash, desert willow, beechleaf frangula, or the nonnative trees Russian olive and tamarisk, or a combination thereof (fig. 1.6, table 1.3). Peachleaf willow communities also occur in this zone. The upper limit of this zone ranges in elevation from about 4,400 feet near the Idaho border (42º N) to 6,100 feet near the Arizona border (37º N). It overlaps the Cool Deciduous zone in elevation, occurring as high as 6,640 feet in Capitol Reef National Park. This zone occurs on the Dixie National Forest in southwestern Utah but is predominantly below the elevations of other national forests in Utah.

Figure 1.6—Warm Deciduous riparian forest zone: Fremont cottonwood and bulrush community at Seven Mile Wash northwest of Moab, Utah, elevation 4,500 feet. USDA Forest Service photo by David Tart.

Riparian forest understory species in this zone include narrowleaf willow, Emory's baccharis, skunkbush sumac, mule-fat, Nebraska sedge, saltgrass, alkali sacaton, scratchgrass, and cheatgrass. This zone supports fewer native species and more exotic species than the Conifer-Aspen zone (table 1.2). Exotic plant species are present on 97 percent of the plots in this zone.

Adjacent riparian shrublands commonly include narrowleaf willow, arroyo willow, and silver buffaloberry communities. Adjacent riparian herblands commonly include cattail, common threesquare, common reed, hardstem bulrush, Mancos columbine, and mountain (Baltic) rush communities.

Riparian Forest Dominance Types

There are 27 riparian forest dominance types in Utah (table 1.4). Thinleaf alder has a very wide elevation range and occurs in both the Cool Deciduous and Conifer-Aspen zones. Table 1.4 also lists the elevation and latitude ranges of each dominance type.

Table 1.4—Species Density and Distribution of Utah Riparian Forest Dominance Types.

Dominance Type	Common Name	n[1]	Elevation (feet)	Latitude (° N)
Conifer-Aspen zone		**76**		
Abies lasiocarpa	subalpine fir	8	7,240–10,140	37.6–42.0
Alnus incana ssp. *tenuifolia*	thinleaf alder	12	7,240–9,200	37.8–40.9
Picea engelmannii	Englemann spruce	20	6,320–11,120	37.4–42.0
Picea pungens	blue spruce	12	7,120–9,520	37.4–39.6
Pinus contorta	lodgepole pine	16	8,600–10,080	40.6–41.0
Populus tremuloides	aspen	8	5,720–9,610	38.1–42.0
Cool Deciduous zone		**124**		
Abies concolor	white fir	—	No data	No data
Acer grandidentatum	bigtooth maple	—	5,290–7,000	39.7–42.0
Acer negundo	boxelder	23	4,960–8,000	37.9–41.8
Alnus incana ssp. *tenuifolia*	thinleaf alder	11	5,600–7,680	37.7–41.4
Betula occidentalis	water birch	27	4,960–8,310	37.3–42.0
Pinus ponderosa	ponderosa pine	3	6,880–7,800	37.8–40.5
Populus angustifolia	narrowleaf cottonwood	55	4,570–8,920	37.6–42.0
Populus × acuminata	lanceleaf cottonwood	2	5,360–6,080	37.8–40.5
Pseudotsuga menziesii	Douglas-fir	1	6,500	No data
Quercus gambelii	Gambel oak	1	6,040	39.6
Salix fragilis	crack willow	1	6,280	41.9

Table 1.4 cont.

Dominance Type	Common Name	n[1]	Elevation (feet)	Latitude (º N)
Warm Deciduous zone		**45**		
Chilopsis linearis	desert willow	1	4,350	No data
Elaeagnus angustifolia	Russian olive	5	4,150–6,050	37.2–42.1
Frangula betulifolia	beechleaf frangula	1	5,000	38.4
Fraxinus velutina	velvet ash	2	5,360–5,570	37.4
Populus deltoides ssp. *wislizeni*	Rio Grande cottonwood	5	4,960–5,360	40.5
Populus fremontii	Fremont cottonwood	19	3,780–6,750	37.0–41.1
Populus × *hinckleyana*	hybrid cottonwood	2	5,790–5,850	37.6
Salix amygdaloides	peachleaf willow	2	4,670–4,710	40.1
Salix gooddingii	Goodding's willow	1	4,240	37.9
Tamarix chinensis	five-stamen tamarisk	3	4,310–5,280	37.0–39.7
Tamarix ramosissima	tamarisk	4	4,660–4,670	40.1

[1]n = number of plots representing each dominance type (i.e., the sample size).

Riparian Forest Community Types

Table 1.5 lists the riparian forest community types that have been described in Utah. (Scientific names follow the PLANTS Database; USDA NRCS 2022). Table 1.6 lists the publications cited in table 1.5 and the geographic areas to which they apply. Exotic species are indicated by both red text and a superscript 1. Table 1.5 also shows the **wetland indicator status** of the dominant tree and characteristic understory species, the **successional status** of the community type along streambanks (i.e., along the **greenline**), and the successional status of the community type away from streambanks within the riparian zone. Wetland indicator status is from the PLANTS Database (USDA NRCS 2022) and Burton et al. (2011). Sources for successional status along streambanks are Burton et al. (2011), Collins et al. (1992), and Winward (2000). Successional status away from streambanks is based on plant community descriptions from the Forest Service's Intermountain Region (Manning and Padgett 1995; Padgett et al. 1989; Youngblood et al. 1985).

Table 1.5—Community type descriptions for Utah riparian forests.

Conifer-Aspen Zone

Community Type Name	Common Name	Publications (Table 1.6)	Species Wetland Indicator Status	Successional Status: Along Bank	Successional Status: Away from Bank
Abies lasiocarpa	subalpine fir		FACU	Late	Late
Aconitum columbianum	Columbian monkshood	10	FACW	Early	Late
Actaea rubra	red baneberry	9, 10	FAC	Early	Late
Calamagrostis canadensis	bluejoint reedgrass	10	FACW	Late	Late
Cornus sericea	redosier dogwood	10	FACW	Late	Late
Deschampsia cespitosa	tufted hairgrass	10	FACW	Early	Late
Elymus glaucus	blue wildrye	10	FACU	Early	Late
Equisetum spp.	horsetail	10	FACW	Late	Late
Senecio triangularis	arrowleaf groundsel	9	FACW	Late	Late
Streptopus amplexifolius	claspleaf twistedstalk	20	FAC	Late	Late
Trifolium longipes[1]	longstalk clover	20	FACW	Early	Early
Alnus incana ssp. *tenuifolia*	thinleaf alder		FACW	Late	E or L
Carex utriculata	NW Territory sedge	10	OBL	Late	Late
Equisetum spp.	horsetail	10	FACW	Early	Late
Mesic forbs[2]	mesic forbs	10	—	E or L	E or L
Mesic graminoids[3]	mesic graminoids	10	—	E or L	E or L
Picea engelmannii	Engelmann spruce		FAC	Late	Late
Aconitum columbianum	Columbian monkshood	9, 10	FACW	Early	Late
Calamagrostis canadensis	bluejoint reedgrass	9	FACW	Late	Late
Caltha leptosepala	white marsh marigold	9, 10	OBL	Late	Late
Carex tahoensis	Tahoe sedge	12	—	—	—
Deschampsia cespitosa	tufted hairgrass	10	FAC	Early	Late
Eguisetum	horsetail	10	FACW	Late	Late
Poa pratensis[1]	Kentucky bluegrass	10	FAC	Early	Early
Salix planifolia	planeleaf willow	10	OBL	Late	Late
Vaccinium uliginosum	bog blueberry	10	FACW	Late	Late
Picea pungens	blue spruce		FAC	Late	Late
Cornus sericea	redosier dogwood	10	FACW	Late	Late
Dasiphora fruticosa	shrubby cinquefoil	10	FAC	Late	Late

Table 1.5 cont.

Community Type Name	Common Name	Publications (Table 1.6)	Species Wetland Indicator Status	Successional Status Along Bank	Successional Status Away from Bank
Poa pratensis[1]	Kentucky bluegrass	10	FAC	Early	Early
Equisetum spp.	horsetail	10, 14	FAC	Late	Late
Salix brachycarpa	shortfruit willow	14	FACW	Late	Late
Pinus contorta	lodgepole pine		FAC	Early	Early
Calamagrostis canadensis	bluejoint reedgrass	9, 10	FACW	Late	Late
Dasiphora fruticosa	shrubby cinquefoil	10	FAC	Late	Late
Deschampsia cespitosa	tufted hairgrass	10	FACW	Early	Late
Elymus glaucus	blue wildrye	10	FACU	Early	Late
Salix planifolia	planeleaf willow	10	OBL	Late	Late
Vaccinium uliginosum	bog blueberry	10	FACW	Late	Late
Populus tremuloides	quaking aspen		FACW	Early	Early
Cornus sericea	redosier dogwood	10	FACW	Late	Late
Equisetum spp.	horsetail	10	FAC	Late	Late
Salix boothii	Booth's willow	10	FACW	Late	Late
Poa pratensis[1]	Kentucky bluegrass	10	FAC	Early	Early
Q. gambelii / Symphicarpos Oreophilus	Gambel oak / mountain snowberry	2	UPL	Early	Early
Veratrum californicum	California false hellebore	10	FACW	Early	Early

[1]Indicates nonnative species.
[2]Mesic forbs include tall fringed bluebells, Franciscan bluebells, Arizona bluebells, common cowparsnip, Columbian monkshood, starry false lily of the valley, Fendler's waterleaf, red baneberry, Richardson's geranium, and stinging nettle.
[3]Mesic graminoids include water sedge, Northwest Territory sedge, American mannagrass, bluejoint reedgrass, blue wildrye, fowl bluegrass, and the nonnatives creeping bentgrass, and Kentucky bluegrass.

Cool Deciduous Zone

Community Type Name	Common Name	Publications (Table 1.6)	Species Wetland Indicator Status	Successional Status Along Bank	Successional Status Away from Bank
Abies concolor	white fir		FAC	Late	Late
Aconitum columbianum	Columbian monkshood	10	FACW	Early	Late

Table 1.5 cont.

Community Type Name	Common Name	Publications (Table 1.6)	Species Wetland Indicator Status	Successional Status Along Bank	Successional Status Away from Bank
Acer negundo	boxelder		FACW		
Artemisia tridentata ssp. *trid.*	basin big sagebrush	4, 16	UPL	Early	Early
Brickellia grandiflora	tasselflower brickelbush	2	—	—	—
Bromus tectorum[1]	cheatgrass	2, 4, 8, 13, 16	UPL	Early	Early
Celtis laevigata var. *reticulata*	netleaf hackberry	4	FAC	Early	Early
Cornus sericea	redosier dogwood	10	FACW	Late	Late
Equisetum spp.	horsetail	10, 4	FACW	Late	Late
Ericameria nauseosa	rubber rabbitbrush	4	UPL	Early	Early
Forestiera pubescens	stretchberry	?	FACU	Late	Late
Mesic forbs[2]	Mesic forbs	10, 4	—	E or L	E or L
Ostrya knowltonii	Knowlton's hophornbeam	1	FAC	Late	Late
Poa pratensis[1]	Kentucky bluegrass	4	FAC	Early	Early
Prunus virginiana	chokecherry	4	FAC	Early	Early
Quercus gambelii	Gambel oak	1, 16, 8	UPL	Early	Early
Rhus trilobata	skunkbush sumac	4, 1	FAC	Early	Early
Tamarix chinensis[1]	five-stamen tamarisk	13	FACW	Early	Early
Alnus incana ssp. *tenuifolia*	thinleaf alder		FACW		
Cornus sericea	redosier dogwood	10	FACW	Late	Late
Equisetum spp.	horsetail	10	FAC	Early	Late
Mesic forbs[2]	mesic forbs	10	—	E or L	E or L
Mesic graminoids[3]	mesic Graminoids	10	—	E or L	E or L
Betula occidentalis	water birch		FACW		
Cornus sericea	redosier dogwood	10, 3	FACW	Late	Late
Equisetum spp.	horsetail	4	FAC	Early	Late
Mesic Forbs[2]	Mesic Forbs	10	—	E or L	E or L
Mesic Graminoids[3]	Mesic Graminoids	10, 4, 3	—	E or L	E or L
Poa pratensis[1]	Kentucky bluegrass	4	FAC	Early	Early
Rhus trilobata	skunkbush sumac	4	FAC	Late	Late
Rosa woodsii	Wood's rose	1	FACU	Early	Early
Salix boothii	Booth's willow	1	FACW	Late	Late
Salix exigua	narrowleaf willow	1	FACW	Late	Late

Table 1.5 cont.

Community Type Name	Common Name	Publications (Table 1.6)	Species Wetland Indicator Status	Successional Status Along Bank	Successional Status Away from Bank
Pinus ponderosa	ponderosa pine		FACU		
Poa palustris	fowl bluegrass		FAC	Early	Early
Salix boothii	Booth's willow		FACW	Late	Late
Populus × accuminata	lanceleaf cottonwood		FACW		
Betula occidentalis	water birch	10	FACW	Late	Late
Cornus sericea	redosier dogwood	10, 13	FACW	Late	Late
Pascopyrum smithii	western wheatgrass	5	FAC	Early	Early
Rhus trilobata	skunkbush sumac	10	FAC	Early	Early
Salix exigua	narrowleaf willow	5	FACW	Late	Late
Populus angustifolia	narrowleaf cottonwood		FACW		
Acer grandidentatum	bigtooth maple	10	FACU	Late	Late
Betula occidentalis	water birch	10, 4, 13	FACW	Late	Late
Cornus sericea	redosier dogwood	10, 13, 5	FACW	Late	Late
Equisetum spp.	horsetail	10	FAC	Late	Late
Juniperus scopulorum	Rocky Mountain juniper	4, 13	UPL	Early	Early
Poa pratensis[1]	Kentucky bluegrass	10	FAC	Early	Early
Rhus trilobata	skunkbush sumac	10, 4, 1	FAC	Early	Early
Rosa woodsii	Wood's rose	10, 5, 3	FACU	Early	Early
Salix exigua	narrowleaf willow	4, 5	FACW	Late	Late
Sparse understory[4]	sparse understory	4, 14	—	Early	Early
Pseudotsuga menziesii	Douglas-fi		FACU		
Acer negundo	boxelder	4	FACW	Late	Late
Betula occidentalis	water birch	1	FACW	Late	Late
Cornus sericea	redosier dogwood	10, 16	FACW	Late	Late
Salix fragilis[1]	crack willow	10	FAC	Early	Early

[1]Indicates nonnative species.
[2]Mesic forbs include tall fringed bluebells, Franciscan bluebells, Arizona bluebells, common cowparsnip, Columbian monkshood, starry false lily of the valley, Fendler's waterleaf, red baneberry, Richardson's geranium, horsetail, and stinging nettle.
[3]Mesic graminoids include water sedge, Northwest Territory sedge, American mannagrass, bluejoint reedgrass, blue wildrye, fowlbluegrass, and the nonnatives creeping bentgrass, and Kentucky bluegrass.
[4]Sparse understory refers to understories with less than 10 percent total cover of shrubs and herbs.

Table 1.5 cont.

Warm Deciduous Zone

Community Type Name	Common Name	Publications (Table 1.6)	Species Wetland Indicator Status	Successional Status Along Bank	Successional Status Away from Bank
Chilopsis linearis	desert willow		FAC		
Artemisia tridentata ssp. *tridentata*	basin big sagebrush	New	UPL	Early	Early
Elaeagnus angustifolia[1]	Russian olive	17, 2, 4, 6, 16	FAC	Early	Early
Fraxinus anomala	singleleaf ash	2, 15, 16	UPL	Early	Early
Fraxinus velutina	velvet ash		FAC		
Betula occidentalis	water birch	10	FACW	Late	Late
Rhus trilobata	skunkbush sumac	10	FAC	Early	Early
Frangula betulifolia	beechleaf frangula	15	FAC	Late	Late
Ostrya knowltonii	Knowlton's hophornbeam	15, 16	FAC	Late	Late
Populus deltoides ssp. *wislizeni*	Rio Grande cottonwood		FACW		
Acer negundo	boxelder	4, 5	FACW	Late	Late
Artemisia tridentata ssp. *tridentata*	basin big sagebrush	19, 5	UPL	Early	Early
Bromus tectorum[1]	cheatgrass	4	—	Early	Early
Distichlis spicata	saltgrass	4	FAC	Early	Early
Poa pratensis[1]	Kentucky bluegrass	4	FAC	Early	Early
Rhus trilobata	skunkbush sumac	4	FAC	Early	Early
Salix exigua	narrowleaf willow	17, 18, 5, 11	FACW	Late	Late
Populus fremontii	Fremont cottonwood		FACW		
Acer negundo	boxelder	5, 1, 16	FACW	Late	Late
Artemisia tridentata ssp. *tridentata*	basin big sagebrush	6	UPL	Early	Early
Baccharis emoryi	Emory's baccharis	2	—	Early	Early
Baccharis salicina	willow baccharis	16	FACW	Early	Early
Distichlis spicata	saltgrass	15	FAC	Early	Early
Elaeagnus angustifolia[1]	Russian olive	16	FAC	Early	Early
Equisetum spp.	horsetail	6, 15	FAC	Early	Early
Ericameria nauseosa	rubber rabbitbrush	6, 1, 15, 16	UPL	Early	Early
Frangula betulifolia – Quercus gambelii	beechleaf frangula – Gambel oak	16	FAC	Early	Early
Fraxinus velutina	velvet ash	2	FAC	Early	Early
Medicago sativa[1]	alfalfa	17	UPL	Early	Early

Table 1.5 cont.

Community Type Name	Common Name	Publications (Table 1.6)	Species Wetland Indicator Status	Successional Status Along Bank	Successional Status Away from Bank
Mesic forbs[2]	mesic forbs	1, 15, 16	—	E/L	E/L
Mesic graminoids[3]	mesic graminoids	1, 15, 16	—	E/L	E/L
Poa pratensis[1]	Kentucky bluegrass	10	FAC	Early	Early
Rhus trilobata	skunkbush sumac	5, 17	FAC	Early	Early
Salix amygdaloides	peachleaf willow	17	FACW	Late	Late
Salix exigua	narrowleaf willow	17, 2, 6, 1, 15, 16	FACW	Late	Late
Salix gooddingii	Goodding's willow	1, 16	FACW	Late	Late
Salix gooddingii – S. exigua	Goodding's willow – narrowleaf willow	16	FACW	Late	Late
Salix lutea	yellow willow	5, 13, 15	FACW	Late	Late
Sparse understory[4]	sparse understory	17, 16	—	Early	Early
Sporobolus airoides	alkali sacaton	17, 15	FAC	Early	Early
Tamarix chinensis[1]	five-stamen tamarisk	15, 16	FACW	Early	Early
Tamarix ramosissima[1]	tamarisk	17	FAC	Early	Early
Populus × hinckleyana			FACW		
Bromus tectorum[1]	cheatgrass	5	UPL	Early	Early
Salix amygdaloides	peachleaf willow		FACW		
Salix exigua	narrowleaf willow	17	FACW	Late	Late
Salix gooddingii	Goodding's willow		FACW		
Salix exigua	narrowleaf willow	6, 15, 16	FACW	Late	Late
Tamarix chinensis[1]	five-stamen tamarisk	6, 1, 16	FACW	Early	Early
Tamarix ramosissima[1]	tamarisk	4	FAC	Early	Early

[1]Indicates nonnative species.
[2]Mesic forbs include starry false lily of the valley, field horsetail, smooth horsetail, and copperweed
[3]Mesic graminoids include mountain rush, swordleaf rush, scratchgrass, and the nonnative beardless rabbitsfoot grass.
[4]Sparse understory refers to understories with less than 10 percent total cover of shrubs and herbs.

Table 1.6—Literature Cited for Community Type Descriptions for Utah Riparian Forests.

Administrative unit(s)	General area	Citation
1. Capitol Reef National Park	Southern Utah	Clark et al. 2009
2. Zion National Park	Southern Utah	Cogan et al. 2004
3. Great Basin National Park	Eastern Nevada	Cogan et al. 2012
4. Dinosaur National Monument	Northern Utah	Coles et al. 2008a
5. Natural Bridges National Monument	Southern Utah	Coles et al. 2008b
6. Arches National Park	Southern Utah	Coles et al. 2009b
7. Timpanogos Cave National Monument	Northern Utah	Coles et al. 2009a
8. Black Canyon of the Gunnison National Park	Western Colorado	Coles et al. 2010
9. National forests	Northern Utah	Mauk and Henderson 1984
10. National forests	Utah	Padgett et al. 1989
11. Navajo National Monument	Northern Arizona	Salas et al. 2010
12. Great Basin National Park	Eastern Nevada	Schulz and Hall 2011
13. Bryce Canyon National Park	Southern Utah	Tendick et al. 2011b
14. Cedar Breaks National Monument	Southern Utah	Tendick et al. 2011a
15. Canyonlands National Park	Southern Utah	Tendick et al. 2012
16. Glen Canyon National Recreation Area	Southern Utah	Tendick et al. 2017
17. Ouray National Wildlife Refuge	Northern Utah	Von Loh et al. 2002
18. Colorado National Monument	Western Colorado	Von Loh et al. 2007
19. Hovenweep National Monument	Southern Utah	Von Loh et al. 2008
20. National forests	Southern Utah	Youngblood and Mauk 1985
21. National forests	Eastern Idaho and western Wyoming	Youngblood et al. 1985

Wetland indicator status describes how often a plant species occurs in wetlands versus nonwetlands. The codes, names, and descriptions for the ratings in table 1.5 are as follows:

OBL (Obligate Wetland): Almost always occur in wetlands

FACW (Facultative Wetland): Usually occur in wetlands but may occur in nonwetlands

FAC (Facultative): Occur in wetlands and nonwetlands

FACU (Facultative Upland): Usually occur in nonwetlands, but may occur in wetlands

UPL (Obligate Upland): Almost never occur in wetlands

Successional status indicates how soon after disturbance a plant community occupies the disturbed site. **Early seral** communities occupy the site soon after disturbance; **late seral** communities develop over a longer period. While this terminology is conventional, early seral communities dominated by invasive species can persist for a very long time without management intervention. Collins et al. (1992) and Winward (2000) assign successional status to riparian plant communities. Burton et al. (2011) assign successional status to individual species and use those to calculate the successional status of any given community.

Assessing Vegetation Condition

Species diversity varies by riparian forest zone (table 1.2) and dominance type, so identifying the zone and dominance type of a site can serve as a starting point for recognizing vegetation symptoms (i.e., indicators of reduced ecological integrity) and stressors. However, classification of community types provides a more detailed framework or baseline for assessing the response of riparian forests to stressors and natural disturbances. Community type descriptions in the publications in table 1.6 describe their successional status in relation to hydrologic conditions, natural disturbances, and vegetation stressors. They also discuss how species composition, species diversity, and community structure are affected by disturbances and stressors. Assessing vegetation symptoms and identifying stressors using groups of indicator species are discussed in Chapter 3. **Indicator species** and their distributions by forest zone are listed in Appendix A.

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Chapter 2: Conditions and Trends of Riparian Forests in Utah

The purpose of this chapter is to describe the historical context and current condition of Utah's riparian forests, and to describe projections of expected future conditions. First, we discuss the historical context by describing changes in riparian **disturbance regimes** since the 1800s. Second, we summarize current riparian forest conditions using broad-scale maps of the entire state. Third, we offer suggestions for finer-scale data sources that may be useful for planning restoration projects. Fourth, we present projections related to climate and resource demands that are likely to affect Utah's riparian forests in the future.

Historical Context

Current riparian conditions in Utah reflect disturbance regimes that have shifted since the early 1800s (Kalra et al. 2008; Webb and Leake 2006). Although riparian ecosystems are inherently dynamic, many of these shifts are beyond the **natural range of variability** and thus may decrease ecosystem resilience to stressors (Stromberg et al. 2013). Changes to **flow regimes** in many of Utah's riparian systems have included decreased peak flows, increased late summer flows below dams, and lowered **baseflow** below diversions (Webb and Leake 2006). Other anthropogenic effects on riparian vegetation include not only changes in flow regimes, but also lowered water tables, introduction of exotic plant and animal species, intensified or altered grazing regimes with livestock introduction, and decline or extirpation of top-level predators and beaver. Extirpation of top-level predators has had cascading effects on riparian forests, such as excessive herbivory of riparian vegetation (Ripple and Beschta 2006). Additionally, fire regimes in riparian forests have been altered by both increased human-caused fire in riparian sites (fig. 2.1) and a decrease in naturally ignited riparian wildfires, which have led to increased fire frequency in some systems and decreased frequency in others (Dwire et al. 2016; Webb and Leake 2006).

The distribution and composition of riparian plant communities, including forests, depend to a large degree on the frequency and magnitude of flood events because riparian species have life histories that are adapted to flood regimes characterized by snowmelt-driven peaks in late spring or early summer (Merritt et al. 2010). A key component of successful riparian forest restoration projects is restoration of the processes that encourage tree **recruitment** and survival (Wohl et al. 2005). Important characteristics of flood disturbance regimes that affect vegetation include flood timing, duration, magnitude, frequency, rate of change in flows (Poff et al. 1997), and the amount and particle size of sediment that is eroded and deposited during floods (Stromberg 2001).

Figure 2.1—A stand of mature Fremont cottonwoods along the Green River in Utah that human-caused wildfire completely killed. USDA Forest Service photo by Sara Goeking.

The historical context of riparian forest conditions in Utah varies across the three riparian forest zones described in Chapter 1. In general, the Warm and Cool Deciduous zones have been subject to more flow regulation and diversion than the Conifer-Aspen zone. Grazing by domestic livestock, feral horses, and to some degree wild ungulates has also altered riparian forest conditions across zones. Wildfire also affects riparian forests across the elevational gradient, but it is unclear the degree to which contemporary fire regimes differ from the past, and to what extent those differences are due to human activities. Impacts due to timber harvest (human effect) and insect epidemics (natural effect) have been more intense for the Conifer-Aspen zone than for riparian forests at lower elevations. Finally, the history of land management differs across the three elevation zones. Most of the Conifer-Aspen and Cool Deciduous zones occur on National Forest System lands, whereas the Warm Deciduous zone occurs within a mixture of privately owned lands, tribal lands, and areas managed by the U.S. Department of the Interior's Bureau of Land Management (BLM) and National Park Service (NPS), and other ownership categories.

Similarly, the three riparian forest zones differ with respect to typical stream size and **geomorphic processes**. The high-elevation Conifer-Aspen zone consists mainly of high-gradient headwater streams where erosion is the dominant sediment transport process. The Cool Deciduous zone contains a combination of relatively small and midsize streams with a wide variety of longitudinal gradients, which results in both erosion and deposition occurring in different areas throughout this zone. The low-elevation Warm Deciduous zone contains the largest streams and rivers, which tend to flow at lower gradients than streams in other zones and therefore experience more deposition.

Broad-Scale Current Conditions and Data Sources

Published sources that describe current riparian forest conditions are limited to broad-scale maps due to a lack of a single program that conducts detailed **inventory**, **monitoring**, or **assessment** of Utah's riparian forests across all elevation zones and land management groups. Although such assessments are possible, they require coordinated data collection and processing, and no single entity has yet undertaken this level of effort. Detailed assessments of riparian forests are difficult across broad scales, such as for the entire State of Utah, because riparian forests are proportionally rare and many are too narrow to be detected by satellite-based remote sensing. Most satellite-based remote sensing uses free Landsat imagery at 30-meter (98-foot) resolution, which is too coarse to map many narrow riparian areas (Macfarlane et al. 2017b). For project-specific work, finer-scale maps are typically required, such as those developed from high-resolution aerial imagery or ground surveys. Given these limitations, here we describe broad-scale maps of riparian areas across the state, and subsequently discuss data sources that may be most useful for project-level planning.

Broad-scale maps are good for estimating the total area and extent of riparian resources across large areas such as entire states, national forests, or BLM districts. However, because they are based on models and remote sensing, they include errors at finer scales. One assumption of most broad-scale maps is that errors at small scales are not systematically biased. This assumption means that in some areas, maps represent riparian forests that do not exist on the ground (errors of commission), and in other areas, maps omit riparian forests that do exist (errors of omission). The assumption of unbiased errors means that these two types of errors cancel each other out in broad-scale analyses.

There are several statewide datasets that use Geographic Information Systems (GIS) and remote sensing tools to produce broad-scale maps of riparian forest conditions and trends. These maps are based on a combination of satellite imagery, statistical models of potential or existing vegetation, ancillary datasets such as precipitation and temperature, and topographic analysis of Digital Elevation Models (DEMs). The broad-scale maps described briefly here include the following:

- Hydrogeomorphic valley classification (HGVC); see Carlson (2009)
- Landscape Fire and Resource Management Planning Tools (LANDFIRE); see LANDFIRE (2018)

- Riparian Condition Assessment Tool (R-CAT), Utah application; see Macfarlane et al. (2017a)
- National Land Cover Database (NLCD); see Homer et al. (2015)

The Hydro-Geomorphic Valley Classification (HGVC) describes the geologic and topographic controls on **fluvial valleys** in relation to stream gradients and surrounding hillslopes (Carlson 2009). It is important to consider the valley type of a stream reach of interest when considering potential forest restoration alternatives. For example, restoration options that may be successful in a low-energy, unconfined stream may be futile in steeper, higher-energy systems that are confined by adjacent hillslopes (see Chapter 4 for specific management options and when to consider them). Carlson's (2009) HGVC consists of nine valley types (table 2.1), which do not change for a given reach at the timescale considered by resource managers (i.e., years to decades, or even centuries in bedrock-controlled systems). Three main characteristics describe each valley type in the HGVC: (1) the amount of physical energy exerted by flowing water and sediment, which is related to valley characteristics such as gradient; (2) "coupling," or influence, of adjacent hillslopes on the valley bottom; and (3) degree of lateral confinement of the channel within the valley. In Utah, Carlson's (2009) HGVC has been applied only to National Forest System lands (fig. 2.2).

Table 2.1—Hydrogeomorphic valley types defined by Carlson (2009) and percentage of valley length in Utah's National Forests in 8 of the 9 hydrogeomorphic valley types. (Percent of length is not calculated for headwater reaches due to challenges in defining the upper ends of headwater reaches.)

Valley type	Valley gradient	Hillslope gradient	Rosgen valley type[a]	Percentage of statewide length
Headwaters	>4%	Both sides >30%	1	not mapped
High-energy coupled	>4%	Both sides >30%	1	34.7%
High-energy open (uncoupled)	>4%	Variable	2, 3, 6, 7	17.1%
Moderate-energy confined	<4%	Variable	2, 3, 6, 7	13.1%
Canyon	Variable	>70%	4	3.3%
Gorge	Variable	>70%	4	1.7%
Glacial trough	<4%	~10% initially then >30%	5	1.9%
Moderate-energy open (unconfined)	<4%	Variable	6, 9	24.6%
Low-energy floodplain	<0.1%	Generally <30%	8, 9, 10, 11	3.6%

[a]The hierarchical Rosgen stream classification system (Rosgen 1994, 1996) is based on a combination of entrenchment, sinuosity, gradient, dominant channel particle size, and measures of channel geometry such as width:depth ratios. It includes 11 major valley types that collectively affect channel morphology.

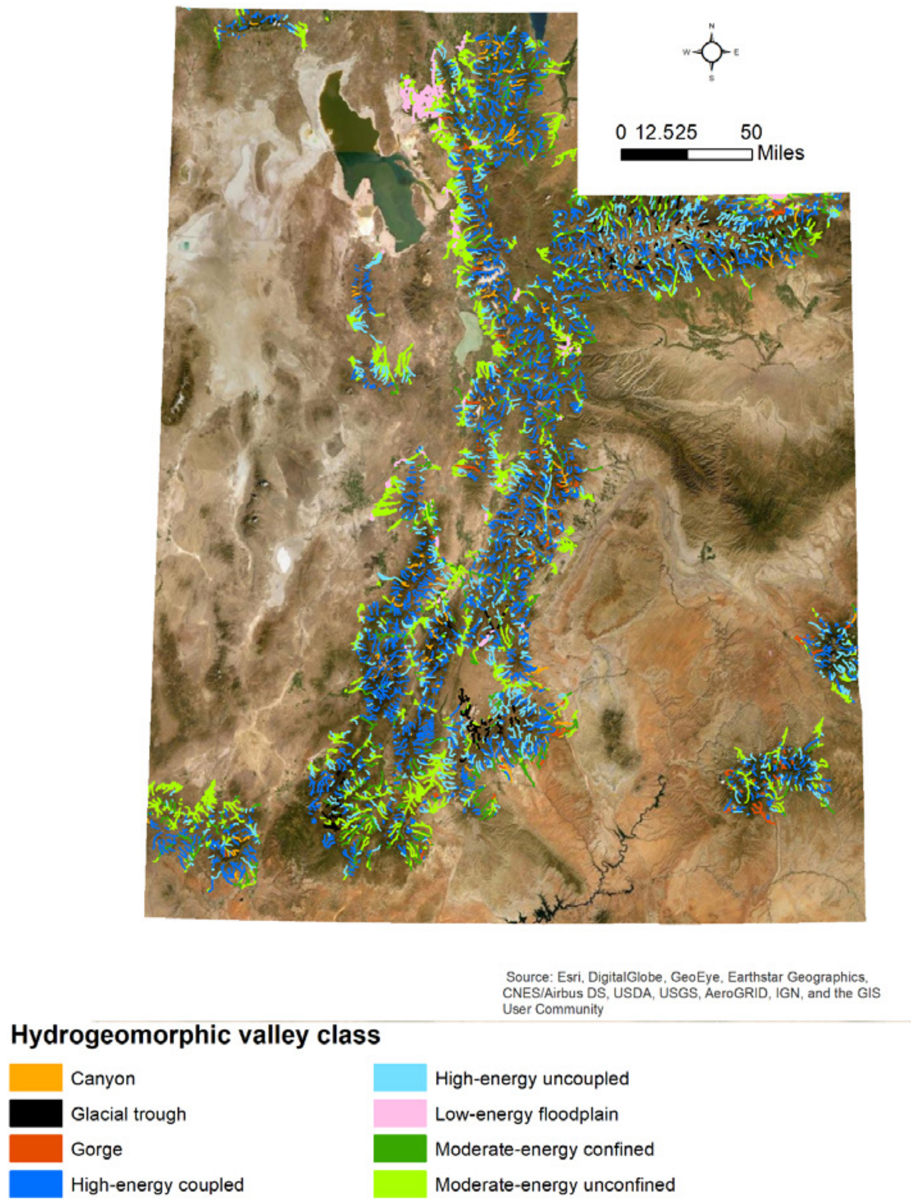

Figure 2.2—Classification of fluvial valleys into the hydrogeomorphic valley types described by Carlson (2009) on Utah's national forests. (Headwater reaches, described in table 2.1, are not included here because of challenges in delineating total length of first-order streams.)

The most common valley types in Utah, in terms of length, are high-energy and moderate-energy types (table 2.1). The high-energy coupled and high-energy uncoupled valley types encompass more than half of the valleys in Utah's national forests (35 percent and 17 percent of statewide stream length, respectively) and occur primarily within the Conifer-Aspen zone. The main difference between these two high-energy types is the degree to which sediment from the adjacent hillslopes, or colluvium, contributes to and is thus "coupled" to the riparian system. Both of these high-energy types occur in steep upper reaches of watersheds near the headwaters where most stream channels do not migrate laterally due to confinement by adjacent slopes. In both high-energy valley types, stream gradients are greater than 4 percent. Adjacent hillslopes are typically steeper than 30 percent in high-energy coupled valleys and variable in high-energy uncoupled valleys. High-energy erosion and deposition zones are highly dynamic, and they do not typically support permanent riparian forests that are distinct from the surrounding uplands.

The other most common valley types in Utah's national forests are moderate-energy unconfined (25 percent of statewide stream length) and moderate-energy confined (13 percent of statewide stream length) valley types, which have gradients less than 4 percent and occur where adjacent hillslopes are variable but typically less than 30 percent. The difference between these two moderate-energy valley types is that unconfined channels tend to migrate laterally, whereas confined channels are constrained within steep hillslopes or bedrock. These types tend to occur within the Cool Deciduous zone, although they can occur in the Warm Deciduous zone.

Other valley types in Utah's national forests represent only minor percentages of total riparian length (table 2.1). However, Utah's riparian forests include many miles within the Warm Deciduous zone that occurs outside of national forests, and can be characterized as canyon, gorge, low-energy floodplain, and moderate-energy systems.

LANDFIRE maps (LANDFIRE 2018) include BioPhysical Setting (BpS) and Existing Vegetation Type (EVT), which have been used to describe historical and current riparian conditions in Utah (Macfarlane et al. 2017a). The LANDFIRE EVT map was developed from a combination of statistical models, field data, Landsat imagery, elevation, and ancillary data such as precipitation and temperature. While the classes in this map include riparian classes, classes representing riparian forests are combined with riparian shrublands or woodlands. LANDFIRE's BpS map represents the vegetation that may have been dominant on the landscape prior to Euro-American settlement and is based on both the current biophysical environment and an approximation of the historical disturbance regime" (see LANDFIRE (2018), BpS page). This layer was developed using numerous state-and-transition models to produce classes that correspond to NatureServe's Ecological Systems classification. The purpose of the BpS dataset is to provide a historical benchmark for understanding the natural range of variability of vegetation cover types, such as through quantitative assessments of vegetation departure from BpS. An additional LANDFIRE dataset that may help managers assess riparian forests, as distinct from riparian areas that may or may not include trees, is Existing Vegetation Cover (EVC), which is generated separately for trees, shrubs, and herbaceous layers. All LANDFIRE datasets are produced at a resolution of 30 meters, based on Landsat resolution, and are freely available online (LANDFIRE 2018).

The R-CAT project (Macfarlane et al. 2017a) encompasses statewide maps as well as a suite of tools that can be applied to finer-scale datasets for project-specific mapping. Existing R-CAT maps have been produced for the entire State of Utah at a resolution of 30 meters based on LANDFIRE data (Macfarlane et al. 2017a). The suite of R-CAT analysis tools, which were used to produce the statewide maps, includes the following functions:

- Valley Bottom Extraction Tool (V-BET; see Gilbert et al. 2016), which uses DEMs to delineate topographic valley bottoms
- Riparian Vegetation Departure (RVD) tool (Macfarlane et al. 2017a), which compares LANDFIRE EVT to LANDFIRE BpS to assess the degree of departure from historical conditions
- Riparian Vegetation Conversion Type (RVCT; see Macfarlane et al. 2017a), which compares LANDFIRE EVT to LANDFIRE BpS to assess the specific type of vegetation conversion relative to historical conditions

Both the Utah datasets and the source code for the suite of tools are provided in Macfarlane et al. (2017a) and can be applied to individual project sites. These types of application are particularly useful where finer-scale input datasets are available.

Summaries based on statewide information from the R-CAT project indicate the extent of current riparian forests relative to the simulated historical extent of riparian forests. Table 2.2 and figure 2.3 show the LANDFIRE EVT orders (LANDFIRE 2018) within the topographic valley bottoms delineated by R-CAT (Gilbert et al. 2016). Approximately 27 percent (3,450 km2, or 852,510 acres) of Utah's riparian areas, as mapped by R-CAT and LANDFIRE EVT, is dominated by trees (table 2.2). Although this document focuses on riparian forests, R-CAT also includes estimates of the types of vegetation conversion that have already occurred throughout Utah's riparian areas, regardless of whether they are riparian forest, riparian shrub, or riparian herbaceous. Figure 2.4 summarizes the RVD and Riparian Vegetation Conversion Type (RVCT) throughout Utah and for specific ecoregions; RVD and RVCT are based on the R-CAT methods and LANDFIRE datasets as described earlier.

Table 2.2—Area and percentage of Utah's valley bottoms (Gilbert et al. 2016) within LANDFIRE Existing Vegetation Type orders (LANDFIRE 2018).

LANDFIRE Existing Vegetation Order	Sum of area within R-CAT[a] riparian valley bottoms in km^2 (acres)	Percentage of total riparian area
Herbaceous- or Nonvascular-dominated	1,364 (337,050)	10.7%
No dominant lifeform	508 (125,529)	4.0%
Nonvegetated	1,147 (283,429)	9.0%

Table 2.2 continued.

LANDFIRE Existing Vegetation Order	Sum of area within R-CAT[a] riparian valley bottoms in km² (acres)	Percentage of total riparian area
Shrub-dominated	6,317 (1,560,958)	49.4%
Tree-dominated	3,450 (852,510)	27.0%
Total	**12,786 (3,159,476)**	**100.0%**

[a]Riparian Condition Assessment Tool (see Macfarlane et al. 2017a)

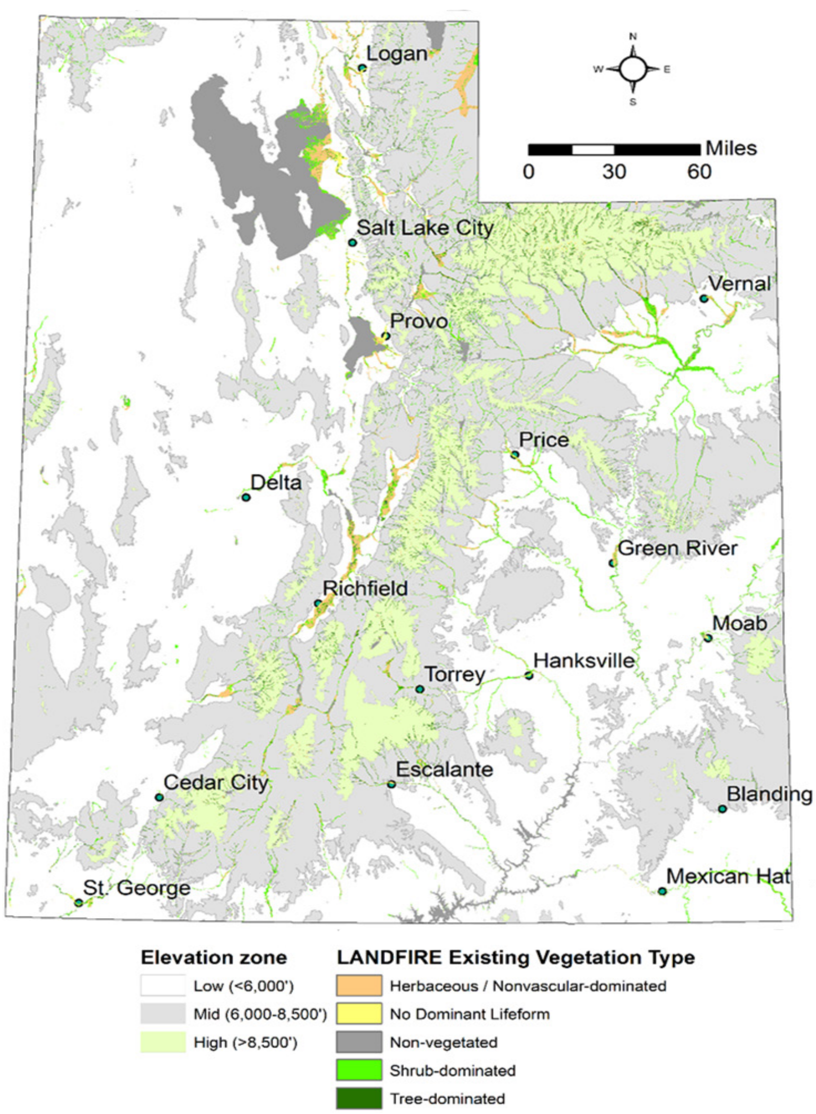

Figure 2.3—Existing vegetation, as mapped by LANDFIRE's Existing Vegetation Type (LANDFIRE 2018). Valley bottoms were delineated by the Riparian Condition Assessment Tool from Gilbert et al. 2016.

