A Guide for Restoring Functionality to Mountain Meadows of the Sierra Nevada

Technical Memorandum

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1 INTRODUCTION

This document is intended to serve as a resource guide for land managers involved in managing, preserving, rehabilitating, and restoring (hereafter simply referred to as "restoring") mountain meadows in the Sierra Nevada. Restoration of mountain meadows requires integrating knowledge of watershed processes, rangeland management, roads and trails management, channel hydraulics, fluvial geomorphology, vegetation, and wildlife resources management. It also requires process-based interpretation of site-specific information and collaboration among resource managers to affect the changes needed to improve meadow functions.

Although there are many excellent books and other sources of information on ecosystem restoration (e.g. Clewell et al. 2005; SER 2004), river restoration (e.g., Simon et al. 2011, Zeedyk and Clothier 2009, Downs et al. 2002, Gregory and Downs 2008, Brookes and Shields 1996), watershed management (e.g., Brooks et al. 2003, Dunne and Leopold 1978, Leopold 1994), and rangeland management (e.g., Holecheck et al. 2010, Heady and Child 1999, Vallentine 1989), there are only a few existing references that integrate these different components within the context of meadow restoration. References are available that address management of meadows and depositional channels in the arid southwest (Zeedyk and Clothier 2009) and the Great Basin (Chambers and Miller 2004a, Chambers and Miller 2011); but none specifically focus on restoring physical and biological processes in meadows of the Sierra Nevada (see Ratliff 1985 for the most recent "state of the meadows" report).

In this document, we summarize the essential aspects of meadow restoration that relate specifically to the Sierra Nevada. We provide guidance on diagnosing the problem and identifying potential solutions, and provide a catalogue of specific field applications and in-depth information reference sources.

In the next section of this guide (*Section 2. Functional and Degraded Meadows*), we provide background on the processes and stressors that can affect meadow condition. With this foundation, we then describe the steps required for developing a restoration approach for a particular meadow (*Section 3. Planning for Meadow Restoration*). In the fourth section of this document (*Section 4. Restoration and Management Actions*), we briefly describe the range of potential actions one can apply in a restoration project. More detailed information sources for each type of action are also recommended. In the fifth and final section (*Section 5. Monitoring and Adaptive Management*), we discuss the importance of monitoring and adaptive management as an integral part of any restoration project. Our hope is that this document will serve as a "primer" on meadow restoration, and that those involved in these important efforts will benefit from the broad and processed-based approach we recommend.

2 FUNCTIONAL AND DEGRADED MEADOWS

What is a meadow and what characteristics and processes maintain a meadow in a healthy or functional state? In this section, we describe the physical and biological characteristics of functioning meadows, as well as some of the sources and responses to stress that can lead to meadow degradation.

2.1 Functional Meadows: Vegetation and the Physical Template

Mountain meadows comprise less than one-tenth of the Sierra Nevada region (Ratliff 1985) yet provide important habitat for over half of the vertebrate species, with one-fifth of the region's terrestrial vertebrate species being dependant on riparian and meadow areas for survival (Ratliff 1985; Murphy et al. 2004). The important role meadows play in sustaining diversity in the Sierras is fundamentally related to the abundance of available water during times when water in the surrounding landscape is severely limited. The physical structure that creates available water in meadows is therefore critical to their existence, and nearly all other ecological values associated with meadows are derived from this condition.

Functional meadows in the Sierra Nevada and Southern Cascades of California are defined as landscape features with the following characteristics (Weixelman et al. 2011):

- A meadow is an ecosystem type composed of one or more plant communities dominated by herbaceous species.
- It supports plants that use surface water and/or shallow groundwater (generally at depths of less than one meter) at some point during the growing season.
- Woody vegetation, like trees or shrubs, may occur and be dense but are not dominant.

Areas that have met these criteria in the past, but are currently in another ecological state due to alterations in hydrology and/or vegetation, but where changes in the current state could result in a land form that does meet the criteria listed above, are referred to as potential meadows. Determining whether or not it is desirable to convert a potential meadow to a functional meadow is part of the land managers' and other stakeholders' purview and not directly discussed in this document. This document provides land managers and other stakeholders guidance for assessing the feasibility of restoring a potential meadow as well as tools for developing an approach and achieving restoration goals.

Intact meadows provide important ecosystem functions for the immediate area and for their watershed (Table 1).

Table 1. Ecosystem functions potentially provided by healthy mountain meadows.

Increase biodiversity	Extend late summer baseflow
Increase late summer water storage	Provide increased forage
Decrease flooding	Support aesthetic values
Decrease sediment load and delivery	Protect Native American cultural values
Improve water quality	

Since these nine ecosystem functions are directly or indirectly dependent on unimpaired hydrologic and geomorphic processes within the meadow, a clear understanding of these processes is required for meadow management and restoration. Weixelman et al. (2011) classified meadows in the Sierra and Southern Cascade ranges into fourteen hydrogeomorphic types. The classification key and meadow type descriptions in the Weixelman et al. 2011 document, along with the discussion of processes provided herein, can provide an initial framework for interpreting processes that can support meadow functions at a given site. In the sections below, we provide an overview of meadow geomorphology, hydrology and interactions between the meadow vegetation and physical template.

2.1.1 Geomorphology

Mountain meadows commonly develop in settings where a small basin or locally wide valley bottom fills with a relatively shallow layer of alluvial and colluvial deposits as a result of downstream bedrock or stratigraphic (e.g., alluvial fan or glacial deposits) base level control. Channel morphology within mountain meadows is controlled by the climate and size of the contributing drainage area, slope of the valley bottom and channel, and sediment mass balance.

A sediment budget describing sediment input, output and storage is useful in understanding geomorphic processes and disturbance mechanisms. Sediment may be delivered to a meadow by surface erosion, rilling, gullying, and mass wasting from adjacent hillslopes or by fluvial transport (bedload or suspended load) from upstream channel reaches. Sediment may also be recruited from within the meadow by channel bed and bank erosion, and by erosion of the meadow surface. Sediment transported within the channel may exit the channel with overbank flow and deposit on the floodplain, accrete onto banks, deposit on the channel bed and in bars, or remain in transport through the reach. Fluvial sediment transport and storage is largely determined by channel slope, flow depths and velocities, roughness elements (e.g., large bed particles, wood, bedforms, and sinuosity or planform curvature), boundary shear stress, and the magnitude and duration of bed mobilizing flows. Although sediment storage in a properly functioning stream channel at equilibrium may increase or decrease over short time scales (i.e., storm events or water years), there is typically little long-term change in storage. An imbalance between sediment supply and transport that leads to channel aggradation, avulsion, or incision is a critical factor related to degradation of meadow ecosystems (discussed in more detail in *Section 2.3. Sources of Degradation*).

2.1.2 Hydrology

Although meadow hydrology is complex and site-specific, a general water balance describing input, output and storage components is useful in understanding hydrologic processes and disturbance mechanisms (Figure 1). The majority of water passing through a mountain meadow enters as surface runoff (e.g., streamflow and overland flow), groundwater, and infiltration of direct precipitation. Surface water input may be routed through the meadow as streamflow, ponded in swales and surface depressions, or transferred to groundwater by infiltration along the channel boundaries and floodplain surface. The rate and timing of groundwater flow into and through the alluvium and/or out through the channel is dependent upon presence of bedrock joints or fractures, the influence of springs in the surrounding bedrock, and characteristics of the meadow alluvial aquifer such as its connectivity to the surrounding bedrock and channel, its geometry (depth and shape), and slope. Hydraulic conductivity of the alluvium varies widely depending on porosity, grain size distribution, texture, and stratification. These basic conditions of a meadow must be known and understood in order to manage and predict changes in the groundwater and surface water flow regimes.

Groundwater storativity[1] in a meadow is determined by the thickness and effective porosity of sediment filling the valley, as well as the groundwater hydraulic gradient, which changes seasonally. The gradient typically slopes away from the channel during the wet period when channel flow is above or near the bankfull elevation (i.e., groundwater recharge is occurring), and the gradient slopes toward the channel during the late spring through fall when streamflow is confined within the bankfull channel. Channel bed elevations and stage heights therefore exert a strong influence on groundwater elevations and storativity in the surrounding meadow, and are a critical factor related to degradation of meadow ecosystems (for more detail, see *Section 2.3. Sources of Degradation*).

[1] Storativity is a measure of how much water can be released from the aquifer and is measured as the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer.

Water exits the meadow through stream flow, groundwater flow, and evapotranspiration. Evapotranspiration depends on climatic factors (temperature, relative humidity), rooting depth, depth to the water table, and vegetation type and amount. The width of the capillary fringe, which increases with finer textured soils, can also increase plant access to groundwater by reducing the depth to available water for plant uptake. Depth to groundwater is a major factor determining the composition of vegetation communities in riparian meadows (Allen Diaz et al. 1991, Chambers and Miller 2004b, Hammersmark 2008, Loheide and Gorelick 2007).

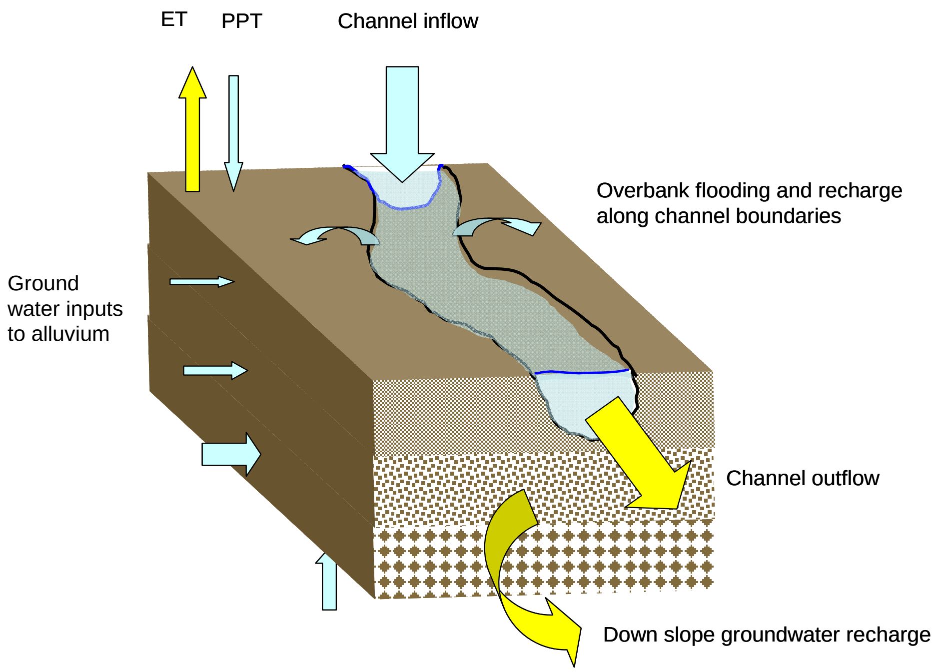

Figure 1. Conceptual water balance for a meadow, illustrating inputs (blue), outputs (yellow), and storage. ET refers to evapotranspiration and PPT refers to precipitation.

2.1.3 Meadow Vegetation

Physical template effects on meadow vegetation

The distribution, density, and type of vegetation in a meadow are largely functions of seasonal depth to groundwater and surface water availability. Ratliff (1985), and more recently Weixelman et al. (2011) classified meadow types by hydro-geomorphologic regime. Ratliff (1985) reported that meadow plant community types were highly correlated to these regimes. Since then, multiple studies in the Sierra Nevada and adjacent Great Basin have demonstrated that meadow plant community composition varies with groundwater hydrology and soil moisture (Allen-Diaz 1991; Castelli et al. 2000, Chambers and Miller 2004b, McIlroy 2008). As illustrated in Figure 2, average depth to groundwater and the rate and timing of groundwater decline within the growing season varies significantly among plant community types (Chambers et al. 2011, McIlroy 2008; Allen-Diaz 1991).

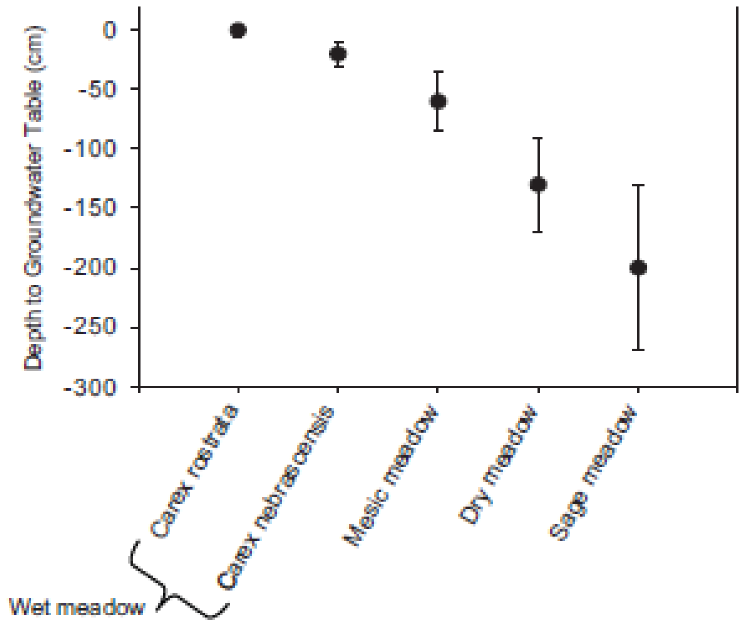

Figure 2. Average water table depths for four different meadow types in the Central Great Basin (means +SE). Reproduced from Chambers et al. 2011.

As suggested by the standard error bars in Figure 2, variability in groundwater levels tolerated by meadow species increases from very wet to dry site species (Chambers et al. 2011, Chambers et al. 2004; Castelli et al. 2000). One must also bear in mind that the occurrence of longer lived species that are only moderately sensitive to groundwater levels could be a reflection of past rather than present conditions. The varying sensitivity to groundwater table depth among meadow plant species can be used to determine which species are reliable indicators of the current depth to groundwater regime.

Rooting activity and primary production are also affected by water table depths even within the same plant community types (Martin and Chambers 2001, 2002; Svejcar and Riegel 1998). Differences are greater in cross-community type comparisons within a single meadow, but even larger among plant community types associated with wet vs. mesic vs. xeric conditions (Ratliff 1985). Site-specific differences, grazing regimes, and water-years can also affect primary production rates (Ratliff 1985). For example, wet meadow plant communities, often dominated by rhizomatous sedges, have two to six times the rooting density and biomass of common mesic meadow grass species such as Kentucky bluegrass (*Poa pratensis*) and tufted hairgrass (*Deschampsia cespitosa*; Manning et al. 1989, Dunaway et al. 1994). A synthesis of above ground production rates for 27 meadows, reported in seven studies, indicates that production is roughly 5-times greater in mesic graminoid and forb dominated meadows than in degraded meadows supporting sagebrush and dry graminoid species (Figure 3; Stillwater Sciences and American Rivers 2011).

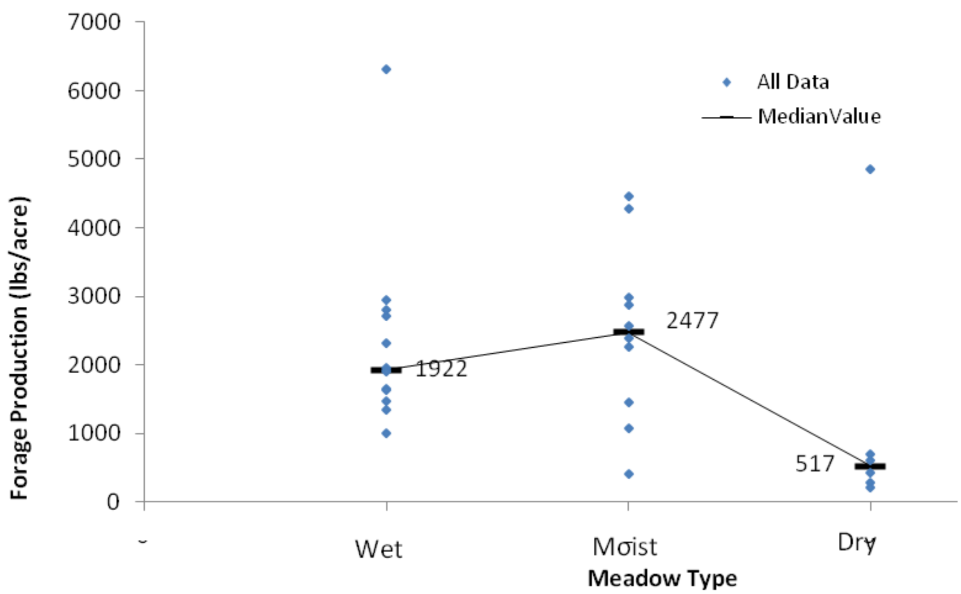

Figure 3. Data points for peak annual above ground biomass forage production in 27 Sierra Nevada meadows with median values highlighted (Stillwater Sciences and American Rivers 2011).

Meadow vegetation effects on the physical template

Although largely controlled by the physical template, the type and distribution of plant communities in a meadow also have multiple feedbacks effects on the physical template, including vegetation effects on bank erosion, sediment deposition, surface soil texture, soil water holding capacity, subsurface groundwater flow rates and water losses to evapotranspiration. Vegetation in the contributing area also has important effects on hydrologic inputs to down gradient meadows. Practitioners can apply this understanding of feedbacks and interactions between vegetation and meadow processes in restoration plans to help move the system in the target direction. The feedback effects that vegetation can have on the physical template and processes in a meadow are described below.

Densely rooting plants can provide increased bank stability. Several studies have found that sedge and rush rooting structures confer greater tensile strength and erosion resistance to channel banks, resulting in more stable stream channels, than do grass species (Micheli and Kirchner 2002a and b, Dunaway et al. 1994, Kleinfelder et al. 1992). In a meadow in the southern Sierra Nevada, for example, Micheli and Kirchner (2002a) report more erodible banks in dry sagebrush dominated meadow areas compared to wet sedge and rush dominated areas. Differences in lateral migration were attributed to a five-fold difference in bank strength provided primarily by sedge species. They also report that rushes were effective at stabilizing coarse bar surfaces. Willows and similar densely rooting riparian shrubs are less sensitive to short periods of drought and provide bank stability for coarser grained sediments (Thorne 1990). Mountain alders are less sensitive to multiple years of drought than willows and are also deeply rooting shrubs which can hold back large particles (cobble to small boulder), thereby providing some stability to the streambed and channel banks even during periods of prolonged drought or lowered groundwater levels.

Plant species composition also affects soil pH and nutrient content. For example, litter from conifers reduces overall nitrogen availability and lowers the soil pH in comparison to litter from most mesic meadow vegetation. Similarly, the presence of nitrogen fixing species such as clovers, lupine, and mountain alder, increases soil fertility; thereby creating favorable conditions for species with moderate to high nutrient demands. The plant community type shifts that occur as one moves from moist to wet meadows (grass and forb dominated to wet sedge and rush dominated plant communities) also co-occur with increases in overall above and below ground biomass production; which, with saturated anoxic conditions and low decomposition rates, lead to production of increasingly organic soils. Organic soils have higher water holding capacity and a wider groundwater capillary fringe than most mineral soils (excluding clays and fine silts), both of which increase the amount and duration of water available in the rooting zone.

Maintaining saturated or very wet conditions and the vegetation required to continuously build peat can be important for sustaining peat meadows. Soils with high organic matter content have much lower saturated hydraulic conductivity than most mineral soils (excluding clays and fine silts)[2]. In meadows where most or all of the channel cuts through highly organic or peat soils, subsurface water movement toward the channel is slower than in meadows where groundwater moves through coarser material to reach the channel. Peat soils require hundreds to thousands of years to develop, but can be lost through drying and oxidation in years to decades (e.g., Merrill et al. 2010). Thus, over the long-term, the maintenance and/or development of highly organic soils can affect the rate and direction of groundwater flow through and out of the meadow.

Sedge and other very wet plant species tend to have higher evapotranspiration rates than mesic species, which in turn have higher evapotranspiration rates than dry-site species. Thus restoring wet or mesic species to a dry site meadow can increase net water loss from the meadow during the growing season (Loheide and Gorelick 2005).

At the watershed scale, forest and shrub cover is critical for both intercepting precipitation and increasing infiltration to groundwater, thereby increasing the proportion of precipitation that percolates to groundwater and subsurface flows in relation to surface runoff. In simple terms, the more infiltration in the watershed, the more groundwater input to the downstream meadow. On the other hand, vegetation in the contributing area also increases evapotranspiration, thereby reducing the net groundwater contribution to downstream alluvial areas (such as a meadow). Increased forest density, a result of a half-century of fire suppression in many parts of the Sierra Nevada, can result in increased evapotranspiration and reduced downstream flows and groundwater inputs. An additional important effect of the very high stocking density of many forests of the Sierra Nevada is increased vulnerability to disease and insect attack, as well as increased frequency of wildfire due to high fuel loads. Thus, the current state of many forested watersheds in the Sierras already could be resulting in long periods of decreased ground and surface water inputs to meadows interspersed with brief periods of high water input directly following catastrophic fire. Some areas of the Sierra are experiencing increased land use conversion of forested areas to dispersed homes and small commercial developments. Like wildfires, such development can reduce infiltration and increase surface peak flows, affecting higher downstream erosion rates and ultimately reducing groundwater inputs to the meadow (Dunne and Leopold 1978).