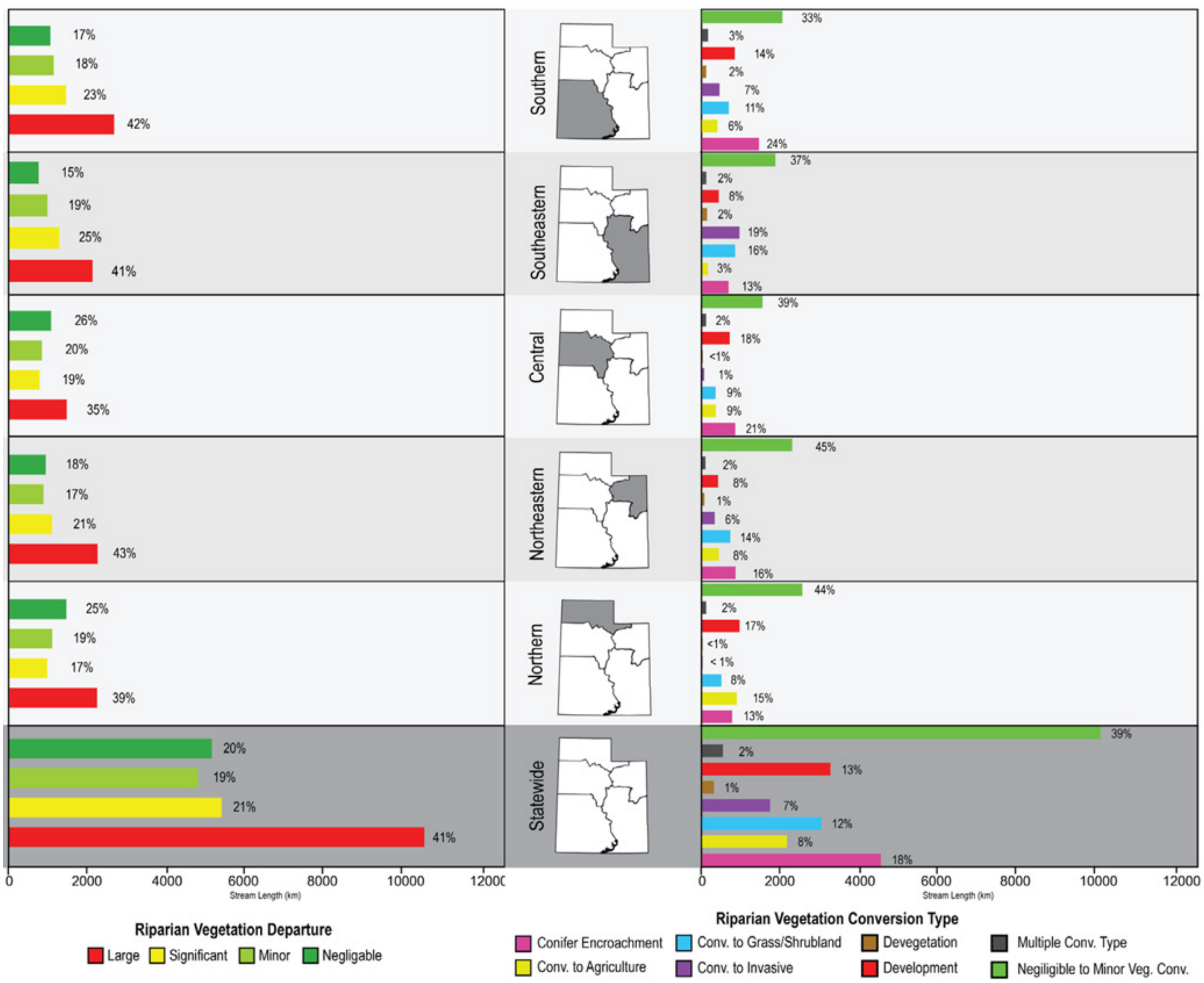

Figure 2.4—Riparian Vegetation Departure (RVD, left) and Riparian Vegetation Conversion Type (RVCT, right) throughout Utah, by U.S. Environmental Protection Agency Level III Ecoregions, across the perennial drainage network of Utah. Image from Riverscapes Consortium n.d.; used with permission.

The National Land Cover Database (NLCD) includes maps of land cover type, tree canopy cover, percent impervious surface (i.e., extent of surfaces that do not allow infiltration), and types of change over time (Homer et al. 2015). All NLCD maps were developed at 30-meter resolution using Landsat satellite imagery. While the land cover types do not explicitly include a riparian class, they do distinguish forest from other cover types, and forest is further divided into deciduous and coniferous forest. The land cover type, tree canopy cover, and percent impervious datasets are often used as inputs to hydrologic models that link upland watershed conditions—including disturbances associated with changes in land cover type—with streamflow (e.g., Mohammed and Tarboton 2014). The most recent layers represent 2016 data. Previous layers as well as change-over-time products extend back to 2011, 2006, and 2001.

Project-Scale Data Projects

Users of this guide should recognize that the data sources mentioned earlier are intended to describe broad-scale context and not site-specific conditions (Merritt et al. 2017). As indicated previously, the spatial resolution of most of these datasets (30 meters) is larger than the width of many ecologically important riparian areas, particularly in desert ecosystems (Macfarlane et al. 2017b). Before planning and executing restoration projects, managers should attempt to obtain or analyze finer-scale data for assessing riparian conditions. For example, the methods used by R-CAT can yield useful results for project planning within narrow riparian systems if they are based on finer-resolution vegetation maps generated from aerial photography (e.g., Macfarlane et al. 2017b).

Because finer-scale data can be difficult and expensive to obtain, here we describe existing, freely available datasets for project-scale assessments that may aid land managers in project planning. They are divided into categories representing (1) vegetation plot data, (2) fine-resolution aerial imagery, and (3) site-specific monitoring data:

1. Vegetation plot data

    - BLM Assessment, Inventory, and Monitoring (AIM) National Aquatic Monitoring Framework—The BLM AIM program recently published guidelines for aquatic monitoring (Miller et al. 2017), and data collected under this program may be useful at a variety of spatial scales (https://aim.landscapetoolbox.org/).

    - The Forest Service's Forest Inventory and Analysis (FIA) program—The FIA program collects data based on a nationally consistent protocol and a probabilistic sample (USDA FS 2021), yet it does not capture adequate riparian data due to the rare distribution of riparian areas across the landscape. Like the NLCD layers described previously, FIA data are best suited to assessments of upland watershed condition at broad scales (https://www.fs.usda.gov/research/programs/fia).

    - Other Forest Service vegetation data – Region 4 of the Forest Service, and individual national forests, collect detailed vegetation data using a variety of sampling protocols for monitoring, mid-level vegetation mapping, and project-level assessments. Some of these data were used to develop the species lists described in Chapter 1 (see the section "Riparian Forests in Utah").

2. Remote sensing data

    - National Agriculture Imagery Program (NAIP)—This USDA imagery program provides multispectral imagery at a resolution of 1 meter (3.28 feet) or smaller and is updated every 2 to 3 years. It is well suited to fine-scale vegetation mapping, particularly for distinguishing trees from other vegetation. Note that despite its no-cost availability, it has not yet been used for statewide riparian forest assessments.

    - Free aerial imagery—Numerous mobile applications (e.g., mobile phone mapping apps) allow users to view high-resolution imagery that can be useful for delineating vegetation types or fluvial surfaces of interest on mobile devices.

    - Fine-scale elevation and other geospatial data are available for much of the state from the Utah Geospatial Resource Center (https://gis.utah.gov/data/elevation-and-terrain/).

3. Site-specific monitoring data

    - Water quality data—The Utah Division of Water Quality, within the Department of Environmental Quality, monitors water quality at many sites throughout the state. Data and user guides are available through the Ambient Water Quality Management System (AWQMS) at https://deq.utah.gov/water-quality/databases-and-information#awqms (note that users are required to create an account to access the data portal).

    - Results from reach level stream and riparian functional assessments: either qualitative assessments such as the Properly Functioning Condition (PFC) assessment, or qualitative or quantitative hybrid assessments such as the Rapid Stream-Riparian Assessment (RSRA) (https://sagelandcollaborative.org/s/RSRA-User-Guide-Version-20_R.pdf).

    - National Wetlands Inventory (NWI)—This program does not yet have substantial or comprehensive coverage within Utah (USDOI FWS 2009), but it is expected to become increasingly useful as more wetland sites are added to the inventory.

    - Riparian and groundwater-dependent ecosystems for specific national forests—A series of recent Forest Service, Rocky Mountain Research Station publications compiled multiple data sources to describe the status, trends, stressors, and resilience of riparian and groundwater-dependent ecosystems in the Ashley National Forest (Smith et al. 2018), Manti-La Sal National Forest (Driscoll et al. 2019), and Dixie and Fishlake National Forests (Smith et al. 2020). These reports are available online at the following links:

- Ashley National Forest: https://doi.org/10.2737/RMRS-GTR-378
- Manti-La Sal National Forest: https://doi.org/10.2737/RMRS-GTR-386
- Dixie and Fishlake National Forests: https://doi.org/10.2737/RMRS-GTR-418

This list may grow as more projects and land management agencies implement new assessment and monitoring programs and subsequently make their data publicly available. Users of this guide are encouraged to contact local offices of the BLM, Forest Service, USDA Natural Resources Conservation Service (USDA NRCS), Utah Division of Water Quality, and Utah Division of Wildlife Resources to determine whether any riparian or aquatic assessment resources exist for their particular project area.

Future Conditions and Uncertainty

Projects that seek to restore ecosystem processes should account for the fact that future conditions are projected to be different from past conditions due to changing demands on water and riparian resources as well as changing climate. Projections are based on climate simulation models, and therefore the exact magnitude of change is uncertain. We limited our brief review of projected changes to those that are anticipated to affect the western United States within this century.

It is possible that riparian forests that maintain access to water will be relatively unaffected by changing climate and resource demands. Such systems can be considered as resilient in the face of future changes. However, several studies predict changes in the timing and magnitude of peak flows due to direct and indirect effects of climate change (Stewart et al. 2004), which are known to affect regeneration and survival of riparian tree species (Stromberg 2001). Specific projections include a shift toward earlier peak flows, with peaks occurring 30 to 40 days earlier in the year (Stewart et al. 2004). Decreases in snowpack have already been observed. Snowpack is projected to decline by up to 60 percent across the western United States, on average, over the next 30 years (Fyfe et al. 2017), which will further decrease both peak and base flows. Riparian forests are considered particularly vulnerable to warmer temperatures because of their dependence on reliable access to water; low elevation forests along small streams are considered the most vulnerable due to both the presence of nonnative plant species and shorter durations of snowpack (Halofsky et al. 2018).

Temperatures are not only projected to increase in the future throughout Utah; increases have already been observed (Dos Santos et al. 2011; Udall and Overpeck 2017). Increasing temperature may also affect regeneration and survival of tree species through three mechanisms. First, higher temperatures will increase potential evapotranspiration and soil moisture deficits during the growing season (Gazal et al. 2006). Differences in water-use efficiency among riparian tree species could lead to declines of native tree species and increases in exotic species such as tamarisk (fig. 2.5), which has a higher water-use efficiency than native cottonwood and willow species

(Nagler et al. 2003), or cheatgrass (fig. 2.6), an annual grass that grows quickly during spring and then dries out by summer.

Figure 2.5—Tamarisk colonizing the active floodplain, which is inundated here during spring runoff. Mature cottonwoods survive on high terraces. USDA Forest Service photo by Sara Goeking.

Figure 2.6—Cheatgrass dominating a Green River terrace in Utah following wildfire. USDA Forest Service photo by Sara Goeking.

Second, the effects of warmer temperatures on streamflow mimic those of drought, as observed in the Colorado Basin during 2000 through 2014 (Udall and Overpeck 2017). This phenomenon led hydrologists to coin the phrase "hot drought" (Udall and Overpeck 2017) to describe periods of lower-than-normal flow caused by higher-than-normal temperatures rather than lack of precipitation. Such temperature-induced droughts are expected to continue or even become more frequent and severe in the future (Udall and Overpeck 2017).

Third, increased temperatures will affect upland watershed condition in ways that alter flows of water and sediment. For instance, a direct effect of increased temperatures and associated moisture deficits has been high drought-related tree mortality throughout the western United States (van Mantgem et al. 2009), due to both direct effects on tree physiology and indirect effects such as increased susceptibility to pathogens and insects (Simler-Williamson et al. 2019). Despite the long-held expectation that tree mortality or canopy removal will inevitably cause an increase in streamflow (Alila et al. 2009; Bosch and Hewlett 1982), in many cases tree mortality has resulted in no change or even decreased streamflow due to altered snowpack dynamics and increased transpiration of surviving and regenerating forest vegetation (e.g., Biederman et al. 2015; Guardiola-Claramonte et al. 2011). In addition, it is almost certain that increased temperatures will lead to intensified fire regimes (Zhu and Reed 2012), which will mean more frequent, more intense, or larger fires (or a combination thereof), although the extent of such shifts in fire regime will vary spatially due to differences in vegetation and topography. At least one study (Sankey et al. 2017) has projected that wildfires in the future will lead to greater erosion and thus increased sedimentation and **turbidity** throughout streams in the western United States.

Although most future projections predict changes in the magnitude and timing of peak flows (Stewart et al. 2004) as well as temperature (Udall and Overpeck 2017), the greatest uncertainty pertains to increasing variability in peak flows, precipitation, and temperature. In some areas, the effects on trees of year-to-year and multiyear variability in climate caused by natural cycles, such as the El Niño-Southern Oscillation (ENSO), may exceed the effects of changes in average temperature or precipitation (e.g., Burt et al. 2015). How these cycles may change under future conditions is not well understood.

In conjunction with climate change, both ongoing and future water management and development may negatively affect riparian forests by disrupting species' life histories and succession. Factors that may further impact Utah's riparian forests include: (1) flow augmentation, such as instream flows that deliver water to downstream users, resulting in increased baseflows; (2) further reduced peak flows and baseflows in areas with withdrawals, flow regulation, or climate-related decreases in streamflow; (3) decreases in sediment delivery due to potential water development projects such as withdrawals or reservoirs that interrupt the flow of sediment or reduce the volume of transportable sediment; and (4) increases in sediment delivery related to wildfire, development, or other changes in upland watershed condition.

The factors we have described—future climate and changing demands on water and riparian resources —collectively present a great challenge to riparian managers. Our intention in listing them here is to emphasize that restoring riparian processes will lead to greater riparian forest resilience in the face of changing future conditions.

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Chapter 3: Factors that Reduce Ecosystem Integrity and Resilience

Introduction

This chapter describes (1) a range of symptoms that are indicative of reduced **ecosystem integrity** and resilience in riparian areas and (2) stressors that potentially cause those symptoms. The goal is to help the riparian manager recognize and quantify indicators of ecological degradation (symptoms), and the factors that may have caused, or may still be causing, the symptoms (stressors). Identification of both symptoms and stressors is necessary before selecting among the potential management options in Chapter 4.

Resilience

Resilient riparian forests can absorb natural disturbances and recover or maintain ecosystem functions and structure. Indeed, natural disturbance regimes are of fundamental importance in maintaining the structure, composition, and function of riparian plant communities. This resilience is a function of the relatively high species diversity supported by the abundant soil moisture. Plant species contribute in different ways to ecosystem attributes and processes such as carbon and nitrogen cycling and the water budget of the ecosystem (Walker et al. 1997). Plant attributes related to these processes include growth rate, mature plant size, biomass, nitrogen-fixing ability, longevity (e.g., perennial, annual), leaf phenology (evergreen vs. deciduous), rooting depth, root distribution, and litter decomposition rate (Walker et al. 1997). Differences in life form, plant height, plant architecture, and phenology also contribute to overall community structure, and thus to wildlife habitat attributes.

The resilience of a plant community is determined by three attributes which are all related to the species composition of the community: **functional redundancy, functional diversity,** and **response diversity**. Within a plant community, functional redundancy refers to multiple species contributing similarly to ecosystem functions or structure (or both) (Enqvist et al. 2003; Leslie and McCabe 2013; Walker et al. 1997). Functional diversity refers to the number of dissimilar species groups making complementary contributions to overall ecosystem function (Enqvist et al. 2003; Leslie and McCabe 2013). The species within a functional group typically differ in their response to various disturbances. Response diversity is "the diversity of responses to environmental change among species contributing to the same ecosystem function" (Enqvist et al. 2003, p. 488). For example, after a fire some species experience 100 percent mortality while others readily resprout. As stressors remove more plant species from a riparian forest, functional redundancy, functional diversity, and response diversity are diminished, making the forest less resilient.

Symptoms, Stressors, and Disturbance

When a riparian forest is subject to one or more stressors outside the range of natural variability for that riparian area, at some point that stress will become detectable and visible as symptoms indicative of an altered ecosystem or reduced integrity. It is the task of a riparian manager to recognize these symptoms, to diagnose what stressors may have led to the symptoms, and if necessary and possible, to prescribe some remedial actions to abate the stress and assist with restoration. The existence of minimally impacted reference sites helps a manager recognize the degree of reduced integrity and develop restoration goals. Reference riparian forests usually would not have been modified by human activities such as agriculture, logging, development, or fire suppression. Ideally, reference forests would be of similar elevation and geomorphology; be dominated by native vegetation; and retain complete ecological functions, processes, and successional states.

Disturbance regimes, including floods and fires, play an important role in maintaining the ecosystem integrity of riparian forests. Some riparian plant species require specific disturbances to regenerate, as when flood depositions and wetting allow cottonwoods and willows to germinate and establish or broken branches become trapped in wetted soils so they can root and become established. Thus, increasing or decreasing the frequency or intensity of flooding or fire may move riparian forests away from their natural dynamic equilibrium. Human alterations can function as stressors that reduce ecosystem integrity and resilience in the face of disturbance regimes. For example, heavy livestock grazing may result in altered species composition, often reducing species and structural diversity, and replacing native, deeply rooted species with nonnative, shallow-rooted, or finely rooted (or combination thereof) species—species that have lesser abilities to withstand impacts from high water flows and other sources of physical disturbance.

In addition, a stressor may itself be a symptom of another stressor, because one stressor may amplify another. For example, forest insects and diseases are stressors, but increases in insect populations may also be symptomatic of higher temperatures that allow more generations of insects to complete their life cycles in a year. Generally, a factor that can be viewed as both a symptom and stressor has been listed in this chapter as a stressor if riparian managers are able to take action to mitigate that stressor and advance riparian forest restoration. One stressor, increasing ambient temperatures over time as a result of climate change, will take global actions to make any significant reductions, though a forest manager may be able to mitigate some of its effects within a particular riparian forest by reducing other stressors (i.e., increasing resilience).

Assessment of Symptoms and Stressors

Assessment of a riparian forest—whether qualitative or quantitative—involves systematically observing or measuring composition, structure, and processes in such a way as to facilitate judgment as to whether a problem exists, how severe the problem may be, and how it may be linked to one or more stressors. Assessments help to estimate the potential and feasibility of various options for eliminating, reducing, or mitigating the problem(s) —that is, how restoration could be undertaken.

A baseline assessment should be conducted before beginning a riparian forest restoration project (See Chapter 5 for methods of assessing various conditions). The baseline assessment provides a snapshot of initial conditions. Ideally, the methods used for the assessment will be repeated as part of a postrestoration monitoring program for several years following the restoration project. Monitoring can provide insights into whether the project is meeting its objectives, or whether additional restoration actions may be needed. Adaptive restoration can maximize the chances of a successful restoration when a restoration action results in an adverse impact. For example, if introducing beavers results in mortality of large trees due to beaver herbivory, then managers may decide to put protective fences around certain trees. By using a baseline, pre-project assessment combined with postrestoration monitoring, managers can identify situations where adaptive management may be warranted to meet project objectives (Nash et al. 2021).

Methods of assessment vary from simple (e.g., photographs or counting an obvious element factor such as number of Russian olive trees) to more rigorous assessments, sometimes requiring specialized skills (e.g., riparian plant species identification) or electronic equipment (e.g., remote sensing of extent of riparian vegetation, drone imagery analysis). Depending on its precision and repeatability, an assessment may serve as a baseline against which subsequent restoration success can be monitored.

If a problem is obvious and can be assessed simply, there may be no need for quantitative or expensive measurements. However, recording precise time and location, even of a photo, is recommended as a best practice because this information characterizes **baseline conditions** for subsequent monitoring. Objective and repeatable methods for assessing symptoms described in this chapter and for monitoring outcomes of restoration efforts are provided in Chapter 5.

In the remainder of this chapter, we describe symptoms (identified by the letter “A”) and stressors (identified by the letter “B”). Each symptom or stressor is also classified into one of three categories: vegetation, **fluvial geomorphology**, and water quality. Each of these three categories is described further in this chapter. The relationship between symptoms and stressors is shown in table 3.1. Potential management options are offered in this table at the intersection of a particular symptom associated with a particular stressor. Note how often more than one potential management option is cited. Very few stressors and very few management options exist in isolation. Stressors are typically linked together in chains of causality, and many management options are linked together in chains of results. Frequently, there is a particular sequence or order in which management options must be implemented for a project to be successful. Appendix D provides a field form and checklist for assessing a riparian forest. Implementation of the management options suggested for specific combinations of symptoms and stressors is described in Chapter 4.

Table 3.1—Decision matrix of observed symptoms, potential stressors, and potential management options for riparian forests.

Management Options

0. Do Nothing (not listed in table)
1. Create Riparian Buffers
2. Remove Conifers
3. Manage Grazing
4. Manage Recreation
5. Install Riparian Plantings
6. Remove Exotic Plants
7. Manage Beaver
8. Stabilize Streambanks
9. Remove or Improve Infrastructure
10. Manage Upland Runoff
11. Alter Streamflows
12. Stabilize Channel Grade
13. Restructure Physical Channel

		Potential Stressors																
		Vegetation							Fluvial Geomorphology					Water Quality/Quantity				
		Ungulate use	Exotic tree establishment	Beaver herbivory	Altered fire regime and fuels	Recreation	Conversion to agricultural use	Forest insects and diseases	Unoccupied beaver habitat	Channel straight-ening or alteration	Riparian infrastructure and floodplain alteration	Upland watershed conditions	Mining/logging legacy	Water diversion	Water addition	Flow variability	Higher ambient temperature	Prolonged or repeated drought
Observed Symptoms: Vegetation	Altered community structure	3	5,6	3,7	2,3,5	4,5,9	1,5	2,5	7	5,13	1,5	10	5	2,3,4,5, 6,11,13		5,11	3,5	3,5,7,11
	Replacement of riparian species by upland species	3			2	4,5,9	1,5		7	5,13	1,2,5,7	2,7		2,3,5,11, 12, 13		5,11	5	2,5,7,11
	Increased invasive species	3,6	5,6		2,3,5,6	4,5,6,9	1,5,6		6	5,6	1,5,6	6,10	6	6			3,5	3,5,6
	Reduced riparian forest acreage			7		1,4	1,5		7	7,9,12,13	1,5,7,9,12	7	5,7,9, 12,13	1,2,3,4, 5,6,9,11,13		11	5	3
	Lack of shade	3	5,7	7	5	1,4,5,9	1,5,6	5	5	7,9,12,13	1,5,9	3,5,10	5,8,11	3,5		11	3,5	
Fluvial Geomorphology	Streambed erosion (incision, entrenchment)	3	6		6,8,12	9,12	12		7,12	7,12	1,7,12	10,12	7,8,9,10, 12,13		11			
	Increased or depleted sediment load	3			5,8,12, 13	8,9,10	1,5		7,12		1,7,9	3,10,12			11		3	3
	Bank erosion	3			4,5,8	4,8,9,10	1,5,8		8,12	5,8	5,8	5,8,13	5,8	8	8	11	5,8	
	Disconnection of floodplain from the channel	3,7	6,13						7,12,13	7,12,13	7,9,12,13			11		11	11	11
	Reduced sinuosity		6,13			1	1,13		7,12,13	7,12,13	1,12,13				12,13			
	Excessive bare soil	3			1,2,3,5, 8,13	4,5,9	1		5,12		3,5						3,4	3,4
	Compacted soil	3				4,9					1,5,9	3,5						
Water Quality/ Quantity	Elevated water temperature	3	5	7	5	1,4,5,9	1	5	7,12	7,9,12,13	1,5,9	3,5	5,8,11,12	7,11	11	11	7	7,11
	Altered macroinvertebrate community	3	5	7	5,10	1,4,5,9	1	5	7,12	7,9,12,13	10	3,10	5,8,11,12	7	11	11	7	7,11
	Altered turbidity	3			1,2,5, 10,12	4,8,9,10	1		7		10	1,9,10	3,4,5,7,8, 9,10,12,13	11	8,13	8,10	8,10	11
	High levels of algae	3				1,4	1		7		3,10	1,3,10					3	3
	Excessive salinity	3,10	5,6			9	1,10,11			8,10	1,8,13	3,10	9	11	11	11		

A. Observed Symptoms

Several symptoms of riparian forest problems are easily recognizable, even when the stressors causing the symptoms may be unclear. We classify symptoms into three types: (1) those exhibited by riparian vegetation; (2) those observed in the interaction between water and adjacent land, that is, fluvial geomorphology; and (3) those manifested in water quality or quantity.

A.1 Vegetation Symptoms

Anthropogenic stressors can alter riparian plant communities in many ways: reducing native species diversity and abundance, altering the physical or age structure (or both) of the plant community, replacing native riparian species with upland species or nonnative plants (or a combination thereof), and reducing tree cover and the amount of shade in the community. Some stressors directly impact the vegetation. Others impact vegetation indirectly by altering fluvial geomorphic attributes of a site. Direct impacts to the vegetation can also result in changes to fluvial geomorphology.

A.1.1 Depleted Native Plant Species Diversity

Riparian forests are some of the most diverse ecosystems in the western United States. Species diversity is most intuitively described in terms of species density, the number of species per unit area (see table 1.2).

High native species density ensures that some plants will be adapted to natural disturbances such as annual fluctuations in streamflow and weather. Both species composition and species density vary in the short term in response to this natural variability, but the ecosystem has the potential to remain resilient in the long term. For example, abundance of individual species may vary between wet and dry years, but in areas with high species density there will be adequate ground cover to protect the soil in most years.

Species density and composition of riparian forest stands can be assessed by determining abundances within five functional groups of riparian species:

1. Late seral species that predominate in minimally stressed riparian forest
2. Native species that proliferate in response to a stressor or natural disturbance
3. Nonnative species that invade in response to a stressor or natural disturbance
4. Nonnative species planted in riparian areas to meet management objectives
5. Native upland species that enter riparian areas from adjacent uplands following a drop in the water table or interruption of natural flood regimes.

Appendix A lists the occurrence of species in these five groups by riparian forest zone. The relative abundance of these five groups provides an initial, general assessment of community composition. The degree to which riparian forest species density may be depleted at a given site is perhaps best judged by comparing the site with an undisturbed or minimally disturbed riparian forest reference site of similar geomorphology and elevation. Community type classifications (tables 1.5, 1.6 in Chapter 1) provide descriptions of both disturbed and undisturbed riparian forest communities. These descriptions are useful for assessing the condition of the riparian forest of concern and in selecting an appropriate reference site.

A.1.2 Altered Community Structure

Plant community structure is the spatial arrangement of plants and life forms resulting from variation in plant size and height, vertical stratification into layers (e.g., different ages or species), and horizontal spacing of plants (Helms 1998; Mueller-Dombois 1974).

In riparian forests, alteration of community structure often involves a reduction in the number of height or diameter classes of trees or shrubs (or both), and in the diversity, height, and cover of herbaceous species. Structural simplification often follows the loss of regeneration or recruitment (or both) of woody plants. Establishment of seedlings of many riparian tree and shrub species is primarily restricted to sediments deposited during periodic flooding (Padgett et al. 1989). Thus, stressors that directly or indirectly alter flood magnitude may lead to reduced seedling establishment and eventually eliminate the shorter height and younger age classes of some woody plants. High levels of herbivory by livestock or wild ungulates (e.g., elk, deer, and moose), or both domestic and wild herbivores, may also lead to suppressed vertical growth of woody plants and depletion of palatable herbaceous species (Padgett et al. 1989).

Altered fire regimes can also change plant community structure. In the Conifer-Aspen zone, reduced fire frequency may result in dog hair thickets of suppressed trees. Over time, this condition can shift diameter and height class distributions toward smaller trees and reduce shrub and herbaceous growth. Reduced fire frequency may also lead to conifers overtopping deciduous trees and shading them out of the stand.

Today, altered community structure is most prevalent in the Warm Deciduous zone, less prevalent in the Cool Deciduous zone, and least prevalent in the Conifer-Aspen zone, reflecting the different intensities of human land use in these zones and the number of introduced exotic riparian species adapted to the Warm Deciduous zone.

A.1.3 Replacement of Riparian Species by Upland Species

Upland plant species (e.g., sagebrush, rubber rabbitbrush) move into riparian areas when a drop in the water table or reduced flow makes conditions too dry for riparian species (Padgett et al. 1989) and high levels of herbivory create open areas. Upland species that enter riparian areas after lowering of the water table are listed in Functional Group 5 in Appendix A.

A.1.4 Increased Invasive Species

Invasive species may enter riparian forests in response to natural or anthropogenic disturbances but may also become dominant in response to stressors. Most invasive species in riparian forests are forbs and grasses (see Functional Group 3, Appendix A), but trees such as Russian olive, tamarisk (i.e., saltcedar, five-stamen tamarisk), and crack willow may be problematic in a given forest (fig. 3.1). Russian olive and tamarisk have such pronounced impacts on riparian vegetation (Pokorny et al. 2020) and geomorphology that we consider them to be both stressors and symptoms. They are described in more detail in Section B.1.2, "Exotic Tree Establishment." Crack willow is an introduced nonnative tree that has replaced narrowleaf cottonwood in some stream reaches along the Wasatch Front.

Figure 3.1—Floodplain dominated by nonnative shrubs and trees, namely tamarisk (light green color) and Russian olive (light gray color). Courtesy photo by Peter Stacey, University of New Mexico.

A.1.5 Reduced Riparian Forest Acreage

Native riparian forest acreage has been lost in Utah due to land use conversion, especially for agriculture. In addition, many streams in Utah have experienced extreme **downcutting** as a result of historical levels of livestock grazing, which removed much of the protective streambank vegetation, as well as a loss of protective vegetation and ground cover on adjacent uplands (Driscoll et al. 2019). To assess whether riparian forest acreage has been reduced, riparian managers should seek aerial photos or other historical evidence of past extent of riparian forest.

A.1.6 Lack of Shade

Riparian vegetation that grows on streambanks shades the water from direct sunlight, which can maintain cool water temperature, and provides cover for wildlife and fish. Mature trees extend their shadows farther across wide streams than shorter vegetation. Shrubs and graminoids provide significant shade on smaller creeks. Intentionally or unintentionally removing streambank vegetation (e.g., by fire, livestock grazing, or recreation; fig. 3.2) can result in the decline of invertebrate, fish, and wildlife habitat quality.

Figure 3.2—Floodplain exhibiting bank erosion, depleted riparian forest species and structure, and lack of shade. Turbidity is high, which may be due to upstream sediment inputs or localized bank erosion. Courtesy photo by Peter Stacey, University of New Mexico.

A.2. Fluvial Geomorphological Symptoms

Fluvial geomorphology refers to the interactions of moving water with surrounding landscapes, particularly stream channels. Fluvial refers to processes associated with running water, geo refers to the Earth, and morphology refers to the **channel** shape. Flowing water and channel shape affect each other. Although fluvial geomorphological symptoms are described separately from vegetative symptoms, vegetation may modify relationships between flowing water, streambanks, and channel shape (fig. 3.3).

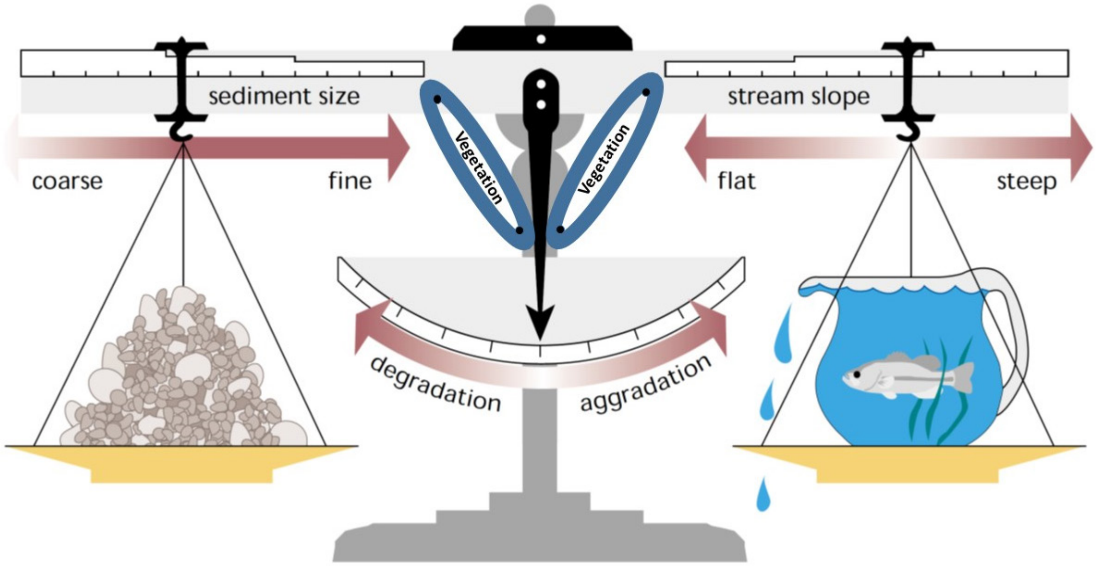


Figure 3.3—Lane's balance (as described by Lane 1955), which demonstrates that sediment size and quantity are in equilibrium with channel slope and water discharge (USDA NRCS 2007f). When one side of the balance is perturbed (e.g., steeper slope, less water, more sediment), the balance shifts and results in either degradation or aggradation of the channel. The blue "rubber bands" in the figure show the buffering effects of vegetation (Nelle 2012).

A.2.1 Streambed Erosion (Incision, Entrenchment)

Streambed erosion is a process by which the elevation of the streambed is lowered. When it occurs at a faster rate than has occurred historically in a particular stream section (i.e., causing downcutting that is uncharacteristic of that site), it becomes a symptom of riparian forest stress. Streambed erosion lowers the river or stream, and often lowers the surrounding water table from which the riparian tree roots draw water.

A.2.2 Increased or Depleted Sediment Load

Sediment is the sand, clay, and silt particles and rock fragments that are transported by and deposited in bodies of water. Whether the **sediment load** is excessive or depleted depends on the natural range of variability of sediment transport and deposition. Some streams have a natural range of variability that includes high loads of fine sediment (e.g., desert rivers fed by spring snowmelt will have high turbidity during spring runoff), while others have lower fine sediment loads but may transport coarse rock fragments (e.g., mountain headwater streams). Thus, the amount and particular sizes of sediment that occurs naturally within a given stream section are a function of watershed geology and geomorphology as well as variability in seasonal and interannual flow.

Excessive sediment is defined here as increased sediment, relative to historical inputs, that enters a water body from accelerated upland soil erosion (e.g., following extreme precipitation, wildfire, high levels of ungulate herbivory, or land clearing) or due to riparian streambank erosion. Sediment in a stream can be depleted below expected levels when inputs from upstream sources are interrupted, for instance by a dam.

While increased or depleted sediment inputs can be symptoms of riparian forest stress, they are usually indicative of some other ultimate stressor (e.g., increased upland erosion). Because many riparian tree species, such as willows and cottonwoods, are dependent on deposits of fine-grained sediment for germination and regeneration (Stromberg 1993), depleted sediment inputs can prevent them from regenerating.

A.2.3. Bank Erosion

Bank erosion is the lateral wearing away of the **banks** of a stream or river and is caused by direct removal of soil and rock by flowing water (**fluvial erosion**). Collapse of a bank (**mass failure**) occurs when the weight of a streambank, or weight placed on the streambank, is greater than the strength of the soil, causing the bank to collapse.

Bank erosion occurs naturally in many sites (e.g., at the outer bend of a meandering stream) and is increasingly seen as an integral process within properly functioning river ecosystems (Florsheim et al. 2008). However, it also occurs as a symptom of riparian degradation when a bank has lost its deep-rooted vegetation and thus provides little resistance to flowing water. Bank erosion often exposes and undercuts the roots of riparian trees. As the roots bind the soil tightly, they form abutments which jut out over the water, and these overhangs often collapse in mass failures when subject to further erosion (fig. 3.4). Mass failure also tends to occur after long-term trampling by livestock or human impacts. Such bank erosion gradually leads to channel widening, which is an additional symptom of degraded riparian vegetation. Water may also have increased capacity to erode when sediment loads are depleted (e.g., below a dam that interrupts the flow of sediment), as illustrated by Lane's balance between the rate of flow and the quantity of sediment that can be entrained and transported (fig. 3.3). Lane's balance demonstrates that stream channels change in response to changes in the amount of sediment or water. A shift in the amount or size of sediment inputs, channel shape, channel slope, or amount of flow can all affect other parts of the stream channel. For example, an increase in the amount of sediment will lead toward aggradation (i.e., deposition; fig. 3.3, right side). The rubber bands labeled as "vegetation" in figure 3.3 represent the ability of riparian vegetation to functionally modulate the effects of changes in sediment or flow inputs. Riparian trees, in particular, stabilize banks and reduce bank erosion. This function of riparian vegetation is particularly important where banks are composed of fine-grained substrate that could otherwise be easily eroded.

Figure 3.4—Tamarisk roots extruding from exposed bank, which lacks native riparian species and overhanging riparian woody vegetation. USDA Forest Service photo by David Tart.

A.2.4 Disconnection of Floodplain from the Channel

A floodplain is an area of low-lying ground adjacent to a stream or river, formed mainly of river sediments and subject to inundation during periods of high discharge (Junk et al. 1989). When streams are connected with their adjacent floodplains, high flows periodically overtop the banks, and overbank flow delivers organisms, sediment, debris, and nutrients from the channel to the floodplain. When a streambed is lowered, or the floodplain is raised or diked such that the stream no longer flows onto the floodplain, sediment that would have otherwise been deposited on the floodplain is transported downstream and the water table drops. Consequently, the roots of riparian vegetation, including riparian trees, lose access to water (fig. 3.5). In addition, most cottonwoods and some other riparian forest trees have evolved to release their seeds during periods of floodplain inundation (Lytle and Merritt 2004). These seeds typically require moist bare mineral soil to germinate and grow. Disconnecting the channel from the floodplain prevents the flooding and sediment deposition needed for successful seedling establishment. Over time, this disconnection contributes to a reduction in riparian forest extent and changes in the size- and age-class distribution of the riparian trees.

Figure 3.5—Example of how an incision of 4 feet may disconnect the root systems of riparian trees from a water source. Courtesy photo by Mary O'Brien, Project Eleven Hundred.

A.2.5 Reduced Sinuosity

The **sinuosity** of a stream or river is its tendency to twist and turn back and forth across its floodplain, or within its valley, in S-shaped patterns over time. A **meander** is one of a series of sinuous curves or windings. A meander is produced by a stream or river as it erodes sediments from an outer, concave bank (**cut bank**), and deposits sediment on an inner, convex bank (**point bar**). Meanders help maintain a stable stream pattern and function and create important aquatic habitat.

When a stream lacks sinuosity or is straightened (or both) (fig. 3.6), the slope of the channel and the speed of flowing water increase, which may lead to scouring and potentially lowering the streambed. A lowered streambed can result in abandonment of longer, lower-gradient meanders, erosion of fine sediment, coarsening of the channel substrate (Gaeuman et al. 2005), and disconnection of the stream from its floodplain (see Section A.2.4, "Disconnection of Floodplain from the Channel").

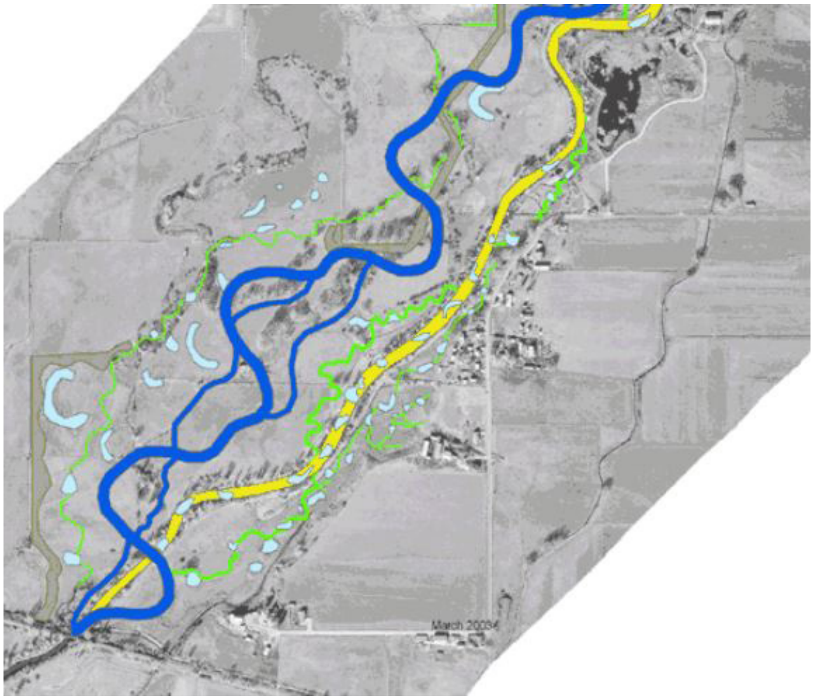


Figure 3.6—A combination of reduced flows and increased sediment supply from upstream gullies resulted in straightening of this Duchesne River channel, 1948-1980. From Gaeuman et al. (2005).

A.2.6 Excessive Bare Soil

The relative proportions of understory vegetation and bare soil vary naturally due to canopy shading (i.e., availability of light) and frequency of flooding. For instance, a dense, mature cottonwood gallery that experiences frequent flooding may have a naturally sparse understory. While bare soil can provide establishment sites for some riparian species, excessive bare soil (i.e., an amount above the natural range of variability) (fig. 3.7) is sometimes a symptom of reduced streamside vegetation, relative to historical conditions, that renders the riparian forest vulnerable to erosion and increased cover of invasive species. Evidence of anthropogenic land uses of the area in question may also suggest whether loss or removal of streamside vegetation is causing increased bare soil.

Figure 3.7—Excessive bare soil. Courtesy photo by Thomas Meinzen, Montana State University.

A.2.7 Compacted Soil

Soil compaction occurs when soil particles are pressed tightly together, reducing pore space between them. Pore space provides room for air and water, and contributes to a healthy environment for plant roots, beneficial microorganisms, and earthworms. Heavily compacted soils have reduced rates of water infiltration and gas exchange (e.g., carbon dioxide, oxygen, water vapor) among air, soil, and vegetation. Soil compaction impedes organic matter cycling and root growth, and in dry years it may lead to stunted, drought-stressed plants (Jordan et al. 2003; vonWilpert and Schaffer 2005).

Compaction by large animal trampling or heavy equipment is most likely to occur with clayey and loamy soils, but even sandy soils, particularly when wet, can be compacted. Wet or moist soils are much more easily compacted than dry soils, and riparian soils stay moist much longer than upland soils, making them more susceptible to compaction.

A.3 Water Quality and Quantity Symptoms

Anthropogenic stressors can alter water quality and quantity in many ways, including raising water temperature, altering the macroinvertebrate community, affecting turbidity, and increasing algal levels and salinity. Some of these symptoms can come about indirectly, for example through increased water temperatures due to decreased shade following reduction in riparian tree canopy. In addition, some symptoms can be further exacerbated by others; for example, the macroinvertebrate community can be depleted through the direct effect of water pollution, but also compounded by increased water temperatures, turbidity, algal levels, or salinity (or a combination thereof).

A.3.1 Elevated Water Temperature

Elevated water temperature reduces the availability of oxygen, carbon dioxide, and other gases important to macroinvertebrates and fish. Because some native fish and amphibian species are highly sensitive to elevated water temperatures (Fraser et al. 2019; Muth et al. 2008), during extended periods of warming, water may lose its potential to support healthy populations of fish and other aquatic organisms and may even eliminate desired species or lead to a change in species diversity.

Several factors influence water temperature. **Surface water** may be heated by ambient air temperature above the water. Lack of riparian shade and direct exposure of the water column to sunlight will elevate water temperature, particularly in smaller streams. Channels with large width-to-depth ratios or reduced summertime flows may also experience increased summertime water temperatures.

A.3.2 Altered Macroinvertebrate Community

The **macroinvertebrate community** of a freshwater stream ecosystem may include worms, arthropods such as aquatic insects and crayfish, and mollusks such as clams, mussels, and snails. Macroinvertebrate communities are useful indicators of aquatic ecosystem health because they are important food sources for fish, easy to collect and identify at the order and class levels (fig. 3.8), have short lifespans, and hence respond quickly to changes in the environment (Chinnayakanahalli et al. 2011; Hawkins et al. 2000). The National Aquatic Monitoring Center (https://namc-usu.org/), associated with Utah State University and BLM, can offer guidance on sampling protocols, process macroinvertebrate samples, and provide reports. By comparing observed to expected macroinvertebrate communities, an average score can be given to a water body that represents its departure from natural conditions (Hawkins et al. 2000). Freshwater macroinvertebrates found in minimally disturbed conditions are indicative of better water quality than those found in streams polluted by sediment, agricultural runoff, or elevated salinity (fig. 3.8).

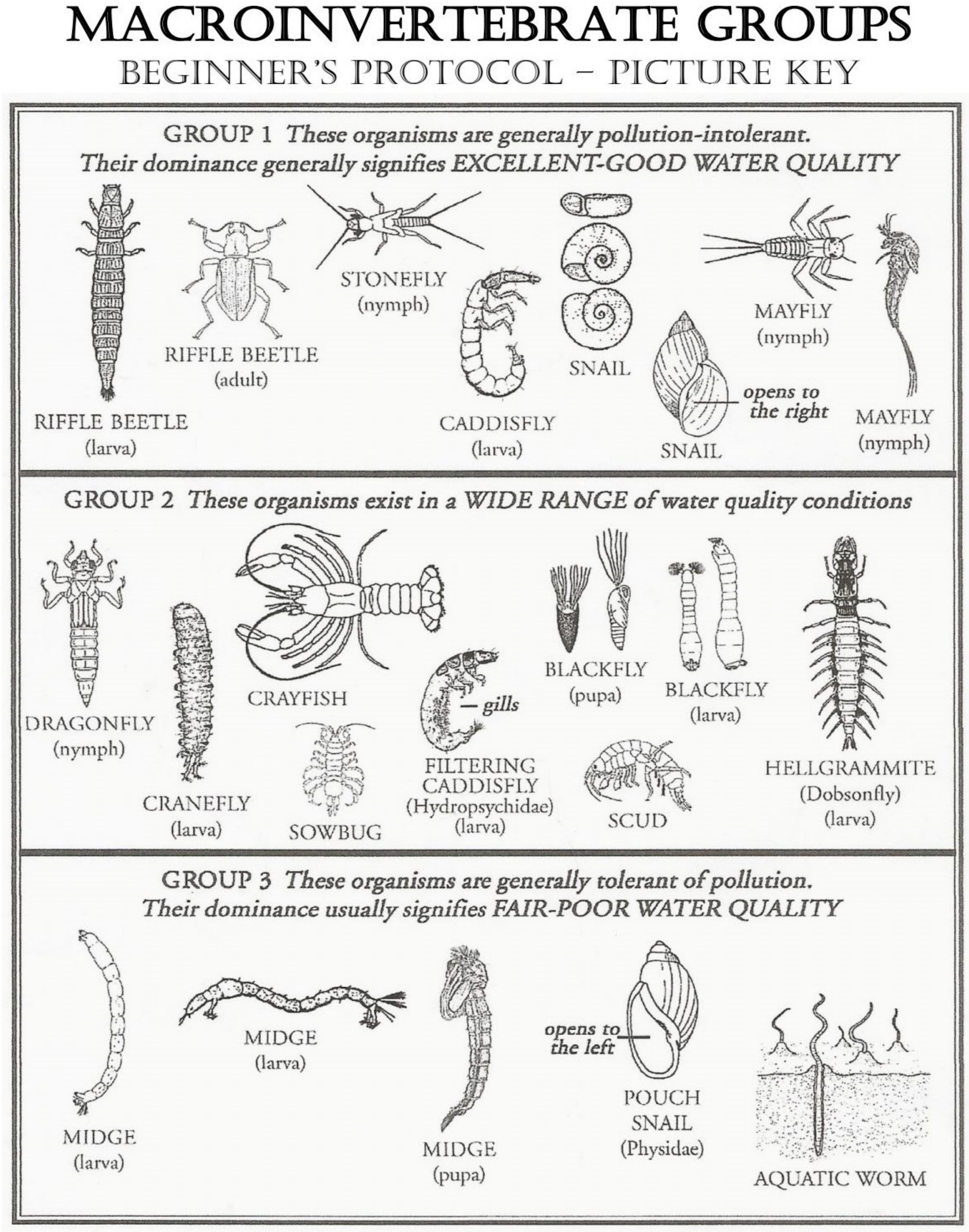


Figure 3.8—Pollution-tolerant and -intolerant macroinvertebrates. Courtesy image by Beaver Water District 2020.

A.3.3 Altered Turbidity

Particles suspended or dissolved in water reflect and scatter light, making the water appear cloudy or murky. Turbidity is a measure of this cloudiness. Particulate matter includes sediment, fine organic and inorganic matter, soluble organic compounds, algae, and other microscopic organisms. Sediment sources include erosion from upland, riparian, streambank, and stream channel areas, each of which may be natural or accelerated through human activities. Increased nutrients and organic matter also feed algae that contribute to turbidity (see Section A.3.4, "High Levels of Algae").

Where natural erosion is high, Utah streams may be naturally turbid. Undisturbed streams in similar geologic and topographic settings and soils may indicate the degree to which a given stream is unnaturally turbid. Turbidity of both disturbed and undisturbed streams is seasonally variable. Streams fed by snowmelt will have highest turbidity during the early snowmelt period. Streams fed by monsoons will have highest turbidity following summer rains. Assessment of turbidity during these periods should be avoided.

Unnaturally high turbidity significantly reduces the aesthetic and recreational quality of lakes and streams and increases the cost of water treatment. It can also harm fish and other aquatic life by reducing food supplies, degrading spawning beds, and affecting gill function.

Observed turbidity may also be lower than expected, particularly below large dams that interrupt and reduce the flow of sediment from upstream. Below diversions, reduced streamflow lowers sediment transport capability, thus reducing turbidity. Unnaturally low turbidity adversely affects some native fishes due to increased predation by nonnative fishes that benefit from increased visibility in clear water (Johnson and Hines 1999; Ward et al. 2016).

A.3.4 High Levels of Algae

The presence of single-celled algae is natural in streams, but high levels of nutrients (especially phosphorus and nitrogen) lead to increased growth of algae and aquatic plants. Elevated water temperatures can also be a cause of high levels of algae in streams. Animal manure, synthetic fertilizer, storm runoff, and wastewater are major sources of nutrient pollution. Algal mats, strands of filamentous algae (fig. 3.9), greenish water, and a smell of rotten eggs (i.e., sulfur) are other indicators of excessive nutrients (USDA NRCS 2017).

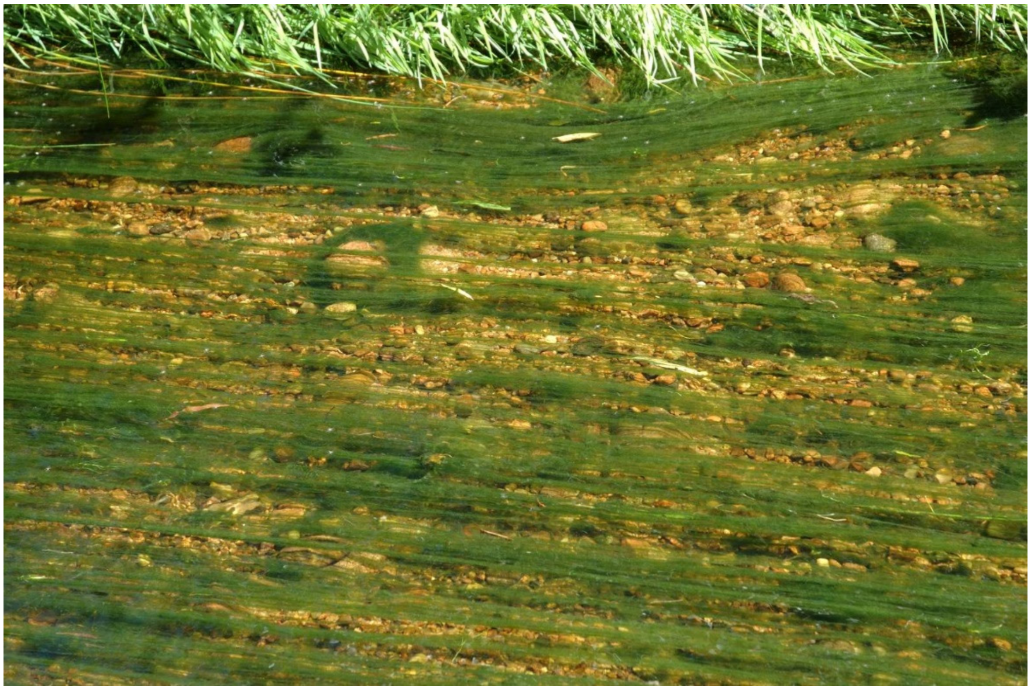


Figure 3.9—Filamentous algae, a sign of high levels of nutrients within the stream. Courtesy photo by Peter Stacey, University of New Mexico.

Algae and aquatic plants provide food and habitat for fish and macroinvertebrates, but high levels of algae decrease the availability of oxygen that fish also need. High levels of algae can produce elevated levels of toxins and bacterial growth that make people and pets sick if they come in contact with or drink the water. The Utah Department of Water Quality maintains a water quality mapper at https://surface-water-quality.ugrc.utah.gov/, which may provide the water quality status of a particular stream.

A.3.5 Excessive Salinity

Salinity refers to the concentrations in water and soils of salts and similar elements, including chlorides, sulfates, carbonates, bicarbonates, calcium, magnesium, sodium, and potassium. Salt occurs naturally in some geologic formations and groundwater aquifers, and it moves in solution in water and soils through natural weathering and transport processes (e.g., dissolution, erosion, and groundwater discharge). Accelerated erosion can transport increased sediment and salt loads into riparian areas and lead to elevated and detrimental levels of salinity in riparian ecosystems. Additionally, irrigation water can transport salts from agricultural areas, causing higher salt concentrations in runoff and groundwater and thereby increasing salinity in riparian areas. Adverse impacts of increased salinity on riparian vegetation and aquatic organisms lead to lower aquatic biodiversity and a loss of desirable vegetation or conversion of plant communities to more salt-tolerant species on riparian fringes (e.g., tamarisk).

B. Potential Stressors

A riparian forest stressor is an environmental condition, external stimulus, or event, typically anthropogenically caused, that negatively affects the growth, survival, or reproduction of some or all organisms in the riparian forest community. Stressors can cause a change in the physiological processes of forest species and can reduce ecosystem resilience, or capacity to return to its previous vegetative composition, physical structure, and processes (or a combination thereof). Changes in the frequency, intensity, or duration of natural disturbances such as fire, flood, drought, or temperature extremes lead to ecosystem stress. Reduced forest resilience can result in any of the symptoms or combinations of symptoms described in the previous section. See table 3.1 for a list of symptoms that are likely to occur as a result of each stressor.

B.1 Vegetation Stressors

B.1.1 Ungulate Use

Excessive ungulate use occurs when plants are exposed to use that is intensive, for extended periods of time, during times when plants are vulnerable, or without sufficient recovery periods (or a combination thereof). Ungulates, particularly cattle, tend to congregate in riparian areas because of the ready access to food, water, and shade. Feral horses and burros likewise congregate near water and within riparian areas and are not herded. Domestic sheep, which are usually actively herded, are less frequently associated with riparian forest symptoms of stress but will readily consume riparian vegetation. Elk and deer are also less often associated than cattle with riparian forest stress because of their lower water consumption rates and reluctance to use riparian areas where humans or predators are present. Like cattle, however, elk and deer readily consume sprouts and saplings of cottonwoods, willows, aspen, and other palatable riparian native species (Beschta and Ripple 2016). Beaver utilize these same woody riparian species for food and dam construction (see Section B.1.3, "Beaver Herbivory").

Herbivory by livestock or wild or feral ungulates (both **grazing** and **browsing**) rarely affects all plant species equally because animals are normally selective in their feeding habits, although the variety of plant species consumed broadens as forage becomes limited during high levels of use. Plants vary in their sensitivity to herbivory throughout the year due to differing life cycles and stages of growth. Herbivory at certain stages will deplete root nutrient reserves or prevent flower or seed production. When herbivory occurs at particular growth stages (e.g., emergence or flowering) for several years in succession, plant reproduction may be adversely affected. Consequently, community composition is typically altered as the more palatable species decrease and less palatable species increase. Species that are highly selected by herbivores may even be eliminated, thus reducing the number of plant species in the plant community. Intensive **utilization** of palatable riparian forest vegetation may also lead to reduction of shade, increased bare ground, and reduced resistance to the establishment and spread of exotic and invasive plant species.

As heavy ungulates seek water in riparian areas, their hooves place stress on overhanging streambanks and can cause them to shear off, increasing sediment input to the stream and widening channels. These widened channels increase solar exposure to the water, which can increase water temperature. When riparian vegetation is depleted by intensive herbivory or trampling (or both), streambanks erode, leading to reduced sinuosity. Trampling by ungulates can also lead to **headcutting** and **incision** of streams or tributaries, which can drop the water table below the reach of riparian vegetation.

Trampling of moist riparian soils and intensive herbivory of understory vegetation increase bare, compacted soils, which reduce availability of water to riparian vegetation. The presence of cattle in streambeds and runoff from bare, compacted streambank soils may lead to increased nutrients from livestock waste that result in excessive algal growth, high turbidity, and elevated levels of coliform bacteria. The composition of the aquatic macroinvertebrate community may be altered as well since particular invertebrates require high levels of dissolved oxygen and low turbidity.

Ranchers and livestock management professionals have become increasingly aware of the implications of the stresses that livestock, particularly cattle, place on riparian areas. Management of livestock in a manner compatible with resilient, diverse riparian vegetation, which includes riparian forests, has become a priority for maintaining the long-term availability of forage and access to water.

B.1.2 Exotic Tree Establishment

The two most invasive, exotic riparian trees in Utah are tamarisk and Russian olive. Other exotic species, such as crack willow and Chinese elm, can be invasive as well.

Tamarisk, a shrub or small tree, thrives in saline riparian soils. Tamarisk further increases salt in these soils by dropping salt-infused leaves. Tamarisk alters ecosystem structure and function through the accumulation of surface salts, changes in fire frequency and intensity, and reductions in species diversity and wildlife habitat (Di Tomaso 1998). The relatively high water use by tamarisk can dry out riparian soils and thus alter vegetation composition. The dense growth of tamarisk (above-ground and below-ground) can armor streams that would otherwise meander, reducing sinuosity. It may also slow flow through the vegetation while accelerating flow through the main channel. The increased flow may increase sediment deposition along streambanks while eroding stream channels, thus potentially disconnecting the floodplain from the channel. The dense growth can also limit human and wildlife use of the riparian areas. Tamarisk displaces native cottonwoods and other native riparian trees that are taller than tamarisk, provide more shade, and eventually generate large woody debris. This concomitant reduction in the amount and quality of canopy cover leads to elevated water temperatures and changes to macroinvertebrate communities.

Russian olive is capable of establishing in a wide variety of conditions (wet or dry), so it spreads quickly and widely throughout riparian areas. The resulting dense monoculture will outcompete native trees. Russian olive trees often enter riparian areas where cottonwoods have been eliminated. Dense growth of Russian olive, like dense growth of tamarisk, can armor streambanks, leading to stream channel narrowing and reduced floodplain inundation. Birds are known to transport Russian olive seeds widely, facilitating expansion into adjacent watersheds. These two exotic tree species support some wildlife; for example, Russian olive supports wild turkey (*Meleagris gallopavo*) and tamarisk, southwestern willow flycatcher (*Empidonax trailii extimus*). Nonetheless, native riparian vegetation contributes to greater avian diversity (Brand 2008).

B.1.3 Beaver Herbivory

In appropriate habitat, dam-building beaver can be premier engineers for stream and riparian restoration. Although beaver use a wide variety of trees and shrubs as construction material, they prefer aspen, cottonwoods, and willows as well as herbaceous species for food (fig. 3.10). Beaver readily cut aspen and cottonwood saplings for food and will fell even large cottonwoods and aspen for dam construction and to reach otherwise inaccessible leaves and twigs. Willows also provide food and materials for dam construction, but often fare better than cottonwoods and aspen in the presence of beaver herbivory because they have multiple stems. Most species within the willow family (i.e., willows, cottonwoods, aspen) sprout from stems (belowground and aboveground portions) as well as roots. However, if beaver cut the stems of mature trees, subsequent ungulate browsing may prevent recruitment (growth above 6.6 feet) from sprouted stems (see Section B.1.1, “Ungulate Use”). Removal of both mature and sprouting aspen and cottonwoods from riparian forests is problematic because regeneration from seed for these taxa is episodic, and may not occur for several years, if at all, following the combination of beaver and ungulate herbivory.

Historically, beaver tended to occur in balance with available vegetation, to the degree that woody materials were sufficient to provide materials necessary for building and maintaining dam structures, while at the same time enhancing and supporting a wide variety of riparian-dependent species. However, as humans altered these systems through a variety of means including livestock grazing, road construction, agriculture, and recreational activities, beaver became an additive stressor in some areas. First, beavers are considered to be a problem when the available vegetation has been reduced, often through the impacts of livestock grazing, which does not allow for adequate regeneration of existing species. In some cases, the impacts of livestock have been so severe that streams become deeply channelized, reducing existing water tables and again not allowing for the regeneration of sufficient woody materials to support beaver. Beavers will then remove any available materials, which can result in a degraded system overall. Young plantings of willows or cottonwoods for recovery may need to be protected from beaver herbivory.

Figure 3.10—Sprouts of a beaver-cut cottonwood, which are vulnerable to browsing. Courtesy photo by Mike Popejoy, Grand Canyon Trust.

Extensive loss from riparian forests of either saplings or mature trees of cottonwoods and aspen may have adverse, short-term consequences, including loss of shade, elevated water temperature, altered macroinvertebrate communities, lack of multiaged canopy structure, and loss of wildlife species habitat provided by overstory cottonwoods and aspen.

B.1.4 Altered Fire Regime and Fuels

In some cases, riparian areas serve as natural fire breaks, while in other cases they may contain more fuels than the surrounding uplands and potentially serve as fire corridors (Everett et al. 2003). When fuels accumulate and conditions are unusually dry, some riparian areas may burn more severely and possibly serve as fire corridors rather than fire breaks (Pettit and Naiman 2007).

Although fire frequency and severity are often lower in riparian areas than upland areas, this is not always the case. Developed recreation sites, such as campgrounds or picnic sites, are often located within riparian forests because of their scenic value and shade. As a result, human-caused wildfires can start within riparian forests (Dwire et al. 2016). Fire suppression, high levels of herbivory, logging and subsequent regrowth, water diversions, channel modifications, and introductions of invasive and upland species have led to shifts in plant species composition, fuel loads, microclimate, and extent of riparian areas; these changes can combine to result in severe fire within and adjacent to riparian areas (Dwire and Kauffman 2003).

Following fire, riparian forests undergo reductions in vegetation and wildlife habitat, including a lack of multiple heights and ages of living shrubs and trees. High levels of bare soil can result in bank erosion, increased sediment input into the stream, and streambed **entrenchment**. Streambed entrenchment following postfire runoff can result in a positive feedback loop for both upland vegetation succession into riparian forests and reduction in riparian forest extent. Both factors create drier riparian areas that have reduced ecosystem function and are more susceptible to future fire.

The disturbed soil may also be vulnerable to increased exotic plant cover. Unless propagules of adapted native plants are available to revegetate the site, the control of invasive plants may lead to establishment of other undesirable plants. Postfire lack of shade and increased sediment load can lead to elevated water temperature and turbidity, reduced macroinvertebrate density or diversity (or both), and fish population declines in affected waterways. Even if a riparian forest does not burn, severe fire within the watershed can result in delivery of sediment, boulders, and debris into the stream channel, affecting riparian forests and downstream waterways, especially during heavy rain events.

Awareness of the links between riparian fuel loads, conifer **encroachment**, and fire risk has led to development of guidelines for fuels treatment specific to riparian areas (Dwire et al. 2016). Some of these treatments combine vegetation (fuel) removal with prescribed burns to decrease fuel loads so that when wildfires do occur, they will burn at a lower severity. Riparian forests are well adapted to disturbance regimes with historical frequencies and severities, and their access to water makes them generally capable of more rapid recovery than adjacent upland areas following severe fires. However, postfire browsing by native ungulates and domestic livestock may slow or prevent vegetative recovery in riparian forests (Dwire et al. 2006).

Conifers are not obligate riparian plants, but they naturally occur in some riparian areas. For example, spruce occur naturally in high-elevation riparian forests. In dry areas, conifers may establish in moist riparian areas but not on adjacent dry slopes. In contrast, juniper may encroach into low-elevation riparian areas due to fire suppression, herbivory of understory vegetation, or disconnection of the channel and floodplain (or a combination thereof). Conifers may provide shade and large woody debris for aquatic habitat, but conifer encroachment often decreases the diversity of riparian plant communities (Dwire et al. 2016). Conifer encroachment into riparian areas can increase fuel loads and change fuel profiles.

B.1.5 Recreation

Riparian forests and adjacent upland areas are popular sites for recreational activities such as motorized and nonmotorized camping, hiking, and fishing because of shade, access to water, and aesthetic value. Roads used to reach riparian areas and campsites often reduce riparian forest acreage. Vehicular and human trampling may eliminate understory vegetation and compact soil, leading to depleted native species diversity, unnaturally high amounts of bare soil, and the introduction and spread of invasive species. Activities in and near the water can cause bank and streambed erosion, which may widen the streambed and reduce sinuosity. Human waste within riparian forest areas may lead to nutrient inputs into the water column that increase algal growth. Increased bare soil in the upland areas contributes to erosion and sediment load and turbidity in the stream. Bare soils containing soluble salts and saline minerals also contribute to salinity in riparian areas when erosion occurs.

The prevalence of recreation in riparian areas increases the risk of fire and spread of invasive plants. Incidental or deliberate removal of tree seedlings and younger trees reduces wildlife habitat and shade, which may elevate water temperature and alter macroinvertebrate habitats. Downed wood and dead trees are frequently collected for firewood and carving of the bark of aspen trees is a problem (Poff et al. 2011) because it is a means of disease entry and spread. Additionally, people often transport insect pests when they bring firewood from elsewhere. For example, the nonnative emerald ash borer (*Agrilus planipennis*) has been transported via firewood and natural dispersal throughout the eastern and central United States. The presence of the emerald ash borer in the Colorado Front Range was confirmed in 2013 (Colorado State Forest Service 2017). Because this invasive beetle attacks and is capable of killing any North American species of ash (Wagner and Todd 2016), it represents a potential threat to Utah's two native ash species, both of which occur in the Warm Deciduous zone.

B.1.6 Conversion to Agricultural Use

Conversion of riparian forest ecosystems to agricultural use has reduced and degraded habitat for native riparian vegetation and terrestrial wildlife, thus changing native species diversity and altering plant community structure along impacted stream segments. In addition, loss of riparian forest can lead to elevated water temperatures and other impacts to aquatic habitats and wildlife. Creation of agricultural fields accompanied by channel straightening or diking has historically reduced sinuosity and increased flow velocity. Finally, some agricultural practices facilitate encroachment by nonnative and invasive plant species, which further impact surrounding riparian forests.

When irrigation practices apply water in excess of the infiltration rate of the soil, and if the field is sloped, excess water may run off the field into the stream channel. Soil remaining bare in an agricultural field can result in soil erosion and delivery of sediment (i.e., increasing turbidity) or pollutants (e.g., pesticides, fertilizers, salts) (or both) to the stream. This influx of sediment, nutrients, and potential pollutants decreases water quality, thus impacting the macroinvertebrate community (fig. 3.8).

Irrigation may increase salinity in soils and groundwater, particularly in arid and semiarid ecosystems. Evaporation of salt-laden irrigation water concentrates the salts in soils, increasing surface soil salinity. High salt content in the root zone may decrease plant-available water, and cause plant stress in plants that are not salt tolerant. Irrigation may also leach salts from the shallow soil zone, dissolve salts that are located deeper in the soil profile, and transport those salts to groundwater that will eventually discharge to streams or springs or become irrigation water.

B.1.7 Forest Insects and Diseases

Insects and pathogens are agents of forest change, and some outbreaks cause landscape-level impacts. For example, widespread insect-caused mortality (fig. 3.11) throughout a watershed may affect the amount of water and sediment reaching riparian forests. The best documented biotic agents of forest change are native bark beetles (family Curculionidae, subfamily Scolytinae), some of which have caused landscape-level change in a relatively short time. Recent large outbreaks have impacted major forest species in Utah such as Engelmann spruce, subalpine and white fir, lodgepole pine, and Douglas-fir (Blackford et al. 2010). There is evidence of new pathogens that can influence alder within riparian areas under stress (Worrall et al. 2010).

Figure 3.11—Mixed-species stand of lodgepole pine and Engelmann spruce with insect-caused tree mortality. USDA Forest Service photo by Forest Inventory and Analysis Program.

Introduced insects and diseases can have ecosystem-altering impacts, fundamentally changing the structure and function of these ecosystems at several scales (Loo 2009; Lovett et al. 2006). For example, balsam woolly adelgid (BWA; Hemiptera: Adelgidae, *Adelges piceae*), a nonnative insect that has been affecting eastern North American fir species, has the potential to seriously impact both riparian and upland ecosystems in several ways. In 2017, ground survey and taxonomic identification confirmed BWA in Utah (Malesky 2018). First, new populations of BWA tend to establish in riparian areas and then spread to upland sites. Second, many of the surrounding susceptible forests have already been substantially impacted by bark beetles, and the combined impacts could be severe enough to reduce stream shading and impact water temperature and flow rates. In the long run, however, impacted ecosystems will experience an increase in down woody material as the recently killed trees senesce and fall. Regional forest health specialists noted extensive subalpine fir mortality on the landscape with noticeable subalpine fir mortality in drainage bottoms. Both ground surveys and increased acreages reported by aerial detection surveys have confirmed a rise in subalpine fir mortality throughout Utah, due in part to BWA and also interactions with native insects, pathogens, and environmental stresses. Vigorously growing trees are preferred hosts of the introduced adelgid and are capable of sustaining larger BWA populations (Hrinkevich et al. 2016). Previous observations in Oregon and Washington have demonstrated that most BWA-caused damage to subalpine fir occurred in mesic environments that supported vigorous tree growth (Hrinkevich et al. 2016).

Climate change and the potential for increased moisture stress in riparian zones as a result of altered timing and amounts of streamflows, as well as increased mean annual temperatures, can directly and indirectly exacerbate impacts from insects and diseases by affecting host tree predisposition and pest life cycles. Consequently, outbreaks of native and introduced forest insects and pathogens are likely to be more common and intense (Simler-Williamson et al. 2019; Sturrock et al. 2011). Stand density also affects the level of stress experienced by individual trees. Sustained overall warmer temperatures can accelerate the development rates of insects and pathogens in forest systems within historically cooler environments where temperatures previously limited development. However, the cumulative effects of climate depend on the seasonal timing of the pest species' reproduction and dispersal, the influence on host susceptibility, and the amount and variability of thermal input, as dictated by geographic location. Most introduced nonnative insects and pathogens in the Intermountain West have not completely populated their potential range, and climate change may impact the rate at which nonnative species expand into previously unoccupied habitats (Malesky et al. 2018). Recent research (Senf and Seidl 2018) indicates that, under pressure from climate change, large-scale insect outbreaks are likely, and that these disturbances can either increase or decrease forest heterogeneity.

If insects or disease remove riparian trees or their leaves, then shade may be reduced either within the forest or, in the case of streambank trees, over the stream. Reduced shade may result in elevated water temperature and altered macroinvertebrate communities.

In order to evaluate effective management options for riparian forest health issues related to insect or disease, accurate diagnosis of the causal agent(s) is required. The Forest Service's Forest Health Protection (FHP) Program provides insect and disease services to land managers and can help with diagnosis of forest health issues. Program specialists provide technical assistance to both public and private land managers on forest health issues and alternative treatment options. More information, including contacts within Utah, are available on the FHP website at https://www.fs.usda.gov/main/r4/forest-grasslandhealth.

B.2 Stressors to Fluvial Geomorphology

B.2.1 Unoccupied Beaver Habitat

Beaver build dams in streams to impound water, because deeper water provides protection from predators and ease of travel through a stream ecosystem. These dams are the mechanism by which beavers benefit riparian forests and streams (Chapter 4, option 7 – Reintroduce Beaver). Beaver prefer to build dams on small- to medium-sized, low-gradient streams (less than 6 percent slope) that flow through valleys not narrowly bounded by steep slopes. They generally populate the lowest-gradient (1 to 2 percent slope) areas first (Pollock et al. 2018). Beaver generally rely on woody riparian plants for construction of dams, and particularly rely on cottonwoods, willows, and aspen for overwintering food. While beaver ponds may drown some trees, the expansion of the riparian area and groundwater recharge allow for increased riparian forest extent along dammed stream segments (Pollock et al. 2018).

Absence of beaver in a beaver-adapted ecosystem, like absence of fire in a fire-adapted ecosystem, may not at first glance appear to be an active stressor. However, their absence can stress riparian forests through the following mechanisms:

- Increased streambed incision
- Disconnection of the floodplain from the water channel
- Excessive sediment load in stream
- Increased bank erosion
- Reduced sinuosity
- Excessive bare soil
- Reduced aquatic macroinvertebrate density and diversity
- Declines in fish populations
- Increased turbidity
- Reduction of riparian community structure
- Transformation of riparian to upland vegetation
- Increased exotic cover

- Reduced riparian forest acreage
- Loss of shade

B.2.2 Channel Straightening or Alteration

Streams were historically straightened, for instance by the use of artificial cutoffs or hardened banks, to move water more quickly through an area in order to prevent flooding. Generally, it is now illegal to straighten a stream without a permit from both the U.S. Army Corps of Engineers and the State of Utah due to the adverse impacts of channel straightening on aquatic ecosystems. Channel straightening and armoring against meanders increases flooding downstream, where the faster-moving water encounters the stream's lower gradient and higher natural sinuosity. In addition, the water will flow at a more uniform speed throughout a straightened stretch, reducing habitat for fish that are dependent on the complexities of a sinuous stream (e.g., pools and riffles).

The rapid velocity of water in a straightened channel results in increased energy in the stream, which leads to either downcutting or lateral bank erosion. When a straightened channel results in downcutting, streambed erosion incises the channel, thus lowering the water table and leaving riparian vegetation isolated from an accessible water source. Additionally, the lack of meanders reduces the length of a riparian forest edge. The lowered water table will eventually result in reduced riparian forest area, and drier soil conditions will promote replacement of riparian species by upland species, whether native (e.g., sagebrush and rubber rabbitbrush) or invasive. All of these symptoms tied to channel straightening can have the ultimate ecological impacts of reduced structure and depleted native species diversity.

Artificial embankments, or **levees**, are sometimes constructed to prevent flooding or to increase available floodplain area for infrastructure, agriculture, or waterfowl habitat. However, this disconnection of a stream from its floodplain reduces overbank flow and the sediment and nutrient input that it provides to a riparian forest. Levees may also be built naturally, as floods deposit their heaviest materials nearest to the stream. An example of such natural levees occurs along the Green River in the Uintah Basin, where a change in flow regime caused by flow diversions and an upstream dam has resulted in disconnection of the floodplain from the stream channel (Walker et al. 2020).

Some stream channels have been widened intentionally for flood control whereas others are widened unintentionally by recreational vehicles or following bank shearing caused by trampling. A widened channel may result in lack of shade and shallower and warmer water, which may then alter macroinvertebrate communities.

B.2.3 Riparian Infrastructure and Floodplain Alteration

Riparian infrastructure includes buildings, roads, other structures, or agricultural land uses that occur within floodplains. A floodplain is the land adjacent to the streambank that experiences flooding during periods of high discharges (Junk et al. 1989). Riparian forests occupy portions or all of a floodplain. In a natural state, most floodplains are replenished with nutrients and sediment during flooding. The floodplain generally consists of accumulations of gravel, sand, silt, or clay (or a combination thereof).

Floodplains are extensively used for human activities and associated infrastructure. Floodplains often are used for agriculture because they are flat; have deep, organically rich soils; and are near water for irrigation. Water may be drained or ditched from floodplains converted to agriculture or other uses where a high water table is undesirable. Roads are often built in or along floodplains that are relatively open and low-gradient. Valley bottoms are also commonly used for dwellings and recreation sites such as campgrounds because of proximity to water with its aesthetic, cultural, and practical values. Industrial facilities are often located in valley bottoms due to the availability of water for extraction and release of wastes.

Depending on the extent and proximity to streams, human land-use alterations can have a substantial impact on riparian forests. Conversion of riparian forests to other land uses, or impacts from adjacent land uses, often leads to the following impacts: reduced native species diversity and riparian forest acreage; altered plant community structure; replacement of riparian species with upland, invasive, or agricultural species; increased bare soil and erosion; increased turbidity; and compacted soil. Loss of riparian forest shade can lead to elevated water temperature. Nutrient runoff from lawns, agriculture, and sewage treatment plants may contribute to excessive algal growth and alter macroinvertebrate communities.

Streambanks are often armored with riprap to protect floodplain facilities and agriculture or recreational activities from flooding, or to stabilize streambanks in an effort to retain or restore riparian vegetation. However, hard bank stabilization, whether for prevention of overbank flooding, reduction of streambank erosion, or restoration of riparian vegetation, constrains stream meander development, with the potential for increasing the speed of streamflow downstream. Faster streamflow can destabilize streambanks downstream, undercutting riparian forest vegetation. If the constraints on meanders result in straightening of the stream, the increased speed of flow may erode the streambed, increase sediment load and turbidity, and further isolate the floodplain and riparian forest roots from water.

B.2.4 Upland Watershed Conditions

Upland watershed conditions are characterized by the type, extent, frequency, and intensity of disturbance and vegetation cover, which influence both the amount and timing of runoff and erosion. Upland watershed condition can be thought of as a giant sponge, where the ability of the sponge to absorb precipitation and transmit water and sediment at rates within the natural range of variability affects the ecosystem integrity of the riparian area. If riparian areas represent the tube of a funnel that transmits surface water, then the upland areas represent the sides of the funnel.

Excessive upland erosion occurs when soil is removed from a hillslope, or eroded, at a faster rate than would be expected due to natural erosion and weathering processes. Upland erosion becomes excessive when its accelerated rate exceeds the natural range of variability, which is site-specific. When water flows over the soil surface, it may cause erosion of the soil surface, sometimes transporting and depositing soil at considerable distance from the source. **Sheet erosion** is the overland transport of sediment without a well-defined channel. If the water becomes concentrated into narrower flow paths, these small but well-defined channels are called **rills**. If runoff continues to incise and enlarge the rills, gullies can form. Gullies are capable of carrying large quantities of sediment in a short period of time.

Severe disturbance commonly increases upland erosion. Following severe wildfire, erosion and runoff rates may increase, leading to elevated turbidity and higher peak flows that may adversely affect macroinvertebrate communities. Aside from severely burned areas, unpaved roads are typically the main source of sediment in streams and rivers. Dense or steep road networks erode at a higher rate than sparser or lower-gradient roads, and thus contribute to higher stream turbidity. Roads with undersized culverts may contribute even more sediment than roads without culverts or with properly sized culverts or bridges. For example, if runoff after a large storm exceeds the capacity of the culverts, the excess runoff will bypass the culvert and may erode the surrounding hillslope. Additionally, erosion of saline soils from upland areas, including unpaved roads, increases salinity in streams and rivers. Silvicultural prescriptions or timber sales often affect upland erosion rates and stream turbidity, depending on the extent of postharvest rehabilitation. Mitigation actions may include decommissioning and reseeding roads or installing water bars to decrease overland flow and erosion.

Upland vegetation cover may also affect streamflow and turbidity. Tree mortality due to widespread insect epidemics can affect the timing of runoff, because it changes the amount of radiation reaching the snowpack and thus influences the snowmelt rate. Similarly, woody vegetation removal in upland areas may increase snow accumulation and snowmelt rates, which in turn may lead to earlier and larger peak flows as well as decreased summer baseflows. Such changes in the magnitude and timing of peak flows may affect the ability of riparian trees such as cottonwoods to regenerate, given their dependence on flood timing and recession rates (Lytle and Merritt 2004), and thus may alter riparian community structure. Intensive herbivory in upland areas can also contribute to more compacted soil, reduced native species diversity, reduced vegetation cover, increased invasive species, and higher erosion and runoff rates if it is severe enough to expose soils in areas that were previously protected with vegetation. Higher erosion and runoff rates may, in turn, cause high levels of algal growth, increased turbidity, and increased salinity.

If significant portions of the upstream watershed are occupied by buildings, roads, and parking lots, then increased runoff from these impervious surfaces will increase the flow in connected waterways, particularly during high flows following high-intensity rainfall or snowmelt, and cause deepening or widening of the stream channel. Increased water and sediment releases from upstream reservoirs may lead to similar results. Overland flows generally are warmer than the waters that receive them, so they will often increase stream temperatures.

B.2.5 Mining and Logging Legacy

Historical extractive activities such as mining and timber harvest may continue to affect fluvial geomorphology within riparian forests for several decades after those activities cease. As described in this section, these activities had persistent effects on fluvial geomorphology, which in turn affects riparian forest structure and composition. Lingering symptoms may include depleted native species diversity, increased invasive species presence, increased presence of upland species in the riparian zone, and altered community structure. Legacy effects of mining and logging are related to, and sometimes similar to, the previously discussed stressors of channel alteration (Section B2.2), riparian infrastructure (Section B2.3), and upland watershed conditions (Section B.2.4).

Persistent geomorphic symptoms of channel alteration due to historical logging and mining occur mainly because of the method used to transport timber and mining products (figs. 3.12, 3.13). In the case of logging operations, logs had to be transported on the ground from their initial harvest site to nearby streams. Horses typically dragged the logs, resulting in downhill-running furrows that collected rainwater and snowmelt and in turn led to increased soil erosion and stream turbidity. On the north slope of the Uinta Mountains, many streams were used to float logs from high-elevation lodgepole pine forests to the Transcontinental Railroad for use as railroad ties (Merritt 2016). If waterways were too small to transport logs and no irrigation canals were nearby, streams were dammed to collect a reservoir of water, which would eventually fill up with logs and then be breached in a torrent to carry the logs downstream (Merritt 2016). Thus, stream channels and banks were subject to erosion due to both higher-than-normal flows and the effects of large logs hitting the banks and channel bed. This type of harvest and transport occurred again every 20 to 30 years as railroad ties were needed for railroad maintenance, continuing until the 1930s (Merritt 2016). Eventually roads and railways took the place of streams for transporting logs, but this infrastructure also affected riparian forests in many cases.

Figure 3.12—Logs being floated down streams from the harvest site to mills. USDA Forest Service historic photo. Date and location unknown.

Figure 3.13—The remains of an old splash dam. Mill Creek, on the north slope of the Uinta Mountains in Utah, contained splash dams that were used to pond water, which was then released to float the logs to mills downstream along the Transcontinental Railroad. USDA Forest Service photo.

Mining invariably results in small areas of very intensely disturbed ground surface, and large amounts of waste rock or mineral debris (mine tailings and mill tailings) left behind. Historically, such wastes were often discharged very near or directly into streams. Piles of tailings or overburden remaining from mining, and unmitigated mine entrances and shafts, may have undergone, or may still be undergoing, increased erosion. Surface and groundwater flows may also have been affected, and such flow impacts may persist. Finally, water chemistry may be impacted, even if active mining operations ended long ago. Mine drainage is usually strongly acidic, and often has elevated concentrations of heavy metals such as copper, zinc, and lead.

The effects of hardrock mining are typically more severe and persistent than the effects of coal mining, simply because hardrock mining requires additional processing to chemically transform (smelt) the raw material. Occasionally, the soil toxicity is high enough to prevent vegetation from growing, leading to the continuous discharge of toxic soils and runoff into streams and riparian areas, with impacts to stream and riparian biota.

B.3 Water Quality and Quantity Stressors

B.3.1 Water Diversion

Withdrawal of water upstream may lower the water table downstream such that it is below the reach of riparian tree roots or riparian forest understory that retains or covers soil. Upland vegetation will then increase within the floodplain, and streambanks may become prone to accelerated erosion. Alternatively, the mature riparian forest trees may remain, but sprouts may fail to regenerate, or seeds may fail to establish with lack of flooding events and deposition events. Disrupting seedling establishment of native riparian forest vegetation also promotes the growth of invasive species, none of which attains the stature of the largest native species. The resulting long-term reduction in riparian shading causes changes in riparian microclimates and increased water temperatures.

Reduced water volume caused by upstream diversions concentrates pollutants and fine sediments introduced below the diversion. Reduced water volume also reduces the temperature dampening provided by deeper water, and reduces the stream’s ability to move coarse sediments downstream.

If water is diverted into an irrigation channel, a rise in water table there may generate riparian vegetation (though perhaps not riparian forests) along the artificial channel. Transbasin diversions (the moving of water from one watershed to another) may result in loss of riparian forest and fluvial geomorphological integrity in the watershed from which water is diverted.

B.3.2 Water Addition

If water is transferred from one stream or watershed to another (e.g., for irrigation), then a channel that was adapted to lower flows may experience bank erosion, and be deepened, straightened, or widened by the force of higher flows. These geomorphological effects may also result in impaired water quality, via higher turbidity from suspension of the finer sediments mobilized by bank or channel erosion.

A good case study on the effects of water addition to a system is provided by Utah State University, which recently reported on the effects of transbasin diversions from the Strawberry Reservoir into Diamond Fork (URMCC 2020). One of the goals of this project was to restore Diamond Fork Creek, from the Diamond Fork pipeline outlet to the Spanish Fork River in Spanish Fork Canyon. These creeks were adversely affected by unnaturally high flows resulting from streamflow imported to the basin from Strawberry Reservoir. These transbasin diversions began in 1916 and continued until 2004. The additions from the Strawberry watershed into Diamond Fork led to a 100-year flood every year. This problem was alleviated in 2004 when a system of pipelines and tunnels (the Diamond Fork System) was completed as part of the Central Utah Project to carry the previously imported water from the Strawberry reservoir to the confluence of Diamond Fork Creek and the Spanish Fork River. The river has subsequently shown a remarkable trend toward recovery. Channels have narrowed in many locations and the riparian vegetation has returned along streambanks. Although the trend toward recovery is promising, some locations remain where the river is straight and lacks aquatic habitat diversity (URMCC 2020).

B.3.3 Flow Variability

Flow variability refers to how high or low flows may be in a given stream reach at various time scales, and it encompasses the duration, frequency, and timing of particular flow magnitudes. It is affected by dams and diversions and by upland watershed conditions, all of which may alter flow variability compared to historical conditions. Changes in flow variability are often accompanied by changes in sediment transport and turbidity.

Hydroelectric dams typically release water within a consistent ranges of release rates, whereas historical seasonal variations ranged from high spring flows to low flows in late summer and fall. Dams typically not only increase low flows, but also dampen high flows and interrupt the flow of sediment for new deposition and floodplain renewal. If more-natural flows are not restored, riparian forest trees that depend on exposed sediments (e.g., post-flooding) and pre-dam interannual flow variability to germinate, such as cottonwoods, may be unable to regenerate (Birken and Cooper 2006). Tamarisk and Russian olive may be able to invade, outcompeting native riparian forest trees and understory vegetation. Such invasive species may thus alter community structure and reduce native wildlife habitat. The dense stems of tamarisk trap and stabilize sediment, which may raise the bank and disconnect the floodplain from the channel (Allred and Schmidt 1999). The combined effects of vertical accretion (i.e., raised banks or floodplains), establishment of dense stands of tamarisk, and reduced interannual flow variability have resulted in limited establishment of native cottonwoods (Birken and Cooper 2006). Low recruitment of native tree species may eventually result in reduced riparian forest area as mature trees die and are not replaced by younger trees. Additionally, sporadic high releases of water from dams may cause accelerated channel erosion, because high flows with little sediment typically degrade, or erode, the reach below the dam (Williams and Wolman 1984) (fig. 3.3). The interruption of sediment transport below dams also means that there is less sediment available for rebuilding floodplains, which may lead to gradual degradation of both the streambed and banks.

The variability of both flow and sediment transport often increases following upland disturbances such as wildfire. Streams that receive rapid overland runoff from steep slopes and experience flood peaks soon after the rain may become unusually turbid from newly eroded sediment.

Regardless of the root cause or causes, changes to flow and sediment transport may impact aquatic organisms such as fish and macroinvertebrates. The reduction of shade resulting from loss of riparian trees may lead to elevated water temperatures. Changes in turbidity affect macroinvertebrate communities (Haden et al. 2003), and in **intermittent streams**, macroinvertebrate community composition may shift due to changes in the duration of wet versus dry periods (Rocha et al. 2012).

B.3.4 Higher Ambient Temperature

The average annual temperature in Utah has risen over 2 °F since the early 20th century (Frankson et al. 2019). The effects of the 2000–2014 drought on water supply were more severe than expected due to higher-than-normal temperatures, which led to decreased availability of water in the Colorado River Basin. This type of temperature-exacerbated water shortage has been referred to as “hot drought” (Udall and Overpeck 2017; see Chapter 3, “Future Conditions and Vulnerability”). Historically unprecedented warming is projected to continue through the 21st century (Udall and Overpeck 2017). Future droughts are expected to be more severe than historical droughts on the Colorado Plateau, because warmer air temperatures cause higher evaporative demand and thus increase moisture stress. The effects of increased temperature alone are expected to reduce Colorado River flows by 20 to 30 percent by the year 2050 (Udall and Overpeck 2017).

Higher ambient (air) temperatures and associated increased evapotranspiration from vegetation and reduced soil moisture may cause a transition from riparian forest species to more drought-tolerant conifers and shrubs, altering the community structure and reducing riparian forest acreage. Invasive, nonnative species that are more drought tolerant, or complete their life cycles quickly during spring periods of moisture availability (e.g., cheatgrass) may invade riparian forests.

Higher temperatures cause decreased snowpack (as more precipitation falls as rain than as snow) and earlier snowmelt, which may lead to reduced or absent late-summer flows and lowering of the water table. At the same time, water demand by riparian forests may increase with higher temperatures.

Higher temperatures may increase the frequency and spatial extent of wildfire in both upland and riparian areas. Wildfire within riparian areas could affect species composition and eliminate or reduce shade within the riparian forest and over the stream. If streambanks are exposed to more solar radiation because of fire or other loss of shade, excessive bare soil may render the streambank more vulnerable to erosion. Sediment from eroding streambanks and unnaturally bare soil may alter the macroinvertebrate community and increase turbidity. High levels of algae can occur in response to nutrients in runoff.

B.3.5 Prolonged or Repeated Drought

Drought can result from abnormally low precipitation, higher temperatures associated with normal precipitation, or both. If drought is prolonged or repeated, access to groundwater by a riparian forest may be reduced, especially if the groundwater sources are shallow. Understory vegetation cover may be reduced, resulting in bare soil vulnerable to erosion and invasive species. Upland vegetation, which is less dependent on near-surface water, may expand into the riparian area. Intense precipitation or high-flow events following drought may cause erosion of soil that has become less protected by vegetation during the drought and increase turbidity in the water. As described in Section B.3.4, “Higher Ambient Temperature,” higher temperatures have exacerbated the severity of recent droughts and are expected to continue to do so in the future (Udall and Overpeck 2017).