[2] Saturated hydraulic conductivity or permeability of clays are generally <0.01 m/day, for silts 0.0001 to 1 m/day, for fine sand 0.01 to 10 m/day, for medium to coarse sand 10 to 3,000 m/day (Dunne and Leopold 1978). Saturated hydraulic conductivity for moderately to well decomposed peat soils derived from herbaceous plant material was measured at 0.004 m/day (Boelter 1968).

2.2 Meadow Degradation and State Transition

In this section we describe how historical and contemporary stressors on meadow processes alter meadow geomorphology, hydrology and plant community composition. Meadow degradation refers to the alteration of meadow structure and processes to an extent that the functions they perform in the landscape are significantly altered. Since the existence of meadows is largely dependent on surface and groundwater hydrologic conditions, meadow degradation is often fundamentally related to hydrologic alteration. Positive feedback among hydrologic, fluvial geomorphic and vegetative responses often exacerbates what may begin as a small perturbation and can hinder recovery.

The USDA and other land management agencies in the USA have been using the language of state and transition models for vegetation changes in rangelands in a non-equilibrium and non-climax theory framework since the early 1990s (Westoby et al. 1989; Stringham et al. 2001a) and many authors have used this as an experimental framework instead of classical succession (e.g., Allen-Diaz and Bartolome 1998; Augustine et al. 1998). The term “state” in “state transition models” refers to alternative and persistent plant communities and their characteristic soil properties that are not part of a reversible, linear succession (Stringham et al. 2001a). Various seral stages or phases of vegetation can occur within the natural range of variability of a given state. Transitions among alternative states can be triggered by management actions and natural or anthropogenic disturbances. Such transitions can be abrupt or gradual with “stabilization” at another alternative state only occurring once the transition is complete (Stringham et al. 2001a). Such a transition to a different state requires crossing over a boundary or threshold, which results in a different potential set of plant communities for the site. Thus thresholds reflect the extreme physical and/or biological conditions that can sustain a given vegetation state at a site.

If management and/or disturbances change the physical and/or biological conditions that control vegetation beyond a given threshold, the site will transition to the new vegetation state. The obvious example in the case of meadows is the shift that occurs when a channel in a meadow supporting a wet sedge community becomes incised and lowers the growing season water table to such an extent that conditions no longer support wet sedge communities, but rather favor more mesic graminoid and forb species. According to the current NRCS definition, once such a threshold is breached, return to the previous state is not possible within a human management timeframe (e.g., <25 yrs) without substantial intervention (Friedel 1991, Stringham et al. 2001b).

Thus, the trajectory of degradation to different states is not linear, but rather marked with thresholds beyond which an increasing amount of intervention is required in order to restore desired states and functions. In general, three levels of degradation can be described.

Level 1: The insulting stressor no longer exists, and the system will eventually recover to its pre-stressor functioning level within a human timescale (e.g., roughly 25 yrs) without intervention. At this first level, no state transition occurs because the system (meadow) is able to resist a change in processes and/or is able to recover its processes to within the natural range of variability of the original state (e.g., the system is “resilient” to the effects of the stressor).

Level 2: The stressor remains active and must be removed or “neutralized” in order for the system to recover to its pre-stressor condition. In this case, continued stress would push the control processes and/or conditions of a meadow across a threshold so that the meadow would then have a different set of potential vegetation types, aka be in a different state.

Level 3: The system has already crossed a state threshold and entered a positive feed back loop that no longer requires the presence of the original stressor(s). In this case, degradation will continue unless actions are taken to re-direct system processes.

Understanding what physical conditions (e.g. groundwater level, degree of soil compaction, percent cover of cheatgrass, etc.) mark a threshold that can initiate transitions among vegetation types can inform restoration designs. Examples of hypothesized state transitions for the Great Basin (Stringham et al. 2001b) are presented in Figure 4 below. Research and/or well-documented monitoring in meadows with similar soils, hydrology, elevation and latitude could provide more locally specific information about state transitions and thresholds for a particular meadow type in the Sierras.

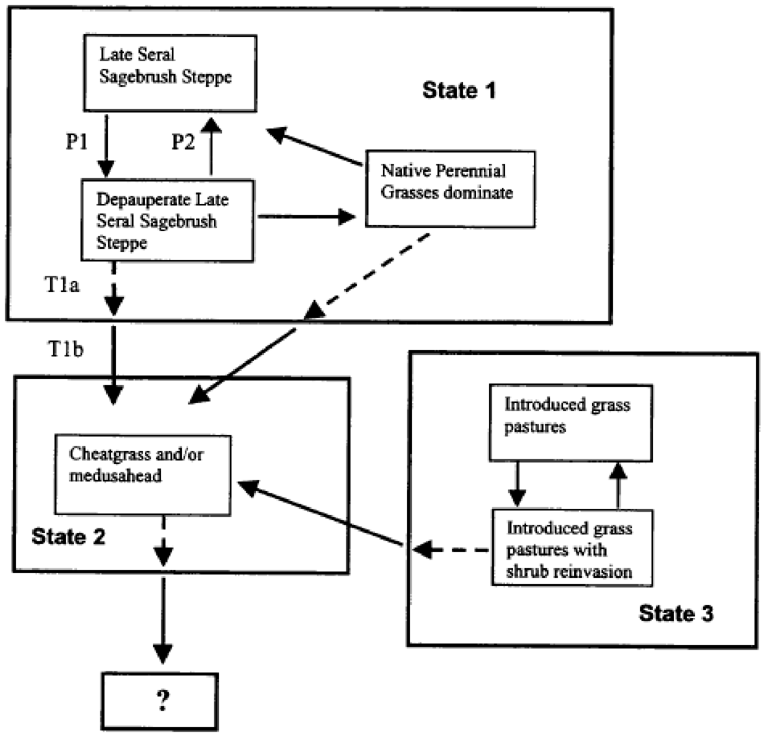

Figure 4. Example of a sagebrush steppe state-transition model with plant community phases in each state. Transition line T1a is reversible, where as transition line T1b is irreversible. Figure from Stringham et al. 2001b.

2.3 Sources of Degradation: Stressors on Meadow Processes and Functions

As described above, meadow hydrology, geomorphology and vegetation are dynamic systems that respond to changes in their physical environments. Large responses, which can include a cascade or chain of events, can profoundly affect how a meadow works and the benefits it provides, such as habitat and groundwater storage. An ecological stressor is defined as "any physical, chemical, or biological entity that can induce an adverse response" (USEPA 2008). In this section we discuss the known and expected effects of human land and water use and climate change on meadow function based on a literature review. Common ecological stressors on meadows of the Sierra Nevada are listed in Table 2.

Table 2. Stressors on meadow processes and function in the Sierra Nevada.

Overgrazing	Recreational Use
Roads and Trails	Residential and Commercial Development
Altered fire regime	Climate change
Invasive Species	

2.3.1 Overgrazing

Overgrazing in the late 1800s and early 1900s resulted in widespread deterioration of meadows in the Sierra Nevada (Menke et al. 1996, Ratliff 1985). Changes to meadows attributed to overgrazing during the late 19th and early 20th centuries include gullying, desiccation, shrub encroachment, and changes in plant species composition, structure, and diversity (Wood 1975, Ratliff 1985, Allen-Diaz 1991, Menke et al. 1996). During 20th century, livestock use of Sierra meadows declined progressively due to economic and other reasons (Menke et al. 1996). Today conditions and grazing-use patterns are improving; however channel incision from heavy historical use has altered many meadows through lowered streambeds and groundwater tables. These changes in meadow hydrology are believed to be the basis for major shifts in plant community composition observed in many Sierra Nevada meadows today.

Livestock grazing can affect plant species composition through the following mechanisms (Trimble and Mendel 1995; Menke et al. 1996, Berlow and D'Antonio 2002):

- Localized plant removal from channel banks (grazing and sheering) and related bank erosion and bank failure when cattle congregate in or adjacent to the channel;
- Increases in soil compaction which increases soil bulk density, lowers infiltration and water holding capacity, which in turn, reduces soil moisture and rooting density and increases surface runoff and erosion;
- Focused areas of compaction and soil displacement to create linear troughs in the soil which can concentrate overland flow and increase local erosion;
- Increases in soil disturbance which offers increased colonization sites for invasive or opportunist species; and
- Selective grazing, which alters competitive conditions for plant species.

Intensive grazing and livestock use in and around meadow channels affect channel structure and increases erosion. Cattle are attracted to the channel for several reasons, including increased amount and palatability of forage, shade from adjacent willows and alder shrubs, and proximity to water for drinking and cooling. Several authors report that grazing rates were 5 to 30 times higher in riparian and meadow areas than in adjacent uplands (Clary and Webster 1989, Platts and Nelson 1985). Others report that the effects of cattle trampling on stream banks increases with soil moisture content, with the greatest effects occurring with over 10% moisture, a likely common condition in moist to wet meadows (Marlow and Pogacnik 1985, 1986; Marlow et al. 1987). A single cow might move in and out of the channel multiple times a day; and during each ingress or egress, damage channel banks and riparian vegetation through trampling, sheering chunks of the bank off into the channel, and creating concentrated flow pathways that are continuous with the channel (Clary and Webster 1990, Trimble and Mendel 1995). The net results can include false set back channel banks, denuded banks vulnerable to increased rates of bank erosion, channel capture by compacted cattle paths, and increased sediment input to the channel as well as other water quality effects (Kauffman and Krueger 1984, Trimble and Mendel 1995).

In both the meadow and its channel, these net effects lower resistance to erosive flows characteristic of rain on snow and other extreme events (Trimble and Mendel 1995).

The direct effects of domestic grazers on plant species composition has been well documented for meadows in the Sierra Nevada. Overgrazing in wet and mesic meadows also can result in the replacement of rushes and sedges by grasses and legumes (Menke et al. 1996), although some sedge and rush species can increase with grazing. For example Nebraska sedge (*Carex nebrascensis*), which has long-lived shoots with primordia (tissue capable of producing new vegetative growth) close to the ground and not easily accessible to grazing animals (Ratliff and Westfall 1992), are most common in meadows with a history of heavy grazing (Menke et al. 1996). Similarly, selective grazing, in which species such as Baltic rush (*Juncus balticus*) and bulrushes (*Scirpus*) are not preferred by livestock, results in greater abundance of these least palatable species (Menke et al. 1996, Ratliff 1985). Meadows with increased bare soil due to trampling and other disturbances show an increase in abundance of opportunistic species, such as Douglas' knotweed (*Polygonum douglasii*) and Kentucky bluegrass (Menke et al. 1996).