There are several regularly updated indices of drought, including US Drought Monitor (https://droughtmonitor.unl.edu), Evaporative Demand Drought Index (EDDI, https://psl.noaa.gov/eddi/), Vegetation Drought Response Index (VegDri, https://vegdri.unl.edu), and Palmer Drought Severity Index (PDSI, https://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi). Intermountain West Climate Dashboard (https://wwa.colorado.edu/resources/intermountain-west-climate-dashboard) presents numerous, constantly updated measures of climate, drought, and water resources for Utah as well as for Wyoming, Colorado, Arizona, and New Mexico.

Chapter 4: Management Options

Introduction

This chapter presents information on management options listed for restoration in the matrix of underlying stressors and observable symptoms of those stressors (table 3.1). Rarely will any single action achieve all restoration goals—even when applied repeatedly and adaptively. The first and most critical step, where feasible, is passive restoration: the cessation of those anthropogenic stressors that are causing degradation or preventing recovery (Kauffman et al. 1997). Stressors may operate at watershed scales, but symptoms will usually be most observable at smaller spatial scales (e.g., along particular stream reaches). While most restoration projects in the past have been implemented at a site scale, in many instances stressors need to be addressed at larger scales, for example at the scale of allotments or watersheds, to achieve significant recovery of previously altered riparian forests.

An excellent general resource for stream restoration is the Forest Service's "Guidance for Stream Restoration" (Yochum 2018). It is comprehensive and includes most of the management options in this chapter. It can be found at: https://www.fs.usda.gov/biology/nsaec/assets/yochumusfs-nsaec-tn102-4guidancestreamrestoration.pdf.

The *Management Support* section at the end of this chapter presents some information on tackling stressors at a broader scale, for example, when the effects of restoration might extend beyond the project scale, when permits may be required, or when partners or other stakeholders should be involved in a restoration project. Frequently, there are authorities that must approve restoration projects, and often agencies can assist in assembling information or funding, finding collaborators, or obtaining permission to modify stream channels. We recommend that readers take the time to become familiar with this section.

0 – Do Nothing

There are a variety of conditions under which taking no action may be appropriate even though a riparian forest is exhibiting symptoms of reduced integrity. The following conditions describe several situations where a manager's best option may be to do nothing, at least for the time being. In these situations, ongoing monitoring is recommended to determine whether the riparian forest condition is improving over time.

1. **The riparian forest ecosystem is subject to disturbances that are within the natural or historical range of variability**.

   Riparian forests occur in dynamic, water-dominated systems, and are therefore adapted to natural disturbances, particularly drought, flooding, and fire. These disturbances act as temporary stressors and may cause riparian forests to exhibit symptoms of stress. The question for managers is whether a particular riparian forest requires active restoration to recover from disturbance, as opposed to cases where passive restoration would be both sufficient and preferable. Managers should regard restoration decisions as experiments.

However, climate change, with associated rising temperatures, earlier snowmelt, repeated or prolonged drought, and more extreme storm events, can render the assessment of natural range of variability more difficult. If these stressors are having long-term impacts on riparian forests, then symptoms will become increasingly visible. Some riparian forest species may no longer be able to rebound after severe drought; establish seedlings on open, moist soils; or compete against exotic trees such as tamarisk or Russian olive. The aftermath of prolonged drought or an insect infestation may look unsightly and appear to have weakened the forest ecosystem. If younger trees are present, however, they may be able to replace the overstory with an altered, but functional, community structure.

Long-term research in riparian forest ecosystems following disturbance is essential, but often lacking (Smith and Finch 2018). Ongoing monitoring can help determine whether the system is trending toward improved versus degraded condition in terms of riparian forest extent and health. To avoid implementing restoration actions needlessly when symptoms are caused by temporary stressors such as prolonged drought, monitoring should occur across multiple growing seasons before managers decide that the stressor and symptomatic responses are outside the natural range of variability.

2. **Passive restoration may occur once previous stressors are no longer present.**

   Riparian forests are highly resilient and often recover if stressors such as recreation, intensive ungulate use, or logging have already ceased. For instance, if a trail or road has been rerouted away from the channel, livestock are no longer present, or native riparian trees are no longer being cut, then riparian forest recovery may require no further action.

   However, the need for restoration depends on the degree to which critical elements of forest health have been compromised. For instance, if trees' access to water has been reduced through channel incision, or if exotic plants are now dominating and altering conditions for native riparian trees, then active restoration may be required.

3. **More time is needed to monitor the effectiveness of a previous restoration action**.

The ideal outcome of restoration activities is that the ecosystem will no longer require intervention. Monitoring after initial restoration activities have been completed is essential to evaluate success. If restoration activities do not produce a sufficient response, for example if invasive understory species continue to establish and dominate or native plantings fail, then the choice of restoration activity may need to be modified. When restoration activities result in unintended or adverse consequences, different strategies should be considered. It is common for restoration of an ecosystem to be iterative, with the need for some actions to be repeated or adapted. Unfortunately, postrestoration monitoring information, particularly long-term monitoring data, is often unavailable to riparian managers.

4. **Restoration may be socially or economically prohibitive.**

   The initial assessment of both symptoms and stressors is essential for estimating the economic costs of restoration. Some restoration activities may be possible (e.g., limiting heavy recreation use or planting drought-resilient native trees) when other actions that would also be desirable may not be economically or socially feasible (e.g., removal of a road or removing upstream levees). Thorough assessment of what stressors are likely to contribute to which symptoms is key to selecting economically and socially feasible activities for conducting restoration activities.

   References suggested in this guide often highlight options that are inexpensive relative to others; for example, controlling the level of a beaver pond, stabilizing a bank, fencing a riparian area, or removing tamarisk are all relatively low-cost. However, the scale of a particular project is a major determinant of costs. Partnering with State or Federal programs, nongovernmental organizations, or research institutions may make a particular restoration effort more economically feasible.

5. **Restoration may require broader-scale intervention**.

   Stressors that arise outside of the project area (e.g., upstream water diversions, upstream presence of Russian olive) may make restoration within a given riparian forest dependent on collaboration or at least consultation with partners. The *Management Support* section at the end of this chapter presents information on tackling stressors at a broader scale.

1 – Create Riparian Buffers

Riparian buffers are areas adjacent to streams designed to intercept pollutants, protect sensitive wildlife from human disturbance, and manage other environmental concerns such as water quality (Dwire and Lowrance 2006). They effectively create, maintain, or increase the area of protected riparian forests. Buffers can alleviate the effects of human developments, agriculture, and transportation infrastructure and recreation, while enhancing wildlife habitat and ensuring a sustainable and diverse riparian forest plant community (Dwire and Lowrance 2006). Buffer zones can also provide connecting corridors that enable wildlife, including large mammals and predators, to move from one important habitat area to another along a well-buffered riparian corridor. The Forest Service has long employed Best Management Practices (BMPs) for timber sales that include recommendations for a minimum width for riparian buffer zones, where cutting does not occur. For example, on National Forest System lands in the Forest Service's Intermountain Region (Region 4), riparian buffers are to extend at least 100 feet from the stream's edge. Studies have confirmed that these buffer strips reduce erosion and pollution that would otherwise be exacerbated by logging practices (Cristan et al. 2016).

In Utah, a set of forest water quality guidelines has been assembled by the Utah Division of Forestry, Fire and State Lands and Utah State University for landowners, loggers, and resource managers (Gropp and McAvoy n.d.). These guidelines are a collection of voluntary, field- applicable practices for use during forestry activities to protect soil and water resources. They are designed to minimize nonpoint source pollution (sedimentation, soil erosion) associated with forestry activities. The Streamside Management Zone (SMZ) described in these BMPs is analogous to riparian buffer zones, in that it is an area or strip of land adjacent to a stream or other body of water where management practices are designed to protect water quality, aquatic wildlife, and wildlife habitat. Trees and vegetation within the SMZ act as a natural filter to keep sediment out of streams, reduce soil erosion, and buffer the stream from degradation caused by nearby activities. While silvicultural activities are not excluded from the SMZ, they should be closely and carefully managed through the BMPs described in the guidelines (Gropp and McAvoy n.d.).

As streams flow through intact riparian forests, wide strips of functioning streamside habitat, including intact riparian forests, should be conserved or set aside from development through protective designations. Riparian forest buffer areas may include or incorporate the following: wide expanses of natural riparian vegetation on either side of the main channel, **filter strips**, adjacent fluvial wildlife habitats in the associated floodplain, and **vegetative barriers** (Bentrup 2008; MacFarland et al. 2017).

A common question asked by managers, conservationists, and practitioners is: "How wide should buffers be?" As summarized in Johnson et al. (2018), the Riparian Reserves of the Northwest Forest Plan designed riparian widths based on site-potential tree heights (the height of an average tree in late succession stage of stand development) and include minimum buffers of one or two average tree heights (Brosofske et al. 1997; Darveau et al. 1995). As a result, riparian buffer zone widths were conceived as varying among areas with different forest composition and site productivity. Riparian reserve widths could also be variable and shaped to local topography and potential interactions with the stream. Thus, riparian management areas were ecologically defined and based on the overall landscape rather than the tape measure (Johnson et al. 2018).

Buffer width guidance of one to two tree heights has been deemed generally suitable to offer protection to maintain populations of some riparian-dependent amphibians and reptiles (Semlitsch et al. 2009). However, if buffer width is intended to maintain natural patterns of long-term channel dynamics and contributions of large wood, buffer strips of closer to 1,000 m (3,300 feet) may be needed (Latterell and Naiman 2007) in areas with broad floodplains. Utah's land types outside of perennial riparian areas are more arid than the Pacific Northwest, where many of these studies occurred. Nevertheless, this guidance for riparian forest buffers can still be helpful.

When creating buffers, riparian managers should consider the slope, soil types, access to water table, flow regime, and connection of the floodplain to the channel, along with the forage, cover, and movement needs of native terrestrial wildlife. Stream channel type and stage of stream evolution may also help in determining the appropriate width of the buffer. Mangers should devise a planting plan and select plant materials based on the current vegetation type and access to water table when active planting is necessary (USDA NRCS 2010b) (see the *Riparian Planting* section in this chapter). Bentrup (2008) and MacFarland et al. (2017) offer good tools and resources for riparian forest buffer planning and design. Last, adequate fencing and other protection measures should be implemented as appropriate to ensure the success of buffer zones.

It should be noted that if riparian buffers are grazed heavily by cattle or elk, their effectiveness as a buffer zone may be diminished. Efforts to control or ameliorate the effects of herbivory and trampling in riparian forest buffer areas should be considered if this restoration strategy is used (management option 3 – Manage Grazing).

Additional information on riparian buffers is available from the following sources (with publishing agency or entity listed first):

- Utah Department of Natural Resources, Department of Natural Resources, Division of Forestry, Fire, and State Lands, *Utah's Forest Water Quality Guidelines: A Technical Manual for Landowners, Loggers and Resource Managers* (Gropp and McAvoy n.d.); https://extension.usu.edu/forestry/files/rural-forests/forest-management/utah-forest-water-quality-guidelines-technical.pdf
- Forest Service, *Conservation Buffers: Design Guidelines for Buffers, Corridors, and Greenways* (Bentrup 2008); https://www.fs.usda.gov/nac/buffers/index.html

- USDA, *Riparian Forest Buffers: An Agroforestry Practice* (MacFarland et al. 2017); https://www.fs.usda.gov/nac/documents/agroforestrynotes/an49rfb01.pdf
- USDA NRCS, *Conservation Practice Standard 391: Riparian Forest Buffer* (USDA NRCS 2010b); https://www.nrcs.usda.gov/resources/guides-and-instructions/riparian-forest-buffer-ac-391-conservation-practice-standard

2 – Remove Conifers

Native conifer encroachment into riparian areas is widespread in Utah. Such encroachment could also be viewed as natural succession due to reduced natural disturbances. In the past such disturbances either removed conifers periodically or prevented their establishment. Without fire, conifer encroachment may inhibit the establishment and growth of native riparian vegetation through competition for space, light, and water. High densities of native conifers in riparian areas have led to increased fire severity through increased fuel loads, which in turn has accelerated loss of mature riparian vegetation and promoted the establishment and competitiveness of invasive vegetation. Fire without flooding can lead to reduction of native riparian vegetation via recruitment failure. Over time, conifer encroachment has led to reduced area of riparian forest.

There are many ecological benefits of removing encroaching conifers from riparian areas. Woody riparian overstory and midstory species are released from competition, as are herbaceous ground cover species. Improved vegetative conditions often result in improvements in sediment transport, whether via erosion or sedimentation. Finally, removal of conifers and subsequent replacement with more succulent vegetation can reduce the risk of uncharacteristically severe fire because of high fuel loadings and ladder fuels.

Removal of encroaching conifers is now routine in upland settings across Utah, but it remains less common in riparian ones due to concerns over environmental impacts of removal efforts. However, this discrepancy in effort is changing (e.g., Upper Provo Watershed Restoration Phase 3; Utah Department of Natural Resources 2019), as the negative consequences of allowing riparian conifer encroachment are gaining recognition. The most natural conifer removal agent is fire, though due to heavy fuel loadings and the potential for loss of desirable, hard-to-replace riparian forest elements, some reduction or rearrangement (or both) of fuels should be considered before reintroducing fire into riparian forests. Because no conifers native to Utah resprout from their roots, herbicides are not necessary to manage conifer encroachment here. Mechanical approaches that selectively target individual trees are appropriate. On small project areas, in situations where target trees are more widely distributed, or in steep or rocky terrain, chainsaws are the tool of choice. In open ground, in situations where target trees are at high densities, and especially at larger scales, skid steers or heavy equipment are employed, fitted with cutting or masticating implements.

Operating wheeled or tracked equipment in riparian areas calls for special care to avoid soil rutting or compaction, water pollution, and damage to desirable vegetation. A masticating head mounted on a tracked excavator can be especially useful for keeping impacts low, due to the machine's lower ground pressure, rotating house, longer reach, and articulated boom. Another useful practice can be to preflag routes of ingress and egress, to minimize driving in the riparian zone and to avoid sensitive areas.

Increasingly, riparian conifer removal is just one element of stewardship or restoration projects involving multiple management options. For example, larger boles (often with the rootwad or some larger limbs still attached) can be placed into streams to increase fish habitat complexity and stream **hydraulic roughness** (Vieux 2016). Smaller boles, and limbs of all sizes, can be either incorporated into post-assisted (or postless) log structures, or piled near the stream channel where beavers can access them for use in constructing dams.

3 – Manage Grazing

Riparian areas require special attention in regard to grazing management because livestock often spend a disproportionate amount of time in riparian areas due to availability of shade, water, and high quality forage. Given the multiple symptoms that are associated with intensive ungulate use (table 3.1), improved grazing management will have multiple benefits for riparian forests.

Typically, when grazing management improves, vegetation structure and function, fluvial geomorphic symptoms (e.g., streambed and bank stability), and water quality improve over time. Average recovery rates are depicted in figure 4.1, but the sequence of recovery will differ depending on the extent to which ecological and physical features and processes have been altered, and the cover and composition of both native species and nonnative species. Figure 4.1 indicates that years, and perhaps decades, will be needed to recover some riparian plant communities and channels, which should come as no surprise as it often took multiple decades or more to alter many riparian areas in the western United States. Changing vegetation composition may require other actions in addition to improved grazing management (e.g., management option 5 – Install Riparian Plantings).

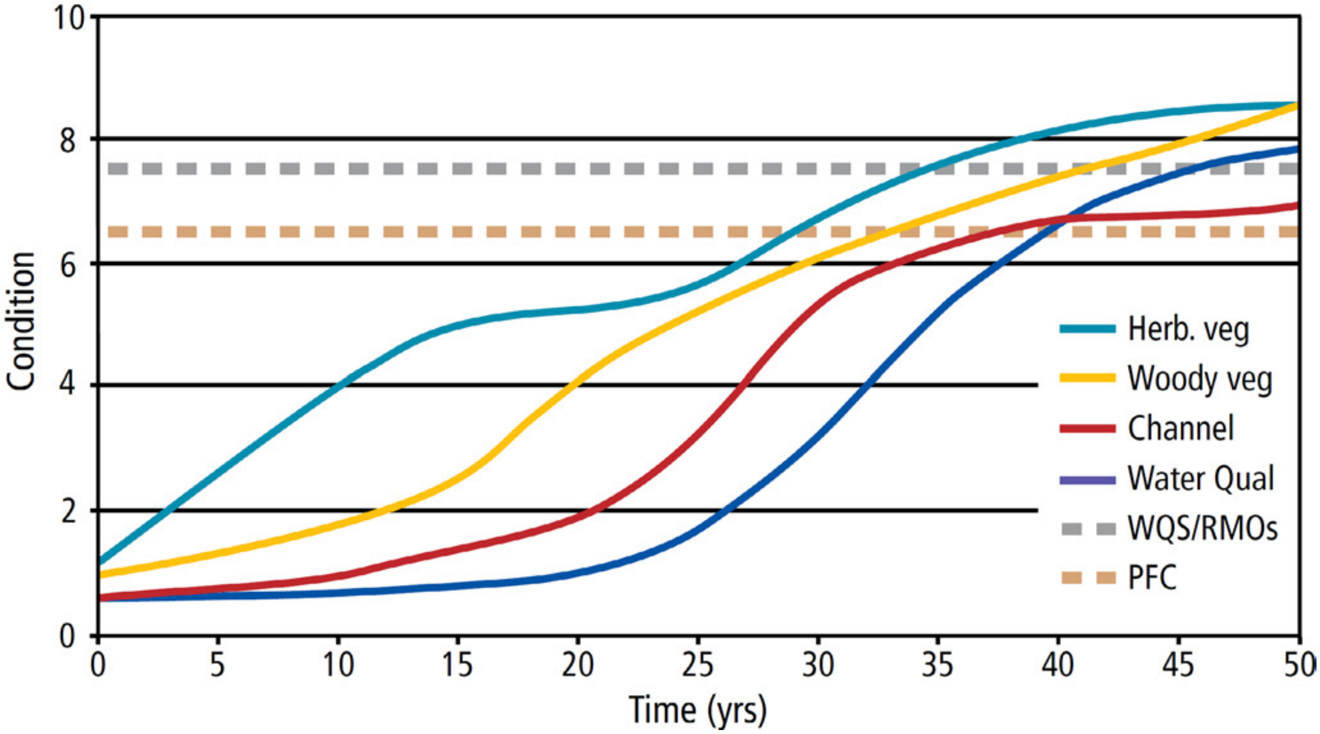


Figure 4.1—Typical recovery rates resulting from grazing management improvements across nonfunctional riparian systems in southern Idaho (Wyman et al. 2006). WQS = Water Quality Standards; RMOs = Resource Management Objectives; PFC = Proper Functioning Condition.

Grazing management can control the following components of livestock grazing:

- Livestock distribution patterns
- Stocking rate
- Grazing duration (length of grazing and rest periods)
- Grazing intensity (amount of forage removed)
- Season of use (and physiological stage of plant growth)
- Kind (species) and class (age or sex) of livestock

When one or more of these components are managed, improvement of plant community composition and structure depends on the diversity and abundance of native species, the abundance of invasive species, and degree of departure of hydrologic function from the natural range of variability. Practices such as fencing (for grazing exclusion or creating a riparian pasture), placing water and supplemental feed in adjacent uplands to reduce time spent in riparian areas, and herding can affect livestock distribution to help accomplish grazing management objectives (George et al. 2011).

Wyman et al. (2006) present several riparian grazing management strategies, with case studies describing their implementation. Some common management actions for grazing riparian areas may include:

- Exclude grazing from severely degraded riparian areas: Use fencing to keep livestock out of heavily damaged riparian areas and to allow recruitment of trees above browse height, monitor area to achieve goals of healthy riparian function, revegetate riparian areas if necessary (management option 5 – Install Riparian Plantings), and allow recovery before resuming grazing.
- Minimize grazing impacts on riparian vegetation: Limit grazing to times when the palatability of upland vegetation is relatively similar to that of the riparian vegetation, install fences to enclose riparian paddocks in which utilization of riparian vegetation is controlled, allow periodic and sufficient rest and recovery for woody and understory riparian species to grow and reproduce, and avoid late- and dormant-season grazing when woody riparian species are most vulnerable to grazing.
- Reduce soil compaction and streambank degradation: Avoid grazing while the soil is wet or saturated; graze while soils are frozen; do not graze riparian areas during high flows when banks are most vulnerable to sloughing; minimize prolonged grazing or congregation around water, under shade, or in other favored areas; discourage the formation of trails, for example, by providing livestock with alternative sources of water and supplemental feed; and establish designated stream crossing areas.

Fall and winter may be the period of greatest use of woody browse species by both livestock and wildlife depending on temperatures, snow depth and duration, availability of other feed, animal concentration, forage and browse preference, and the extent of the woody plant community (George et al. 2011; Wyman et al. 2006). Frequent or lengthy use during the “hot” season can be detrimental to both woody and herbaceous species due to the tendency for livestock to concentrate use on riparian areas at those times (Wyman et al. 2006). Shortening the duration of grazing and providing growing-season rest or deferment in all pastures lessen animal impacts and provides for growth or regrowth (Provenza 2003).

Planning grazing management may be complex due to biological, ecological, social, or logistical variables (or a combination thereof) that may have to be considered. Wyman et al. (2006) discuss several tools that can assist livestock managers in determining whether the timing, intensity, and duration of grazing are appropriate for a riparian pasture. Monitoring and adaptive management are essential (fig. 4.2).

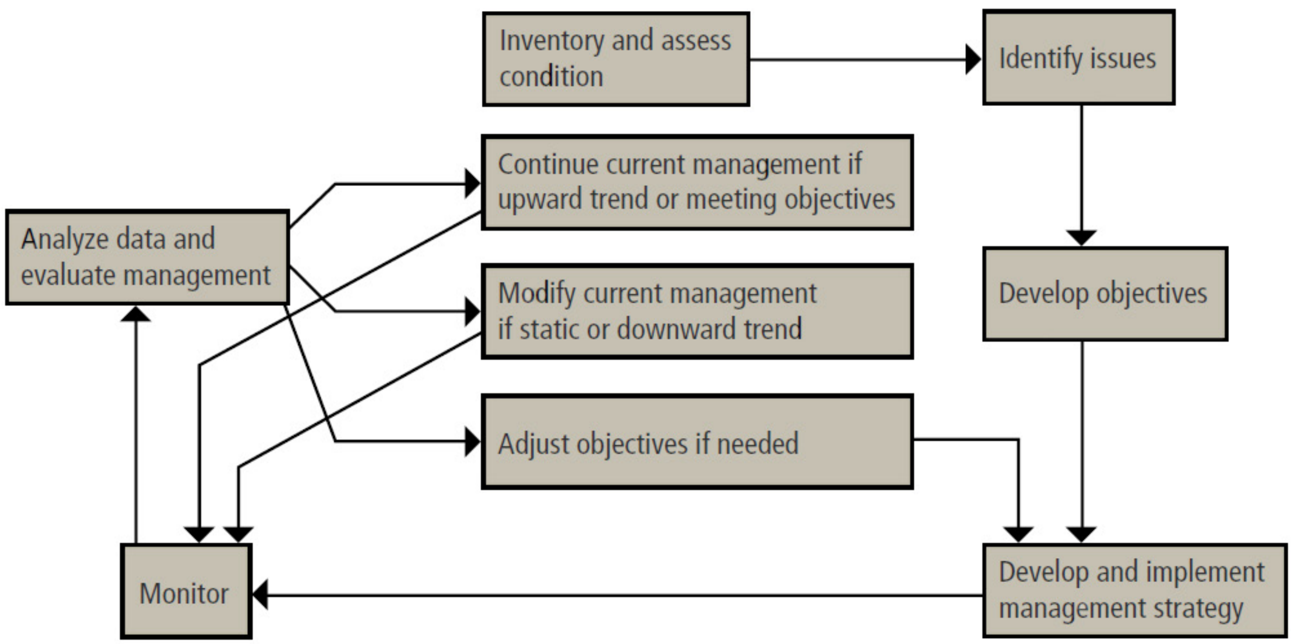


Figure 4.2—An adaptive grazing management planning process. Photo from Wyman et al. 2006; used with permission.

Adaptive management is an iterative process that requires keen observation and monitoring with application on a variety of timescales. The need for flexibility and options is critical. For example:

- Turnout date into a pasture could be planned (long-term) based on expected physiological stage of plant growth, weather, soil moisture, and streamflow, but altered in the short term based on actual observed conditions (e.g., an unusually cold and wet spring).
- Grazing duration and livestock removal dates could be planned (long-term) based on expected forage production, herd size, use, growing conditions, and goals for rest during the growing season, but altered in the short term based on actual observed conditions (e.g., drought).

Intensive wildlife browsing, particularly by deer and elk, can also cause negative riparian impacts. In areas where top predators have been extirpated, subsequent additional browsing by native ungulates has been shown to have long-term negative impacts on riparian vegetative recruitment and extent (Beschta and Ripple 2012). Furthermore, with the recovery of a large-predator guild, riparian areas have begun widespread recovery (Beschta and Ripple 2016) except in areas where high levels of ungulate herbivory, from bison, continue to occur (Beschta et al. 2020). Important considerations in riparian forest rehabilitation include proper management of ungulate populations and their predators, which includes hunting and recreation management.

Expertise in grazing management should be sought when planning grazing in riparian areas. Additional information is available from the following sources (with publishing agency or entity usually listed first):

- USDOI BLM, TR 1737-20, *Grazing Management Processes and Strategies for Riparian-Wetland Areas* (Wyman et al. 2006); https://www.blm.gov/sites/default/files/documents/files/TR_1737-20_0.pdf
- Wyoming Game and Fish Department, Habitat Extension Bulletin No. 53, *Fencing Guidelines for Wildlife* (Wyoming Game and Fish Department 2004); https://extension.usu.edu/rangelands/files/Friendly_Fences.pdf
- Foraging Behavior: Managing to Survive in a World of Change—Behavioral Principles for Human, Animal, Vegetation, and Ecosystem Management (Provenza 2003); https://psfaculty.plantsciences.ucdavis.edu/gmcourse/module_resources/module2/Resources/A.ForagBehave_toc_preface.pdf
- USDOI BLM, TR 1737-23, *Multiple Indicator Monitoring (MIM) of Stream Channels and Streamside Vegetation* (Burton et al. 2011); https://www.blm.gov/sites/default/files/documents/files/TR_1737-23.pdf
- USDOI BLM, TR 1737-14, *Riparian Area Management—Grazing Management for Riparian-Wetland Areas* (Leonard et al. 1997); https://www.blm.gov/documents/national-office/blm-library/technical-reference/riparian-area-management-grazing

4 – Manage Recreation

Riparian areas are popular sites for recreational activities, including camping, swimming, hiking, horseback-riding, boat access, and use of motorized vehicles such as recreational vehicles (RVs), off-road vehicles, all-terrain vehicles, and motorbikes. Human and vehicle use in or adjacent to riparian areas have multiple implications for riparian ecosystems and riparian forests (Burr et al. 2008), including:

- Compaction of soils
- Loss of ground cover vegetation
- Lack of woody plant recruitment and altered plant community succession
- Reduction of native species diversity
- Introduction or spread of nonnative or invasive species
- Disturbance or modification of wildlife habitat
- Loss of limbs and downed wood to firewood collection
- Bank and streambed erosion (particularly at vehicle stream crossings)

- Loss of riparian shade and increased stream temperature
- Sedimentation from bank and streamside erosion
- High levels of algae
- Water pollution by human and dog waste
- Reduction of pollution-intolerant aquatic macroinvertebrates

These adverse recreational impacts are largely a result of physical trampling, repeated travel to the stream, and elimination of ground cover vegetation, particularly at campsites or by recreational vehicles. Thus, limiting the presence of recreational activities to 200 feet or more from water's edge for as much of the stream length as possible will offer the greatest protection for the riparian forest. However, recreationists are specifically drawn to activities within riparian areas, and management must draw recreation away from riparian areas wherever possible and direct it to areas more resistant to degradation. This is particularly essential for recreational vehicles and user-created routes and campsites, which can reasonably be expected to remain outside of the appropriate buffer zone. User-created campsites should be decommissioned if within a riparian area, and relocated out of floodplains. Routes should not be immediately adjacent to creeks, but should be on or rerouted to higher ground. If trails must be located within riparian areas, they should be located on inside bends, where stream energy is lower. Access locations should be separated by areas of dense, intact riparian forest. Off-road vehicle, hiking, and other routes that are leading to riparian forest degradation should be closed, rerouted, or otherwise modified. Switalski and Jones (2008) offer helpful planning guidance for Best Management Practices for off-road vehicle use on forest lands.

Stream crossings should be minimized to the extent possible, should be established in areas where the streambed is stable or can be stabilized, and should approach and cross perpendicular to the stream. Further specifications for stream crossings, as well as bridges and ford crossings, may be found in the *USDA Natural Resources Conservation Service Conservation Practice Standard for Stream Crossings* (USDA NRCS 2011).

Designation of campsites away from the riparian forest is important where recreational use is common. This will allow for increased occupation of the riparian area with woody riparian vegetation, riparian shade, native ground cover, and reduced bank erosion and flow of nutrients and other pollutants into the stream. The establishment of hardened campsites 200 feet away from the riparian area, along with distinct paths to a stream, can be effective at containing camping and recreational vehicles and reduce upland and bank erosion. Other possibilities include restricting campfires or overnight camping to reduce the risk of firewood gathering, fires in the riparian area, and trampling (fig. 4.3).

Figure 4.3—An example of an area along the Colorado River near Moab, Utah, where land managers have restricted recreational uses, such as overnight camping and campfires. Fire can spread rapidly in dry grasses and potentially kill riparian forest vegetation. USDA Forest Service photo by Sara Goeking.

Refuse management, including containment of human waste, is critical for avoiding both bacterial contamination and large nutrient inputs to adjacent streams. Resulting algal blooms can in turn clog waterways and thus affect riparian forests. Educational signs and materials can provide information on the inherent values and vulnerabilities of the specific riparian area, for instance the role of large woody debris, habitat needs of local wildlife, the danger of fire from campfires, and the positive benefits of restrictions. To maintain large woody debris, recreationists can be encouraged not to remove large logs and dead fallen trees in the creek, along banks, or in a floodplain. Where planting of vegetation is needed for restoration, or bank stabilization is underway, signage can explain why recreation should not occur in such areas.

Additional information is available from the following sources:

- *Best Management Practices for off-road vehicle use on forestlands: A guide for designating and managing off-road vehicle routes* (Switalski and Jones 2008); https://www.biologicaldiversity.org/programs/public_lands/off-road_vehicles/pdfs/ORV_BMP_2008.pdf

- USDA NRCS, *Conservation Practice Standard 578: Stream Crossing* (USDA NRCS 2011); 578 Stream Crossing (usda.gov); https://www.nrcs.usda.gov/resources/guides-and-instructions/stream-crossing-no-578-conservation-practice-standard

5 – Install Riparian Plantings

One of the most common and easily observed symptoms of a degraded riparian forest is lack of vegetation. Riparian vegetation provides vital buffering effects to **hydrogeomorphic processes** (fig. 3.3) and supports a wide range of functions and values (Chapter 1).

Merely planting riparian vegetation without addressing the root cause of its decline (stressors such as recreation, agriculture, grazing, altered hydrology or channel, infrastructure) is rarely effective in the long term. Once a stressor or stressors are alleviated or circumvented, woody riparian vegetation will commonly establish on its own. However, direct planting may be required when appropriate species are absent, or when invasive species hinder natural establishment of desirable species. Planting is also necessary as a follow-up to implementing other options that create disturbance (management options 2 – Remove Conifers, 6 – Remove Exotic Plants, 8 – Stabilize Streambanks, 9 – Remove or Improve Infrastructure, 13 – Restructure Physical Channel).

The success of plantings depends on numerous factors (USDA NRCS 2007h), including:

- Species selected (see Chapter 1 and Appendix A)
- Seed viability and weed contamination (for projects using seed)
- Source and quality of plant materials
- Procurement methods
- Installation, handling, and transportation techniques
- Method of application
- Time of year
- Soil compaction
- Soil type
- Nutrients
- Salinity
- Presence of ice
- Sediment
- Debris load (e.g., wood moved during high flows)
- Flooding

- Accessibility to water (depth to water table)
- Drought
- Hydrology
- Climate
- Location relative to the stream (horizontal and vertical distance)

The uses of riparian areas should be considered when planning riparian plantings. Managing the effects of recreation and herbivory (e.g., livestock, elk, rabbit, beaver) during establishment and lifespan of the planting is often necessary and commonly overlooked, yet these measures may help ensure success of the planting.

It is important to select species that are adapted to site characteristics (e.g., temperature, elevation, soil type). Chapter 1 and Appendix A contain information that is useful in selecting appropriate species. One key to successful riparian planting is matching the species to the specific riparian site or "zone" (fig. 4.4) (Hoag et al. 2001a). Species selection should be tailored to the objectives of the project, providing for the maintenance of the basic functions (e.g., hydrologic function) and desired values (e.g., habitat, aesthetics, native diversity, pollinators, aquatic organisms). Different species of plants have different needs or tolerances for water table depth, inundation frequency and duration, drought, and resistance to erosive forces (Hoag et al. 2001a, 2008).

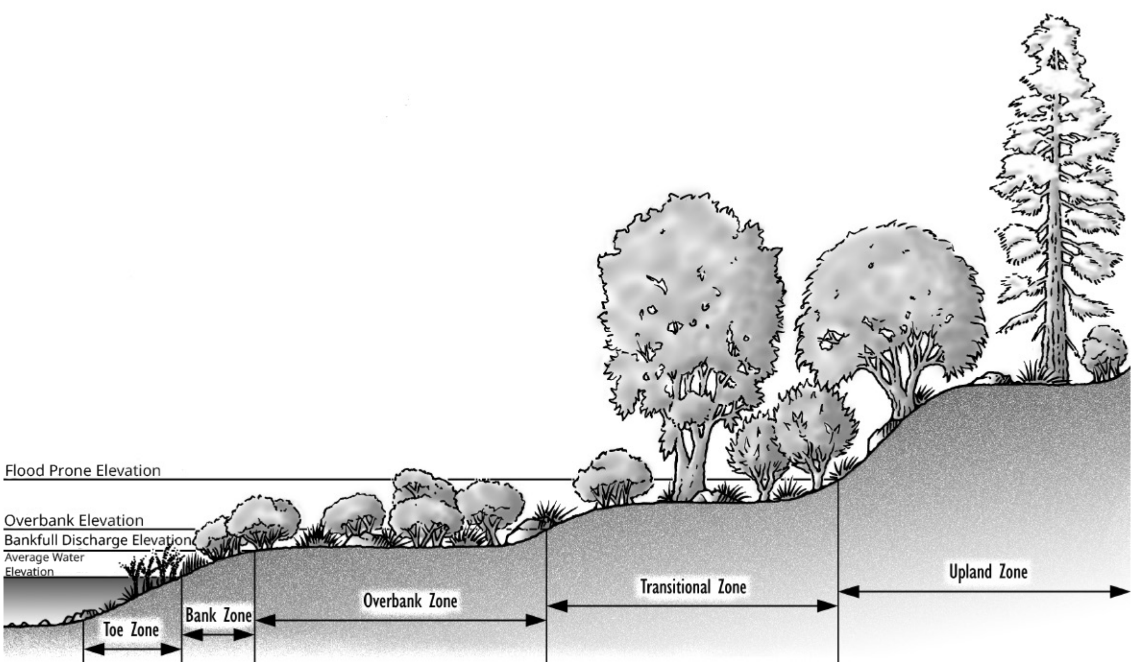


Figure 4.4—General depiction of a riparian planting zone, which can be used to determine where riparian species should be planted in relation to the waterline. Note that not all streams look like this one. In practice, some of these zones may be absent. Image from Hoag et al. 2001; used with permission.

Many woody riparian plants such as willows and cottonwoods can be propagated from dormant cuttings. Techniques such as dormant pole plantings are simple and can be readily applied (Hoag 2007). One key to success is to ensure that the poles are planted deep enough that they have access to the water table. This step can be challenging on many sites where banks are high and terraces are well above the adjacent stream. Specialized equipment and techniques may be necessary in these instances (see end of this section for a list of resources).

Containerized or bare-root plants can be used for establishing woody riparian vegetation. For many species that are difficult to propagate from cuttings, this is the preferred option. Overcoming a deep water table requires the use of specialized techniques for preparing and planting (USDA NRCS 2007a).

Seeding of perennial understory species can be beneficial when appropriate management (e.g., grazing management), site preparation, invasive plant control, and adequate site stability are present (USDA NRCS 2010a). Basic seeding techniques should be followed for projects in drier riparian zones (Dreesen et al. 2006; Ogle et al. 2011). Special techniques including seed pretreatments may be required for sedges and rushes (Hoag and Zierke 1998; Sellers and Hoag 1997). Sod mats (Hoag 2008b) or plugs (Hoag et al. 2001b) may be used to establish grasses, sedges, and rushes where seeding is not feasible. Streambank bioengineering (management option 8 –Stabilize Streambanks) entails the use of live and dead herbaceous and woody plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction, and vegetative establishment. In simple terms, streambank soil bioengineering uses plants and sometimes inert material to increase the strength and structure of the soil (Giordanengo et al. 2016; Hoag and Fripp 2002, 2005).

The myriad of techniques, species, and factors that should be considered when planting riparian vegetation is challenging. Additional information is available from the following sources (with publishing agency usually listed first):

- USDA NRCS, Conservation Practice Standard 391: *Riparian Forest Buffer and Conservation Practice Standard 390: Riparian Herbaceous Cover* (USDA NRCS 2010b,a); https://www.nrcs.usda.gov/resources/guides-and-instructions/riparian-forest-buffer-ac-391-conservation-practice-standard

- USDA NRCS, Riparian/Wetland Project Information Series No. 16, *Riparian Planting Zones in the Intermountain West* (Hoag et al. 2001a); https://riversedgewest.org/sites/default/files/2022-06/Riparian_Planting_Zones_Intermountain_West.pdf

- USDA NRCS, *Field Guide for the Identification and Use of Common Riparian Woody Plants of the Intermountain West and Pacific Northwest Regions* (Hoag et al. 2008); https://www.nrcs.usda.gov/plantmaterials/idpmcpu12618.pdf

- USDA NRCS, Plant Materials Technical Note No. 23, *How to Plant Willows and Cottonwoods for Riparian Restoration* (Hoag 2007); https://www.nrcs.usda.gov/plantmaterials/idpmctn7064.pdf
- USDA NRCS, Plant Materials Technical Note No. 6, *The Stinger: A Tool to Plant Unrooted Hardwood Cuttings* (Hoag 2011); https://www.nrcs.usda.gov/plantmaterials/idpmstn10789.pdf
- USDA NRCS, Plant Materials Technical Note No. 21, *Planting Willow and Cottonwood Poles under Rock Riprap* (Hoag 2008a); https://www.nrcs.usda.gov/plantmaterials/idpmctn7777.pdf
- USDA NRCS, Plant Materials Technical Note No. 39, *Waterjet Stinger: A Tool to Plant Dormant Unrooted Cuttings of Willow, Cottonwood, Dogwood, and Other Species* (Hoag et al. 2001b); https://www.nrcs.usda.gov/plantmaterials/idpmctn1083.pdf
- USDA NRCS, Guidelines for Planting Longstem Transplants for Riparian Restoration in the Southwest, *Deep Planting: The Ground Water Connection* (USDA NRCS 2007a); https://www.nrcs.usda.gov/plantmaterials/nmpmcbr7106.pdf
- USDA NRCS, *Seeding Xeric Riparian Sites Following Removal of Invasive Phreatophytes* (Dreesen et al. 2006); https://www.nrcs.usda.gov/plantmaterials/nmpmcpg6608.pdf
- USDA NRCS, Plant Materials Technical Note 10, *Pasture and Range Seedings Planning-Installation-Evaluation-Management* (Ogle et al. 2011); https://www.nrcs.usda.gov/plantmaterials/idpmstn10790.pdf
- USDA NRCS, Riparian/Wetland Project Information Series No. 13, *A Reference Guide for the Collection and Use of Ten Common Wetland Plants of the Great Basin and Intermountain West* (Hoag and Zierke 1998); https://www.nrcs.usda.gov/plantmaterials/idpmcarwproj13.pdf
- USDA NRCS, Riparian/Wetland Project Information Series No. 10, *Seed Germination Enhancement for Carex nebrascensis* (Nebraska sedge) (Sellers and Hoag 1997); https://www.nrcs.usda.gov/plantmaterials/idpmcarwproj10.pdf
- USDA NRCS, Plant Materials Technical Note 22, *Wetland Sodmats* (Hoag 2008b); https://www.nrcs.usda.gov/plantmaterials/idpmctn8293.pdf
- USDA NRCS, Plant Materials Technical Note 38, *Users Guide to the Description, Propagation, and Establishment of Wetland Plant Species and Grasses for Riparian Areas in the Intermountain West* (Hoag et al. 2001c); https://www.nrcs.usda.gov/plantmaterials/idpmctn10749.pdf

- USDA NRCS, *Streambank Soil Bioengineering Guide for Low Precipitation Areas* (Hoag and Fripp 2002); https://www.nrcs.usda.gov/plantmaterials/idpmcpussbfglpa.pdf
- USDA NRCS, Riparian/Wetland Project Information Series No. 18, *Streambank Soil Bioengineering Considerations for Semi-arid Climates* (Hoag and Fripp 2005); https://www.nrcs.usda.gov/plantmaterials/idpmcar5981.pdf
- *Living Streambanks: A Manual of Bioengineering Treatments for Colorado Streams* (Giordanengo et al. 2016); https://cwcb.colorado.gov/sites/cwcb/files/Biostabilization_Manual_072416_0.pdf

6 – Remove Exotic Plants

The reasons for the presence of undesirable vegetation vary in important ways, but the common denominator is that current environmental conditions are sufficient for their continued existence on the site (see table 3.1 for numerous stressors that contribute to high riparian-zone cover of native upland species, or invasive exotic species). Therefore, merely removing undesirable vegetation from a riparian zone without addressing the root cause of its arrival and persistence is not likely to be effective in restoring a plant community composed solely of desirable vegetation (Shafroth et al. 2010). It is best to remove undesirable vegetation (active restoration) after first alleviating stressor(s) (passive restoration).

Managers may actively remove undesirable vegetation by a wide variety of methods, all falling within the broader categories of physical, chemical, and biological approaches (table 4.1).

Table 4.1—Overview of some plant removal approaches commonly used in Utah.

General Method	Pros	Cons
Developed biological agents (USU Extension, 2000)	Exceptionally selective, very few if any direct impacts to non-target organisms. Inexpensive for the landowner.	Requires a tremendous effort to get a new biocontrol agent-development program started. Lack of general control – very species-specific. Effectiveness generally lags behind weed production. Only applicable against thoroughly established weeds in a suppression strategy. Not applicable for an eradication strategy.

Table 4.1 continued.

General Method	Pros	Cons
Herbicide	Moderately selective options are available. Potential for good residual control with some pre-emergents (which inhibit seed germination but do not affect existing plants). Potential for highly acute but fleeting effects with some post-emergents (which only affect existing plants and lack residual control).	Lots of information to digest. Users must properly match target with agent. May impact desired native plants. Some herbicides require certification. Potential for leaching or drift. Soil and weather factors can be highly influential in effectiveness. Public relations concerns may exist, particularly if non-chemical options for least herbicide use have not been considered.
Physical – manual and mechanical	Can be highly selective. Fewer third-party safety or liability risks than fire, less public relations risk than herbicides. Readily accessible to nearly anyone.	Laborious and expensive; can result in large amounts of slash, reduced access, increased fuel loading and fire risk. Results are often temporary if herbicide use is not included. Physical disturbance can multiply weed problems.
Prescribed fire	Can be inexpensive. Can be selective, depending on variable plant response (death vs damage vs stimulation). Removes biomass, can improve access for additional subsequent control efforts	Requires training and experience. Inherently dangerous. Liability due to risk of escape, risk of resource damage.

The following list presents an overview of some plant removal approaches commonly used in Utah, and their advantages and disadvantages.

1) Developed biological agents (USU Extension 2000).

    a. Advantages: This method can be exceptionally selective, with very few if any direct impacts to nontarget organisms. It is typically inexpensive for the landowner.

    b. Disadvantages: This method requires a tremendous effort to get a new biocontrol agent-development program started. General control is difficult, as the method is typically species-specific. Effectiveness generally lags behind weed production. This method is applicable only against thoroughly established weeds in a suppression strategy and is not applicable for an eradication strategy.

2) Herbicide

    a. Advantages: Moderately selective herbicide options are available. Herbicides have the potential for good residual control with some pre-emergents (which inhibit seed germination but do not affect existing plants). They potentially have highly acute but fleeting effects with some postemergents (which affect only existing plants and lack residual control).

b. Disadvantages: The large amount of information about herbicides can be difficult to digest. Users must properly match target with agent. Herbicides may impact desired native plants. Some herbicides require certification. Application has the potential for leaching or drift. Soil and weather factors can be highly influential in effectiveness. Public relations concerns may exist, particularly if nonchemical alternatives to herbicide use have not been considered.

3) Physical methods: manual and mechanical

   a. Advantages: Physical removal can be highly selective. It presents fewer third-party safety or liability risks than fire and less public relations risk than herbicides. It is readily accessible to nearly anyone.

   b. Disadvantages: Physical removal is laborious and expensive, and it can result in large amounts of slash, reduced access, increased fuel loading, and fire risk. Results are often temporary if herbicide use is not included. Physical disturbance can multiply weed problems.

4) Prescribed fire

   a. Advantages: Prescribed fire can be inexpensive. It can be selective, depending on variable plant response (death vs. damage vs. stimulation). It removes biomass and can improve access for additional subsequent control efforts.

   b. Disadvantages: Implementing prescribed fire requires training and experience. It is inherently dangerous and presents potential liability due to risk of escape or resource damage.

Numerous field guides (Lowry et al. 2017; USDA Forest Service 2014) and resources detail the appropriate uses of these diverse methods. There are also a growing number of well-documented examples such as the Logan River restoration project at Rendezvous Park (Olsen 2017). The various removal methods are often used in combination or series. For example, a manager might begin with a cool underburn to improve access, then manually remove or rearrange some woody material, and finally (in the case of species that resprout) apply herbicide to the freshly cut stumps. The correct method(s) and their effective timing and—if appropriate—sequence depend on the plant species targeted for removal and on potential adverse impacts to plants, wildlife, soils, people, and other values (Fremont County Weed Management 2015; Patterson and Worwood 2010).

In removing undesirable vegetation, it is essential to have realistic expectations of success. Even after both the underlying stressors and the undesirable vegetation have been reduced or eliminated, long-term success may still require active maintenance to prevent the site's recolonization by weeds (Tamarisk Coalition 2008). Factors such as altered flow regime, presence of uncontrolled populations upstream, extent of disturbed soils, inadequate site occupancy by desirable riparian vegetation, posttreatment drought, or other circumstances that would hinder or prevent natural plant establishment and dominance may require a maintenance program.

Additional information is available from the following sources (with publishing entity listed first):

- Utah State University Extension, *Noxious Weed Field Guide for Utah* (Lowry et al. 2017); https://digitalcommons.usu.edu/extension_curall/1352/
- Utah State University Extension, *Different Treatment Options for Russian Olive* (Patterson and Worwood 2010); https://digitalcommons.usu.edu/extension_curall/1056/
- Fremont County Weed Management, *Weed Management Preferences* (Fremont County Weed Management 2019); https://fremontcountyco.gov/files/weed-control/weedmgmtchart2019.pdf
- Utah State University Extension, *Saving Utah's Landscape, Biocontrol of Tamarisk* (Utah State University Extension 2000); https://digitalcommons.usu.edu/extension_curall/1379/
- Tamarisk Coalition, Riparian Restoration: *Assessment of Alternative Technologies for Tamarisk Control, Biomass Reduction and Revegetation* (Tamarisk Coalition 2008); https://old.riversedgewest.org/sites/default/files/resource-center-documents/Assessment_of_Alternative_Technologies_General_7-21-2008_%28FI.pdf

7 – Manage Beaver

Restoration practitioners increasingly use beaver to accomplish stream, wetland, and floodplain restoration. By creating new and more complex habitat in degraded systems, beaver and the dams that they build have the potential to help restoration practitioners achieve objectives. Potential and occupied beaver habitat exists within watersheds that are being used for many purposes, some of which may exist in apparent or unavoidable conflict with beaver activities or structures. This section briefly reviews the benefits that may be provided by beaver, the habitats in which beaver are most successful, and how some conflicts with beaver can be managed.

Benefits that may be provided by beaver include:

- Increased water retention in beaver ponds and below-ground
- Increased baseflows due to steady release of water from behind dams and saturated soil

- Valuable slow-water habitat for birds, waterfowl, fish, aquatic invertebrates, mammals, and amphibians
- Decreased peak flows as dams act as “speed bumps” and moderate water release
- Increased sinuosity with slower flows and multiplicity of channels
- Expansion of riparian forest habitat area and complexity with overflow onto the floodplain, extension of riparian habitat length around ponds, and raised water table; riparian species may replace upland species
- Improved community structure with multiple layers of woody and understory vegetation.
- Increased shade from woody riparian vegetation and increased understory vegetation
- Increased wetland area with increased surface and subsurface water; after abandonment, open water wetlands may drain to become moist “beaver meadows”
- Increased groundwater recharge as retained water infiltrates the soil and channel water spreads onto the floodplain
- Sediment retention behind dams, which raises (aggrades) the level of the streambed and may reconnect the streambed with its floodplain
- Temperature moderation as water in the sediment is not exposed to the sun or to ambient air temperatures, whether hot or cold
- Nutrient cycling as beaver ponds trap woody and herbaceous vegetation and organic and inorganic material in ponds
- Reduced algae, as the ponds and wetlands act as sinks for nutrients that would support algal growth
- Macroinvertebrate diversity and production supported by increased detritus
- Regular and free maintenance of dams

Human-fabricated imitations of dams, called “beaver dam analogues” (fig. 4.5) or BDAs (see management option 12 – Stabilize Channel Grade) can provide similar benefits and may assist creation of habitat favorable for beaver or increase beaver activity (Nash et al. 2021).

Although beaver can occupy a wide variety of habitats, three physical attributes are basic to where beaver can build dams: stream gradient, stream and valley bottom width, and vegetative condition (Pollock et al. 2018). An extensive community of woody species—both for dam construction and as food, particularly for winter storage and consumption—are essential. If herbivory by elk or livestock on palatable woody plants that are harvested by beaver is significant, these plants cannot grow and beaver cannot occupy a site or remain.

The following considerations noted in the *Beaver Restoration Guidebook* (Pollock et al. 2018) are useful for deciding whether a given stream or stream reach may be hydrologically suitable for beaver occupation:

- Beaver prefer to build dams on small- to medium-sized, low-gradient streams (<6 percent slope) that flow through unconfined valleys, and generally populate the lowest gradient (slope <1–2 percent) sites first.
- Beaver generally avoid constrained valleys with high-gradient streams but will colonize this less-preferred habitat if their population densities are high.
- Beaver also occupy large rivers but restrict their dam-building to off-channel habitat fed by **hyporheic** (beneath-streambed) flow, groundwater channels, and tributary channels that flow across the floodplains of the larger river channel. They also will build seasonal dams across large rivers during low flow conditions.
- Beaver also build dams on lakes, wetlands, estuaries, and almost any water body where additional water can be retained and thus safety from predators gained and habitat improved (from a beaver's perspective) by building a dam.

There is a long and ongoing history in the development of strategies for predicting where existing or potential beaver habitat exists. There is no single tool appropriate for assessing a watershed in terms of habitat capacity for beaver, but see the map within Utah (fig. 4.6) generated with the Beaver Restoration Assessment Tool (or BRAT). The BRAT models the capacity of a watershed to support dam-building activity by beaver. The capacity is estimated using publicly available GIS data on watershed topography, hydrology, and vegetation to combine five factors:

1. A source of perennial water
2. Existing bank vegetation for foraging and dam-building materials
3. Vegetation within 100 m (328 feet) of the edge of the stream to support beaver colonies
4. Likelihood that dams could be built across the channel
5. Likelihood that a dam is capable of withstanding typical floods

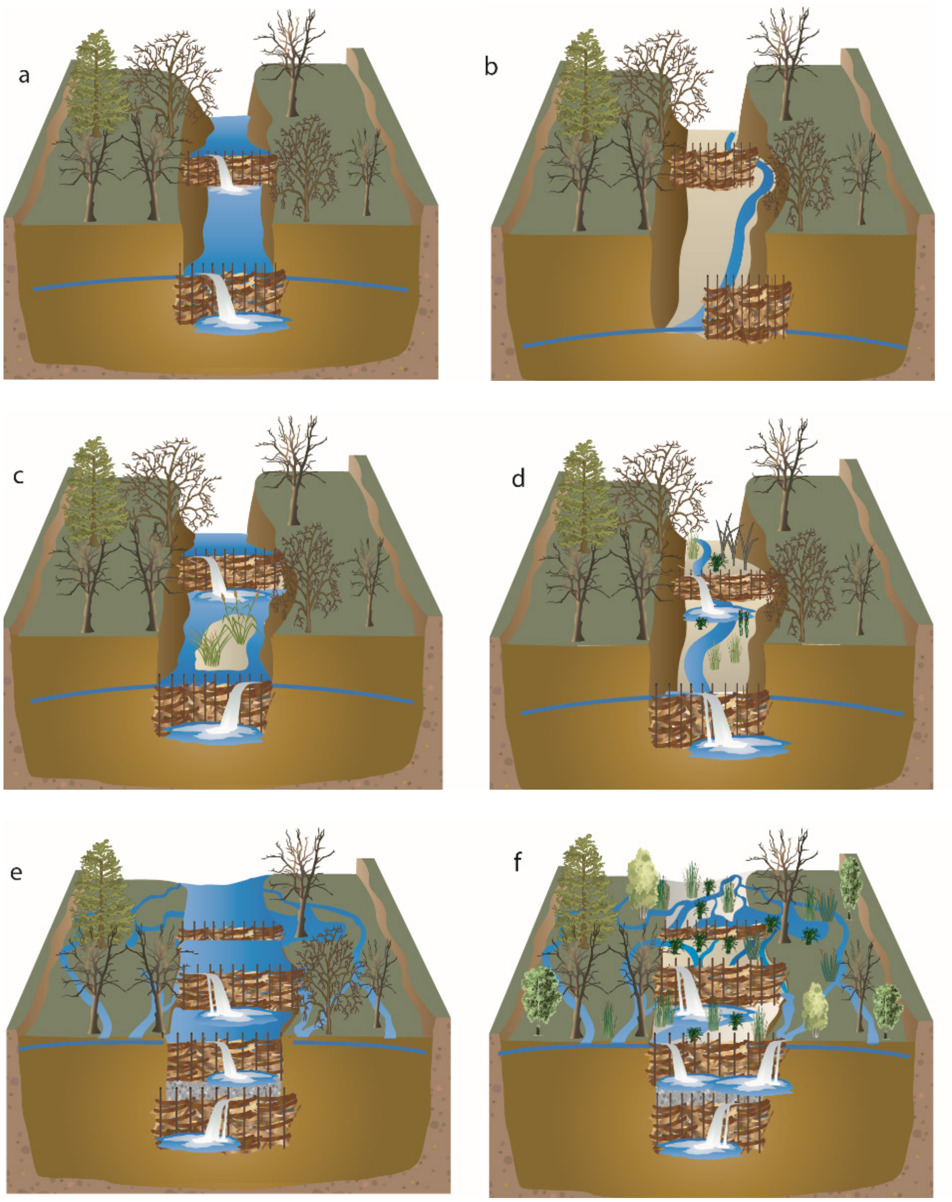


Figure 4.5a-f—Illustration showing how beaver dams affect the development of incised streams: (a) Beaver will dam streams within narrow incision trenches during low flows, but stream power is often too high, which results in blowouts or end cuts that (b) help widen the incision trench, which allows an inset floodplain to form. (c) The widened incision trench results in lower stream power, which enables beaver to build wider, more stable dams. (d) Because streams that have recently incised often have high sediment loads, the beaver ponds rapidly fill up with sediment and are temporarily abandoned, but the accumulated sediment provides good establishment sites for riparian vegetation. This process repeats itself until (e) the beaver dams raise the water table sufficiently to reconnect the stream to its former floodplain. Eventually, (f) vegetation and sediment fill the ponds, and the stream ecosystem develops a high level of complexity as beaver dams, live vegetation, and dead wood slow the flow of water and raise groundwater levels. Multithread channels are thus formed, often connected to floodplain wetlands such that the entire valley bottom is saturated. Image from Pollock et al. 2014; used with permission.

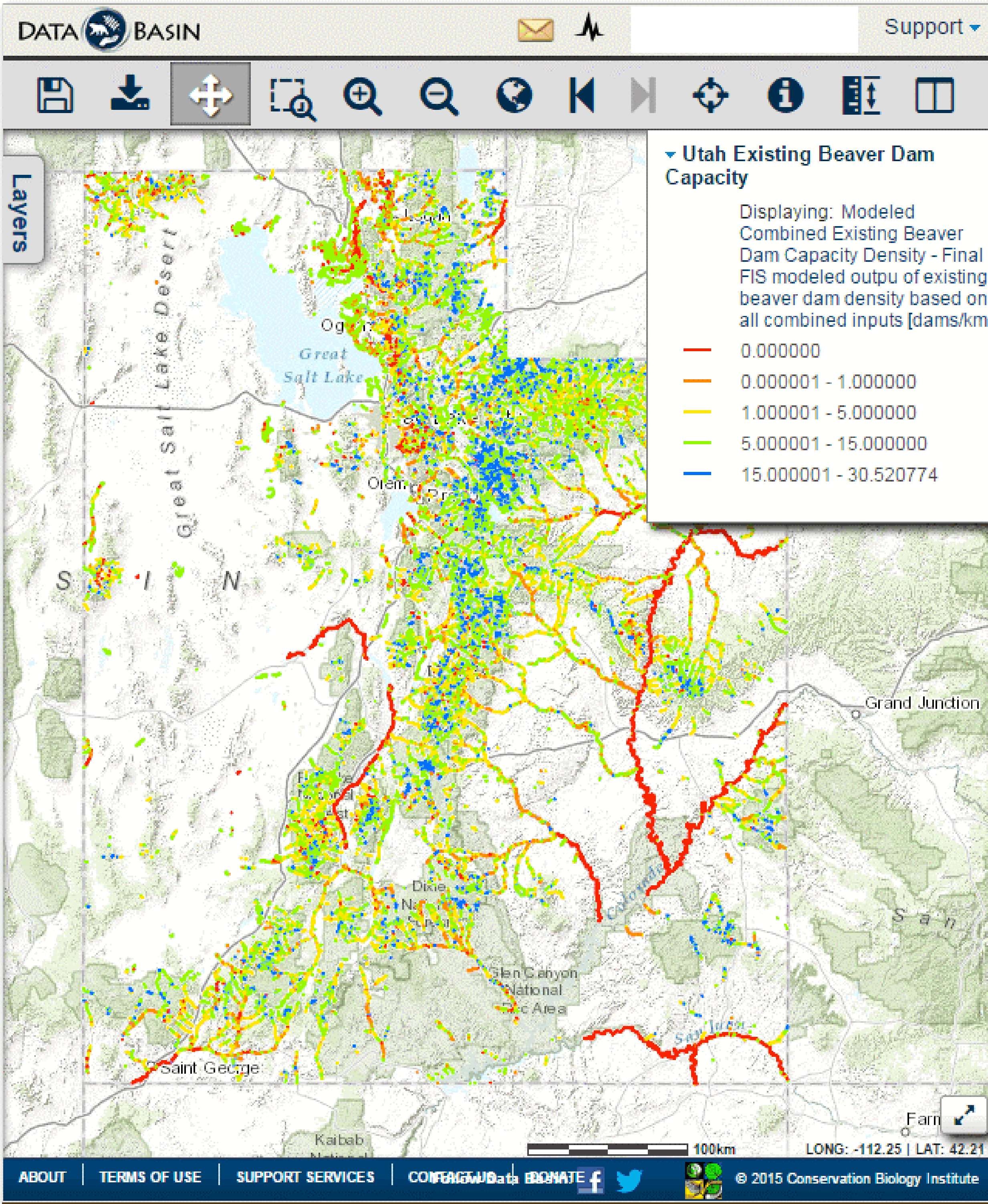


Figure 4.6—Existing Utah beaver dam capacity. Image from Macfarlane et al. 2015; used with permission.

Stream segments are assigned to different beaver restoration categories based on existing and historical capacity, riparian habitat condition or recovery potential, and probability of conflicts with human land uses.

As a complement to BRAT, the Riparian Condition Assessment Toolbox (R-CAT) includes a suite of stream network assessment tools that variously delineate valley bottoms, assess riparian vegetation, evaluate floodplain condition, and estimate recovery potential of riparian areas. The R-CAT models have been developed across the State of Utah (Macfarlane et al. 2018). These tools can be used to estimate whether riparian areas currently provide or could in the future provide habitat for beaver.

Beaver restoration projects may require time when they involve the need to address landowner concerns. In addition, because beavers have specific habitat needs and preferences, it may take time to find where beaver prefer to locate (Nash et al. 2021). However, the habitat benefits of the colony may begin to be achieved rapidly, as hydrologic, geomorphologic, and biological changes occur in response to beaver dam construction. The benefits of beaver restoration projects may extend for decades or longer, particularly if the goal is to initiate process-based changes to the physical condition of streams and riparian areas over large spatial scales.

There are three common unwanted consequences of beaver presence, all of which have highly effective solutions (Chapter 4 in Pollock et al. 2018). These unwanted consequences include cutting or gnawing of trees that are deemed important to retain, unwanted flooding as the beaver pond expands, and blockage of culverts. Desirable trees can be protected with wire cages or application of latex paint mixed with sand to tree boles. When beaver dam ponds flood land where inundation is incompatible with infrastructure or other land uses, a **flexible pond leveler** (fig. 4.7) is generally effective at lowering water levels behind a dam while allowing the dam and beavers to remain. A large-diameter, flexible pipe is inserted horizontally through the beaver dam the upstream intake pipe is protected from clogging with a mesh fence.

Culvert inlets are vulnerable to damming by beavers, with consequent road flooding and roadside erosion. A cost-effective, low-maintenance solution is to build a rectangular or trapezoidal-shaped fence with heavy-duty cattle panel wire mesh. Combining culvert fencing with a pond leveler may provide water levels compatible with the culvert and ensure fish passage. Arch-shaped culverts that span the stream width are less likely to be dammed.

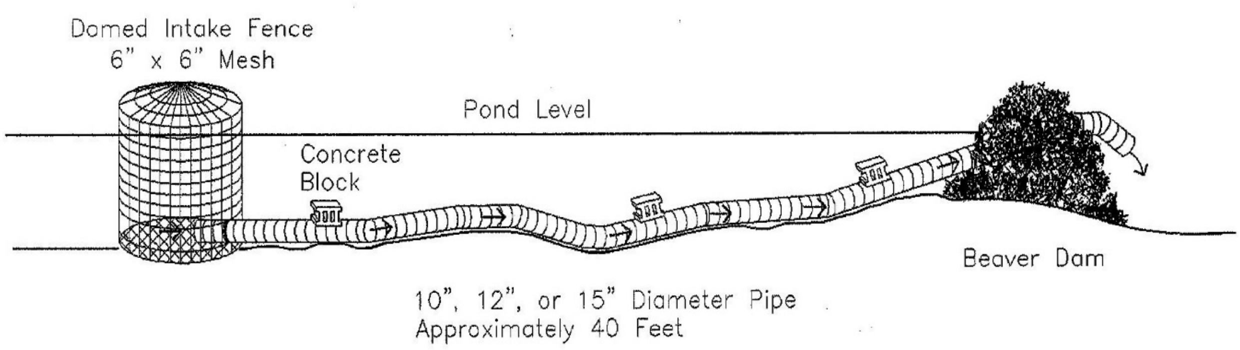


Figure 4.7—Design specifications for a flexible pond leveler that is used to reduce beaver pond water levels to an acceptable level. Diagram courtesy of Beaver Solutions LLC.

Translocation or removal of lone beavers or beaver families may be necessary when their presence is incompatible with particular uses on land or in water, as for example, beaver damming an irrigation ditch the function of which is to efficiently deliver water without obstruction. The State of Utah recognizes beaver as "protected wildlife" in State code, and manages beaver as furbearing animals, with management responsibility delegated to the Utah Division of Wildlife Resources (UDWR) in the Department of Natural Resources. Trapping beaver (including for live capture) requires both a furbearer license and a trap registration license. In addition, it is illegal to move live wildlife without consulting with UDWR. With beaver specifically, there are concerns about spreading invasive species such as quagga mussels (*Dreissena rostriformis bugensis*) and whirling disease (disease agent: *Myxobolus cerebralis*), and there are quarantine protocols in place to help prevent such spread. Any manager wanting to capture and move live beavers in Utah needs to contact the Utah State Game Mammal Coordinator for information on how to do it legally.

Additional information is available from the following sources (with publishing agency or entity listed first):

- USDOI FWS, *The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplain* (Pollock et al. 2018); https://www.beaverinstitute.org/wp-content/uploads/2023/03/The-Beaver-Restoration-Guidebook-v2.01.pdf
- Utah Department of Natural Resources, Division of Wildlife Resources, *Utah Beaver Management Plan* (UDWR 2017); https://wildlife.utah.gov/pdf/furbearer/beaver_plan_2010-2020.pdf
- Utah State University, *"Beaver Restoration Assessment Tool (BRAT)"* (Utah State University n.d.); https://brat.riverscapes.net
- Riverscapes Consortium, *Riparian Condition Assessment Toolbox* (R-CAT; Riverscapes Consortium n.d.); https://rcat.riverscapes.net

8 – Stabilize Streambanks

Bank erosion is a common and obvious problem in many riparian forest systems. The causes of bank erosion can vary and are often cumulative. Prior to embarking on a project, managers should determine whether the observed bank erosion is caused by current and ongoing management, in which case those management practices should be addressed first, rather than past stressors that no longer exist. Bank stabilization practices may be needed to protect infrastructure, reduce the amount of sediment in the stream, prepare for planting, or encourage natural regeneration. The local type of valley bottom in the context of the channel evolution model should be identified. Generalized channel evolution models (fig. 4.8) illustrate the need to allow banks to erode, at least in valley bottoms that are unconfined by bedrock, in order to achieve an improved channel condition with a widened floodplain. In some cases, bank stabilization may not be appropriate and may have adverse effects on riparian forests. Therefore, it is important that managers identify the dominant processes at their site to determine whether stabilization is needed to mitigate bank erosion versus allowing natural bank migration to occur.

Streams experience a succession process illustrated in a channel evolution model (fig. 4.8). For each class within a channel evolution model, there are specific **morphological**, sediment-related, hydraulic, and biological relationships. Understanding former channel positions and types will help the user identify how the current channel fits within a channel evolution model. Relict vegetation (e.g., mature cottonwoods on high terraces) and soil characteristics (e.g., historical flood deposits or wetland soil characteristics) may provide clues about former water table depths and channel types (Dickard et al. 2015). Identifying where a stream falls within the channel evolution model may help determine whether bank erosion requires intervention or whether the channel may recover passively. For example, systems in Classes IV and V (fig. 4.8) represent situations of passive recovery. In those systems, eroding banks can provide the sediment source needed to increase channel or floodplain width, thereby enabling the stream to achieve a new equilibrium (Zeedyk and Clothier 2014). Such situations may not require intervention to stabilize banks.

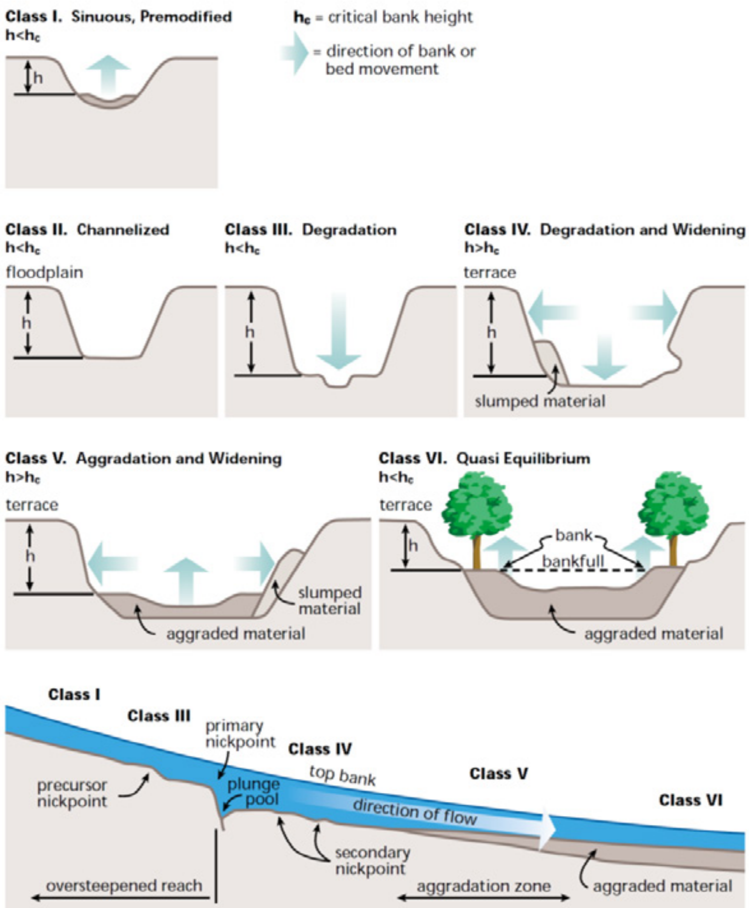


Figure 4.8—Depiction of a channel evolution model showing a disturbed or unstable stream in varying stages of disequilibrium along its length or profile. A channel evolution model theoretically may help predict future upstream or downstream changes in habitat and stream morphology. Courtesy image from FISRWG 2001.

As mentioned in Chapter 3, decreased sinuosity can lead to increased bed erosion and eventual disconnection of the stream from its floodplain. In channels where there is a risk of future degradation (downcutting), bank protection is generally ineffective over the long term if the channel degrades (USDA NRCS 2007f) (management option 12 –Stabilize Channel Grade); see figure 4.8 (Class III and Class IV) for an illustration of the potential for bank failure due to channel degradation. Various approaches exist for determining the appropriate sinuosity for the channel, which is defined by **meander belt width** (fig. 4.9) and **meander length** of a channel, and those approaches are described in detail elsewhere (USDA NRCS 2001; Zeedyk 2009). Before identifying the locations of any bank protection structures, managers should identify the historical limits on the width and extent of stream meanders (fig. 4.9).

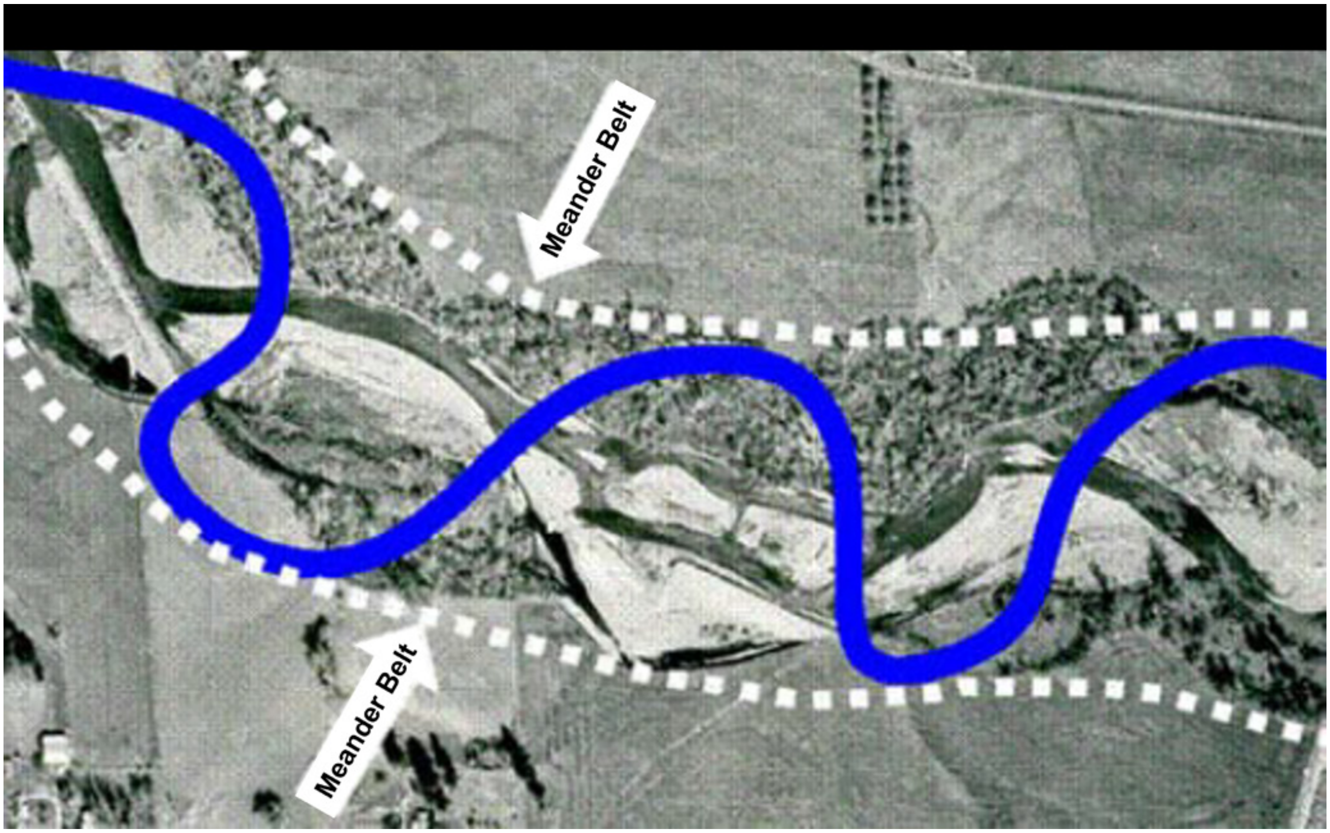


Figure 4.9—Historical meander migration limits (USDA NRCS 2007g). The meander belt (shown by the dashed white lines on both sides of the channel) indicates the extent to which meanders may have existed historically. The blue line indicates one possible historical channel configuration.

Bank stabilization techniques can be divided into two major categories: inert structures (inelastic or rigid, typically rock) and streambank soil bioengineering (flexible, malleable, and incorporating plants). Some techniques and structure designs incorporate aspects of both.

Bioengineering is generally preferable for riparian forest restoration projects when considering alternatives because of the incorporation of woody vegetation. Inert structures often have unintended consequences. For example, **gabions** can be problematic to fisheries when the wires break down and impale fish. Bioengineering practices are surprisingly comparable to rock structures in their ability to withstand shear stresses (table 4.2). Engineering expertise is required for a sound design (USDA NRCS 2007h). Bioengineering approaches are typically less expensive than inert structures in their initial construction and long-term maintenance or replacement (fig. 4.10).

Table 4.2—Permissible shear and velocity for selected lining materials (Fischenich 2001; Giordanengo et al. 2016). Riprap is described below in terms of D50, which is the median grain size, or the particle size at which 50 percent of particles are smaller.

Boundary category	Boundary type	Permissible shear stress (lb/ft2)	Permissible velocity (ft/sec)
Soils	Sandy loam (noncolloidal)	0.03–0.04	1.75
	Silty loam (noncolloidal)	0.045–0.05	1.75–2.25
	Firm loam	0.075	2.5
	Stiff Clay	0.26	3–4.5
	Shales and hardpan	0.67	6
Gravel or cobble	1-inch	0.33	2.5–5
	2-inch	0.67	3–6
	6-inch	2.0	4–7.5
	12-inch	4.0	5.5–12
Vegetation	Class A turf	3.7	6–8
	Class B turf	2.1	4–7
	Class C turf	1.0	3.5
	Long native grasses	1.2–1.7	4–6
	Short native and bunch grass	0.7–0.95	3–4
	Reed plantings	0.1–0.6	Not applicable
	Hardwood tree plantings	0.41–2.5	N/A
Temporary degradable rolled erosion control products (RECPs)	Jute net	0.45	1–2.5
	Straw with net	1.5–1.65	1–3
	Coconut fiber with net	2.25	3–4
	Fiberglass roving	2.0	2.5–7
Nondegradable RECPs	Unvegetated	3.0	5–7
	Partially established	4.0–6.0	7.5–15
	Fully vegetated	8.0	8–21
Riprap	6-inch D50	2.5	5–10
	9-inch D50	3.8	7–11
	12-inch D50	5.1	10–13
	18-inch D50	7.6	12–16
	24-inch D50	10.1	14–18

Table 4.2 continued.

Boundary category	Boundary type	Permissible shear stress (lb/ft2)	Permissible velocity (ft/sec)
Bioengineering	Wattles	0.2–1.0	3
	Reed fascine	0.6–1.25	5
	Coir roll	3–5	8
	Vegetated coir mat	4–8	9.5
	Live brush mattress (initial)	0.4–4.1	4
	Live brush mattress (grown)	3.9–8.2	12
	Brush layering (initial or grown)	0.4–6.25	12
	Live fascine	1.25–3.1	6–8
	Live willow stakes	2.1–3.1	3–10
Hard surfacing	Gabions	10	14–19
	Concrete	12.5	>18

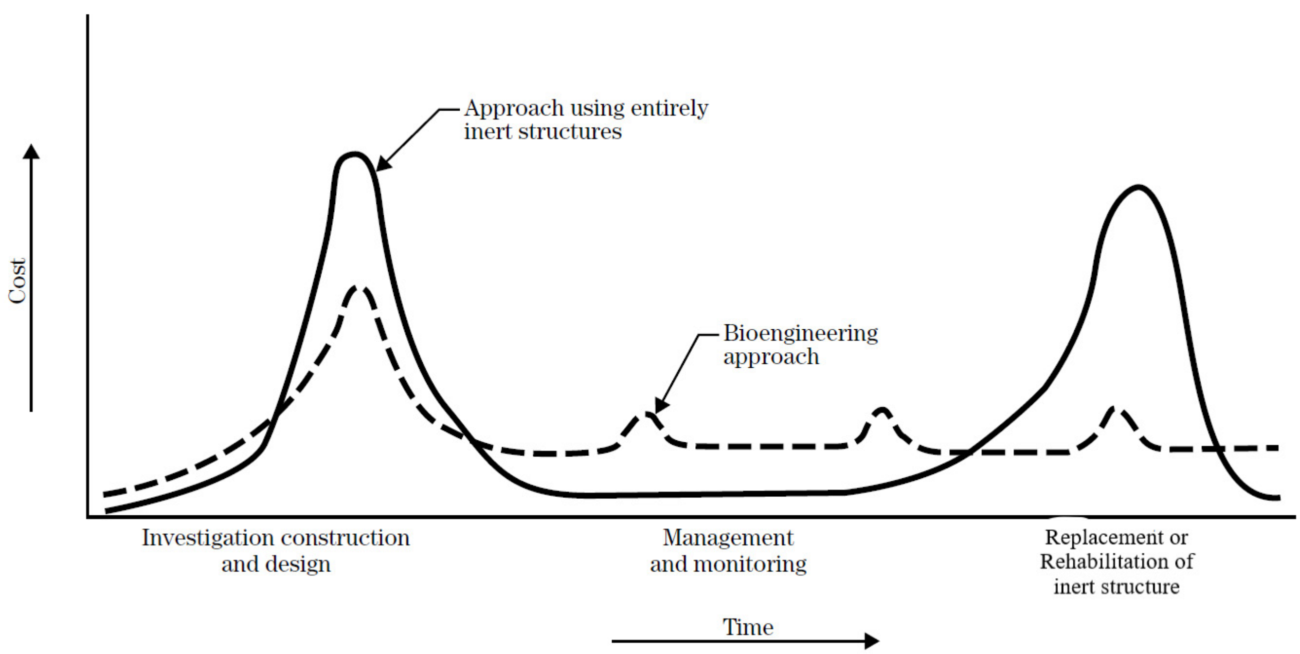


Figure 4.10—Illustration of expenditure profiles for soil bioengineering and inert structures (USDA NRCS 2007h). While inert structures (e.g., gabions) may last longer, their drawbacks include the introduction of artificial materials into the ecosystem as well as higher cost. In contrast, bioengineered structures can break down over time, and thus are less permanent; they are also less expensive.

The materials and structures used for bank protection have varying degrees of ability to resist shear stress and velocities of streamflow. It is important to know the parameters of expected flows in order to size materials and design structures appropriately. The relative strength of various bank materials and stabilization structures is presented in table 4.2. Specific types of inert structures and streambank soil bioengineering are described in the next two sections.

Inert Structures

Streambank Armor Protection With Stone Structures (riprap, gabions, etc.)

These techniques typically involve importing quantities of large rock, preparing the eroding bank by sloping and excavating a keyway (a trench that extends below the river bed level) at the toe, and placing the rock to create a barrier to the erosive forces of high flows. It is extremely effective, but it is expensive and prevents vegetation establishment. There are some alternate designs that incorporate vegetation (fig. 4.11) (USDA NRCS 2007j,k).

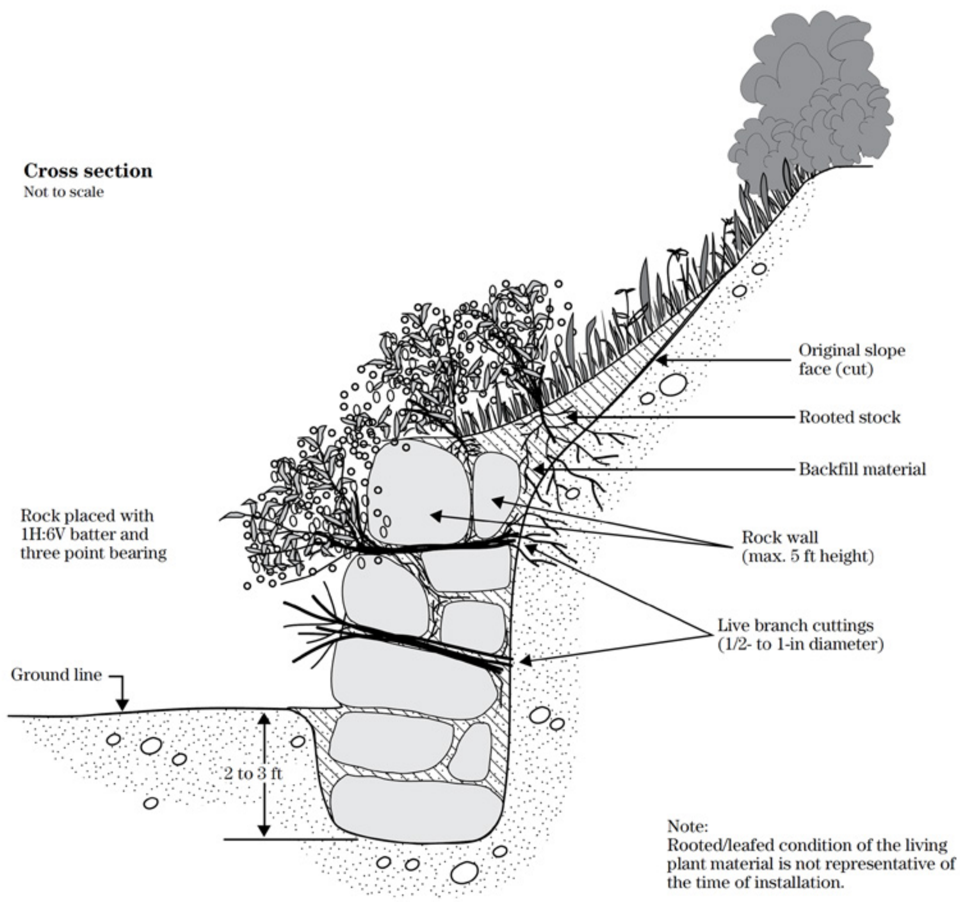


Figure 4.11—Details of a vegetated rock wall. USDA image from NRCS 2007k.

Flow Directing Techniques (rock barbs, spurs, J-hooks, vanes, etc.)

These techniques include using large rock or wood to create structures at intervals along an eroding bank to direct the flow away from the bank. They are often used to shield banks from eroding flows, build up the toe of the bank, and direct flows to create a stable alignment (USDA NRCS 2007g). Typically, ample space between the structures remains for vegetation establishment on the bank. Other techniques are often incorporated with these types of structures (e.g., tree revetments, plantings, large woody material). They can be designed to enhance fish habitat by incorporating a few simple alterations (fig. 4.12) (Harman and Starr 2011).

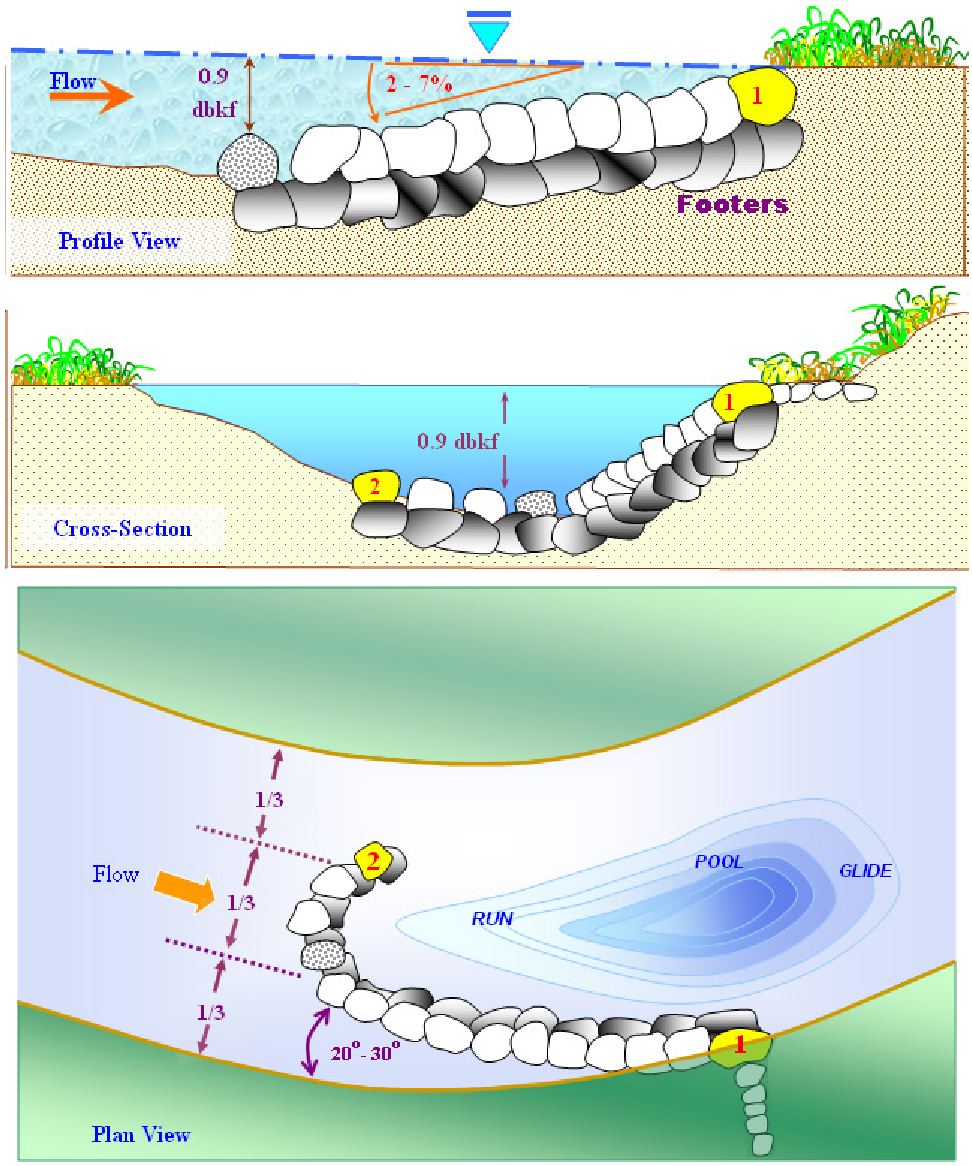


Figure 4.12—Plan, profile, and section views of the J-hook vane structure. USDA image from NRCS 2007c.

Large Woody Material (LWM) (root wads, log vanes, tree revetment, etc.)

Riparian forests often have a supply of large wood on site to supply material for these structures. Large woody material structures are intended to provide habitat and stabilization until woody riparian vegetation and stable bank slopes can be established. Large woody material decays within a few years unless it is continuously submerged. Woody structures are best applied to channels that are at least moderately stable, have gravel or finer bed material, and need wood for habitat. Streams with low sediment transport or steep, high-energy systems transporting large cobbles and boulders are usually not good candidates for woody material structures (USDA NRCS 2007i). Various techniques to slow or redirect streamflow at the bank require different types of woody material and arrangements (fig. 4.13).

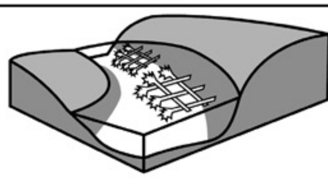
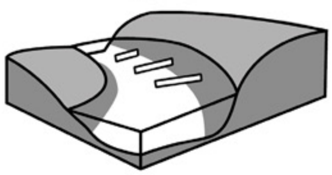
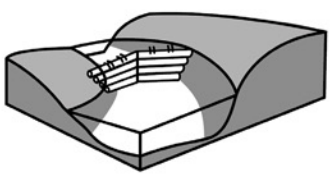
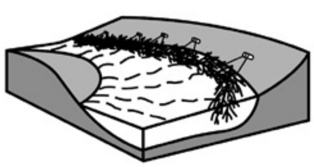
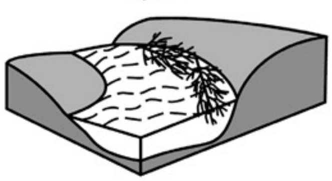
Configuration	Sketch	Description	Strengths
Engineered logjams		Intermittent structures built by stacking whole trees and logs in crisscross arrangements	Emulates natural formations. Creates diverse physical conditions, traps additional debris
Log vanes		Single logs secured to bed protruding from bank and angled upstream. Also called log bendway weir	Low-cost, minimally intrusive
Log weirs		Weirs spanning small streams comprised of one or more large logs	Creates pool habitat
Rootwads		Logs buried in bank with rootwads protruding into channel	Protects low banks, provides scour pools with woody cover
Tree revetments or roughness logs		Whole trees placed along bank parallel to current. Trees are overlapped (shingled) and securely anchored	Deflects high flows and shear from outer banks; may induce sediment deposition and halt erosion
Toe logs		One or two rows of logs running parallel to current and secured to bank toe. Gravel fill may be placed immediately behind logs	Temporary toe protection

Figure 4.13—Classification of large wood instream structures. USDA image from NRCS 2007i.