Grazing also affects vegetation structure and overall biomass, with direct impacts to dependent wildlife. Intensive grazing can prevent or suppress regeneration of willow stringers along the meadow channel. This represents a loss of nesting and foraging habitat for many meadow dependent bird species (Skovlin 1984). For example nesting densities of birds that nest in the shrub canopy, such as willow flycatcher, Lincoln's and white crowned sparrows (all meadow dependant species) were found to be reduced with intensive grazing (Fleischner 1994, Saab et al. 1995 in Siegel and DeSante 1999). Ground nesting bird density and reproduction are also impacted by trampling and reduced ground cover that occurs with intensive grazing (PRBO 2011).

2.3.2 Roads

Roads affect the physical and biological processes of the ecosystems they traverse. Impermeable road surfaces increase surface runoff and overland flow, affecting the timing and volume of flow events in downtream watercourses (King and Tennyson 1984, Wemple et al. 1996) and increasing channel erosion (Montgomery 1994, Furniss et al. 1998, Gucinski et al. 2001). Valley bottom roads and railroads concentrate runoff to the adjacent channel, and the associated drainage infrastructure (e.g., culverts) is susceptible to failure, which has resulted in capture of concentrated surface runoff, severe erosion, and high sediment delivery to the nearby channel. The construction of roads and railroads within narrow valley bottoms often straightened the adjacent stream channel and reduced the floodplain area. These changes often have the effect of converting a sinuous, low-gradient stream channel to a steeper, less sinuous channel with higher flow velocities and more erosive power. Where stream channel boundaries are mobile, the response to these changes is typically incision. Unsurfaced roads result in the greatest amount of surface erosion (Megahan and Kidd 1972). Roads or landings built in or along one side of meadows often result in long-term soil compaction, which greatly reduces water holding capacity, infiltration, and the water filtering of function meadows. Roads constructed in and along meadows and/or associated stream channels can also directly introduce non-native species to the meadow communities and can isolate the stream channel from a portion of its floodplain (Gucinski et al. 2001).

2.3.3 Altered fire regime

Fire suppression and cessation of intentional burning to control vegetation in meadows during most of the 20th century has resulted in upland species encroachment within and along the edges of meadow, as well as an increase in stand-replacing fires in the meadow contributing areas. Except for the past 100 years, humans have used fire to manage Sierra meadows for over 8,000 years (Anderson 2006; Menke et al. 1996). Archeological evidence indicates that throughout the past eight to ten thousand years, Native Americans burned meadows every ten to twelve years in order to control conifer encroachment and to promote the growth of preferred vegetation for basket weaving, game species, and medicinal uses (Anderson 2006). Euro-American sheepherders entered the landscape nearly 200 years ago (Menke et al. 1996), and also used fire to increase forage production. These early settlers burned meadows more frequently - every 2 to 5 years (K. Deal, Eldorado National Forest Archeologist, pers. comm. with A. Merrill, Stillwater Sciences, 2007). There is evidence that the US federal land management agency 20th century policies of fire suppression and cessation of using fire to manage meadows have resulted in conifer encroachment. The Forest Service and other federal land management agencies now use prescribed fire in land management. For example, the Forest Service and partners are currently investigating the possibility of using mechanical tree removal and controlled burns to reduce and possibly reverse conifer encroachment in a handful of meadows in the El Dorado National Forest and the Lake Tahoe Basin Management Unit. These groups are planning to use light ground fires to eliminate young encroaching conifers within the meadows and along the meadow edge.

Fire suppression-induced changes in the fire regime within the meadow drainage area can also impact the meadow. Through both indirect (erosion in surrounding uplands) and direct means (meadow burning), intense wildfires are likely to have greater negative effects on mountain meadows than are more frequent low intensity ground fires. Large, stand-replacing fires in a meadow's contributing area can diminish evapotranspiration losses to such an extent that meadow surface and groundwater inputs increase for the first several years following the fire (Sugihara et al. 2006). For example, a 2-foot (60 cm) rise in the saturated zone of a meadow was observed one year following a large stand-replacing fire in its contributing area (2007 Antelope fire; D. Weixelman, US Forest Service, pers. comm. with A. Merrill, Stillwater Sciences, 24 September 2008). Such stand replacing fires can also temporarily increase surface runoff and sediment delivery to downstream channels. Large deposits of sediment and coarse woody debris introduced to the channel in a meadow can result in fining of the bed surface and channel aggradation, widening, and avulsion. Accelerated sediment delivery may be related to post-wildfire erosion, disturbance by overgrazing, remobilization of hydraulically mined sediment, erosion from poorly designed or maintained roads, or disturbance by other types of development. Channel aggradation typically doesn't have a significant effect on groundwater storage, but can result in more frequent flooding, bank instability, and reduced surface flow during low flow periods.

Finally, fire suppression in the surrounding uplands and ecotones reduces habitat quality along the meadow-forest boundary by replacing willow and alder thickets (excellent habitat for willow flycatcher and other bird species) with dense under and mid story fir tree species. Dense understory and midstory trees compete with each other and overstory trees for resources, slowing the regeneration of large trees. Large trees are important habitat features for cavity nesting birds and bats as well as raptors, great gray owls and other hunting birds. Forest wildlife and forest bird species are commonly found in the highest density along the meadow-forest edge (DeSante 1995) and many of these species depend directly or indirectly on the highly productive meadows for food and water. For example, great gray owls forage almost exclusively on meadow rodents (e.g., meadow voles), although they roost in tall trees or snags in the adjacent forest.

2.3.4 Invasive species

Invasive non-native plant species can directly and indirectly alter the habitat, productivity, water and nutrient availability, and aesthetic values associated with natural ecosystems. Invasive, non-native plant species are often early invaders after soil disturbance, and can to out-compete and replace native vegetation. Replacement of native plant communities with non-native species may change soil microbial populations and, thus, nutrient cycling processes (e.g., Corbin and D'Antonio 2004, Hawkes et al. 2006). Many weedy annuals have shallow root systems that make them poor candidates for stabilizing soil surfaces and providing erosion protection. Non-native species of particular concern in Sierra meadows can be found in the recent document produced by the California Invasive Plant Council (Cal IPC 2011).

Table 3 presents weed species that occur in the Sierra Nevada (including Eastern Sierra Nevada), that have a Cal IPC rating of moderate or high[3], and that are reported to occur in wetlands and/or riparian areas. There are other important weed species that can invade dry meadows that are not included in the list below but that can be found in the Cal IPC database or in the Cal IPC (2011) report on Invasive Plants in the Sierra Nevada. Several of these species are currently only reported in small and limited areas but have the potential, based on observations in other regions of the country, to spread rapidly and have important ecological effects. As climate change affects the hydrology and other aspects of Sierran ecology, new invasive weed species will be able to inhabit the Sierra Nevada range. Thus both the spread of invasive species and the changing geographic range of suitable habitat require on-going vigilance for spotting and controlling new weed introductions to the Region, while still managing for invasives that have already become established.

D'Antonio et al. (2004) found very low occurrence of non-native species in high-elevation Sierra meadows; but many of the meadows surveyed contained saplings of the native lodgepole pine (*Pinus contorta* ssp. *murrayana*). These pine saplings were observed in a range of conditions, from trailside disturbances, dry disturbed soil, and de-watered meadow areas near erosion gullies, to relatively undisturbed and/or boggy meadows. Although lodgepole pine is a native species, evidence suggests that events during the 20th century increased their cover in Sierra meadows (Millar et al. 2004). Like D'Antonio et al. (2004), Bauer et al. (2002) studied meadows of the Kern Plateau in the southern Sierra Nevada and concluded that while non-native invaders were rare, invasion of meadows by a native upland species, sagebrush (largely *Artemisia rothrockii*), is widespread. This work corroborates findings of Berlow and others for high elevation and east side meadows in the Sierra Nevada (Berlow et al. 2002, 2003). As mentioned above, the most common means by which invasive non-native species are introduced to meadows is via hikers along recreational trails, vehicles along roads and in timber harvest areas, and via livestock (cattle, sheep, pack animals).

[3] A Cal IPC rating of "**high**" refers to species that have "severe ecological impacts on physical processes, plant and animal communities and vegetation structure." Their reproductive biology and other attributes are conducive to moderate to high rates of dispersal and establishment. Most are widely distributed ecologically. A Cal IPC rating of "**moderate**" refers to "species with substantial and apparent—but generally not severe—ecological impacts on physical processes, plant and animal communities, and vegetation structure. Their reproductive biology and other attributes are conducive to moderate to high rates of dispersal, though establishment is generally dependent upon ecological disturbance. Ecological amplitude and distribution may range from limited to widespread."

Table 3. Cal IPC listed species that occur in the Sierra Nevada with a rating of moderate or high and are likely to occur in moist or wet meadows. Dry meadows could have other invasive species listed in the Cal IPC database.

Scientific name	Common name	Cal IPC rating
Arundo donax	Giant reed	High
Centaurea maculosa	Spotted knapweed	High
Cortaderia selloana	Pampasgrass	High
Hedera helix, H. canariensis	English ivy, Algerian ivy	High
Lepidium latifolium	Perennial pepperweed	High
Onopordum acanthium	Scotch thistle	High
Rubus armeniacus	Himalaya blackberry	High
Sesbania punicea	Scarlet wisteria	High
Spartium junceum	Spanish broom	High
Tamarix parviflora	Smallflower tamarisk	High
Tamarix ramosissima	Saltcedar, tamarisk	High
Acroptilon repens	Russian knapweed	Moderate
Ailanthus altissima	Tree-of-heaven	Moderate
Alhagi maurorum	Camelthorn	Moderate
Atriplex semibaccata	Australian saltbush	Moderate
Cirsium vulgare	Bull thistle	Moderate
Conium maculatum	Poison-hemlock	Moderate
Dipsacus fullonum	Common teasel	Moderate
Dittrichia graveolens	Stinkwort	Moderate
Holcus lanatus	Common velvet grass	Moderate
Hordeum marinum, H. murinum	Mediterranean barley	Moderate
Leucanthemum vulgare	Ox-eye daisy	Moderate
Polygonum cuspidatum	Japanese knotweed	Moderate
Polygonum sachalinense	Sakhalin knotweed	Moderate
Rumex acetosella	Red sorrel, sheep sorrel	Moderate
Vinca major	Big periwinkle	Moderate

2.3.5 Recreational use

Recreational use of meadow ecosystems has the potential to affect meadow processes and health. In the high Sierra meadows, packstock grazing is believed to be a major current source of damage (Menke et al. 1996). In many of these higher elevation meadows, disturbance and grazing effects from packstock are believed to be greater than those due to feedstock (Menke et al. 1996. Dispersed and developed recreation activities in meadows may alter meadow hydrology through soil compaction and stream bank trampling and chiseling, and increase habitat fragmentation due to trails and campgrounds located within or adjacent to the meadow (Menke et al. 1996). Off road vehicle use in meadow areas has had significant negative and long lasting effects on meadows since these vehicles are heavy and even single passes across organic meadow soils can result in long-lasting soil compaction. Compacted soils have lower water holding capacities and infiltration rates than undisturbed soils and can thus increase surface water runoff, increasing channel erosion. Recreational uses of the Sierra Nevada are expected to increase with the expected tripling of the Sierran population between 1990 and 2040 (Duane 1996).