Streambank Soil Bioengineering

Streambank soil bioengineering uses plants as structural components to stabilize and reduce erosion on streambanks. Stabilizing streambanks through the integration of natural vegetation has many advantages over using hard armor linings alone. By using live plants to provide physical protection from erosion, extreme channel adjustments can be buffered (management option 5 – Install Riparian Plantings), and restoration of the channel to a naturally functioning state can be accelerated.

When selecting the best-suited soil bioengineering techniques, managers should have a clear understanding of the ecological systems of the adjacent areas. Selection of species and techniques will play an initial role in site stabilization and, ultimately, serve as the foundation for the ecological restoration of the site (management option 5 – Install Riparian Plantings).

Bioengineering techniques such as brush mattresses, fascines, vertical bundles, brush layering, brush packing, crimping and seeding, wattle siltation fence, live brush sills, brush trench, willow clump planting, vegetated geogrids, and brush spurs are ways to both physically protect banks from erosion and meet vegetation establishment objectives (Giordanengo et al. 2016; Hoag and Fripp 2002; USDA NRCS 2007h). Geotextile fabrics and rolled erosion control products (RECPs) are commonly incorporated into bioengineering projects with the expectation that their contribution to stabilization is temporary until the vegetation becomes established. Structures can be designed to maximize aquatic habitat features or stream shading and to protect banks from erosion. Streambank soil bioengineering is not universally applicable. There are important factors to consider for its successful application and long-term sustainability (USDA NRCS 2007h).

One example of a bank stabilization project occurred in 2016 and 2017 at the Denzil Stewart Nature Park, Logan, Utah, on the banks of the Logan River. This project was implemented following a large flood in 2011. The primary objectives were to (1) stabilize the riverbank, (2) control future erosion, and (3) plant native riparian vegetation that would improve bird habitat and park aesthetics. A secondary objective was to demonstrate best practices for bank stabilization and protection to nearby landowners with properties located adjacent to the Logan River. The bank stabilization plan was developed in a partnership between Logan City and two consulting firms. To implement the project, heavy equipment was used to create rock structures along the streambank similar to the vegetated rock wall structure shown in figure 4.11. Then community volunteers spent several organized workdays planting native species. Therefore, this project combined management options 8 (Stabilize Streambanks) and 5 (Install Riparian Plantings) to meet the objective of stabilizing banks. Tree species included narrowleaf cottonwood, boxelder, and bigtooth maple, all of which were planted on floodplain surfaces that sit relatively high above the stream channel (fig. 4.14). Below that floodplain level, volunteers also planted several native species of shrubs. This bank stabilization project was part of a larger conservation action plan for the Logan River (Logan City 2016a,b).

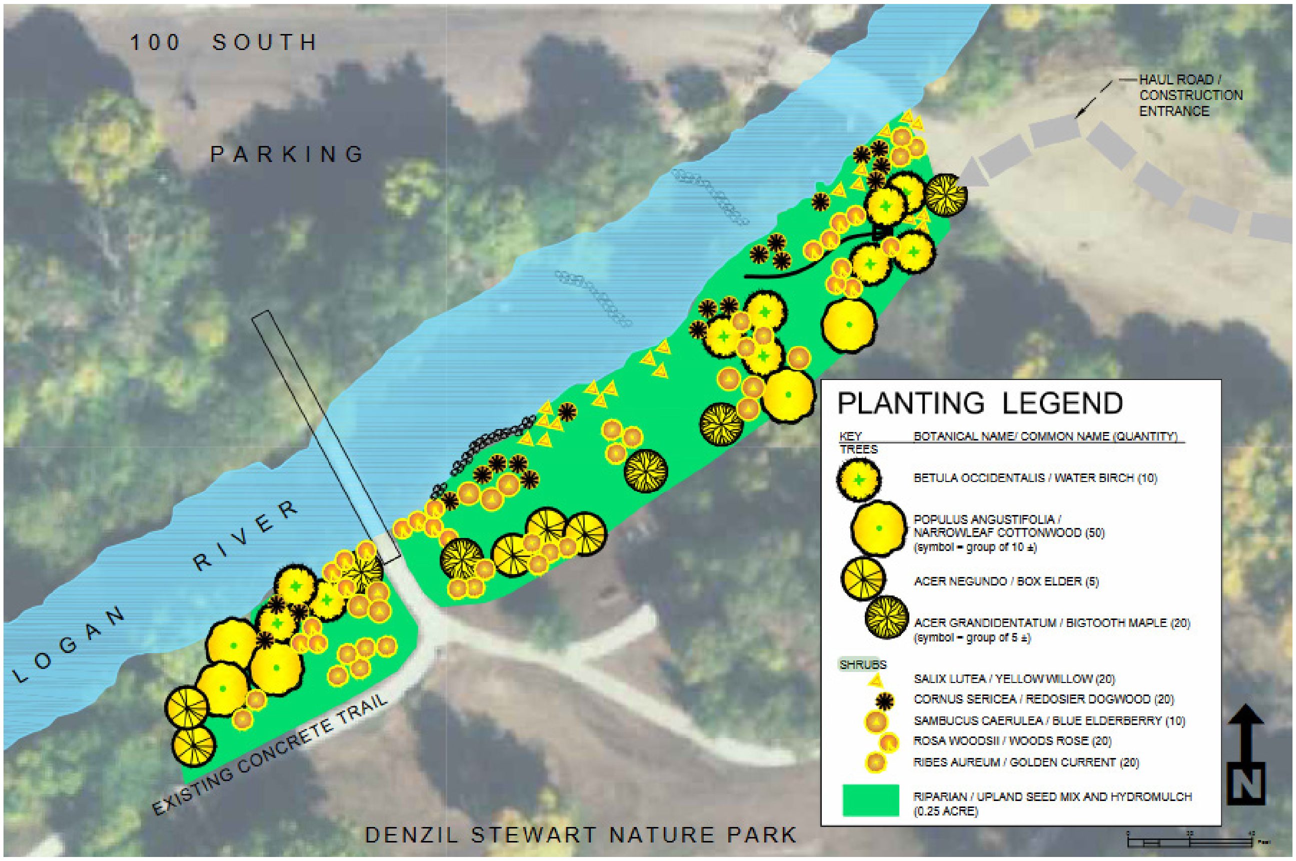


Figure 4.14—An example of a multistage bank stabilization project, undertaken at Denzil Stewart Nature Park along the Logan River in Logan, Utah. The first stabilization action consisted of using heavy machinery to create a wider floodplain surface (area highlighted in green) and adding boulders and cobbles to stabilize the banks. The second action was to plant native trees and shrubs. Photo from Logan City 2016a; used with permission.

Additional information is available from the following sources (with publishing agency or entity usually listed first):

- USDA NRCS, *National Engineering Handbook Part 654: Stream Restoration Design* (USDA NRCS 2007e); https://directives.sc.egov.usda.gov/landingpage/8d0f4807-640a-4656-afd2-e7df3df7fab5

- Federal Interagency Stream Restoration Working Group, *National Engineering Handbook Part 653: Stream Corridor Restoration—Principles, Processes, and Practices* (FISRWG 2001); https://directives.sc.egov.usda.gov/landingpage/c00a10de-e1f7-4d75-877a-a51e00ed3c53

- *Introduction to Induced Meandering* (Zeedyk 2009); https://issuu.com/quiviracoalition/docs/an_introduction_to_induced_meanderi
- USDA NRCS, *National Engineering Handbook Part 654, Technical Supplement 14I: Streambank Soil Bioengineering* (USDA NRCS 2007h); https://directives.nrcs.usda.gov//sites/default/files2/1712931151/7366.pdf
- USDA NRCS, *National Engineering Handbook Part 654, Technical Supplement 14H: Flow Changing Techniques* (USDA NRCS 2007g); https://directives.nrcs.usda.gov//sites/default/files2/1712931147/7365.pdf
- *Living Streambanks: A Manual of Bioengineering Treatments for Colorado Streams* (Giordanengo et al. 2016); https://cwcb.colorado.gov/sites/cwcb/files/Biostabilization_Manual_072416_0.pdf
- USDA NRCS, National Engineering Handbook Part 654, Technical Supplement 14K: Streambank Armor Protection with Stone Structures (USDA NRCS 2007j); https://directives.nrcs.usda.gov//sites/default/files2/1712931154/7369.pdf
- USDA NRCS, *National Engineering Handbook Part 654, Technical Supplement 14M: Vegetated Rock Walls* (USDA NRCS 2007k); https://directives.nrcs.usda.gov//sites/default/files2/1712931158/7371.pdf
- *Natural Channel Design Review Checklist* (Harman and Starr 2011); https://www.epa.gov/sites/default/files/2015-07/documents/ncd_review_checklist.pdf
- USDA NRCS, *National Engineering Handbook Part 654, Technical Supplement 14J: Use of Large Woody Material for Habitat and Bank Protection* (USDA NRCS 2007i); https://directives.nrcs.usda.gov//sites/default/files2/1712931152/7367.pdf
- USDA NRCS, *Streambank Soil Bioengineering Guide for Low Precipitation Areas* (Hoag and Fripp 2002); https://www.nrcs.usda.gov/plantmaterials/idpmcpussbfglpabklt.pdf

9 – Remove or Improve Infrastructure

There are cases where riparian forest restoration will necessitate the modification of various types of transportation infrastructure, including roads, culverts, or bridges, and other types of structures such as buildings. Historically, human settlement has typically included roads that follow river and stream courses. These roads often interfere with the natural fluvial geomorphology and hydrology of the watercourse.

When possible, a road's deleterious effects on a riparian forest can be obviated by simply temporarily or permanently closing the road to use, or even obliterating the road and restoring the riparian forest. This action may be the most helpful course to overcome the damaging effects of roads in riparian corridors, especially when stream channels have been straightened to accommodate road placement. This is true regardless of whether a road was constructed for past mining or logging activities, or is currently used for recreation, agriculture, or another purpose. Road decommission, closure, or removal ultimately helps restore riparian forest community structure (including shade), native riparian species diversity, and riparian forest acreage, while assisting in reducing bare and compacted soils. These changes lead to reduced erosion from streambeds, banks, and adjacent slopes with concomitant sediment loading, turbidity, and salinity, and thus also to improved consequences for water quality and the aquatic community. Helpful guidance for minimizing the impacts of roads and road closure activities in riparian and wetland areas is offered by Wiest (1998).

Often, bridges, culverts for water and fish passage, and in-stream structures used in previous restoration efforts need augmentation, improvement, or enlargement to both achieve the original restoration goals and preserve other desired riparian forest values and function. Yochum (2018) includes many helpful references for augmenting and improving fish passage structures at dam sites and road crossings. To reduce road crossing barriers, the replacement of traditional culverts with rock ramp open-water crossings (Mooney et al. 2007), open-bottom arches and box structures, and bridges is recommended (Yochum 2018). If improperly sited or built, however, bridges sometimes require retrofitting or decommissioning. For discussion and references for dam decommissioning, see management option 11 – Alter Streamflows.

In fall 2012, the Forest Service decommissioned and relocated a road from a riparian area on Saddle Creek, in Elk Valley on the Uinta-Wasatch Cache National Forest. The Forest Service decommissioned approximately 2 miles of existing road and eliminated six fords across Saddle Creek. To decommission the road, the Forest Service obliterated, recontoured, ripped, and water-barred the old road and restored the riparian area and stream channel degraded by the Saddle Creek Road. Personnel physically closed the old road to all motorized traffic, planted native seed and willow cuttings along the streambanks, and reestablished portions of the stream channel. Approximately 2 miles of new road were constructed upslope of the old road location (USDA FS 2012).

Detailed information about appropriate design of transportation infrastructure that encroaches on stream channels is available from the following sources (with publishing agency or entity usually listed first):

- USDOT Federal Highway Administration, Hydraulic Engineering Circular No. 20, *Stream Stability at Highway Structures* (Lagasse et al. 2012); https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif12004.pdf
- USDOT Federal Highway Administration, Hydraulic Design Series Number 6, *River Engineering for Highway Encroachments: Highways in the River Environment* (Richardson et al. 2001); https://www.fhwa.dot.gov/engineering/hydraulics/pubs/nhi01004.pdf

- *Bridge Scour and Stream Instability Countermeasures: Experience, Selection and Design Guidance, volumes 1 and 2* (Lagasse et al. 2009); https://www.fhwa.dot.gov/engineering/hydraulics/pubs/09111/09112.pdf
- Forest Service, *A Landowner's Guide to Building Forest Access Roads* (Wiest 1998); https://efotg.sc.egov.usda.gov/references/Delete/2017-6-24/No_45_A_Landowners_Guide_to_Building_Forest_Access_Roads.pdf
- Forest Service, Technical Note TN-102.4, *Guidance for Stream Restoration* (Yochum 2018); https://www.fs.usda.gov/biology/nsaec/assets/yochumusfs-nsaec-tn102-4guidancestreamrestoration.pdf
- USDOI Bureau of Reclamation, *Rock Ramp Design Guidelines* (Mooney et al. 2007); https://www.usbr.gov/tsc/techreferences/mands/mands-pdfs/RockRampDesignGuidelines_09-2007_508.pdf

10 – Manage Upland Runoff

Land use, disturbance, and vegetation management in upland portions of watersheds can have a significant effect on the amount of water and sediment flowing downstream, and potentially overland, into riparian areas. One symptom of upland watershed conditions that may be adversely affecting riparian forests is increases in upland erosion. Another is runoff that may occur rapidly and result in high peak flows following large rainfall events. For example, intense rainfall after severe wildfire can result in large floods that scour and remove native riparian vegetation, resulting in altered community structure, depleted species diversity, and increased water temperature. If not addressed, such events can lead to invasion by exotic species. The direct effects of such events on physical riparian characteristics include increased bare soil, and streambed and bank erosion. The indirect effects, particularly when riparian trees are removed, include increased turbidity and altered macroinvertebrate communities. Runoff from agricultural areas may include high nutrient levels, leading to high levels of algae in the stream or increased salinity. Thus, upland runoff can cause a number of symptoms of stress in riparian forests. Management of upland portions of the watershed can mitigate several of these symptoms by modulating the input of water, sediment, and nutrients to riparian ecosystems.

The stressors related to upland runoff differ from most other stressors of riparian forest degradation in that they typically occur in the upper portions of the watershed and are often far away from the riparian forests of interest. Addressing such stressors may therefore require working across multiple jurisdictions and vegetation types. Note that the stressors operating in upland areas are, in some cases, the same stressors that may be operating within or adjacent to riparian forests. Examples include impacts due to invasive species, grazing, recreation, and roads. While previous sections of this chapter focused on restoration actions that mitigate those stressors within or adjacent to riparian forests, here we focus only on mitigating those stressors in upland areas that may be far from the riparian forest of concern.

It is often difficult to determine whether upland erosion and runoff are operating within the natural range of variability. As mentioned in management option 0 – No Action, monitoring over multiple growing seasons may be required to determine whether stressors are operating within this range. However, in the case of severe wildfire, managers typically know that the fire occurred and thus are aware of the possibility of increased erosion and post-storm runoff. Even though large or severe wildfire may be within the natural range of variability, the damage to riparian ecosystems may be unacceptable for ecological or socioeconomic reasons and thus warrant immediate mitigation via upland postfire vegetation management.

If upland disturbance or land use change is suspected of causing riparian forest degradation via increased erosion and runoff, managers must first consider what upland disturbances or land use changes have occurred. Examples of upland conditions that may result in increased runoff and sediment transport to downstream riparian areas include severe wildfire, timber harvest, heavy grazing, road construction, and conversion of natural vegetation to impervious or paved areas. If such conditions exist, the next step is to design a mitigation strategy. Specific management actions that can mitigate excessive upland erosion and runoff include planting, mulching, contouring or terracing, and reduction of future risk via management of existing vegetation. Each of these actions is described in the following discussion. All are intended to slow the rates of runoff and erosion.

Planting typically occurs when an area has been completely denuded of vegetation. Planting may be accomplished by aerial seeding (i.e., from airplanes or drones), ground-based seeding, or manual planting of seedlings. Aerial seeding is the best option for rapidly covering vast areas, and seed mixtures usually contain grass species that are quick to establish. Ground-based seeding covers smaller areas and may include a mix of herbaceous and woody vegetation. Planting of seedlings is usually used in cases where managers want to establish trees or shrubs, and failure rates are sometimes high due to factors such as inappropriate seasonal timing, dry conditions, presence of pathogens, degraded seed stock, or herbivory.

An alternative to planting is mulching in strategic areas, although in many cases seeding and mulching occur simultaneously. In some cases, mulch provides immediate surface roughness and absorbency that reduce runoff and erosion and increase infiltration (USDA NRCS 2007b). Mulch may consist of various materials, including straw, wood strands, or hydromulch (a combination of natural fibers, fertilizer, and seeds). As with seeding, mulch can be applied aerially or from the ground (fig. 4.15). Because seed and mulch may contain unintended weeds and weed seeds, using certified weed-free materials can reduce the potential for introducing or spreading undesirable species.

Figure 4.15—Straw mulch being applied from a tractor and blower in a recently burned area. USDA Forest Service photo from Robichaud et al. 2010.

A historical method of slowing runoff and erosion was contouring or furrowing. This method was widely used in Utah following overgrazing during the early 1900s, when steep, mountainous areas experienced debris flows following years of overgrazing. Objectives included slowing runoff and trapping sediment following wildfire (Robichaud et al. 2010). However, its effectiveness was questionable and today it is no longer used (Jeff Bruggink, USDA Forest Service Region 4 Soil Scientist, personal communication, 2019).

Reduction of future risk via management of existing vegetation is the most proactive, and least reactive, of the management options covered here. This strategy involves either active or passive vegetation thinning to minimize the risk of future severe wildfires, insect epidemics, or diseases in forested watersheds. Active thinning is often accomplished either via silvicultural thinning prescriptions or prescribed fire, and these two treatments are sometimes used consecutively. Passive thinning may occur as a result of managed wildfires. This type of upland vegetation management requires extensive planning, site selection, and collaboration among multiple land managers and stakeholders, and often takes years to accomplish. Because such projects usually include many miles of streams and associated riparian areas, project plans should include stipulations for protecting riparian areas against adverse effects of upland treatments.

One example of a risk-reduction effort is the Canyons Healthy Forest Restoration Act project on the Manti-La Sal National Forest in southern Utah. The project area covers 30,000 acres and includes salvage logging of beetle-killed Engelmann spruce (fig. 4.16), with the objective of reducing the risk of future severe fire.

Figure 4.16—Beetle-killed spruce on the Manti-La Sal National Forest (Utah), which is targeted for salvage logging as part of a project to reduce the risk of future severe wildfires. USDA Forest Service photo.

Any of the treatment options discussed here requires coordination with multiple resource managers. Most successful upland vegetation management projections include collaboration among stakeholders and careful evaluation of the costs, benefits, and legal considerations for each option.

Additional information is available from the following source:

- USDA NRCS, *National Engineering Handbook Part 630, Chapter 12: Hydrologic Effects of Land Use and Treatment* (USDA NRCS 2007b); https://directives.nrcs.usda.gov//sites/default/files2/1712930611/7302.pdf

11 – Alter Streamflows

Opportunities to change altered flow regimes through dam removal or modifying diversions (e.g., by altering them to improve flow or by changing operational timing) could be explored when those actions are expected to have the desired effect. Lane's balance (fig. 3.3) illustrates the effects of changing the amount of flow and sediment, as well as the buffering effect of vegetation.

Increasing the amount of flow can result in channel degradation or downcutting, particularly where riparian vegetation has been previously compromised by another factor (e.g., fire, livestock grazing). This is because streams tend to adjust to the increase in flow by increasing the size or amount of sediment eroded and redistributed, or by decreasing the channel slope in reaches where erodible banks allow lateral adjustment and thus increased sinuosity.

Increasing flow is not recommended if sediment supply is too high (e.g., due to severe wildfire in the upland part of the watershed). Similarly, the use of dams or diversions to reduce flow can help slow streambed and bank erosion, which may reduce turbidity and high sediment loads.

The timing and amount of streamflow can be important for seed germination and successful seedling establishment of native tree species such as cottonwoods. Extended periods of sustained soil moisture due to flooding or high flows allow roots to grow to depths where moisture levels are more constant, thus avoiding desiccation during low-flow periods. Well-timed dam releases can be used to extend or increase high flows, which facilitate regeneration of native species, and subsequently can address issues related to native species diversity, altered community structure, and replacement of riparian species by upland species. When altered flow timing, or flow augmentation, succeeds in encouraging recruitment of native riparian trees, additional symptoms of riparian forest stress may also be addressed, such as reduced forest acreage, lack of shade, elevated water temperature, and altered macroinvertebrate communities. In some cases, replacement of nonnative tamarisk with native tree species may also help reduce high levels of salinity.

Dam removals are increasingly being implemented as a primary approach for addressing such impairments as the lack of sediment, large wood, particulate organic matter, and longitudinal connectivity for aquatic organisms. Dams are commonly removed due to their age, loss of function, and obsolescence. Removals are often motivated by concerns (and listings under the Endangered Species Act of 1973) for anadromous fish, such as in the Pacific Northwest (fig. 4.17). Frequently, the greatest concern and expense regarding removals are the fate of reservoir sediment, nutrients, contaminants, and organic matter after dam breach (Yochum 2018).

Figure 4.17—The Elwha River returning to its original channel following removal of a large dam in Olympic National Park, Washington. USDOI National Park Service photo.

Based on available studies on dam removals, a summary review (Foley et al. 2017) reached the following conclusions:

- Physical responses are typically fast, with the rate of impounded sediment erosion largely dependent on sediment characteristics and dam-removal strategy
- Ecological responses to dam removal differ among the affected upstream, downstream, and reservoir reaches
- Dam removal tends to quickly reestablish connectivity, restoring the movement of material and organisms between upstream and downstream river reaches
- Geographic context, river history, and land use significantly influence river restoration trajectories and recovery potential because they control broader physical and ecological processes and conditions

Efforts to change the timing or magnitude of flow can be implemented not only through dam management, but also through improvement of irrigation infrastructure. Examples of situations where improved irrigation systems and agreements have benefited riparian forests are provided here. Castle et al. (2016) describe several case studies from Colorado illustrating attempts to increase instream flows through improvements in irrigation efficiencies and water rights lease agreements.

Riparian plant communities are particularly dependent on access to groundwater and are thus susceptible to degradation when water tables drop. In stream systems that experience summer dewatering and subsequent shallow groundwater loss, chronic dewatering has resulted in the death of riparian species and subsequently destabilized formerly stable streambanks. The following examples describe situations where enhancement of instream flows resulted in higher water tables.

Irrigation diversions typically dewater the North Fork of the Ogden River during the summer. Typically, a percentage of water diverted at a diversion structure is lost from the irrigation system through conveyance losses into the ground or through evaporation. This deficiency has been partially solved through efforts to enhance low-flow conditions by improved irrigation efficiency and water leasing. In theory, on-farm and conveyance efficiency improvements allow more water to be maintained in-stream from the point of diversion. In many circumstances losses are reduced by enclosing the conveyance system (e.g., converting open or unlined ditches to pipeline), so the amount of water diverted is more closely linked to the amount of water applied on the field.

Other efficiency improvements include on-farm efficiency such as converting from flood irrigation to sprinklers. This approach relies on the idea that less water is applied to a field, thus optimizing water use and leaving the conserved, unused water in the stream. There are a few pitfalls with this approach. It is important to understand the dynamics of flood irrigation return flows within a system. If a large number of farmers converts from flood to sprinkler irrigation, it can affect the longitudinal flow dynamics, as return flows often supplement downstream water rights. Understanding these connections is important. Second, when an irrigation company or multiple companies or users consolidate to a single larger water company, their use patterns can change from turns to simultaneous use. Such consolidated use can lead to further channel dewatering. For example, in Chalk Creek near Coalville, Utah, when several irrigation diversions for flood irrigation along a 2.5-mile reach were consolidated into a single diversion for sprinkler irrigation, the consolidation resulted in periodic channel dewatering during the summer, even though the total amount of irrigation water used was reduced.

Another tool applicable in rivers and streams with chronic low flows or dewatering is to keep water in-stream through lease agreements with individual water users. These can be either long-term (10-year) fallowing agreements under the “Instream Flow to Protect Trout Habitat” statute (Utah State Legislature 2008), or extremely flexible short-term agreements. The short-term agreements include split-season agreements where the water user agrees not to irrigate fields during the late season (typically after July 1) or triggered option agreements where water users agree to a full-season or split-season fallow during low-flow years. In all of these examples, the producer may be compensated for lost production (e.g., by nongovernmental organizations), typically at the market value of their crop. These leases have been used in limited areas throughout Utah, and partnering organizations such as Trout Unlimited are interested in participating in them in priority reaches.

12 – Stabilize Channel Grade

Stream channel degradation is a common problem in riparian forest ecosystems that is caused by excess hydraulic energy in the stream channel. That excess energy is often due to increased flow velocity caused by increased runoff or alteration of the natural stream morphology. Specific types of channel degradation include downcutting and headcutting. Downcutting describes lowering of the streambed, which may occur anywhere along a stream channel. Headcutting occurs wherever there is an abrupt drop in the streambed elevation relative to adjacent hillslopes. This drop is called a knick-point and tends to migrate upstream or upslope as it is eroded (fig. 4.18).

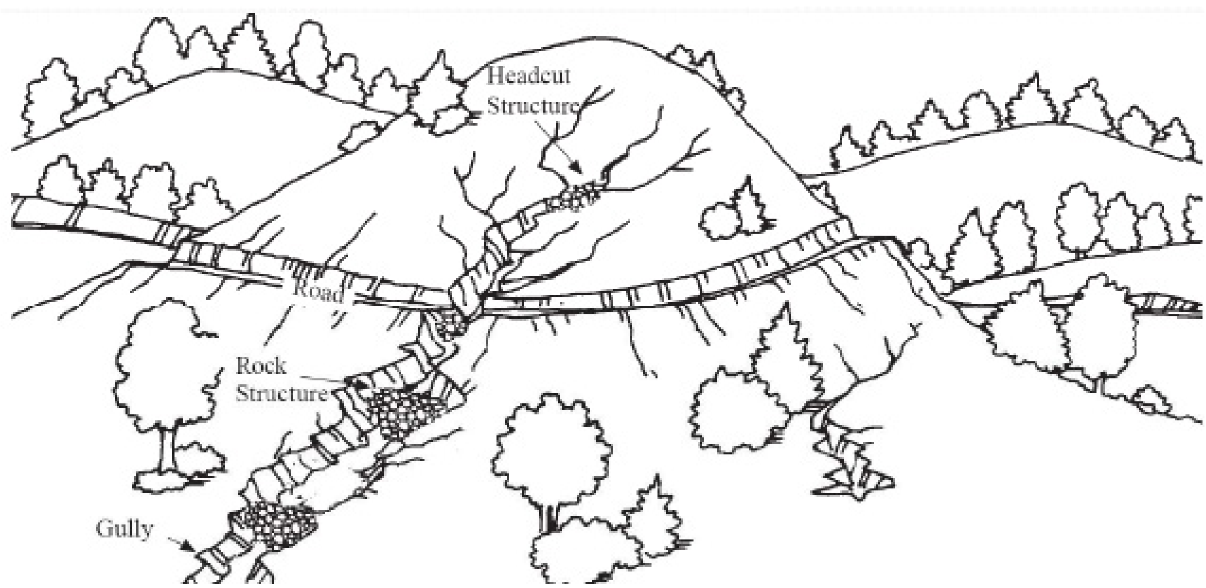


Figure 4.18.—Typical locations of grade stabilization structures intended to prevent further headcutting or downcutting (shown as "headcut structure" and "rock structure," respectively) Image from Keller and Sherar 2003; used with permission.

Channel degradation is easily observable in severe cases. Symptoms may include channel incision, separation of the channel from the floodplain, bank erosion, increased sediment load, and large amounts of bare soil on floodplains. Severe channel degradation will negatively impact new riparian tree recruitment, or even remove trees through bank erosion. These negative impacts may be reversed by addressing the causes of channel degradation, although active planting may be required. Reestablishment of riparian trees will often remediate secondary, in-channel symptoms of channel degradation, including lack of shade, elevated water temperature, and elevated turbidity.

Grade stabilization structures require careful design specifications and can be expensive to construct. Poor design may have unintended adverse effects on other parts of the stream channel. Such structures are typically applied to solve localized problems and not used in restoration projects. Therefore, these structures should be designed and installed by qualified specialists such as hydraulic engineers.

The main solution to channel degradation is grade stabilization, which involves constructing control structures that slow the velocity of water to prevent further downcutting or headcutting. The different types of structures used for grade stabilization can be grouped into three categories: **stabilizers**, **drop structures**, and **debris basins** or **check dams**. Stabilizers prevent downcutting. Drop structures create more-gradual channel slopes, which reduce scour in high-velocity areas and can prevent additional headcutting. Check dams trap sediments that may abrade or further erode the channel if allowed to continue downstream.

Stabilizers are also referred to as grade control structures. Typical materials include rock mulch, rock gabions, cross vanes (fig. 4.19), or in less severe cases and smaller streams **beaver dam analogues** (BDAs), **post-assisted log structures,** or woody debris. Grade control structures slow water velocity in the channel by decreasing the channel slope. In areas of headcutting, they may also be used to retain ponded water, which can increase soil moisture retention, facilitate recruitment of riparian vegetation, and prevent the headcut from migrating farther upstream (i.e., up-slope).

A less expensive alternative to solid stabilizer structures are BDAs, which are channel-spanning structures that mimic beaver dams. A classic BDA consists of posts pounded into the channel bed and banks, with willow or other branches woven in among the posts (fig. 4.20) (Wheaton et al. 2019). Beaver dam analogues are permeable, allowing water and some sediment to flow through them. Variations on BDAs use other materials and may not involve posts. These structures may assist with beaver restoration or expand riparian forests even in the absence of beaver (Nash et al. 2021; Pollock et al. 2017).

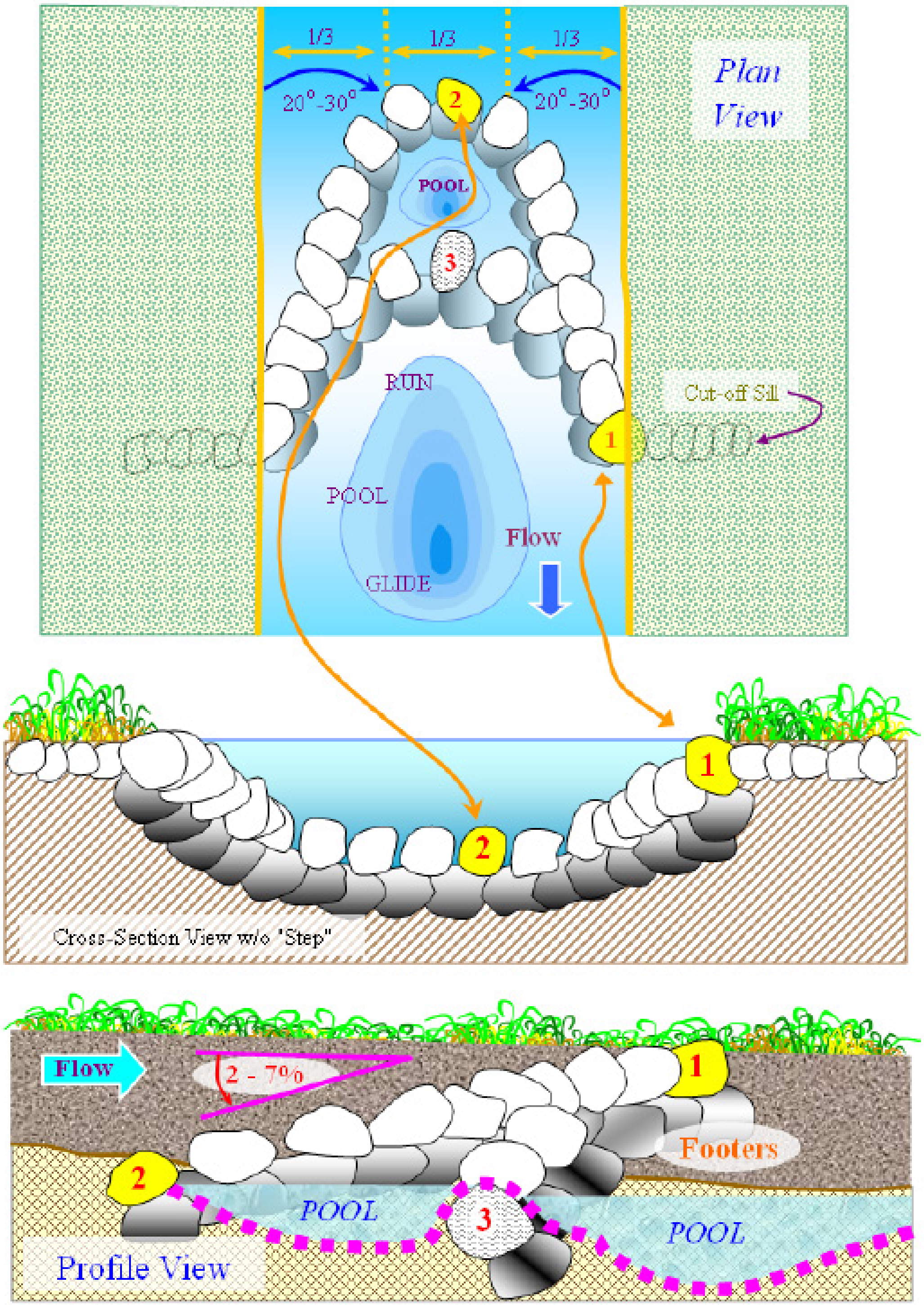


Figure 4.19—Plan view, cross-section, and profile of a cross vane. USDA image from NRCS 2007c.

Figure 4.20—A beaver dam analogue (BDA), created from posts pounded into the streambed and bank, on Miller Creek in central Utah. Channel aggradation is occurring 6 months after installation. Jordan Nielson, with Trout Unlimited, stands nearby. Courtesy photo by Allison Jones, Allison Jones LLC.

Just as beavers build dam complexes along long stretches of stream, a series of BDAs allows for expanding their alteration of the aquatic and riparian ecosystem along the stream corridor. BDAs can:

- Create pool habitat upstream and downstream of the structure
- Improve floodplain connectivity
- Expand cover (or extent) of riparian vegetation
- Prevent decreased stream sinuosity
- Create multithreaded channels
- Nourish streams by retaining organic matter and sediment

- Reduce bank erosion
- Establish beaver colonies by providing protection for relocated beaver

Drop structures are typically constructed from either concrete or rock gabions (fig. 4.21). Unlike stabilizers, which slow the flow of water, drop structures include a scour hole that directly absorbs the force of flowing water below the vertical drop (fig. 4.22). Because they typically span the entire channel with a solid connection to each bank, they also stabilize banks. The control structure causes the aggradation of sediment above it and decreases the bed slope. Existing headcuts can be controlled with drop structures placed either above or below the headcut.

Figure 4.21—Example of a rock gabion drop structure. USDA NRCS photo.

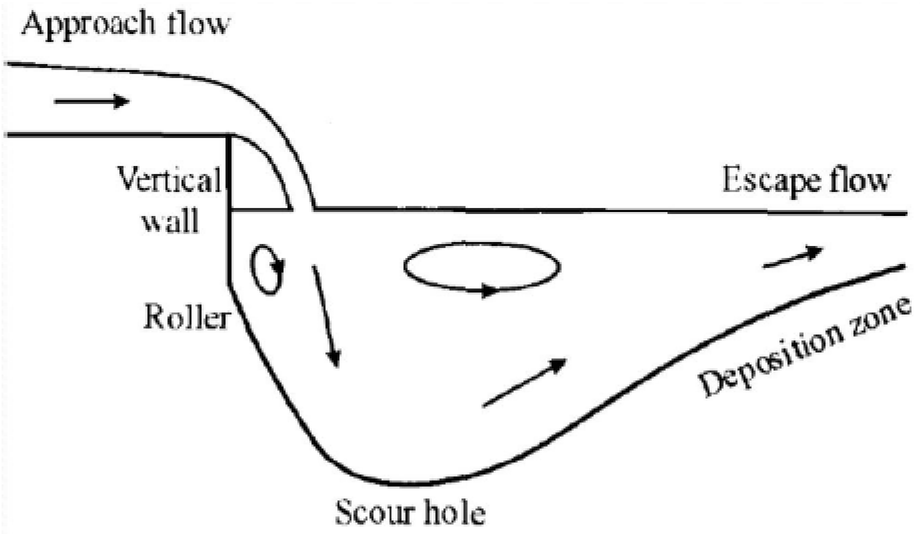


Figure 4.22—Schematic diagram of a stone drop structure (USDA NRCS 2007f).

Both drop structures and check dams often include a notched weir in the center of the structure to direct flow in the center of the channel. They also include erosion-resistant material on the downstream side of the structure to protect the channel from additional scour. Because these types of structures impede fish movement, the design should include a method for fish passage whenever possible.

Several considerations can help increase success following installation of a grade stabilization structure. One key design consideration is protection of the streambed and banks both upstream and downstream of the stabilization structures, because such structures may result in increased velocity and bank erosion in adjacent areas, potentially resulting in the channel bypassing the structure. It is also important to evaluate whether upstream erosion will increase sediment inputs behind the grade stabilization structure, and if so, to mitigate the source or cause of erosion prior to restoration. If the area immediately surrounding the grade stabilization structure is subject to grazing, recreation, or other physical impacts, it should be fenced to protect the structure's integrity.

The best treatment for channel degradation is prevention. Streams that have recently experienced an increase in gradient or are expected to experience increased flow velocity (e.g., due to recent fire in the upland parts of the watershed), are vulnerable to future channel degradation during high-flow events. Continued or increased degradation can be prevented by addressing sections of channel that are vulnerable to further degradation (e.g., knick-points and steep channel slopes). Restoration to former channel grade elevations is often unfeasible and sometimes impossible.

Grade stabilization structures require careful design specifications and can be expensive to construct. Poor design may have unintended adverse effects on other parts of the stream channel. Therefore, such structures should be designed and installed by qualified specialists such as hydraulic engineers.

Additional information is available from the following sources (with publishing agency or agency usually listed first):

- USDA NRCS, *National Engineering Handbook Part 654: Stream Restoration Design* (USDA NRCS 2007e); https://directives.nrcs.usda.gov//sites/default/files2/1712931220/Part%20654%20-%20Stream%20Restoration%20Design.pdf
- Federal Interagency Stream Restoration Working Group, *National Engineering Handbook Part 653: Stream Corridor Restoration—Principles, Processes, and Practices* (FISRWG 2001); https://directives.nrcs.usda.gov//sites/default/files2/1712931078/Part%20653%20-%20Stream%20Corridor%20Restoration%20Principles%2C%20Processes%2C%20and%20Practices.pdf
- USDA NRCS, *National Engineering Handbook Part 654, Technical Supplement 14G: Grade Stabilization Techniques* (USDA NRCS 2007f); https://directives.nrcs.usda.gov//sites/default/files2/1712931145/7364.pdf
- USDA NRCS, *Conservation Practice Standard: Grade Stabilization Structure* (USDA NRCS 2014); https://www.nrcs.usda.gov/resources/guides-and-instructions/grade-stabilization-structure-no-410-conservation-practice
- *The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains* (Pollock et al. 2018); https://www.fws.gov/media/beaver-restoration-guidebook

13 – Restructure Physical Channel

Physical channel restructuring is typically the most expensive type of stream restoration and is therefore recommended only in situations where the natural sinuosity of the channel has been modified from its natural range of variability. Channel design experts determine whether a stream meets this criterion by examining historical air photos and reference channels in nearby watersheds, if they exist, and consulting the known history of the site. Examples of such situations include (1) channels that have been straightened (e.g., in agricultural areas), (2) new channels created by river diversions or excessive bank erosion, and (3) restoration of original channel **planform** following diversions created for mining or other intensive land uses. Physical channel restructuring is sometimes referred to as natural channel design or channel restoration design, all of which are defined as “the reconstruction of a river channel to a stable geometric configuration that is self-sustaining and in balance with imposed flow and sediment regimes and the character of the catchment landscape” (Soar and Thorne 2001, p. 24). Channel restructuring is discouraged in cases where less intrusive restoration options—such as bank or bed stabilization—can meet management objectives (Soar and Thorne 2001).

Most often, the objective of physical channel restructuring is to restore a channel's historical planform, or two-dimensional layout as viewed from above (e.g., in a map or aerial photo); dimensions (width, depth, and cross-sectional shape); and profile (slope). A common objective in restoring a river's historical planform is to increase its sinuosity by adding meanders. In nearly all cases, heavy equipment is required to move soil, gravel, cobbles, and boulders. The placement of these substrates should be carefully specified by hydraulic engineers or other channel restoration specialists, who will prescribe the location, slope, and height of each substrate material to meet specifications for width, depth, cross-sectional shape, sinuosity, meander radius and wavelength, and channel slope (Soar and Thorne 2001). In situations where previous modification of the channel has resulted in altered overland flow or sediment inputs, physical channel restructuring can also improve water quality and potentially reduce salinity, particularly when agricultural runoff has impacted the site.

Physical channel restructuring is intended to restore the planform and thus alleviate symptoms of stress in riparian forests. When a channel's planform is very different from its historical range of variability, a restructured and restored channel may have more meander bars and thus more sites for regeneration of native species. Physical restructuring can also reconnect the channel to its floodplain if it was previously incised. Because physical restructuring often decreases the channel gradient, postrestoration flow velocity decreases, and in turn, streambed erosion and turbidity will decrease. When physical channel restructuring creates conditions that allow riparian trees to reestablish, the following biotic symptoms of stress are likely to improve: depleted native species diversity, altered community structure, replacement of riparian species with upland species, and lack of shade. Consequently, it is likely that riparian forest acreage will be expanded, water temperature will decrease, and macroinvertebrate community density and diversity will increase.

In Utah, one of the largest channel restructuring projects to date is the Provo River between Jordanelle Reservoir and Deer Creek Reservoir (fig. 4.23a-b). The river was straightened during the 1950s and 1960s as part of the Provo River Project to provide for agricultural land and downstream water consumption. Between 1999 and 2009, the Provo River Restoration Project excavated abandoned meanders, reestablished the river's historical planform, and added features for fish and invertebrate habitat, recreational access, and revegetation (URMCC 2009). The total cost of this publicly funded project was $10 million for construction plus $35 million for land acquisition to accommodate the expanded (but original) planform (URMCC 2009). Postrestoration monitoring indicates that project objectives were achieved in the lower section of the target section of the Provo River but not in the upper section, and Erwin et al. (2016) provide a technical summary of the reasons for different outcomes.

Figure 4.23a-b—Provo River in Utah before (a) and after (b) restoration, which included physical channel restructuring to increase sinuosity. Image from URMCC 2009; used with permission.

Any project-level planning should involve civil engineers, fluvial geomorphologists, vegetation ecologists, and fisheries ecologists, at a minimum, to ensure that the project meets restoration objectives and does not introduce additional stressors.

Additional information is available from the following sources (with publishing agency listed first):

- USDA NRCS, *National Engineering Handbook Part 654: Stream Restoration Design, Chapter 12: Channel Alignment and Variability Design* (USDA NRCS 2007d) and *Chapter 11: Rosgen Geomorphic Channel Design* (USDA NRCS 2007c); https://irrigationtoolbox.com/NEH/Part%20654/CHAPTERS/Chapter-12.pdf https://semspub.epa.gov/work/01/557060.pdf

- U.S. Army Corps of Engineers, *Channel Restoration Design for Meandering Rivers* (Soar and Thorne 2001); https://apps.dtic.mil/sti/pdfs/ADA396990.pdf

- Forest Service, Technical Note TN-102.4, *Guidance for Stream Restoration* (Yochum 2018); https://www.fs.usda.gov/biology/nsaec/assets/yochumusfs-nsaec-tn102-4guidancestreamrestoration.pdf

MANAGEMENT SUPPORT

Before embarking on any riparian restoration project, the proponent or project manager needs to determine whether other people or organizations should be consulted. In the case of a restoration project envisioned to occur partly or entirely on public lands, it is critical to consult all affected stakeholders, and we strongly recommend development of an interdisciplinary team of specialists in soil science, hydrology, botany, fuels, archaeology, and fisheries and wildlife biology. However, even if a project is expected to occur only on a single private parcel, the determination of whether to consult other people or organizations must be made. There are two immediate reasons for doing so: (1) Some form of legal compliance or approval may be required, and (2) additional resources or expertise may be available to improve or enlarge the project. More fundamentally, few watersheds are or can be managed by a single entity; collaborative effort is a practical norm and often a legal requirement. A project could be ineffectual or worse if undertaken alone, and to avoid this outcome the problem may need to be tackled at a broader scale than a single parcel or ownership. Besides the physical outcomes, there are also social factors to consider. For example, even the apparently minor act of planting riparian vegetation on private property can upset downstream water users, if they feel their water rights are being infringed—and they may be correct.