2.3.6 Development

Human settlements most often happen along rivers and in meadow areas. One of the best known examples of conversion from meadow to residential development in the Sierra Nevada occurred during the 1960s in the South Lake Tahoe keys (Murphy and Knopp 2000). Other former meadows likely existed in currently urbanized areas, such as Grass Valley and Placerville. With expectations of increasing populations in the Sierra Nevada over the next 50 years (Duane 1996), development pressure on existing meadows is likely to increase. The greatest and most near-term increase in the development pressure is expected to occur within the vicinity of transportation corridors and along the outskirts of established communities.

2.3.7 Climate change

A rapidly changing climate is affecting all ecosystems; understanding what these changes are and how they might affect meadows in the Sierra Nevada is an important part of managing these systems in the 21st century. We can use what we know about meadow responses to past climate changes to guess the likely responses of these systems to the current and future climate change effects. Overall, recently observed changes to on-going climate change indicate that the future will bring increased water stress and increased frequency of extreme, “destabilizing” events. Understanding the climatic and geomorphic history of a place can provide clues about the potential type and rate of response to future climatic changes and help inform managers about a meadow’s likely trajectory in response to management or restoration actions.

Large climatic changes have happened in the past and can help inform us about possible hydrogeomorphic responses of modern ecosystems to the current rapidly changing climate. For example, a shift from relatively moist to relatively dry conditions in the past 5,000 years led to an imbalance in the sediment supply and transport in the Central Great Basin, resulting in a net increase in channel and valley bottom alluvial deposits (Miller et al. 2001). Riparian areas and meadows in this arid region are still responding to this past climatic shift (Chambers and Miller 2004b). Geomorphic response to climate change in other areas has been more variable, even within the same region (Bull 1991; Knighton 1998). Sensitivity to changes in climate and/or other perturbations vary among watersheds based on factors such as bedrock controls, parent material erosivity, basin relief, and vegetation cover (Downs and Gregory 1993). Knowing the history of a particular meadow and its watershed and responses of these systems to large past events (e.g., floods, clear cutting and/or wildfires in the contributing area), can provide important insights on the sensitivity of the area to changes in climate and other perturbations.

Leading scientists agree that a rise in temperature will occur even under the best emission reduction scenarios (IPCC 2007). Increased temperatures lead to greater rates of evapotranspiration and increased plant water demand. There is further evidence that these warmer temperatures will raise snow elevation levels and will increase the frequency of "rain on snow" events at critical mid-elevation Sierra forests, increasing peak flows and flooding associated with winter storms. A diminished spring snowpack has been observed in most of the western U.S. during the last half of the 20th century (Mote et al. 2005). Most general circulation model scenarios estimate that there will be a 36% to 70% reduction of Sierra snow by 2050 (Dettinger et al. 2004) and even greater losses by the end of the century (Figure 5, Hayhoe et al. 2004). Finally, studies have also documented that peak snow melt is beginning at increasingly earlier dates. By 2002, the start of the spring snow melt pulse in the northern and central Sierra Nevada occurred roughly one to three weeks earlier than in 1948 (Peterson et al. 2008).

Because many Sierra meadows are snowmelt dependent systems, the reduction in spring snowpack and conversion of some fraction of winter precipitation from snow to rain, along with increased evaporative demand, could result in the conversion of some currently moist and/or wet mountain meadows to drier systems. Unpublished work by Eric Berlow and associates in the Southern Sierra using 20 yr of NDVI Landsat data (1986-2006) has identified late summer drying trends in some meadows but not others in southern Sierra. More work is underway to understand trend differences (Yosemite, Sequoia, Kings Canyon, and Devils Post Pile) (E. Berlow, USGS, pers. comm., 15 November 2011).

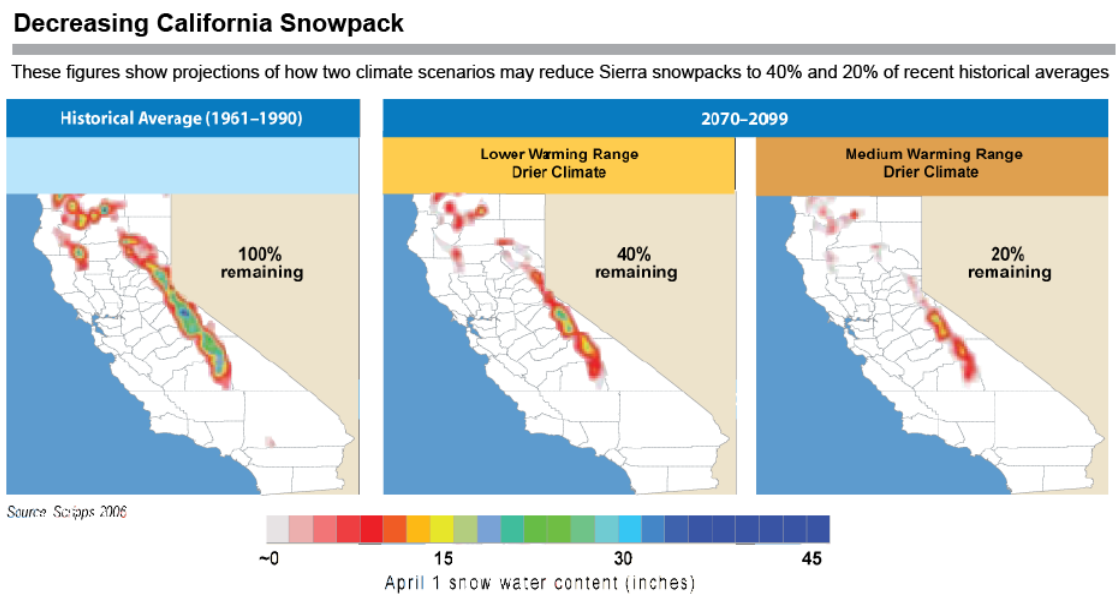

Figure 5. Projections in change in spring snowpack in the Sierra Nevada for the end of the 21st century based on medium vs. high CO_2 emissions scenarios (Luers et al. 2006). Projections indicate decreases in snowpack by over half of the current levels.

As illustrated in Figure 5, snowmelt dependent meadows in the northern and Central Sierra and along lower elevations of the entire mountain range will be most strongly affected during this century. However local areas in the high elevation central and southern Sierra are also expected to experience large decreases in snowpack over the next 50 years. These extreme forecasts emphasize the importance of managing the contributing area to maximize infiltration and groundwater recharge, which should in turn, provide groundwater inputs to meadows. Understanding linkages between meadows and their contributing areas will improve our understanding of how shifts in water inputs from snow melt to groundwater will affect water availability in the receiving meadows.

Studies on 20 and 50 year projections of changes in snowpack and temperature should be performed to identify areas in the Sierra where meadows are most likely to experience drastic, moderate, or minimal changes in hydrologic inputs. This would be a first important step for prioritizing areas and approaches for addressing the effects of climate change on mountain meadows. Other studies which identify meadow types that are most susceptible to large impacts due to drought and/or increased frequency and intensity of extreme events would also be an important move towards managing meadows for the effects of climate change. As an example of current relevant work looking at moisture trends in Sierra Meadows, Eric Berlow and associates are using MODIS data from 2001 through 2007 to estimate recent changes in annual spring melt dates and number of snow covered days; while others (such as Qinghua Guo of U.C. Merced) are downscaling an ensemble of general circulation models which can then be applied to examine local and regional effects of predicted changes in the April 1 snow water equivalent on hydrology of meadows across the region (E. Berlow, USGS, pers. comm., 15 November 2011).

In summary, climate change is expected to cause decreased ground and surface water inputs and increased ground and surface water losses via evapotranspiration. These combined effects could increase water stress on meadow vegetation, possibly leading to whole vegetation shifts. In addition, changes in annual peak flows are expected to affect the sediment balance in alluvial meadow systems, possibly requiring that systems be more robust (e.g., less prone to scouring) and/or more resilient than they have been in the past in order to maintain current levels of function. Land managers should try to understand the likely climate related stresses particular to their meadows, and adjust management goals to increase the meadows resistance to long-term water stress and high flow events, in particular.

2.4 Three Common Pathways of Meadow Degradation

The following sections focus on three of the most common pathways of meadow degradation: channel incision, sagebrush conversion, and conifer encroachment. There are other forms of stress and pathways of degradation affecting mountain meadows than the three described below, but we have attempted to emphasize the most common situations.

2.4.1 Channel Incision and Related Effects

One of the most pervasive and severe ecological impacts to Sierran mountain meadows occurs through gullying and channel incision (Mitchel 1986, Odion et al. 1988, Schoenherr 1995, Linquist and Wilcox 2000). Initially, channel incision may be triggered by a number of different land use practices working alone or in combination. Channel incision is commonly related to one or more of the following stressors:

- Channelization, straightening, and other structural controls installed in the meadow to improve drainage or manipulate water for agriculture, mining, and other land uses;
- Modifications to the channel or valley bottom that lower the local base level;
- Changes in surface runoff patterns and channel geometry by construction of valley bottom railroads, roads, and trails, and overgrazing;
- Changes in the magnitude and duration of drainage basin runoff related watershed disturbances (e.g., wildfire, overgrazing, and logging); and
- Changes in the magnitude and duration of drainage basin runoff related to climate change (Loheide et al. 2009).

Once initiated, incision can then propagate through a meadow by entrainment of channel bed material throughout a channel reach, upstream migration of knickpoints generated by base level lowering, or by groundwater sapping and headcut retreat. As a channel incision propagates through the meadow, the channel becomes disconnected from its floodplain and a larger proportion of surface water inputs and sediment load are routed within the bankfull channel. The increased routing of water and sediment within the bankfull channel results in less overbank flow, less floodplain sedimentation, reduced groundwater recharge, and shorter residence of hydrologic inputs within the meadow. The shorter residence time minimizes the positive filtering effects on water quality (Merrill 2001, Stubblefield et al. 2006, Naiman et al. 2005). Confinement of peak flows within a deeper channel results in higher shear stress on the bed and banks, increased frequency and duration of bed-mobilizing flows, and greater overall sediment transport capacity. An increase in transport capacity without a coincident increase in sediment supply can result in coarsening of the channel bed, evacuation of channel sediment storage, and destabilization of channel bed and banks. These effects often create a positive feedback loop leading to further channel incision.

Incised channels can access more groundwater and create a steeper hydraulic gradient between points of regional groundwater input and output. The steeper hydraulic gradient can increase groundwater flow rates, allowing more rapid drainage of groundwater storage and thus lowering the overall groundwater table in the meadow (Figure 6). Water once stored in the rooting zone drains to the lowered water table and is released from storage through the eroded channel bed and banks, resulting in decreased plant available water, decreased groundwater storage capacity in the meadow and reduced summer stream-flows (Hammersmark et al. 2008; Cornwell and Brown 2008). Emergence of groundwater along headcuts and/or channel banks (groundwater sapping) can result in seepage erosion, especially in alluvial valley fill composed of highly permeable sand and fine gravel. Downstream channel reaches with perennial flow often become intermittent or dry due to loss of water storage capacity in the meadow aquifers that feed them (Lindquist et al. 1997). More rapid drainage and a lower water table can profoundly alter seasonal soil moisture conditions and result in conversion of wet meadow plant communities to mesic or dry plant communities (discussed in more detail below). A change in plant species composition from wet sedge and rush dominated communities to drier site species assemblages can result in increased bank instability and channel migration rates (Micheli and Kirchner 2002a).

The effects of channel incision on stream discharge, overbank flows, groundwater recharge, and evapotranspiration rates (due to vegetation change) are summarized in Figure 6. Changes in groundwater storage capacity are indicated by the rectangles drawn to the left of each cross-section and by the difference in the volume of alluvium below the channel bed levels of the healthy (left) and incised (right) channels. In this figure (as in Figure 1 above), blue arrows indicate water inputs and yellow arrows indicate water outputs.

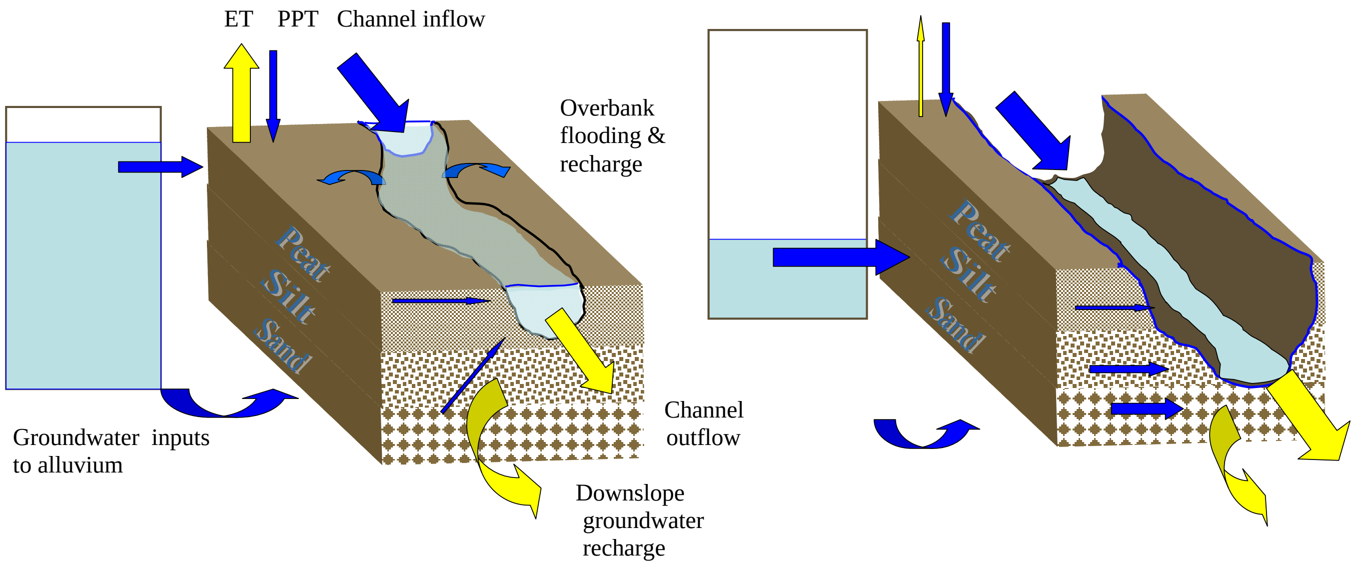

Figure 6. Generalized cross-sections showing hydrologic inputs and outputs in a functional vs. incised meadow channel.

Effectively rehabilitating an incised channel network requires an understanding of the sources of the problem. If restoration actions treat the symptoms (e.g., eroding channel banks or incised channel dimensions) rather than the cause of degradation (e.g., concentrated runoff or increased channel slope resulting from straightening), the erosive forces acting on the stream reach will eventually undermine progress toward recovery. Perrazo meadow in Tahoe National Forest is an example of a meadow with a highly incised channel where much of the meadow had converted to sagebrush and dry grass vegetation types (Figure 7). A series of restoration projects are underway to restore the hydrology of this meadow.

Figure 7. Perrazo Meadow in Tahoe National Forest prior to restoration. This was an example of a meadow in which channel incision had resulted in lowered groundwater tables and vegetation type conversion (Photo taken in summer 2005 by A.G. Merrill).

2.4.2 Meadow conversion to Sagebrush Scrub

Conversion of grass and sedge dry meadows to sagebrush scrub is likely the result of one or more types of threshold transitions due to changes in meadow hydrology (lowering of the groundwater table through incision), changes in the fire regime (through fire suppression), and/or overgrazing (Odion et al. 1988, Schoenherr 1995). Findings from a study on meadows in the southern Sierra Nevada indicate that bare soil churned up by livestock and livestock grazing, as well as gophers, can directly favor sagebrush establishment in meadows without large changes in groundwater hydrology (Berlow et al. 2002). Competition studies between sagebrush and native meadow herbaceous species in incised, dried meadows indicate that native herbaceous species will only out-compete sagebrush with both groundwater level restoration and sagebrush removal (Berlow et al. 2003).

Historically, American ranchers and settlers used fire to remove sagebrush from meadows. Several recent studies demonstrated that sagebrush cover in dry meadows can be reduced and grass forage species increased through prescribed fire (Chambers and Linnerooth 2001; Wambolt and Payne 1986). Although relatively little work on sagebrush in the Sierra Nevada has been published, a large literature on fire and European grass invasion of intermountain west sagebrush steppe habitats exists. Despite the negative effects of an emerging positive feedback occurring between invasive annual grasses and fire frequency and intensity in the sagebrush steppe, the resulting decrease in sagebrush cover with increased fire frequency supports application of prescribed fire for sagebrush control in the Sierra Nevada (Wyoming Interagency Vegetation Committee 2002).

2.4.3 Conifer Encroachment

Conifer encroachment into mountain meadows in the Pacific Northwest and California Sierra Nevada has been reported by many authors (Vale 1981, Rochefort et al. 1994, and Taylor 1995, Griffiths et al. 2005). Since meadows are more diverse than adjacent forests, replacement of meadow vegetation by conifer forest reduces local and landscape biodiversity (Haogo and Halpern 2007). In the central Sierra Nevada, encroachment occurs most commonly with lodgepole pine and to a lesser amount, red and white fir (Figure 8). Western hemlock encroachment in meadows also occurs within the zone of this species (Taylor 1995). Conifer encroachment into mountain meadows has been attributed to several (non-exclusive) causes, including climate effects (Helms 1987 and Woodward et al. 1995, Millar et al. 2004), cessation of grazing (Dunwiddie 1977, Vale 1981, Miller and Halpern 1998), and fire suppression (Arno and Gruell 1986, Hadley 1999). Millar et al. (2004), argue that conifer invasion in these meadows occurred during a single mid 20th century pulse that was triggered by climatic conditions. It is possible that all of these factors allow for increased conifer cover in existing meadows.

Figure 8. Meadow experiencing conifer (lodgepole pine) encroachment in Eldorado National Forest. August 2010 (photograph by A.G. Merrill).

Studies of Native American meadow management, charcoal, obsidian, and tree fire-scars in and adjacent to meadows in the central Sierra Nevada indicate that prior to Euro-American contact, meadows were burned every 6–10 years and during the 19th century, sheep ranchers burned more frequently (every 4 years or more) to control conifer encroachment and encourage growth of forage species (Rice 1983; Ferrell 1993; Gethen 1993, 1994; Anderson and Smith 1997; Anderson 2006; K. Deal, Eldorado National Forest Archeologist, pers. comm. with A.G. Merrill, Stillwater Sciences, 2007). As described in *Section 4.2.2.3. Prescribed burns, shrub and tree removal*, the Forest Service and others are experimenting with the application of prescribed burns to limit or reverse conifer invasion of mountain meadows. Thus both water availability and fire regime are likely to be the most important factors controlling conifer encroachment in mountain meadows. (V. Hendon, Pacific Ranger District Fuels Officer, El Dorado National Forest, and H. Safford, Regional USDA Forest Service ecologist, pers. comm. with A.G. Merrill, Stillwater Sciences, 24 September 2008).

3 PLANNING FOR MEADOWS RESTORATION

With the background information on meadow processes, stressors, and common pathways of degradation provided above, we can now shift our focus to how one builds an understanding of the conditions affecting a particular meadow and how one uses that understanding to develop an effective and well tailored restoration approach. In this section, we outline some of the steps required for developing a meadow restoration plan, including (1) articulating project goals, (2) identifying the target state, (3) characterizing the source(s) of stress and whether or not they are on-going, and (4) developing a management approach with specific project objectives and prioritized actions. We do not address regulatory compliance, which is an important and required step. However, much of the information and analysis required for NEPA and CEQA review is gathered and analyzed during development of a restoration plan, as described in the sections below.

3.1 Articulating Project Goals

People restore meadows for many different reasons. Some common goals for meadow restoration include improved wildlife habitat, increased groundwater storage, increased forage production, improved downstream water quality, and improved recreational and cultural value. Ultimately, goals for restoration reflect a combination of site potential and stakeholders' values. Clear articulation of restoration goals is critical and will help maintain the clarity needed to guide the restoration planning, implementation and adaptive management process. Identifying the goals for restoration will also help the management team gage progress toward achieving those goals. Project goals should be conceived of broadly, so that they give focused direction for the project but still accommodate an evolving understanding of the project meadow. Project objectives are more specifically tied to restoration plans. Table 4 includes examples of potential goals for a meadow restoration project.

Table 4. Hypothetical goals for meadow management and restoration.