Table 4.3 summarizes some of the reasons for consulting other people or organizations before embarking on a riparian restoration project.

The material presented next is intended to illustrate some of the necessities and opportunities that may pertain to a particular situation; there is no intent here to present an exhaustive, authoritative summary. We list some examples of required coordination to facilitate project compliance with laws and regulations, and partnership opportunities to improve project scale and performance. These examples may pertain only to a particular situation, and the following summary is merely intended to be illustrative, not exhaustive or authoritative.

Section 73-3-29 of the Utah Code (Utah State Legislature 2014) requires any person, governmental agency, or other organization wishing to alter the bed or banks of a natural stream to obtain written authorization from the State Engineer prior to beginning work. The Stream Alteration Program was implemented in 1972 in order to protect the natural resource value of the State's streams and protect the water rights and recreational opportunities associated with them. The U.S. Army Corps of Engineers issued Programmatic General Permit 10 (PGP-10), which allows an applicant to obtain both State approval and authorization under Section 404 of the Clean Water Act though a single application process. Although not all stream alteration activities qualify for approval under PGP-10, many minimal-impact projects can be approved under this joint permit agreement.

Table 4.3—Some of the reasons for consulting other people or organizations before embarking on riparian restoration projects.

Management Option	Relative complexity, or advisability of prior consultation	If medium or high, why?
0. Do Nothing	Low	not applicable
1. Create Riparian Buffers	Low	not applicable
2. Remove Conifers	Low	not applicable
3. Manage Grazing	Low	not applicable
4. Manage Recreation	Low	not applicable
5. Install Riparian Plantings	Low	not applicable
6. Remove Exotic Plants	Medium	The smaller the parcel, the more influenced it is by weed populations on adjacent and other nearby properties. Weed control is much more effective when conducted at larger scales.
7. Manage Beaver	High	Beavers are not small animals. They require considerable food, water and space. A new beaver population is very likely to spread both upstream and downstream for some distance, causing friction among neighbors. Finally, it is illegal for private citizens to move live wildlife.
8. Stabilize Stream Banks	Medium	Intervening in the stream succession process requires significant technical expertise. In Utah it also frequently requires a streambed alteration permit. Finally, effects of this intervention can propagate downstream for some distance, and may affect other people.
9. Remove or Improve Infrastructure	Medium	The infrastructure in question may be public property, or it may belong to other private interests (not the landowner). If it does belong to the landowner, use of federal monies for its removal may invoke the need for a cultural-resource survey.
10. Manage Upland Runoff	Medium	The smaller the parcel, the more influenced it is by what happens on neighboring properties. Runoff management is more effective when conducted at larger scales.

Table 4.3 continued.

Management Option	Relative complexity, or advisability of prior consultation	If medium or high, why?
11. Alter Stream Flows	High	Modifying the relative proportions of water and sediment in a channel is likely to result in downstream channel downcutting or channel meandering. These effects can propagate for some distance, adversely affecting other people.
12. Stabilize Channel Grade	High	Intervening in the stream succession process requires significant technical expertise. In Utah it also frequently requires a streambed alteration permit. Finally, effects of this intervention can propagate downstream for some distance and may affect other people.
13. Restructure Physical Channel	High	Intervening in the stream succession process requires significant technical expertise. In Utah it also frequently requires a streambed alteration permit. Finally, effects of this intervention can propagate downstream for some distance and may affect other people.

In accordance with Section 319 (b)(1) of the Clean Water Act of 1977, the governor of each State shall develop a management program with the purpose of reducing nonpoint source pollution from navigable waters within the State. The State of Utah has delegated the management of the Statewide Nonpoint Source Program to the Division of Water Quality within the Department of Environmental Quality. The Division of Water Quality has identified the approach that will be used to manage nonpoint source pollution in surface water and groundwater throughout Utah. There is a State plan that contains long-term objectives and tasks to help improve Utah's Nonpoint Source Program, as well as annual milestones to determine program effectiveness. That plan was developed with the participation of various State, Federal, local, and private entities that have a vested interest in the protection and restoration of water quality throughout the State. The State of Utah uses a watershed approach to manage nonpoint source (NPS) pollution throughout the State.

Utah's Watershed Restoration Initiative (WRI) is a partnership-based program designed to improve high priority watersheds throughout Utah. Since 2006, WRI partners have completed over 2,100 projects, treating more than 1.8 million acres State-wide. Program goals for WRI include protection and rehabilitation of vital habitat for wildlife, reduction of catastrophic wildfire risks in treated areas, improvement of water quality and quantity, increased forage for sustainable agriculture, and growth of economic opportunities for local communities.

Maintaining healthy watersheds requires cooperative effort. As of 2019, over 500 agencies, organizations, and individuals have contributed to WRI projects by providing funding or in-kind assistance. Restored and rehabilitated acres are only made possible through a diverse partnership of State and Federal government agencies working together with nongovernmental organizations, industry, elected officials, and private landowners.

The USDA Natural Resources Conservation Service (NRCS), a charter member of WRI, offers voluntary programs to eligible landowners and agricultural producers to provide financial and technical assistance to help manage natural resources in a sustainable manner. Through these programs, the agency approves contracts to provide financial assistance to help plan and implement conservation practices that address natural resource concerns or opportunities to help save energy and to improve soil, water, plant, air, animal, and related resources. The NRCS's Agricultural Conservation Easement Program (ACEP) contains provisions to protect, enhance, and restore wetlands, including riparian areas with perpetual easements.

The U.S. Fish and Wildlife Service in the Department of the Interior is another charter member of WRI. Its Partners for Fish and Wildlife Program also provides financial and technical assistance to private landowners, tribes, and schools on a voluntary basis to improve fish and wildlife habitat for Federal trust species (which in Utah include migratory birds, threatened or endangered species, interjurisdictional fish, and other species of concern). Field biologists work one-on-one with landowners and partners to plan, implement, and monitor activities. Working together with more than 45,000 landowners and 3,000 conservation partners around the Nation, this program has successfully restored over 1,000,000 acres of wetland habitat, 3,000,000 acres of upland habitat, and 11,000 miles of streams.

The Utah Department of Agriculture and Food (UDAF) offers two programs to assist with natural resource management on public and private land in Utah. The Utah Grazing Improvement Program (GIP) seeks to improve the sustainability of rangelands and watersheds, and the Invasive Species Mitigation Grant program is available for projects that target highly invasive weed species.

Once a management option or suite of options is selected, it is important to document the condition that the manager is seeking to change. Chapter 5 offers a diversity of monitoring options that will allow a manager to measure progress toward restoration goals—or the need for course-correction if the option selected is not leading to desired results. The method used to measure pre-restoration condition (baseline) should, if possible, be the same method used to measure change once restoration activities are undertaken.

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Chapter 5: Monitoring Riparian Forest Restoration

After symptoms and stressors have been identified through an initial assessment of the riparian forest (Chapter 3), restoration goals have been identified, and management options have been selected (Chapter 4), choices will need to be made about how to monitor the progress and effectiveness of restoration efforts (whether passive or active) in meeting or moving toward the desired conditions. Although a desired condition may appear simple (e.g., “increase the number of cottonwood sprouts reaching 6 feet in height”), it should be described in a way that allows for monitoring. As noted in Chapter 3 for riparian forest assessment, monitoring methods (found in the list starting on p. 142) may be qualitative or quantitative.

A **qualitative method** for monitoring lacks any measurement or quantification. For instance, a photo of an eroding streambank or the observation of lack of young cottonwood trees would be considered qualitative. A numerical score may be assigned to the degree of erosion, or to broad categories of presence of young cottonwood trees, but that number would not be derived from direct measurement. Even if a simple monitoring method such as repeated photo from fixed points is used, the photo files should be carefully georeferenced, labeled with date and site name or site code, and stored for later comparisons.

A **quantitative method**, on the other hand, involves systematically measuring some factor related to the riparian system, including the forest. For instance, a transect belt within which the height and diameter of cottonwoods encountered are recorded is a quantitative method. If the beginning and end of the transect are marked with a stake, repeat measurements made along that same transect by another assessor at about the same time would be expected to be the same or nearly so. Moreover, each permanently fixed transect could be measured (monitored) repeatedly for the same indicator (e.g., young cottonwood recruitment) years later to determine change or trend. Data gathered using a quantitative method should be retained, as well as any summary or report produced using the data. If statistical analysis of the quantitative data is desired, the number of data points necessary to establish statistical significance should be determined before monitoring.

The primary criterion for useful monitoring is that it is objective and **repeatable**, regardless of whether it uses simple, qualitative methods or more precise quantitative methods. A method is considered objective if the results and their representation are not influenced by personal feelings or opinions. A method is considered repeatable if it can be repeated by another person within a determined margin of error. Ideally, a person using the same protocol as another person would collect very similar data. Stating the monitoring methods prior to beginning restoration actions helps ensure objective results; in other words, results are not biased by the manager’s hopes or prior expectations. For example, are monitoring points selected systematically (randomly or at regular spacing), or might they be selected to represent sites with the greatest need for restoration? Either method can be acceptable, depending on the intended use of results.

The monitoring method should be economically feasible to repeat over time, as postrestoration recovery or other riparian forest changes may be slow or sporadic. Due to time and funding constraints, qualitative methods are often used in lieu of quantitative methods.

The following list offers links to numerous monitoring methods, from simple and qualitative methods to more intensive and quantitative methods. The following assessment methods can be used to estimate the current status of the functions, processes, and structure of a stream or riparian area. Monitoring methods include the collection and analysis of indicators to measure changes in the amounts, spatial distribution, or condition of riparian or stream parameters over time. These assessment and monitoring methods have been field-tested, and most have been used by government agencies. However, modifications of any method are possible, depending on the question being asked. Regardless, full descriptions of methods used should accompany any results presented or reports prepared. Source documents for the following qualitative and quantitative assessment and monitoring methods are provided starting on page 148.

Vegetation related

Observed symptom: Depleted native species diversity

Assessment methods

- AWN Chapter 3
- PFC1 Items 5 and 9
- PFC2 Item 6
- US&RM Methods

Monitoring methods

- MIM Greenline composition
- MVRRA Vegetation cross-section composition and greenline composition
- NRCP Vegetation sampling
- SVA Key species and composition

Observed symptom: Altered community structure

Assessment methods

- AWN Chapter 3
- PFC1 Items 8 and 11
- PFC2 Item 7; photos
- RSRA Indicator 14
- SVAP2 Elements 4 and 5
- US&RM Methods

Monitoring methods

- MIM Woody species age class
- MM Chapter 11
- MVRRA Woody species regeneration
- NRCP Vegetation sampling
- Photo monitoring
- SVA Key species and composition

Observed symptom: Replacement of riparian species with upland species

Assessment methods

- API
- AWN Chapter 3
- PFC1 Items 9, 10, and 11
- PFC2 Item 8
- Photos
- RS
- SVAP2 Elements 4 and 5
- US&RM Methods

Monitoring methods

- API
- MIM Greenline composition
- MVRRA Vegetation cross-section composition and greenline composition
- NRCP Vegetation sampling
- Photo monitoring
- RS
- SVA Key species and composition

Observed symptom: Increased invasive species

Assessment methods

- AWN Chapter 3
- RSRA Indicators 17 and 18
- PFC1 Item 9
- PFC2 Item 6
- Photos
- US&RM Methods

Monitoring methods

- API
- MIM Greenline composition
- MM Chapter 23
- MVRRA Vegetation cross-section composition and greenline composition
- NRCP Vegetation sampling
- SVA Key species and composition
- Photo monitoring
- RS

Observed symptom: Reduced riparian forest acreage

Assessment methods

- API
- PFC1 Item 13
- PFC2 Item 11
- Photos
- RS

Monitoring methods

- API
- MVRRA Vegetation cross-section composition
- NRCP Vegetation sampling; photo monitoring
- RS

Observed symptom: Lack of shade

Assessment methods

- API
- PFC1 Item 13
- PFC2 Item 11
- Photos
- RS
- RSRA Indicator 2
- SVAP2 Element 6

Monitoring methods

- API
- MIM Woody species height class
- NRCP Vegetation sampling
- Photo monitoring
- RS

Fluvial geomorphology related

Observed symptom: Streambed erosion (incision, entrenchment)

Assessment methods

- GSSR Preliminary field assessment
- PFC1 Item 3
- PFC2 Item 16
- Photos
- RSRA Indicator 3
- SVAP2 Element 1

Monitoring methods

- MM Chapter 14
- MIM Greenline-to-greenline width
- MVRRA Vegetation cross-section composition
- NRCP Physical feature measurement
- Photo monitoring
- Scour chains

Observed symptom: Increased or depleted sediment load

Assessment methods

- GSSR Preliminary field assessment
- PFC1 Items 3, 4, and 19
- PFC2 Items 4, 5, and 17
- Photos
- PSIAC
- SVAP2 Element 1

Monitoring method

- MIM Substrate

Observed symptom: Bank erosion

Assessment methods

- GSSR Preliminary field assessment
- PFC1 Items 8, 9, 11, and 13
- PFC2 Items 6, 7, 9, 11, 15, and 17
- Photos
- RSRA Indicator 4
- SVAP2 Element 3

Monitoring methods

- Erosion pins
- MIM Streambank alteration, streambank stability and cover, and substrate
- MVRRA Greenline bank stability
- NRCP Physical feature measurement
- Photo monitoring

Observed symptom: Disconnection of floodplain from the channel

Assessment methods

- GSSR Preliminary field assessment
- PFC1 Item 3
- PFC2 Item 13
- RSRA Indicator 3
- SVAP2 Element 1

Monitoring methods

- API
- MIM Greenline-to-greenline width
- MVRRA Vegetation cross-section composition
- Photo monitoring

Observed symptom: Reduced sinuosity

Assessment methods

- GSSR Preliminary field assessment
- MM Chapter 14
- PFC2 Item 3
- SVAP2 Element 1

Monitoring methods

- API
- MIM Greenline-to-greenline width
- MVRRA Vegetation cross-section composition
- NRCP Physical feature measurement
- Photo monitoring

Observed symptom: Excessive bare soil

Assessment methods

- GSSR Preliminary field assessment
- IIRHv4 Indicator 4

- PFC1 Item 13
- PFC2 Item 11
- Photos
- SVA Attributes and methods

Monitoring methods

- MIM Streambank alteration
- MM Chapter 15
- Photo monitoring
- SVA Attributes and methods

Observed symptom: Compacted soil

Assessment methods

- GSSR Preliminary field assessment
- MM Chapters 7 and 18

Monitoring methods

- MIM Streambank alteration
- MM Chapters 7 and 18
- Photo monitoring

Water quality or quantity related

Observed symptom: Elevated water temperature

Assessment methods

- PFC1 Item 15
- RSRA Indicator 2
- SVAP2 Element 6

Monitoring method

- USU BMP Section 4 and Appendix B

Observed symptom: Altered macroinvertebrate community

Assessment methods

- Macroinvertebrate Key
- RSRA Indicator 11
- SVAP2 Elements 13 and 14

Monitoring methods

- National Aquatic Monitoring Center
- USU BMP Section 4 and Appendix B

Observed symptom: Altered turbidity

Assessment methods

- SVAP2 Element 7
- TM

Monitoring methods

- TM
- USU BMP Section 4 and Appendix B

Observed symptom: High levels of algae

Assessment methods

- PFC1 Items 5 and 16
- RSRA Indicator 1
- SVAP2 Element 8

Monitoring methods: None known at this time.

Observed symptom: Excessive salinity

Assessment method

- SVAP2 Element 16

Monitoring methods

- Contact Utah Department of Environmental Quality, Division of Water Quality for potential measurements (https://deq.utah.gov/division-water-quality)

Source documents for the preceding methods are as follows:

- API: Aerial photo interpretation (contact local NRCS or USU Extension specialist)
- AWN: Assessing the Water Needs of Riparian and Wetland Vegetation in the Western United States (Cooper and Merritt 2012); https://www.fs.usda.gov/research/treesearch/41207
- National Aquatic Monitoring Center: Utah State University and BLM Bug Lab; https://qcnr.usu.edu/research/namc/

- Erosion pins: Use of Erosion Pins in the study of Slope Evolution (Haigh 1976); https://www.academia.edu/47831296/Use_of_Erosion_Pins_in_the_Study_of_Slope_Evolution
- GSSR: Guidance for Stream Restoration (Yochum 2018); https://efotg.sc.egov.usda.gov/references/public/CO/TN-102.3_Yochum_106p_2017_sm.pdf
- IIRHv4: Interpreting Indicators of Rangeland Health Version 4 (qualitative) (Pellant et al. 2005); https://www.blm.gov/sites/blm.gov/files/documents/files/Library_BLMTechnicalReference1734-06.pdf
- Macroinvertebrate Key: Key to Macroinvertebrate Life in Ponds and Rivers in Utah (Utah State University Extension n.d); https://extension.usu.edu/waterquality/macrokey/
- MIM: Multiple Indicator Monitoring of Stream Channels and Streamside Vegetation (quantitative) (Burton et al. 2011); https://www.blm.gov/sites/blm.gov/files/documents/files/TR_1737-23.pdf
- MM: Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems Volume II (quantitative) (Herrick et al. 2009); https://www.blm.gov/sites/default/files/documents/files/Library_BLMTechnicalReference1734-08_V2.pdf
- MVRRA: Monitoring Vegetation Resources in Riparian Areas (quantitative) (Winward 2000); https://www.fs.usda.gov/treesearch/pubs/5452
- NRCP: The National Riparian Core Protocol: A Riparian Vegetation Monitoring Protocol for Wadeable Streams of the Conterminous United States (Merritt et al. 2017); https://www.fs.usda.gov/treesearch/pubs/55365
- PFC1: A User Guide to Assessing Proper Functioning Condition and the Supporting Science for Lentic Areas (qualitative) (Prichard et al. 2003); https://www.blm.gov/documents/national-office/blm-library/technical-reference/riparian-area-management-user-guide
- PFC2: Riparian Area Management: Proper Functioning Condition Assessment for Lotic Areas (Dickard et al. 2015); https://www.blm.gov/sites/blm.gov/files/documents/files/TR_1737-15.pdf
- PSIAC: Factors Affecting Sediment Yield in the Pacific Southwest Area (PSIAC 1968); https://www.tucson.ars.ag.gov/unit/publications/PDFfiles/1745.pdf#:~:text=Nine%20factors%20are%20recommended%20forconsideration%20in%20determining%20the,erosion%2C%20and%20channel%20erosion%20and%20sediment%20trans%20port
- RS: Remote sensing - contact local NRCS (https://www.nrcs.usda.gov/conservation-basics/conservation-by-state/utah#contact) or USU Extension specialist (https://extension.usu.edu/water-impacts)

- RSRA: User's Guide: Rapid Assessment of the Functional Condition of Stream-Riparian Ecosystems in the American Southwest (qualitative) (Stacey et al. 2021); https://static1.squarespace.com/static/57c5f6aa579fb31d71581457/t/622a33e7595d03722306c866/1646933016447/RSRA+User+Guide+Version+2.0+-+Website.pdf
- Scour chains: Scour Chain Employment in Gravel Bed Rivers (Laronne et al. 1994); https://www.sciencedirect.com/science/article/pii/034181629490040X
- SVA: Sampling Vegetation Attributes: Interagency Technical Reference (quantitative) (Coulloudon et al. 1999a); https://www.nrcs.usda.gov/sites/default/files/2022-09/stelprdb1044175.pdf
- SVAP2: Stream Visual Assessment Protocol Version 2 (qualitative) (USDA NRCS 2017); https://www.nrcs.usda.gov/sites/default/files/2022-10/SVAP2%20National%20Bio%20Handbook%20Part%20614.pdf
- TM: Turbidity Measurement (mostly quantitative) (Robens Institute 1996; see section 2.33); https://apps.who.int/iris/bitstream/handle/10665/66334/WHO_EOS_96.4_1.p163-202.pdf?sequence=4&isAllowed=y
- US&RM: Utilization Studies and Residual Measurements (mostly quantitative) (Coulloudon et al. 1999b); https://efotg.sc.egov.usda.gov/references/public/NM/range92a6_interagn-UtilizStudies1.pdf
- USU BMP: Best Management Practices Monitoring Guide for Stream Systems (Mesner and Paige 2011); https://digitalcommons.usu.edu/extension_curall/1161/

Several questions may be important to ask before deciding which monitoring method(s) to use, including:

1. Which symptom(s) are most important to measure over time?

There is no need to monitor symptoms that are not likely to change, given the particular restoration actions being taken, or that are not of primary concern to the riparian manager. Basically, the key response variable or variables that the manager is seeking to modify with the restoration method—for instance, number of cottonwood sprouts growing above 6 feet in height—should be monitored.

For example, if a manager plants native trees after removing Russian olive, the two most important features to monitor are the Russian olive (Are the trees resprouting?) and the trees or other vegetation that have been planted (Are the plants surviving? Reaching maturity?). There would be no need to monitor shade. However, if unintended consequences are possible, such as increased exotic understory species as a result of the disturbance involved in the restoration, monitoring of such consequences should be considered.

2. Do both key symptom(s) and stressor(s) need to be monitored?

While changes in symptoms may be the purpose of restoration activities, a manager may need to also monitor changes in key stressors, particularly if stressors are being managed differently but continue to affect the system. For instance, if seedlings are not reaching heights of 6 feet or more due to intensive elk browsing, and wildlife managers have held a targeted hunt to reduce the elk numbers, the manager may want to monitor elk numbers, along with the height distribution and browse of the tree seedlings.

3. Do the monitoring measurements need to be multiyear? If yes, at what time intervals?

A combination of monitoring method difficulty and expected rate of change in a symptom is likely to determine the feasibility and usefulness of multiyear monitoring and monitoring intervals. Some monitoring methods are simple, such as establishing photo points to record floodplain reconnection with a channel after beaver reintroduction, and could easily be repeated annually. Measuring increases in understory species composition following relocation of recreational roads may require multiyear measurements, but annual measurements would be time-consuming with little change year-to-year.

4. Do the features being monitored change each year? If yes, during which seasons are postrestoration changes readily detected?

Monitoring data should be collected during seasons that are most likely to exhibit postrestoration trends, because intended effects of riparian forest restoration may be more evident during some seasons than others. For instance, if fish reproduction is being monitored, during which month would spawning or young-of-year be observed? If managers seek increased diversity of understory species, during which times of the year will different species be identifiable? Over time, depending on the variable being monitored, the monitoring interval can increase, for instance, monitoring annually for the first 3 to 5 years and then every other year or every 3 years.

The various qualitative and quantitative methods listed on pp. 142-148 are suggested for measuring particular symptoms. These methods differ in the technical expertise or time and precision required, but regardless of monitoring method used, it is important to establish baseline conditions before restoration actions begin. If baseline conditions are not clearly documented, the nature and magnitude of posttreatment changes may be difficult to reconstruct. Baseline monitoring should use the same method(s) that will be used in subsequent monitoring.

A greater degree of precision and quantification may be desirable if the results will be compared with results at other locations, or if the restoration method is an experimental or new method. A restoration site is often compared with a control site or reference site. In such cases, comparable data must be taken from these sites for pairing with restoration sites to determine treatment effects. A riparian forest of similar elevation, vegetation, and soil type that exhibits the type of conditions that the restoration action hopes to achieve can be useful as a reference site. The reference site will ideally be subject to similar climatic and weather conditions that may affect the key symptom(s). After the restoration process has begun, the nature of changes that are being monitored can be compared with conditions at the reference site.

Because drought or other climate or weather factors may affect a particular symptom such as water temperature or macroinvertebrate density at the same time as riparian restoration efforts, it is important to identify control sites that display the same conditions and symptom(s) of concern, but are not subject to the same restoration actions. The same methods for measuring baseline and subsequent features should be used in the control site and in the restoration site.

Properly designed exclosure studies can provide useful insights into grazing effects. Monitoring and research comparing grazed areas with ungrazed exclosures should be set up carefully. Exclosure study design will vary depending on variables being measured. An exclosure with high fencing (about 8 feet in height) will exclude all large ungulates, and measurements inside the exclosure will not reflect ambient use that occurs when livestock are not present. An exclosure with low fencing (about 3 feet) to exclude only livestock may not be used by wild ungulates if it is of small size. See George et al. (2011, p. 226) for resources and a discussion on how to set up livestock exclosures.

Monitoring some types of change, such as trends in macroinvertebrate diversity, requires advanced technical expertise. In those cases, a State, Federal, nongovernmental, or academic partner may be willing to help establish baseline and periodic monitoring.

There are many monitoring methods to address any given monitoring objective, and we have listed only some commonly used methods. If monitoring is done by a Federal or State agency, specific protocols and data formats may be required. Others, such as an academic researcher, landowner, or organization, may select other protocols to answer monitoring questions.

Glossary

Assessment—An estimate of the current status of an ecosystem's functions, processes, and structure in an area of interest, based on interpretation of locally collected information.

Bank erosion—Wearing away of the banks of a stream or river.

Banks—The land alongside a body of water; the sides of a stream or river between which the flow is confined.

Baseflow—Sustained low flow in a river during dry or fair-weather conditions, but not necessarily all contributed by groundwater; includes contributions from interflow and groundwater discharge.

Baseline conditions—The status of a site prior to restoration, management actions, or other impacts. Baseline conditions are typically documented by using photos and an initial assessment that may include qualitative and quantitative measurements. The results of future monitoring are compared against baseline conditions to evaluate the impact of the restoration or treatment. This approach is useful at individual sites, regardless of whether control sites are available for comparison.

Beaver dam analogue—Human-made structure designed to mimic the form and function of a natural beaver dam.

Browsing—Feeding on leaves, buds, or shoots of woody plants such as shrubs or trees (contrast with Grazing).

Channel—The bed and banks of a stream or river.

Check dam—A grade stabilization structure intended to trap sediments that may abrade or further erode the channel if allowed to continue downstream.

Constancy—The percentage of plots or sampling units in which a plant species occurs within a given dataset.

Control site—A site that is intentionally not restored to serve as a comparison against a similar site that is restored. A control site is similar to a reference site; the main difference is that a control site is intentionally maintained with no intervention for restoration, whereas the treatment or restoration site is targeted for restoration, and then the control versus treatment sites are compared to determine the effect of restoration. An ideal control site is as similar to the restoration site as possible so that any future differences between sites can be reasonably attributed to restoration actions. Both the control site and restoration site should be subject to the same initial assessment and subsequent monitoring.

Cut bank—The outside, nearly vertical bank of a water channel (stream), which is continually undergoing erosion.

Debris basin—A grade stabilization structure intended to trap sediments and reduce flood risk downstream.

Disturbance—A temporary change in environmental conditions that results in changes in ecosystem processes or composition. Disturbances may be natural or caused by humans. Riparian disturbances affect riparian forests either indirectly (e.g., via hydrologic impacts or their effects on valley morphology) or directly (e.g., via scouring, grazing, or clearing of vegetation for development).

Disturbance regime—The combined frequency, severity, and timing of a disturbance.

Downcutting—Vertical, downward erosion of a streambed or floodplain, typically due to an increase in water velocity following upstream disturbance or alteration of the channel.

Drop structure—A grade stabilization structure intended to create more gradual channel slopes, which reduce scour in high-velocity areas and can prevent additional headcutting.

Early seral—Pertaining to plant communities that develop shortly after disturbance of a site. In the absence of stressors or further disturbance, vegetation composition and structure change quickly and early seral communities are replaced over time by mid- to late seral communities. (Also see Successional status.)

Ecosystem integrity—The capacity of a community of plants, animals, and the physical environment (i.e., an ecosystem) to maintain ecosystem processes, support native plant and animal populations, and recover from natural disturbances.

Encroachment—The process of native plant species gradually colonizing new areas, or assuming a degree of cover or dominance that exceeds the natural range of variability.

Entrenchment—The vertical containment of a stream and the degree to which it is incised in the valley floor.

Ephemeral stream—A stream that is dry most of the year and contains water only during and immediately after a rainfall event.

Erosion—The displacement of soil by natural processes (e.g., water, wind, ice, or gravity) or anthropogenic disturbances (e.g., road cuts, use of off-highway vehicles), or both.

Exclosure—An area fenced to exclude animals.

Filter strip—A strip or area of herbaceous vegetation that removes contaminants from overland flow.

Flexible pond leveler—A flexible pipe placed in and perpendicular to a beaver dam at the height of a desired pond level. The intake pipe upstream of the dam is surrounded by fencing to prevent clogging; the pipe creates a permanent leak through the dam.

Floodplains—Areas that are periodically inundated by the lateral overflow of rivers or lakes or by direct precipitation or groundwater (or both).

Flow regime—The timing and magnitude of high and low flows in a stream or river, as well as the rate of change and variability of flows within and among years. Variability occurs in response to climatic factors such as precipitation, temperature, and evapotranspiration, and in response to drainage basin characteristics such as land use, land cover, and geology.

Fluvial erosion—Removal of material by flowing water (e.g., sediments, rocks) from the bed or banks of a stream or river.

Fluvial geomorphology—The study of the form and function of streams, including movement of both water and sediments, and the interaction between streams and the landscape around them.

Fluvial valley—A valley formed or modified by flowing water.

Functional diversity—(1) The presence of multiple species that contribute to similar ecosystem functions while occupying different niches or (2) the number of functional groups of species within and ecosystem.

Functional redundancy—The presence of multiple species that contribute to the same ecosystem function or structure (or both).

Gabion—A grade stabilization or bank stabilization structure consisting of a wire container filled with rock, broken concrete, or other material, used in the construction of dams, retaining walls, etc.

Geomorphic processes—Processes that produce existing topography, including erosion, weathering, deposition, and earth movement. Drivers of geomorphic processes include water, ice, wind, chemical reactions, plate tectonics, and volcanism. Water is the main driver of fluvial geomorphic processes, that is, those pertaining to streams and rivers. (Also see Hydrogeomorphic processes.)

Grazing—Feeding on grass or other herbaceous forage (contrast with Browsing).

Greenline—The first perennial vegetation that forms a lineal grouping of community types on or near the water's edge. Most often it occurs at or slightly below the bankfull stage.

Groundwater—The portion of water below the surface of the ground at a pressure equal to or greater than atmospheric pressure; water occurring in the zone of saturation in an aquifer or soil.

Headcutting—Erosion of a streambed or tributary channel due to an abrupt elevational drop in the bed profile that causes water velocity to increase; headcutting typically erodes in an upstream or upslope direction.

Hydraulic roughness—The measure of the amount of frictional resistance that water encounters when passing over land and channel features.

Hydrogeomorphic processes—Geomorphic processes caused by moving water. (Also see Geomorphic processes.)

Hydrologic processes—The component processes of the water cycle. Examples include rainfall, runoff, infiltration, recharge, evaporation, transpiration, and sublimation.

Hyporheic—Denoting the area beneath or adjacent to the bed of a river or stream that is saturated with water.

Incision—The natural or stressor-accelerated process by which a stream or river cuts downward into its bed, deepening the active channel.

Indicator species—A species whose presence, abundance, or vigor indicates particular conditions, site history, or environmental features of a site.

Intermittent stream—Natural channel in which water does not flow continuously.

Inventory—(1) The systematic acquisition, analysis, and organization of resource information needed for planning and implementing land management. (2) The objective quantification of the amount, composition, condition, and productivity of resource types or parameters within specified levels of statistical precision.

Late seral—Pertaining to native plant communities which are in dynamic equilibrium with the hydrologic and geomorphic features of the fluvial surfaces on which they occur. Late seral plant communities are more stable than early seral to mid-seral communities in composition and structure. Changes in the characteristics of a fluvial surface will often lead to further plant succession toward a different late seral plant community. (Also see Seral.)

Levee—A ridge adjacent to a stream that prevents water from inundating the adjacent floodplain. Levees may be natural, such as those created by deposition of sediments during high flows or constructed for flood control purposes.

Macroinvertebrate community—An assemblage of invertebrates that are visible to the eye without the aid of a microscope, variously including arthropods (insects, mites, scuds, and crayfish), mollusks (snails, limpets, mussels, and clams), annelids (segmented worms), nematodes (roundworms), and Platyhelminthes (flatworms). Aquatic macroinvertebrates live on, under, and around rocks and sediment on the bottoms of lakes, rivers, and streams.

Management options—Alternative restoration actions that a riparian manager may take to address or mitigate observable symptoms caused by particular stressors; the management options considered in this guide are summarized in table 3.1 for the intersection of each symptom and stressor.

Mass failure—The downslope movement of soil in response to gravitational stresses. Mass failure of a streambank occurs when the weight of a streambank, or weight placed on the streambank, is greater than the strength of the soil.

Meander—A curve in a stream, with velocity faster on the outside curve and slower on the inside curve.

Meander belt width—The lateral distance (perpendicular to valley) between the outside edges of two meanders.

Meander length—The channel distance between the apex of two sequential meanders.

Monitoring—The collection and analysis of resource data to measure changes in the amounts, spatial distribution, or condition of resource types or parameters over time.

Morphological—Pertaining to landforms, with emphasis on the processes that create and maintain topographic landforms, including hillslopes, valleys, floodplains, and stream channels.

Natural disturbance—See Disturbance.

Natural range of variability—Ecological conditions, and the spatial and temporal variation in these conditions, that are relatively unaffected by people, within a period of time and geographic area appropriate to an expressed goal (Landres et al. 1999).

Passive restoration—The cessation of those anthropogenic activities that are causing degradation or preventing recovery.

Perennial stream—A stream that flows throughout the year.

Planform—The two-dimensional contour or outline of landforms such as stream channels, as seen from above.

Plant community structure—The vertical and horizontal spatial arrangement of plants differing in size, height, and life form (e.g., mosses, grasses, forbs, shrubs, and trees).

Point bar—A low, curved ridge of sand, sediment, or gravel along the inner bank of a meandering stream.

Post-assisted log structure—Hand-built structure in a stream channel consisting of logs held in place by posts. These structures mimic and promote the accumulation of wood in the channel, which in turn traps sediment.

Qualitative assessment—A type of assessment or monitoring that lacks measurement or quantification.

Quantitative assessment—A type of assessment of monitoring that includes directly measuring an attribute of interest.

Qualitative method—A technique used to obtain data that lacks measurement or quantification. For example, the degree of erosion may be classified using a numerical score (e.g., 1 to 5, with 5 being the most erosion), but that number would not be derived from direct measurement of erosion. A method should be designed to be as repeatable and objective as possible.

Quantitative method—A technique used to obtain data that includes measurement or quantification. For example, erosion may be monitored using soil depth gauges along a transect with measurements repeated over time. A method should be designed to be as repeatable and objective as possible.

Recruitment—Survival of plants in a particular area to a particular age, height, or size class. For woody plants subject to browsing, recruitment is typically considered to be the attainment of a height (e.g., approximately 6 feet in cases where cattle browsing is present) above which the upper, leading buds will be inaccessible to browsing by the ungulates that are present.

Reference site—A site that serves as a model, or baseline point of reference, for restoring another site.

Regeneration—Seedlings or new stems of plants. In the case of woody plants, regeneration typically refers to seedlings or suckers (new stems produced vegetatively from existing roots) less than 6 feet tall.

Repeatable—Having the ability to obtain the same results while using the same method and equipment when repeating a study.

Resilience—The capacity of an ecosystem to absorb disturbance and recover or maintain system composition, structure, or function (or a combination thereof).

Response diversity—The range of reactions to disturbance or environmental change among species that contribute to the same ecosystem function (Enqvist et al. 2003; Leslie and McCabe 2013).

Restoration—See Riparian forest restoration.

Rill—A small channel eroded into the soil surface by runoff that can be filled easily and removed by normal tillage.

Riparian area—Ecosystems that occur along perennial, ephemeral, or intermittent streams or around the edges of lakes, ponds, springs, bogs, and meadows.

Riparian forest—Riparian areas that currently support, or historically supported, native woody vegetation at least 5 meters (16 feet) tall at maturity.

Riparian forest restoration—Actions that improve the health or resilience (or both) of riparian forest where it is currently present and where environmental conditions are suitable for long-term persistence.

Runoff—The portion of precipitation that flows over the land surface, as surface water, rather than infiltrating the soil or ground.

Salinity—The amount, or concentration, of dissolved salts in water.

Sediment—Soil that has been broken down into smaller particles by weathering and is subsequently transported by water, wind, or ice, or by the force of gravity acting on the particles.

Sediment load—Sediment moved by some erosive force, such as wind or water (typically water in this document), including both suspended sediment and bedload sediment (i.e., sediment that moves along the bed of a stream or river while making physical contact with the bed).

Sedimentation—The settling of suspended sediments (see also Sediment load); it typically occurs when water velocity slows to the point at which the sediment transport capacity of the water decreases, such as at the inflow to a reservoir, pond, lake, or pool.

Sheet erosion—The removal of a relatively uniform, thin layer of soil by rainfall and largely unchanneled surface runoff.

Sinuosity—The ratio of the stream length to the valley length; a measure of how much a stream channel bends or curves throughout a particular section of interest.

Soil compaction—Consolidation, reduction in porosity, and collapse of the structure of soil when subjected to surface loads; effects of excessive soil compaction include decreased gas exchange for plant roots, beneficial soil fungi, earthworms, and invertebrates, as well as reduced infiltration rates.

Species composition—A description of the kinds and amounts of plant species present in a community, stand, or sample area. Composition can be described qualitatively with a list of species, or quantitatively using either absolute abundance of species or relative proportions of species.

Species density—The number of plant species per unit area measured in a fixed area plot within a single ecological community. Using the same sample area across communities allows for meaningful comparison of species density.

Species diversity—A measure of the number or relative abundances (or both) of species in a community or an area of interest. Low diversity refers to few species or unequal abundances. High diversity refers to many species or very similar abundances (or both).

Streambed erosion—Scouring of soil and cutting of streambanks or beds by running water. Sometimes called stream-channel erosion or streambank erosion.

Stressors—Physical, chemical, and biological factors that impact the condition and integrity of ecosystems and can change the trajectories of species and ecosystems. Stressors can be natural (e.g., fire, insect outbreaks), or anthropogenic (e.g., climate change, fire, livestock grazing, or recreation).

Successional status—A designation of plant communities when they occur in the transition from an immediate postdisturbance community to a stable community in equilibrium with the environment; typically categorized as early, mid-, or late seral. Successional status is synonymous with seral stage.

Surface water—Water flowing or stored on the Earth's surface.

Symptom—An indicator of a stressor acting on a species or ecosystem, often with undesirable effects.

Turbidity—The degree to which a transparent liquid scatters light; usually a measure of the amount of suspended material in liquid.

Utilization—The proportion or degree of current year's forage production that is consumed or destroyed by animals (including insects). Utilization may refer to a single plant species, a group of species, or the vegetation as a whole. Utilization is synonymous with use. This process requires comparing the amount of herbage left compared with the amount of herbage produced during the year.

Vegetative barriers—Permanent strips of stiff, dense vegetation established along the general contour of slopes or across concentrated flow areas.

Water quality—The characteristics of water in a particular water body, including chemical, biological, and physical characteristics.

Water table—The upper surface of groundwater, or of the saturated zone, where the water is at atmospheric pressure.

Wetland indicator status—A qualitative rating describing how often a plant species occurs in wetlands versus uplands.

Woody debris—Pieces of trees such as twigs, branches, limbs, or tree trunks that occur in a stream and provide structure that contributes to important instream fish habitat.

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Appendix A. Functional Groups of Riparian Indicator Species

Table A.1 lists indicator plant species for riparian forests in Utah. It shows each species distribution across the riparian forest zones and indicates how commonly it occurs in each zone. This list is derived from a vegetation plot database housed at the Intermountain Regional Office of the U A Forest Service. A total of 294 riparian forest plots with complete species lists were queried: 92 plots in the Conifer-Aspen zone, 142 in the Cool Deciduous zone, and 60 in the Warm Deciduous zone. These plots were sampled on all the national forests in Utah (Mauk and Henderson 1984; Padgett et al. 1989; Pfister 1972; oungblood 1985; Youngblood et al. 1985), four national parks (Clark et al. 2009; Coles et al. 2009; Tendick et al. 2011b, 2012), three national monuments (Coles et al. 2008a,b; Tendick 2011a), and the Ouray National Wildlife Refuge (Von Loh et al. 2002).

Database queries counted the number of plots where each species was present within each riparian forest zone (Chapter 1) and calculated the constancy of each species (the percentage of the plots in which a species occurs) within each zone. Based on constancy, species were classed as major (M), minor (m), rare (+), or absent (-). Constancy values and descriptions of these classes are shown at the end of table A.1.

The indicator species in table A.1 are grouped as follows, based on their ecological response to stressors and natural disturbances:

Group 1 includes late seral species that predominate in minimally stressed riparian forest. No single riparian forest stand is expected to include all of these species. A more specific list of late se al species can be determined by identifying the riparian community type that the stand represents and consulting the description of that type. For example, managers could consult *Riparian Community Type Classification of Utah and Southeastern Idaho* by Padgett et al. (1989); other such classifications are listed in Chapter 1.

Group 2 includes native species that proliferate in response to a stressor or a natural disturbance. Due to the dynamic nature of riparian systems, these species may be abundant over a small area or a short period of time, or both. When they occupy large areas for long periods, they are usually indicators of a stressed ecosystem.

Group 3 includes nonnative species that invade riparian forests in response to a stressor or a natural disturbance. They can also be considered stressors themselves because they did not occur in Utah prior to the arrival of European settlers in North America. Some of these species do not have natural enemies in Utah (e.g., insects, fungi, diseases). This advantage can help them outcompete native species in a stressed or disturbed ecosystem.

Group 4 includes nonnative species planted in riparian areas to meet human management objectives. In some cases, these species were seeded underneath a tree canopy. In other cases, they may have been seeded following a stand-removing event in a riparian forest.

Group 5 includes native upland species that enter riparian areas from the adjacent uplands following a drop in the water table or interruption of natural flood regimes. The drop in water table is often due to a stressor such as a water diversion but may also result from natural drought periods.

The number and abundance of species in these five groups within a given riparian forest stand provide only a general indication of how much the vegetation has been affected y stressors. A more specific assessment of the vegetation composition requires use of a community type classification guide, as noted previousl .

Table A.1—Distribution of Utah riparian forest indicator species by riparian forest zone.

Group 1—Late seral species present in minimally stressed riparian systems.