Goals	Processes to support goals	Sources of degradation of processes	Objectives to restore processes
Increase forage	High graminoid productivity	Lowered groundwater table due to channel incision	Halt and reverse channel incision to restore higher groundwater table
Improve willow fly catcher habitat	Growth and maintenance of dense and extensive willow thickets along channel	Intense grazing pressure	Reduce grazing pressure through altered grazing regime and/or exclosures
Increase sediment storage	Reduced channel incision and increased overbank	Channel incision and reduced overbank flow	Halt and reverse incision, restore overbank flow to

	flooding		floodplain
Increase plant and wildlife biodiversity	Actively meandering channel, increased connectivity between overbank flooding and groundwater	Channel geometry and floodplain area constrained by roadway; lowered groundwater table	Remove constraints on channel and floodplain, restore higher groundwater table

3.2 Defining Target State(s) and Directions

Determining the target state and trajectory of the meadow is a management decision that should be made based on the natural resources potential of the system and the human values driving the need or desire for restoration. In many cases, management will require balancing a combination of these values. Determining the time-scale for achieving this level or type of functionality is also a management decision.

As discussed in *Section 2.2. Meadow Degradation and State Transition*, degraded meadow states are divided into three categories:

1. Capable of reversing to a non-degraded state on its own,
2. Capable of attaining a non-degraded state with active removal of the stressor; and
3. Requiring active change in physical and/or biological boundary conditions in order to transition to a non-degraded state.

In many cases, restoration goals are attainable with small changes in conditions and/or management that can shift the current plant community types to a different seral stage and/or distribution. Those cases where restoration goals lie within the current range of variability would fall into either category 1 or 2 above.

For those situations where restoration goals require a significant change in the meadow condition (category 3 above), a central focus must be on addressing biological and physical thresholds that maintain the meadow in its current state and the means by which those conditions can be moved beyond the current boundaries so that the meadow can enter a different (target) state. Thus, while meadow restoration can include a wide array of goals, one must determine whether or not those goals can be attained given the existing conditions (state), or if restoration needs to involve a change in the current physical and biological controls. Once the state or trajectory of change is attained, other desired characteristics of the meadow can be built onto this foundation either simultaneously or in sequence.

"Restoration" of a meadow to a pre-existing state may not be feasible or desirable in some circumstances, since the surrounding conditions (climate, wildlife use, and/or plant species composition) have been changed and are continuing to change. However, knowing the history of a site, the processes that affect it and its historical range of variability can be extremely important for understanding the range of potential physical conditions and biological characteristics of a site. This information forms the basis for developing a feasible and robust restoration plan. To this end, it is important to identify the potential state(s) that the meadow can attain and the realistic range of meadow characteristics and processes that might be associated with that state. For example, if a moist meadow has undergone a state transition to sagebrush scrub due to channel incision and lowered groundwater levels, it is important to assess the potential hydrologic conditions and controls for a restored version of that site. Identification and characterization of one or several reference sites can be of great help in this step. Characterization of a hypothesized target state for the project meadow is likely to be described as likelihoods and directional trends rather than a detailed set of features and process rates. In this example, the sagebrush scrub meadow might, with rewatering, support a moist graminoid dominated meadow as interpreted from historical photographs and descriptions. However, the density, exact species combination, and channel flow characteristics should not be set out as specific goals, since these are too difficult to anticipate.

In the following section, we discuss specific questions and information needs for determining which of the above three categories a meadow is in, in relation to the target state or trajectory.

3.3 Identifying Sources of Degradation and Needs for State Transition

With this theoretical understanding of physical processes controlling the meadow template and potential responses by the plant communities provided in *Section 2. Functional and Degraded Meadows*, you can research what has and is occurring in your project meadow as a basis for constructing a conceptual model of what is stressing the system and how it might respond to potential changes in management. This important step involves collecting, analyzing and synthesizing information on reference meadows and the project meadow, including sources of degradation and links between the project meadow and upstream and downstream environments. Information is gathered to address the following key questions:

1. What are the mechanisms initially responsible for meadow degradation?
2. Are these mechanisms currently active?
3. If these mechanisms are still active, how are they distributed in time and space and what are the primary effects?
4. If these mechanisms are no longer active, is the system recovering toward a quasi-equilibrium state with desirable functionality and what is the anticipated time scale for recovery?
5. Do positive feedback mechanisms limit the potential for recovery without intervention?
6. Can the meadow system recover to a desirable state with intervention, and if so, what measures are required and what is the likely time-scale for recovery?

The primary point in this step is to determine whether or not causes of degradation are still active and whether or not the system has moved beyond the point of being able to recover with little or no active restoration. In many cases, it may be difficult to definitively assign cause and effect. Climatic variation, historical grazing, and construction of railroads, roads, and trails can have similar effects (e.g., channel incision). Differentiating the relative importance of disturbances that initially occurred decades or even centuries ago is often illusive. What you really want to know at this point is whether or not you need to remove a current source of disturbance, and what level of action is required to establish a trajectory that achieves the target functional state within the needed time scale.

In the sections below, we outline the information needs and how to analyze this information in order to address the questions listed above. Gathering much of this information will overlap with NEPA/CEQA documentation needs.

3.3.1 Classify project meadow and identify Reference Sites

One of the first steps in developing an understanding of the project meadow is to place it in context of the range of meadow types, and to identify reference meadows that are of the same hydrogeomorphic type, but in better condition. An excellent classification of Sierra Nevada meadows, based on hydrogeomorphology, is Weixelman et al. 2011. This document includes a dichotomous key that can be used to classify your particular meadow, as well as general descriptions of the associated geology, hydrology, soils and vegetation associated with each type. Overall, Weixelman et al. 2011 identifies fourteen types of meadows.

Reference sites can provide critical guidance in developing a restoration plan and in interpreting pre and post monitoring data. Identify one or more reference meadows that are within the same hydrogeomorphic class and bioregion as your project site, but that are in a condition that more closely represents the restoration target condition. Identification, characterization and monitoring of one or several reference site(s), which represent(s) what is believed to be the target condition of the restoration site meadow is critical for establishing realistic restoration objectives and monitoring goals. Information from the reference site(s) can be used to characterize potential site conditions, to estimate acceptable levels of temporal and spatial variation in hydrogeology, plant community composition and structure, and to help interpret hydrologic and vegetation responses to change. Specific characteristics and processes to measure in the reference site(s) need to be developed according to project needs. At a minimum, groundwater levels and plant community composition in relation to plant water availability and soil texture should be assessed. Identification of appropriate reference site(s) must be done carefully and with a thorough understanding of both project and reference site(s) hydrology, geomorphology, and vegetation dynamics.

3.3.2 Land use and fire history

A first step in understanding the state of a meadow in relation to potential condition(s) is to learn about its historical condition and stressors. Much of the information on 20th century management history might be available through current or previous land owners, or through publically available data. In other cases, clues in and around the meadow can provide information about site history. Key information critical for interpreting causes of degradation and potential restoration approaches are outlined below.

Key aspects of land use history in the contributing area:

- Fire history (location, size, severity);
- Land use history (logging times and methods, mining operations, agricultural land use, development);
- Occurrence of railroads, roads, skid trails, landings, and trails (density, location, surface type, seasonal use intensity, drainage infrastructure); and
- Major sediment sources resulting from historical land uses.

Key aspects of land use history in the meadow:

- Fire history;
- Roads, trails, and associated drainage infrastructure (e.g., culverts);
- Recreational uses (e.g., camp sites, mountain biking trails);
- Grazing regimes or packstock grazing;
- Special status plants or wildlife (presence in recent or distant past); and
- Archeological resources (required for NEPA/CEQA compliance).

A topographic map as well as other GIS layers on roads, road-stream crossings, fire and logging history can be obtained from the public lands management agency or the Department of Fish and

Game. Local land owners and managers can also be interviewed to learn about past land uses such as fire, grazing, and logging. Valuable clues on land use history can be gathered during site visits to the meadow and parts of the contributing watershed. Such clues can include observations of cat scars, burned snags, stumps (estimate of age and size can tell you how long ago they were harvested or burned), as well as the presence and condition of trails and roads.

Clues on fire history (e.g., buried charcoal), historical grazing, and recreational uses will be hard to find within the meadow itself. Obvious indicators of grazing in the recent past include cow paddies, hoof prints, browse lines, and rangeland infrastructure (fencing, water troughs). More subtle clues may include plant communities dominated by species known to be resistant to grazing or selected against by livestock, such as Baltic rush and Nebraska sedge. Historical information on the presence of special status plants and wildlife can be obtained through queries to the NDDB, CNDDB, and USFWS databases as well as BIOS (CDFG) if possible. If the site is in or near publically managed lands, land managers may be queried regarding known current or historical occurrences of threatened, endangered and special status species within the area. If large scale changes in the meadow are part of potential plans, the presence and location of archeological resources will need to be identified by qualified professionals as part of CEQA/NEPA review.

3.3.3 Physical processes

Once the land use chronology in the watershed and within the meadow is developed, the next step is to evaluate the past and present influences of these land uses on hydrologic and geomorphic processes at the watershed and meadow scales. This step requires collecting basic information about the physical structure of the watershed, the meadow, and the channel network developed within it.

Key attributes of the watershed include the following:

- Contributing drainage area to the meadow;
- Topography and relief;
- Geology and geomorphic features related to water and sediment delivery;
- Climate (temperature and precipitation records); and
- Hydrology (stream flow records).

Key physical attributes of a meadow include the following:

- The character and extent of bedrock and other resistant geologic units forming the boundary conditions for groundwater flow at depth and along the valley margins;
- The properties of the alluvium filling the valley (e.g., depth, stratification, density, porosity, grain size distribution, hydraulic conductivity);
- Base level controls (bedrock and/or stratigraphic) within and at the downstream extent of the meadow;
- Slope of the meadow surface relative to valley bottom slopes upstream and downstream of the meadow;
- Points of surface and groundwater input and output; and
- Sensitivity to degradation due to incision or avulsion.

Key geomorphic attributes of the channel network include the following:

- Channel dimensions (slope, width and depth, cross sectional area);
- Bed material (immobile framework, thickness and grain size distribution of the mobile fraction, sediment storage features);
- Bank geometry and material properties (height, slope, stratification, grain size, density, porosity, hydraulic conductivity, stability);
- Bank vegetation;
- Historical record of channel shape and grain size; and
- Sensitivity to degradation due to incision or avulsion.

This information is used to develop an understanding of the causes and future potential for meadow degradation, to describe the processes by which the meadow site is degrading, and to assess the likelihood of success of different treatment options (Chambers and Miller 2011). Much of this information is readily available or can be interpreted from existing topography, geology, and soils maps. The properties of valley alluvium can often be inferred from channel bank exposures or from sediment cores taken from the meadow surface. Points of surface and groundwater input and output can be observed or interpreted from maps, but an understanding of the importance of different inputs and controls on outputs commonly requires field data collection to confirm map interpretations. In many cases, little information is available to describe surface and groundwater hydrology at the site of interest. If records are not available for a site, stream flow can be estimated by pro-rating flow from other nearby sites with similar elevation, climate, and physiography.