				Riparian forest zone[b]		
Code	Scientific nam	Common name	Wetland indicator status[a]	Warm Deciduous	Cool Deciduous	Conifer-Aspen
Forbs						
ACCO4	*Aconitum columbianum*	Columbian monkshood	FACW	-	m	m
ACRU2	*Actaea rubra*	red baneberry	FAC	-	m	m
AQCO	*Aquilegia coerulea*	Colorado blue columbine	FACU	-	+	m
ARMO4	*Arnica mollis*	hairy arnica	FAC	-	-	m
CALE4	*Caltha leptosepala*	white marsh marigold	OBL	-	-	m
EQAR	*Equisetum arvense*	field horsetai	FAC	m	M	M
EQHY	*Equisetum hyemale*	scouringrush horsetail	FACW	m	m	m
EQLA	*Equisetum laevigatum*	smooth horsetail	FACW	m	m	-
ERPE3	*Erigeron peregrinus*	subalpine fleaban	FACW	-	-	M
EUOC4	*Euthamia occidentalis*	western goldentop	FACW	m	-	-
GABO2	*Galium boreale*	northern bedstraw	FACU	-	+	M
GATR3	*Galium triflorum*	fragrant bedstraw	FACU	+	+	m
GEAM3	*Gentianella amarella*	autumn dwarf gentian	FACW	-	-	m
GERI	*Geranium richardsonii*	Richardson's geranium	FACU	-	m	M
GEVI2	*Geranium viscosissimum*	sticky geranium	FAC	-	+	M
GEMA4	*Geum macrophyllum*	largeleaf avens	FACW	-	m	M
HEMA80	*Heracleum maximum*	common cowparsnip	FACW	-	m	m
MAST4	*Maianthemum stellatum*	starry false lily of the valley	FACU	m	M	M

Code	Scientific nam	Common name	Wetland indicator status[a]	Riparian forest zone[b] Warm Deciduous	Cool Deciduous	Conifer-Aspen
MECI3	*Mertensia ciliata*	tall fringed bluebells	FACW	-	+	M
MIGU	*Mimulus guttatus*	seep monkeyflowe	OBL	-	+	m
MIPE	*Mitella pentandra*	fivestamen miterwor	FAC	-	-	m
MIST3	*Mitella stauropetala*	smallflower miterwor	FAC	-	-	m
ORSE	*Orthilia secunda*	sidebells wintergreen	FACI	-	-	m
OSBE	*Osmorhiza berteroi*	mountain sweetroot	FACU	-	m	m
POBI6	*Polygonum bistortoides*	American bistort	FACW	-	-	M
POGR9	*Potentilla gracilis*	slender cinquefoil	FAC	-	+	M
PYAS	*Pyrola asarifolia*	liverleaf wintergreen	FAC	-	-	m
RACY	*Ranunculus cymbalaria*	alkali buttercup	OBL	m	+	+
SAOD2	*Saxifraga odontoloma*	brook saxifrage	FACW	-	-	m
SETR	*Senecio triangularis*	arrowleaf ragwort	FACW	-	+	m
SIPR	*Sibbaldia procumbens*	creeping sibbaldia	FACU	-	-	m
STAM2	*Streptopus amplexifolius*	claspleaf twistedstalk	FAC	-	-	m
SYSP	*Symphyotrichum spathulatum*	western mountain aster	FAC	-	-	m
THFE	*Thalictrum fendleri*	Fendler's meadow-rue	FAC	-	+	M
THOC	*Thalictrum occidentale*	western meadow-rue	FACU	-	m	+
THIN	*Thelypodium integrifolium*	entireleaved thelypody	FACW	m	-	-
TRPA5	*Trifolium parryi*	Parry's clover	FAC	-	-	m
VIAD	*Viola adunca*	hookedspur violet	FAC	-	+	m
Graminoids						
AGEX	*Agrostis exarata*	spike bentgrass	FACW	+	-	m
BRCI2	*Bromus ciliatus*	fringed brome	FAC	-	+	M
CACA4	*Calamagrostis canadensis*	bluejoint	FACW	-	+	M
CASC	*Calamagrostis scopulorum*	ditch reedgrass	FAC	m	+	+
CAST36	*Calamagrostis stricta*	slimstem reedgrass	FACW	-	-	m
CADI6	*Carex disperma*	softleaf sedge	OBL	-	-	m

				Riparian forest zone[b]		
Code	Scientific nam	Common name	Wetland indicator status[a]	Warm Deciduous	Cool Deciduous	Conifer-Aspen
CAHE8	*Carex heteroneura*	different nerve sedg	FAC	-	-	m
CAPE42	*Carex pellita*	woolly sedge	OBL	-	+	m
CAUT	*Carex utriculata*	Northwest Territory sedge	OBL	-	m	m
DAIN	*Danthonia intermedia*	timber oatgrass	FACU	-	+	m
DECE	*Deschampsia cespitosa*	tufted hairgrass	FACW	-	+	M
DISP	*Distichlis spicata*	inland saltgrass	FAC	m	-	-
ELPA3	*Eleocharis palustris*	common spikerush	OBL	m	+	-
ELCA4	*Elymus canadensis*	Canada wildrye	FAC	m	-	-
ELGL	*Elymus glaucus*	blue wildrye	FACU	-	m	m
FEID	*Festuca idahoensis*	Idaho fescue	FACU	-	-	m
GLST	*Glyceria striata*	fowl mannagrass	OBL	-	+	m
JUDR	*Juncus drummondii*	Drummond's rush	FACW	-	-	m
LECI4	*Leymus cinereus*	basin wildrye	FAC	m	+	-
LUPA4	*Luzula parviflora*	smallflowered woodrus	FAC	-	+	m
LUSP4	*Luzula spicata*	spiked woodrush	FACU	-	-	m
MUAS	*Muhlenbergia asperifolia*	scratchgrass	FACW	m	-	-
PHAL2	*Phleum alpinum*	alpine timothy	FAC	-	+	M
PORE	*Poa reflexa*	nodding bluegrass	OBL	-	-	m
SPCR	*Sporobolus cryptandrus*	sand dropseed	FACU	m	+	-
Shrubs						
ACGL	*Acer glabrum*	Rocky Mountain maple	FAC	-	m	+
BASA4	*Baccharis salicifolia*	mule's fat	FAC	m	-	-
COSE16	*Cornus sericea*	redosier dogwood	FACW	+	M	m
DAFR6	*Dasiphora fruticosa*	shrubby cinquefoil	FAC	-	-	M
LOIN5	*Lonicera involucrata*	twinberry honeysuckle	FAC	-	+	M
PAMY	*Paxistima myrsinites*	Oregon boxleaf	FACU	-	m	m
RIAU	*Ribes aureum*	golden currant	FAC	+	m	-
RIIN2	*Ribes inerme*	whitestem gooseberry	FAC	-	m	m

				Riparian forest zone[b]		
Code	Scientific nam	Common name	Wetland indicator status[a]	Warm Deciduous	Cool Deciduous	Conifer-Aspen
SABO2	*Salix boothii*	Booth's willow	FACW	-	+	m
SAEX	*Salix exigua*	narrowleaf willow	FACW	M	m	+
SAGE2	*Salix geyeriana*	Geyer's willow	OBL	-	-	m
SAGL	*Salix glauca*	grayleaf willow	FACW	-	-	m
SALU2	*Salix lutea*	yellow willow	FACW	+	m	+
SAPL2	*Salix planifolia*	diamondleaf willow	OBL	-	-	m
SARA2	*Sambucus racemosa*	red elderberry	FACU	-	-	m
VACE	*Vaccinium cespitosum*	dwarf bilberry	FAC	-	-	m
Trees						
ABLA	*Abies lasiocarpa*	subalpine fi	FACU	-	+	M
ACNE2	*Acer negundo*	boxelder	FACW	m	M	-
ALINT	*Alnus incana* ssp. *tenuifolia*	thinleaf alder	FACW	-	m	m
BEOC2	*Betula occidentalis*	water birch	FACW	m	M	m
FRVE2	*Fraxinus velutina*	velvet ash	FAC	m	+	-
PIEN	*Picea engelmannii*	Engelmann spruce	FAC	-	+	M
PIPU	*Picea pungens*	blue spruce	FAC	-	+	M
PICO	*Pinus contorta*	lodgepole pine	FAC	-	-	M
PIPO	*Pinus ponderosa*	ponderosa pine	FACU	-	m	+
POAN3	*Populus angustifolia*	narrowleaf cottonwood	FACW	-	M	m
PODEW	*Populus deltoides* ssp. *wislizeni*	Rio Grande cottonwood	FACW	m	+	-
POFR2	*Populus fremontii*	Fremont cottonwood	FACW	M	+	-
POTR5	*Populus tremuloides*	quaking aspen	FACU	-	m	M
PSME	*Pseudotsuga menziesii*	Douglas-fi	FACU	-	m	+
SAAM2	*Salix amygdaloides*	peachleaf willow	FACW	m	+	-
SAGO	*Salix gooddingii*	Goodding's willow	FACW	m	-	-

Group 2—Native species that proliferate following ground disturbance or excessive herbivory.

Code	Scientific nam	Common name	Wetland indicator status[a]	Riparian forest zone[b]		
				Warm Deciduous	Cool Deciduous	Conifer-Aspen
Forbs						
ACMI2	*Achillea millefolium*	common yarrow	FACU	-	m	M
AGGL	*Agoseris glauca*	pale agoseris	FAC	-	-	m
APCA	*Apocynum cannabinum*	Indianhemp	FAC	m	+	-
CACO6	*Cardamine cordifolia*	heartleaf bittercress	FACW	-	+	m
CISC2	*Cirsium scariosum*	meadow thistle	FAC	-	+	m
FRVE	*Fragaria vesca*	woodland strawberry	FACU	-	+	m
FRVI	*Fragaria virginiana*	Virginia strawberry	FACU	-	+	M
GLLE3	*Glycyrrhiza lepidota*	American licorice	FAC	m	-	-
IVAX	*Iva axillaris*	povertyweed	FAC	m	+	-
MEAR4	*Mentha arvensis*	wild mint	FACW	-	m	m
RUOC2	*Rudbeckia occidentalis*	western coneflowe	FAC	-	+	m
SOGI	*Solidago gigantea*	giant goldenrod	FACW	m	+	-
TRLO	*Trifolium longipes*	longstalk clover	FACW	-	+	m
URDI	*Urtica dioica*	stinging nettle	FAC	-	m	m
VECA2	*Veratrum californicum*	California false hellebore	FAC	-	+	m
VEWO2	*Veronica wormskjoldii*	American alpine speedwell	FACW	-	-	m
XAST	*Xanthium strumarium*	rough cockleburr	FAC	m	-	-
Graminoids						
AGSC5	*Agrostis scabra*	rough bentgrass	FAC	-	-	m
CAMI7	*Carex microptera*	smallwing sedge	FAC	-	+	M
HOJU	*Hordeum jubatum*	foxtail barley	FAC	m	-	-
JUARL	*Juncus arcticus* ssp. *littoralis*	mountain rush	FACW	M	m	m
PHAR3	*Phalaris arundinacea*	reed canarygrass	FACW	m	+	-
POPA2	*Poa palustris*	fowl bluegrass	FAC	-	m	m
SPAI	*Sporobolus airoides*	alkali sacaton	FAC	m	+	-

Code	Scientific nam	Common name	Wetland indicator status[a]	Riparian forest zone[b] Warm Deciduous	Cool Deciduous	Conifer-Aspen
Shrubs						
CHLI3	*Chrysothamnus linifolius*	spearleaf rabbitbrush	FAC	m	-	-
CLLI2	*Clematis ligusticifolia*	western white clematis	FAC	m	M	+
PRVI	*Prunus virginiana*	chokecherry	FACU	-	m	+
RHTR	*Rhus trilobata*	skunkbush sumac	UPL	M	m	-
RILA	*Ribes lacustre*	prickly currant	FAC	-	+	m
ROWO	*Rosa woodsii*	Woods' rose	FACU	m	M	m
RUID	*Rubus idaeus*	American red raspberry	FACU	-	+	m

Group 3—Nonnative species that occupy riparian areas following ground disturbance or excessive herbivory.

Code	Scientific nam	Common name	Wetland indicator status[a]	Riparian forest zone[b] Warm Deciduous	Cool Deciduous	Conifer-Aspen
Forbs						
CYOF	*Cynoglossum officinale*	gypsyflowe	FACU	-	m	-
LASE	*Lactuca serriola*	prickly lettuce	FACU	m	+	-
LELA2	*Lepidium latifolium*	broadleaved pepperweed	FAC	M	+	-
MEOF	*Melilotus officinalis*	sweetclover	FACU	M	m	+
RUST4	*Rumex stenophyllus*	narrowleaf dock	FACW	m	-	-
SATR12	*Salsola tragus*	prickly Russian thistle	FACU	m	+	-
SOOL	*Sonchus oleraceus*	common sowthistle	UPL	m	-	-
TAOF	*Taraxacum officinale*	common dandelion	FACU	m	M	M
TRDU	*Tragopogon dubius*	yellow salsify	UPL	m	m	+
Graminoids						
AGST2	*Agrostis stolonifera*	creeping bentgrass	FACW	m	m	m
BRDI3	*Bromus diandrus*	ripgut brome	UPL	m	-	-
BRTE	*Bromus tectorum*	cheatgrass	UPL	M	m	-
POPR	*Poa pratensis*	Kentucky bluegrass	FAC	M	M	-

Code	Scientific nam	Common name	Wetland indicator status[a]	Riparian forest zone[b]		
				Warm Deciduous	Cool Deciduous	Conifer-Aspen
POMO5	*Polypogon monspeliensis*	annual rabbitsfoot grass	FACW	m	+	-
Trees						
ELAN	*Elaeagnus angustifolia*	Russian olive	FAC	m	+	-
TACH2	*Tamarix chinensis*	five-stamen tamaris	FACW	m	+	-
TARA	*Tamarix ramosissima*	saltcedar	FAC	M	+	-

Group 4—Seeded nonnative species.

Code	Scientific nam	Common name	Wetland indicator status[a]	Riparian forest zone[b]		
				Warm Deciduous	Cool Deciduous	Conifer-Aspen
Forbs						
MESA	*Medicago sativa*	alfalfa	UPL	m	-	-
TRRE3	*Trifolium repens*	white clover	FACU	+	m	m
Graminoids						
AGCR	*Agropyron cristatum*	crested wheatgrass	UPL	m	-	-
BRIN2	*Bromus inermis*	smooth brome	FACU	+	m	+
DAGL	*Dactylis glomerata*	orchardgrass	FACU	-	m	+

Group 5—Native upland species that enter riparian areas after lowering of the water table.

Code	Scientific nam	Common name	Wetland indicator status[a]	Riparian forest zone[b]		
				Warm Deciduous	Cool Deciduous	Conifer-Aspen
Forbs						
AMAC2	*Ambrosia acanthicarpa*	flatspine burr agweed	UPL	m	-	-
ANMI3	*Antennaria microphylla*	littleleaf pussytoes	UPL	-	+	m
ARCO9	*Arnica cordifolia*	heartleaf arnica	UPL	-	-	M
ARLA8	*Arnica latifolia*	broadleaf arnica	FAC	-	-	m
ARDR4	*Artemisia dracunculus*	tarragon	UPL	m	+	-

Code	Scientific nam	Common name	Wetland indicator status[a]	Riparian forest zone[b]		
				Warm Deciduous	Cool Deciduous	Conifer-Aspen
ARLU	*Artemisia ludoviciana*	Louisiana sagewort	FACU	M	+	+
CALI4	*Castilleja linariifolia*	Wyoming Indian paintbrush	UPL	m	+	+
CHAN9	*Chamerion angustifolium*	firewee	UPL	+	-	M
CICA10	*Cirsium calcareum*	Cainville thistle	UPL	m	+	-
COCA5	*Conyza canadensis*	Canadian horseweed	UPL	m	-	-
DAWR2	*Datura wrightii*	sacred thorn-apple	UPL	m	-	-
EPAN4	*Epilobium anagallidifolium*	pimpernel willowherb	FACU	-	-	m
HEVI4	*Heterotheca villosa*	hairy false goldenaster	UPL	M	+	-
IPAG	*Ipomopsis aggregata*	scarlet gilia	UPL	m	+	-
LALA3	*Lathyrus lanszwertii*	Nevada pea	UPL	-	-	m
LIPO	*Ligusticum porter*	Porter's licorice-root	FACU	-	-	m
MACA2	*Machaeranthera canescens*	hoary tansyaster	UPL	m	+	-
MEAR6	*Mertensia arizonica*	aspen bluebells	UPL	-	+	m
OSDE	*Osmorhiza depauperata*	bluntseed sweetroot	UPL	-	+	M
PAMU11	*Packera multilobata*	lobeleaf groundsel	UPL	m	+	-
PERA	*Pedicularis racemose*	sickletop lousewort	UPL	-	-	m
PODI2	*Potentilla diversifolia*	varileaf cinquefoil	UPL	-	-	m
PSJA2	*Pseudostellaria jamesiana*	tuber starwort	UPL	-	-	m
SESE2	*Senecio serra*	tall ragwort	FACU	-	+	m
Graminoids						
ACHY	*Achnatherum hymenoides*	Indian ricegrass	UPL	m	+	-
BRMA4	*Bromus marginatus*	mountain brome	UPL	-	+	m
CAGE2	*Carex geyeri*	Geyer's sedge	UPL	-	+	m
CARO5	*Carex rossii*	Ross' sedge	UPL	-	-	m
ELTR7	*Elymus trachycaulus*	slender wheatgrass	FACU	+	+	m
FEBR	*Festuca brachyphylla*	alpine fescue	UPL	-	-	m

Code	Scientific nam	Common name	Wetland indicator status[a]	Riparian forest zone[b] Warm Deciduous	Cool Deciduous	Conifer-Aspen
HECO26	*Hesperostipa comata*	needle and thread	UPL	m	+	-
PASM	*Pascopyrum smithii*	western wheatgrass	FAC	m	+	-
POFE	*Poa fendleriana*	muttongrass	UPL	m	m	-
POSE	*Poa secunda*	Sandberg bluegrass	UPL	-	-	m
POWH2	*Poa wheeleri*	Wheeler's bluegrass	UPL	-	-	m
TRSP2	*Trisetum spicatum*	spike trisetum	FACU	-	-	M
VUOC	*Vulpia octoflora*	sixweeks fescue	UPL	m	-	-
Shrubs						
AMAL2	*Amelanchier alnifolia*	Saskatoon serviceberry	FACU	-	m	m
ARFI2	*Artemisia filifolia*	sand sagebrush	UPL	m	-	-
ARTRT	*Artemisia tridentata* ssp. *Tridentata*	basin big sagebrush	UPL	m	+	-
BAEM	*Baccharis emoryi*	Emory's baccharis	UPL	m	-	-
CHVI8	*Chrysothamnus viscidiflorus*	green rabbitbrush	UPL	m	+	-
ERNA10	*Ericameria nauseosa*	rubber rabbitbrush	UPL	M	m	+
GUSA2	*Gutierrezia sarothrae*	broom snakeweed	UPL	m	+	-
JUCO6	*Juniperus communis*	common juniper	FACU	-	+	M
MAFR3	*Mahonia fremontii*	Fremont's mahonia	UPL	M	+	-
MARE11	*Mahonia repens*	creeping barberry	UPL	-	m	+
OPMA2	*Opuntia macrorhiza*	twistspine pricklypear	UPL	M	-	-
OPPO	*Opuntia polyacantha*	plains pricklypear	UPL	M	-	-
RIMO2	*Ribes montigenum*	gooseberry currant	UPL	-	+	m
SYOR2	*Symphoricarpos oreophilus*	mountain snowberry	UPL	+	M	m
VAMY2	*Vaccinium myrtillus*	whortleberry	FACU	-	-	m
VASC	*Vaccinium scoparium*	grouse whortleberry	FACU	-	-	M
Trees						
ABCO	*Abies concolor*	white fi	UPL	+	m	-
ACGR3	*Acer grandidentatum*	bigtooth maple	FACU	+	m	+
FRAN2	*Fraxinus anomala*	singleleaf ash	UPL	M	+	-

Code	Scientific nam	Common name	Wetland indicator status[a]	Riparian forest zone[b]		
				Warm Deciduous	Cool Deciduous	Conifer-Aspen
JUOS	*Juniperus osteosperma*	Utah juniper	UPL	M	+	+
JUSC2	*Juniperus scopulorum*	Rocky Mountain juniper	UPL	M	M	+
PIED	*Pinus edulis*	twoneedle pinyon	UPL	+	m	-
QUGA	*Quercus gambelii*	Gambel oak	UPL	M	m	-

[a]Codes and descriptions for wetland indicator status are as follows:

Code	Name	Description
OBL	Obligate Wetland	Almost always occur in wetlands
FACW	Facultative Wetland	Usually occur in wetlands, but may occur in nonwetlands
FAC	Facultative	Occur in wetlands and nonwetlands
FACU	Facultative Upland	Usually occur in non-wetlands, but may occur in wetlands
UPL	Obligate Upland	Almost never occur in wetlands

[b]Codes and descriptions for constancy are as follows:

Code	Name	Description
M	Major species	Often present (≥20% constancy)
m	Minor species	Occasionally present (5–19.9% constancy)
+	Rare species	Seldom present (<5% constancy)
-	Absent	Absent in available plot data (constancy = 0)

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Appendix B. Plant Names Used in the Body of This Guide

All the plant common names appearing in the text or tables in the body of this guide are listed here with the corresponding scientific names. Species appearing only in Appendix A are not repeated here.

Common name	Scientific nam
alfalfa	*Medicago sativa*
alkali sacaton	*Sporobolus airoides*
American mannagrass	*Glyceria grandis*
arrowleaf ragwort	*Senecio triangularis*
arroyo willow	*Salix lasiolepis*
ash	*Fraxinus* spp.
aspen (or quaking aspen)	*Populus tremuloides*
aspen bluebells	*Mertensia arizonica*
basin big sagebrush	*Artemisia tridentata* ssp. *tridentata*
beechleaf frangula	*Frangula betulifolia*
bigtooth maple	*Acer grandidentatum*
blue spruce	*Picea pungens*
blue wildrye	*Elymus glaucus*
bluejoint reedgrass	*Calamagrostis canadensis*
bluntseed sweetroot	*Osmorhiza depauperata*
bog blueberry	*Vaccinium uliginosum*
Booth's willow	*Salix boothii*
boxelder	*Acer negundo*
broadleaved pepperweed	*Lepidium latifolium*
bulrush	*Schoenoplectus* spp.
California false hellebore	*Veratrum californicum*
cattail	*Typha* spp.
cheatgrass	*Bromus tectorum*
Chinese elm	*Ulmus parvifolia*
chokecherry	*Prunus virginiana*
claspleaf twistedstalk	*Streptopus amplexifolius*
Columbian monkshood	*Aconitum columbianum*
common cowparsnip	*Heracleum maximum*
common dandelion	*Taraxacum officinale*

Common name	Scientific nam
common juniper	*Juniperus communis*
common reed	*Phragmites australis*
common threesquare	*Schoenoplectis pungens*
common yarrow	*Achillea millefolium*
copperweed	*Oxytenia acerosa*
cottonwood	*Populus* spp.
crack willow	*Salix fragilis*
creeping bentgrass	*Agrostis stolonigera*
desert willow	*Chilopsis linearis*
Douglas-fi	*Pseudotsuga menziesii*
Drummond's willow	*Salix drummondii*
Emory's baccharis	*Baccharis emoryi*
Engelmann spruce	*Picea engelmannii*
Fendler's meadow-rue	*Thalictrum fendleri*
Fendler's waterleaf	*Hydrophyllum fendleri*
field horsetai	*Equisetum arvense*
fi	*Abies* spp.
five-stamen tamaris	*Tamarix chinensis*
fowl bluegrass	*Poa palustris*
Franciscan bluebells	*Mertensia franciscana*
Fremont cottonwood	*Populus fremontii*
fringed brome	*Bromus ciliates*
Gambel oak	*Quercus gambelii*
Geyer's willow	*Salix geyeri*
Goodding's willow	*Salix gooddingii*
grouse whortleberry	*Vaccinium scoparium*
hardstem bulrush	*Schoenoplectis acutus*
horsetail	*Equisetum* spp.
hybrid cottonwood	*Populus ×hinckleyana*
Kentucky bluegrass	*Poa pratensis*
Knowlton's hophornbeam	*Ostrya knowltonii*
lanceleaf cottonwood	*Populus ×accuminata*

Common name	Scientific nam
lodgepole pine	*Pinus contorta*
longstalk clover	*Trifolium longipes*
Mancos columbine	*Aquilegia micrantha*
mountain (Baltic) rush	*Juncis arcticus* ssp. *littoralis*
mountain silver sagebrush	*Artemisia cana* ssp. *viscidula*
mountain snowberry	*Symphoricarpos oreophilis*
mule-fat	*Baccharis salicifolia*
narrowleaf cottonwood	*Populus angustifolia*
narrowleaf willow	*Salix exigua*
Nebraska sedge	*Carex nebrascensis*
netleaf hackberry	*Celtus laevigata* var. *reticulata*
Northwest Territory sedge	*Carex utriculata*
peachleaf willow	*Salix amygdaloides*
planeleaf willow	*Salix planifolia*
ponderosa pine	*Pinus ponderosa*
rabbitsfoot grass	*Polypogon* spp.
red baneberry	*Actaea rubra*
redosier dogwood	*Cornus sericea*
Rio Grande cottonwood	*Populus deltoides* ssp. *wislizeni*
Richardson's geranium	*Geranium richardsonii*
Rocky Mountain juniper	*Juniperus scopulorum*
rubber rabbitbrush	*Ericameria nauseosa*
Russian olive	*Elaeagnus angustifolia*
sagebrush	*Artemisia* spp.
saltcedar	*Tamarix ramosissima*
saltgrass	*Distichilis spicata*
scratchgrass	*Muhlenbergia asperifolia*
shortfruit willow	*Salix brachycarpa*
shrubby cinquefoil	*Dasiphora fruticosa*
silver buffaloberr	*Sheperdia argentea*
singleleaf ash	*Fraxinus anomala*
skunkbush sumac	*Rhus trilobata*

Common name	Scientific nam
smallwing sedge	*Carex microptera*
smooth horsetail	*Equisetum laevigatum*
spike trisetum	*Trisetum spicatum*
starry false lily of the valley	*Maianthemum stellatum*
sticky geranium	*Geranium viscosissimum*
stinging nettle	*Urtica dioica*
stretchberry	*Forestiera pubescens*
subalpine fi	*Abies lasiocarpa*
subalpine fleaban	*Erigeron peregrinus*
sweetclover	*Melilotus officinalis*
swordleaf rush	*Juncus ensifolius*
Tahoe sedge	*Carex tahoensis*
tall fringed bluebells	*Mertensia ciliata*
tamarisk	*Tamarix* spp.
tasselflower bric ellbush	*Brickellia grandiflora*
thinleaf alder	*Alnus incana ssp. tenuifolia*
twinberry honeysuckle	*Lonicera involucrata*
tufted hairgrass	*Deschampsia cespitosa*
velvet ash	*Fraxinus velutina*
Virginia strawberry	*Fragaria virginiana*
water birch	*Betula occidentalis*
water sedge	*Carex aquatilis*
western wheatgrass	*Pascopyrum smithii*
western white clematis	*Clematis ligusticifolia*
white fi	*Abies concolor*
white marsh marigold	*Caltha leptosepala*
willow	*Salix* spp.
willow baccharis	*Baccharis salicina*
Wolf's willow	*Salix wolfii*
Woods' rose	*Rosa woodsia*
yellow willow	*Salix lutea*

Appendix C. Plant Identification Resou ces

The following list is intended to provide some Utah plant species identification resources; it is not comprehensive.

1. A Guide to the Trees of Utah and the Intermountain West
   Description: Dichotomous keys, descriptions, drawings; includes all species for the intended area
      Publication: Kuhns, M.R. 1998. A guide to the trees of Utah and the Intermountain West. Logan, UT: Utah State University Press.

2. A Utah Flora
   Description: Dichotomous keys, all words; requires technical botany knowledge and includes all species for the intended area
      Publication: Welsh, S.L.; Atwood, N.D.; Goodrich, S.; Higgins, L.C.; eds. 2016. A Utah flo a. 5th ed. Provo, UT: Brigham Young University.

3. Atlas of the Vascular Plants of Utah
   Description: Spatial distribution maps of 2,438 vascular plant species in Utah
      Publication: Albee, B.J.; Shultz, L.M.; Goodrich, S. 1988. Atlas of the vascular plants of Utah. Salt Lake City, UT: Utah Museum of Natural History.

4. Common Wetland Plants of Colorado's Southern Rocky Mountains: A Pocket Guide
   Description: Descriptions, drawings, photos (no keys)
      Publication: Culver, D.R. 2018. Common wetland plants of Colorado's Southern Rocky Mountains: A pocket guide. Fort Collins, CO: Colorado State University, Colorado Natural Heritage Program. [Online]. https://cnhp.colostate.edu/cwic/library/field-guides [Accessed 26 February 2020].

5. Common Wetland Plants of Colorado's Western Slope: A Pocket Guide
   Description: Descriptions, drawings, photos (no keys)
      Publication: Culver, D.R. 2018. Common wetland plant of Colorado's Western Slope: A pocket guide. Fort Collins, CO: Colorado State University, Colorado Natural Heritage Program. [Online]. https://cnhp.colostate.edu/cwic/library/field-guides [Accessed 26 February 2020].

6. Field Guide to Colorado's Wetland Plants: Identification, Ecolog , and Conservation
   Description: Descriptions, drawings, photos (no keys)
      Publication: Culver, D.R.; Lemly, J.M. 2013. Field guide to Colorado's wetland plants: Identification, ecolog , and conservation. Fort Collins, CO: Colorado State University, Colorado Natural Heritage Program. [Online]. https://cnhp.colostate.edu/cwic/library/field-guides [Accessed 26 February 2020].

7. Field Guide to Intermountain Rushes

Description: Descriptions, drawings, color photos

Publication: Hurd, E.G.; Goodrich, S.; Shaw, N.L. 1994. Field guide to Intermountain rushes. Gen. Tech. Rep. INT-306. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 56 p. https://www.fs.usda.gov/research/treesearch/24234

8. Field Guide to Intermountain Sedges

Description: Descriptions, drawings, color photos

Publication: Hurd, E.G.; Shaw, N.L.; Mastrogiuseppe, J.; [et al.]. 1998. Field guide to Intermountain sedges. Gen. Tech. Rep. RMRS-GTR-10. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 282 p. https://www.fs.usda.gov/research/treesearch/6196

9. Field Guide to the Willows of East-Central Idaho

Description: Dichotomous keys, descriptions, drawings, photos, maps

Publication: Brunsfeld, S.J.; Johnson, F.D. 1985. Field guide to the willows of east-central Idaho. Bull. No. 39. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station. Available at: https://www.lib.uidaho.edu/digital/fwres/items/fwres202.html [Accessed 26 February 2020].

10. Grasses and Grasslike Plants of Utah: A Field Guide

Description: Descriptions, color photos

Publication: Banner, R.; Pratt, M.; Bowns J. 2011. Grasses and grasslike plants of Utah: A field guide. Logan, UT: Utah State Universit . https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=2188&amp=&context=extension_curall&amp=&sei- [Accessed 26 February 2020].

11. Grasses of the Intermountain Region

Description: Dichotomous keys, descriptions, drawings, maps; includes all species for the intended area

Publication: Anderton, L.K.; Barkworth M.E., eds. 2009. Grasses of the Intermountain Region. Logan, UT: Utah State University, Intermountain Herbarium.

12. Intermountain Flora

Description: Geological and botanical history of the Intermountain West. Seven volumes. Dichotomous keys, drawings; requires technical botany knowledge and includes all species for the intended area.

Publication: Cronquist, A.; Homgren, N.H.; Homgren, P.K.; [et al.]. 1972–2012. Intermountain flo a: Vascular plants of the Intermountain West, U.S.A. 7 vols. Bronx, NY: The New York Botanical Garden Press.

13. Manual of the Carices of the Rocky Mountains and Colorado Basin

Description: Dichotomous keys, descriptions, drawings

Publication: Hermann, F.J. 1970. Manual of the Carices of the Rocky Mountains and Colorado Basin. Agricultural Handbook. 374. Washington, DC: U.S. Department of Agriculture, Forest Service.

14. North American Wildland Plants: A Field Guide

Description: Dichotomous keys, descriptions, drawings

Publication: Stubbendieck, J.; Hatch, S.L.; Landholt, L.M. 2003. North American wildland plants: A field guide. Lincoln, NE: University of Neb aska Press.

15. Noxious Weed Field Guide for Utah

Description: Descriptions, color photos

Publication: Delliston, N.D.; Whitesides, R.; Dewey, S.A.; [et al.]. 2003. Noxious weed field guide for Utah. Logan, UT: Utah State Universit . https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=2351&context=extension_curall [Accessed 26 February 2020].

16. Plant Identification erminology: An Illustrated Glossary

Description: Defines botanical terms with d awings

Publication: Harris, J.G.; Harris, M.W. 1994. Plant identification terminology: An illustrated glossary. Spring Lake, UT: Spring Lake Publishing.

17. Pocket Guide to Sagebrush

Description: Descriptions, drawings, color photos; includes all species for the intended area

Publication: Shultz, L. 2012. Pocket guide to sagebrush. PRBO Conservation Science. https://digitalcommons.usu.edu/sagestep_reports/20/ [Accessed 26 February 2020].

18. Rocky Mountain Flora

Description: Dichotomous keys, mostly words; requires technical botany knowledge and includes all species for the intended area

Publication: Weber, W.A. 1976. Rocky Mountain flo a. Niwot, CO: University Press of Colorado.

19. Rocky Mountain Region Willow Identification Field Guid

Description: Dichotomous keys, descriptions, color photos

Publication: Dorn, R. 1997. Rocky Mountain Region willow identification fiel guide. Denver, CO: U.S. Department of Agriculture, Forest Service.

20. Sagebrush of Colorado: Taxonomy, Distribution, Ecology and Management

Description: Dichotomous keys, descriptions, color photos; includes all species for the intended area

Publication: Winward, A.H. 2004. Sagebrush of Colorado: Taxonomy, distribution, ecology and management. Denver, CO: Colorado Department of Natural Resources, Division of Wildlife, Department of Natural Resources.

21. Uinta Basin Flora

Description: Dichotomous keys, all words; requires technical botany knowledge and includes all species for the intended area

Publication: Goodrich, S.; Neese, E. 1986. Uinta Basin flo a. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region in cooperation with the USDA Forest Service Ashley National Forest and the US DOI Bureau of Land Management Vernal District. 320 p.

22. Vascular Plants of Northern Utah: An Identification Manua

Description: Dichotomous keys, mostly words; requires technical botany knowledge and includes all species for the intended area

Publication: Shaw, R.J. 1989. Vascular plants of northern Utah. Logan, UT: Utah State University Press.

23. Weeds of the West

Description: Descriptions, color photos

Publication: Whitson, T.D.; Burrill, L.C.; Dewey, S.A.; [et al.] 2012. Weeds of the West. 11th ed. Newark, CA: Western Society of Weed Science in cooperation with the Western United States Land Grant Universities Cooperative Extension Services. 631 p. http://www.wyoextension.org/agpubs/pubs/wsws-1.pdf [Accessed 29 January 2022].

24. Wetland Plants of Great Salt Lake

Description: Descriptions, color photos; sorted by habitat

Publication: Downard, R.; Frank, M.; Perkins, J.; [et al.]. 2018. Wetland plants of Great Salt Lake: A guide to identification, communities, and bird habitat. Logan, UT: Utah State University Extension. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=2777&context=extension_curall [Accessed 26 February 2020].

25. Wildflowers and Other Herbaceous Plants of Utah Rangelands: A Field Guid

Description: Descriptions, color photos

Publication: Banner, R.; Pratt, M.J.; Bowns, M.J.; Reid, C. 2013. Wildflowers and other herbaceous plants of Utah rangelands: A field guide. Utah State University Extension. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=2768&context=extension_curall [Accessed 26 February 2020].

26. Wildflowers of the Mountain est

Description: Descriptions, color photos; sorted by flower colo

Publication: Anderson, R.M.; Gunnell, J.; Goodspeed, J.L. 2012. Wildflowers of the Mountain West. University Press of Colorado.

27. Woody Plants of Utah

Description: Dichotomous keys, descriptions, color photos; includes all species for the intended area

Publication: Van Buren, R.; Cooper, J.G.; Shultz, L.M.; Harper, K.T. 2011. Woody plants of Utah. Logan, UT: Utah State University Press.

Plant Identification Apps for And oid and IOS phones

1. EDDMapS West

   Description: Invasive species identification, mapping, noxious weed list

2. Flora of the Wasatch

   Description: Identifies plant species when user selects information about a plant, such as flower color and shape, leaf ar angement, and location. Includes over 350 species in the Wasatch area of Utah with photographs; accuracy varies.

3. IDWeeds

   Description: Invasive species identificatio

4. PlantNet

   Description: Identifies plant species from a photog aph; accuracy varies.

5. PlantSnap

   Description: Identifies plant species from a photog aph; accuracy varies.

6. Utah Wildflower

   Description: Identifies plant species when user selects information about a plant, such as flower color and shape, leaf ar angement, and location. Includes over 3,200 species of all plant life forms throughout Utah with photographs; accuracy varies.

7. Virginia Tech Tree ID

   Description: Identifies woody plants at use ’s GPS location with a series of questions; accuracy varies.

Websites

There are many plant identification websites (e.g., https://plants.usda.gov).

USDA PLANTS Database provides information about plants, mosses, liverworts, hornworts, and lichens throughout the United States.

Herbaria

http://sweetgum.nybg.org/science/ih/

Description: Worldwide index of herbaria where user can search for herbarium locations specifically in Utah. The list of herbaria includes herbarium manager contact information and specific herbarium websites. Some of the websites have a virtual herbarium link where there are photos of pressed specimens.

APPENDIX D. Riparian Forest Assessment Form

Assessment Steps:

Step 1. Identify the dominance type(s), forest zone, and community type(s) within your assessment area.

Latitude DD: _________________ Longitude DD: _________________ Elevation (feet): _________________

Dominance type(s): ___________________ Determine the tree species with the most canopy cover within the assessment area.

Forest zone: ___________________ Use latitude and elevation to locate your site in figure 1.2. Locate your dominance type(s) in table 1.4. Compare species composition to table 1.3.

Community type(s): ___________________ Identify the community type(s) from table 1.5 using the most geographically appropriate vegetation guide listed in table 1.6.

Step 2. Identify the hydrogeomorphic valley type for the assessment area.

Valley type: ______________________________ Use the criteria in table 2.1 from Carlson (2009).

Step 3. Identify all understory species from Appendix A that occur in the assessment area.

___________________________ ___________________________ ___________________________

___________________________ ___________________________ ___________________________

___________________________ ___________________________ ___________________________

___________________________ ___________________________ ___________________________

Step 4. Estimate relative abundance (i.e., canopy cover) of each understory functional species group described in Appendix A.

Group 1 – Late seral species that dominate minimally disturbed sites.	______%
Group 2 – Native species that can dominate after disturbance.	______%
Group 3 – Nonnative invasive species that can dominate after disturbance.	______%
Group 4 – Nonnative species planted by humans.	______%
Group 5 – Native upland species that enter riparian areas when water tables drop.	______%
TOTAL	100%

Step 5. Check off symptoms present in the assessment area, using descriptions in Chapter 3.

______ Depleted native species diversity

______ Altered community structure

______ Replacement of riparian species by upland species

______ Increased invasive species

______ Reduced riparian forest acreage

______ Lack of shade

______ Streambed erosion

______ Increased or depleted sediment load

______ Bank erosion

______ Disconnection of floodplain from the channel

______ Reduced sinuosity

______ Excessive bare soil

______ Compacted soil

______ Elevated water temperature

______ Altered macroinvertebrate community

______ Altered turbidity

______ High levels of algae

______ Excessive salinity

Step 6. Check off stressors that could be causing symptoms, using descriptions in Chapter 3.

______ Ungulate use

______ Exotic tree establishment

______ Beaver herbivory

______ Altered fire regime and fuels

______ Recreation

______ Conversion to agricultural use

______ Forest insects and diseases

______ Unoccupied beaver habitat

______ Channel straightening or alteration

______ Riparian infrastructure and floodplain alteration

______ Upland watershed conditions

______ Mining and logging legacy

______ Water diversion

______ Water addition

______ Flow variability

______ Higher ambient temperature

______ Prolonged or repeated drought

Step 7. Decide on restoration objectives.

____

____

____

Step 8. Use table 3.1 to compare where an observed symptom intersects with a potential stressor to determine possible management options to restore the assessed riparian forest based on your restoration objectives.

Select your selected management options:

☐ 0 – No Action
☐ 1 – Create Riparian Buffers
☐ 2 – Remove Conifers
☐ 3 – Manage Grazing
☐ 4 – Manage Recreation
☐ 5 – Install Riparian Plantings
☐ 6 – Remove Exotic Plants
☐ 7 – Manage Beaver
☐ 8 – Stabilize Streambanks
☐ 9 – Remove or Improve Infrastructure
☐ 10 – Manage Upland Runoff
☐ 11 – Alter Streamflows
☐ 12 – Stabilize Channel Grade
☐ 13 – Restructure Physical Channel

Step 9. Collect baseline monitoring data based on your restoration objectives. Table 5.1 lists some commonly used methods.

Selected monitoring methods: ____

____

<u>Implementation Steps:</u>

Step 10. Implement the selected management options in the proper order.
Step 11. Monitor results using same methods used to collect baseline data.
Step 12. Evaluate effectiveness of the management options used.
If management was ineffective, reassess which stressor(s) are causing the symptom(s).
Step 13. Adjust or change management option(s) as needed.

Assessment Form Instructions

Step 1. Identify the dominance type(s), forest zone, and community type(s) within your assessment area.

Identify the dominance type(s) in your area prior to identifying the riparian forest zone and the community type(s). Assign one or more dominance types to your assessment area based on the tree species with the most canopy cover. It is possible to have more than one dominance type, even in an area of a few acres, because riparian forests can be hydrologically and biologically complex.

Identify the riparian forest zone using two approaches:

1. Use your area's latitude (decimal degrees) and elevation (feet) to determine which zone it falls within using figure 1.2
2. Locate your dominance type(s) in table 1.4 to see the zone in which they typically occur. If your dominance type(s) occur in more than one zone, then complete step 3 and compare your species composition list to table 1.3.

If all the dominance types and the latitude and elevation results do not agree, assign the zone based on the preponderance of the evidence, especially the proportion of the assessment area occupied by each dominance type.

Identify the riparian community type(s), listed in table 1.5, present or dominating your assessment area using your species list (step 3) and the most geographically relevant vegetation guide from table 1.6. Padgett et al. (1989) is comprehensive for riparian vegetation on National Forest System lands in Utah. Some riparian forest types on national forests are also described by Mauk and Henderson (1984) and Youngblood and Mauk (1985). The remainder of the vegetation guides in table 1.6 are for individual national parks and monuments in Utah or adjacent Nevada or Colorado. No published vegetation classifications are available for Bureau of Land Management (BLM) lands in Utah, but the National Park Service publications are applicable to adjacent BLM lands.

Step 2. Identify the hydrogeomorphic valley type for the assessment area.

The valley types in table 2.1 are defined based on the valley g adient (percent slope of the valley floor) and the percent slope of both valley sides. alley types differ in natural rates of streambed and bank erosion, sediment loads, and stream sinuosity. Descriptions of these valley types (Carlson 2009) provide a reference point for recognizing most of the fluvial geomorphology symptoms in table 3.1

Step 3. Identify all understory species from Appendix A that occur in the assessment area.

Numerous plant identification resources, requiring varying degrees of botanical training, are listed in Appendix C. Work through the understory species list in Appendix A and identify which are present in the assessment area, using plant guides best suited to your botanical expertise. You should also record the presence of nonnative or upland tree species (groups 3 and 5 in Appendix A). It may also be useful to note how abundant each species is, based on percent cover (e.g., a lot, some, a little).

Step 4. Estimate relative abundance of each understory functional species group described in Appendix A.

Using the species list from step 3, estimate the proportion of total understory cover provided by each of the five functional groups, adding up to 100 percent. Use these values, along with the descriptions in Chapter 3, to assess native species diversity, replacement of riparian species by upland species, and abundance of invasive species. The relevant community type description(s) can also help with these.

Step 5. Check off symptoms present in the assessment area, using descriptions in Chapter 3.

Vegetation Symptoms: Use the information compiled in steps 1, 3, and 4, Chapter 3 descriptions, and relevant community type descriptions to determine which symptoms are present.

Fluvial Geomorphology Symptoms: Use the descriptions in Chapter 3 and the valley type from step 2 to determine which symptoms are present.

Water Quality and Quantity Symptoms: Use the descriptions and related information in Chapter 3 to determine which symptoms are present.

Step 6. Check off stressors that could be causing symptoms, using descriptions in Chapter 3.

For each symptom present, use table 3.1 to see which stressors could be causing or contributing to that symptom. Each cell in that row containing numbers indicates that the stressor in that column could be a factor. Blank cells in a row indicate that associated stressor could not be a factor. For example, the "high levels of algae" symptom row could be caused by one or more of the following stressor columns: ungulate use, recreation, conversion to agricultural use, unoccupied beaver habitat, riparian infrastructure and floodplain alte ation, or upland watershed conditions.

Work through table 3.1 for each identified symptom and put a check mark (or a dot tally) next to each stressor that may be contributing to that symptom using the descriptions in Chapter 3. Assessing some stressors may require knowledge of upstream or adjacent upland conditions.

Step 7. Decide on restoration objectives.

Objectives can be thought of as which symptoms you wish to eliminate or reduce within the assessment area. They should also include a measurable indicator of success. Your restoration objectives must be decided before appropriate management options can be selected.

Often, there will be multiple objectives that must be achieved in a certain order to be effective. or example, disconnection of the floodplain or altered streamflow y need to be addressed before reintroducing some native riparian species. Based on the identified symptoms and stressors, determine the order in which your objectives should be pursued.

Step 8. Use table 3.1 to compare where an observed symptom intersects with a potential stressor to determine possible management options to restore the assessed riparian forest based on your restoration objectives.

Based on the symptom you wish to address (or address first) and the identifie stressors, circle the management options that may move the riparian forest toward your objective. For example, management options for the high levels of algae symptom and recreation stressor are: 0 – Do Nothing, 1 – Create Riparian Buffers, and 4 – Manage Recreation.

Review each of those options in Chapter 4. Select among those options based on expected effectiveness, p actical and financial feasibilit , and social feasibility. Be sure to include monitoring costs in evaluating financial feasibilit . Use the references in Chapter 4 to select specific methods to implement your selected management option(s).

Step 9. Collect baseline monitoring data based on your restoration objectives. Table 5.1 lists some commonly used methods.

Choose a monitoring method for the measurable indicator(s) of success selected in step 7. Conduct baseline monitoring to quantify conditions prior to implementing your management action(s).

Continue with Implementation Steps 10 through 13.

References

Carlson, E.A. 2009. Fluvial riparian classification for national forests in the western United States. Fort Collins, CO: Colorado State University. Thesis. 194 p. https://www.fs.usda.gov/biology/nsaec/assets/carlson_thesis_version_11.pdf [Accessed 6 December 2021].

Mauk, R.; Henderson, J. 1984. Coniferous forest habitat types of northern Utah. Gen. Tech. Rep. INT-170. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 90 p. https://www.fs.usda.gov/rm/pubs/rmrs_gtr292/int_gtr170.pdf

Padgett, W.; Youngblood, A.; Winward, A. 1989. Riparian community type classification of Utah and southwestern Idaho. R4-Ecol-89-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 191 p. https://www.researchgate.net/publication/286929782_Riparian_community_type_classification_of_Utah_and_southeastern_Idah_

Youngblood, A.; Mauk, R. 1985. Coniferous forest habitat types of central and southern Utah. Gen. Tech. Rep. INT-187. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 89 p. https://www.fs.usda.gov/research/treesearch/34457