3.3.4 Vegetation response

With an understanding of the land use history and physical processes affecting the meadow, the next step is to assess the meadow vegetation. Plant species composition, plant community types and distribution, and plant characteristics hold a wealth of information on recent past and current site conditions. Some of the common vegetation indicators of meadow history and current status are summarized below.

- Distribution and extent of wet, mesic, and dry site plant community types provide information on current and/or recent seasonal patterns in the depth to groundwater.
- Presence of willow thickets adjacent to the channel or in low areas of the meadow floodplain often indicate frequent flooding of these areas since willow seed germination and/or vegetative recruitment is promoted by frequent flooding.
- Vegetation cover, type and rooting density along channel banks indicate bank stability and disturbance intensity.
- Distribution and cover of plants belonging to different functional groups (see Table 5 below and Appendix A) can reflect recent histories of disturbance such as compaction and grazing intensity.

Plant species traits, commonly available from resources such as the USDA plants database and the Jepson manual, have been used by Region 5 range ecologists to classify species into seral status indicator groups (Weixelman 2011). The presence and abundance of different seral status groups can be used to indicate the condition of a meadow within the potential range of the existing “state.” Species expected in a more highly disturbed area, for example, would show ruderal or weed-like traits, such as rapid above ground growth, high reproduction rates, and short life spans (annuals); in contrast, plant species expected in an undisturbed area would have characteristics that make it a good competitor or stress tolerator. Such late seral status species would be longer lived (perennials), put more energy and growth into underground structures at least in the first year or more, and have slower reproduction rates with greater investment in each seed. A sample of the full Region 5 Forest Service list of meadow species and their wetland indicator status and indicator class for meadow seral status in wet, mesic and dry meadows is provided in Table 5 below. The complete list can be found in Appendix A. Each plant species is also placed into one of ten possible plant functional groups based on species natural history traits: graminoid-upland, graminoid deeply rooting, graminoid shallowly rooting, taproot adapted to wet conditions, taproot adapted to dry conditions, annual, woody plant adapted to dry conditions, woody plant adapted to wet conditions, rhizomatous forb adapted to dry conditions, rhizomatous forb adapted to wet conditions.

Using these resources and field observations to address the four bulleted points listed above, you can develop a better understanding of groundwater levels, flooding, bank stability, and soil disturbances and vegetation responses in the project meadow.

Table 5. Example of plant species wetland indicator status and with seral ratings (early [E], mid [M], and late [L]) for each species and for each meadow type (wet, moist, or dry) for the Sierra Nevada. (Region 5; Dave Weixelman). See Appendix A for full list.

Scientific name	Wetland	Wet	Moist	Dry	Function	N Fixer	Grass	Grasslike	Forb	Woody	Life history	Root	HT	Laterals
Bromus suksdorfii	FAC	E	M	L	Gramupl	0	1	0	0	0	2	8	5	2
Bromus tectorum	UPL	E	E	E	Gramupl	0	1	0	0	0	1	1	4	1
Carex abrupta	FACW	L	L	L	Grampdeep	0	0	1	0	0	2	16	4	3
Carex aquatilis	OBL	L	L	L	Grampdeep	0	0	1	0	0	2	25	5	3
Carex athrostachya	FACW	L	L	L	Grampdeep	0	0	1	0	0	2	17	4	3
Carex aurea	OBL	L	L	L	Grampdeep	0	0	1	0	0	2	16	3	4

3.4 Developing a Science-Based Approach

Once you have articulated you project goals, defined your target meadow state, identified the source(s) of degradation and level of on-going degradation effects, you can begin to develop an approach for restoring the meadow. A restoration approach involves the following critical steps:

1. Define a set of management objectives based on:
    a. geomorphic, hydrologic, and biological processes responsible for degradation;
    b. linkages between the channel and groundwater flow system;
    c. future potential for meadow degradation; and
    d. reference site information on site conditions and processes.
2. Define the level of manipulation required to meet the above management objectives.
3. Identify types of actions that might be possible for the site.
4. Perform a feasibility, impacts, and costs analysis to select site-appropriate methods that will meet the management objectives.

5. Develop a more specific restoration design with management objectives tailored to each action.
6. Articulate process-based success criteria to support monitoring and adaptive management.

Step 1, defining management objectives, can be completed based upon overall goals for target states and trajectories as discussed in *Section 3.2. Defining Target States and Directions*, combined with information gathered on sources of degradation and potential meadow states as described in *Section 3.3. Identifying Sources of Degradation*. At this point, you can articulate management objectives for addressing on-going sources of degradation (e.g. reduce or eliminate focused flows towards channel in areas due to roads and trails) and define specific objectives for the target meadow state and/or trajectory (e.g. increased frequency of overbank flows and elevating groundwater levels during the growing season in floodplain areas adjacent to the channel). You can also identify areas where potential degradation might occur in the future and state management objectives that will ameliorate the potential degradation (e.g. minimize or disallow pack animal use within the meadow during the growing season). One or several reference sites should be used to guide these objectives.

In Step 2, you must use the information and understanding of the processes affecting the meadow to develop a conceptual model of how the site is currently functioning, how it has responded to potential stressors in the past, and whether or not it is currently constrained from shifting to the target state or along the target trajectory. You will need to determine whether or not there are positive feedback effects currently exacerbating any existing stressors or processes of degradation. Based on these interpretations and conceptual model of factors affecting the meadow processes, evaluate the level of manipulation required to meet the objectives articulated in Step 1.

In Step 3, you will need to identify different options for how you might reach the objectives described in Step 1. A list of potential types of actions is presented in *Section 4. Restoration and Management Actions* of this document.

In Steps 4 and 5, the feasibility analysis and full restoration design can be executed with widely varying degrees of specificity and sophistication. Conditions, process rates and controls in the reference sites can importantly inform these designs. Construction level designs can be developed as part of step 5 based on findings from modeling system responses under different conditions (e.g., modeling groundwater, hydraulics, sediment transport, and aquatic habitat). Engineering level designs specify the precise characteristics about materials to be used for the restoration, such as the volume, texture, porosity, shear strength and compressibility of fill material, slope, geometry, and planform characteristic of the channel, floodplain dimensions, and dimensions of instream structures. Revegetation designs can also be highly specified. With systems as complex and dynamic as mountain meadows, it is impossible to be sure that all potential scenarios have been played out and integrated into a design, but intensive modeling and engineering analysis helps ensure that many of the potential system responses have been considered and integrated into the plan. However, rigorously researched and prescribed restoration designs are not always necessary or feasible. A solid understanding of the landscape and principles discussed in *Section 2. Functional and Degraded Meadows* should be the guides to determining the most important design aspects to consider and intensity of analysis required.

In step 6, success criteria for processes supporting the physical template should be defined in terms of process characteristics such as rate, frequency and intensity. For example, one might set increased extent and frequency of overbank flooding as a success criteria (target flood frequencies and lateral extents can be established as hypotheses). By defining success criteria as a process rather than structural characteristic (such as depth of channel or slope of adjacent floodplain), restoration and adaptive management actions will be focused on processes that create and maintain the physical template, resulting in more enduring outcomes than efforts that only change the site characteristics themselves.

Success criteria for vegetation can be defined as directional changes towards broadly defined vegetation types (e.g. decreased extent of dry meadow community types and increased extent of native wet meadow community types). Again specific thresholds for changes in extent over a given time period can be used as hypotheses to assess whether or not the conceptual model developed for the meadow is correct.

3.5 The Approach Applied to Three Common Examples

In the next three subsections, we discuss how the approach described above can be applied to meadows experiencing the three most common forms of meadow degradation: 1. channel incision; 2. sagebrush conversion; and 3. conifer encroachment. .

3.5.1 Channel incision

3.5.1.1 Identifying sources of degradation, restoration objectives and required level of manipulation

Channel incision can occur due to one or a combination of many stressors, as discussed in *Section 2.3. Sources of Degradation*. The first step in addressing channel incision is to determine whether or not there are active processes that are causing or exacerbating incision. It is not important to determine which of several potential inactive sources of degradation had the greatest impact. Once you have identified on-going sources, or determined that there are none, the extent of current incision and active erosion can be used as a metric for determining the level of manipulation required to feasibly restore the reach. For the Great Basin, Chambers and Miller (2011) classify incised channels in order to discuss ranges of management options. These classifications are tailored to the Great Basin and might not reflect the appropriate threshold sizes for all or parts of the Sierra Nevada, but we present them as a useful starting point:

1. *Low to moderate depths of incision* (0- 2x bankfull channel depths) which might be capable of returning to the non-degraded state by removing the source of stress or by minor actions such as stabilizing knickpoints, installing in-stream and bank stabilization structures.
2. *Highly incised channels* (>2x bankfull channel depths) which are still actively incising or eroding can be treated through stream stabilization methods including appropriate techniques to halt on-going incision and channel bank retreat.
3. *Fully incised channels* (>2x bankfull channel depths which have reached quasi-equilibrium in the incised state) might be treated through channel reshaping and alignment. Alternatively, vegetation treatments can be used to optimize plant community composition and structure within the degraded state. In-set floodplains can be encouraged to support riparian communities, creating a less extensive but rich native wet or moist meadow area.

3.5.1.2 Potential types of actions

Actions that address the first set of conditions (low to moderate depths of incision) might include reducing concentrated runoff from roads and trails, reversing accelerated runoff through revegetation in areas affected by compaction due to grazing, wildfire disturbance, roading, and other forms of construction, and redirecting or dispersing concentrated flow toward more stable environments. These actions might involve upslope projects that cover large areas and are implemented over long time periods, or may involve site-specific revegetation projects that address runoff and erosion within the meadow. A set of actions that might address the second set of conditions (highly incised channels) include stabilization of eroding channel bed and banks through revegetation and/or other geotechnical means, increasing roughness to the channel to reduce flow velocities, increasing sediment storage, promoting more connectivity with the floodplain, and raising channel bed elevations through local base level controls. In cases where channel incision is severe (fully incised channels), channel realignment to other locations within the meadow may be necessary. Descriptions of these actions and recommended resources for more in-depth information are provided in *Section 4. Restoration and Management Actions*.

3.5.2 Sagebrush conversion

3.5.2.1 Identifying sources of degradation

A first step in assessing a meadow subject to sagebrush conversion is to identify the extent of invasion in the meadow. Is the sagebrush only encroaching in the high and xeric soil areas of the meadow? Or is sagebrush also moving into the moister areas? Is there a natural seed source of sagebrush adjacent to the meadow?

Once you have an idea of the extent and distribution of the sagebrush, look for the source stressors that have facilitated its germination and survival in each invaded area of the meadow. As mentioned in *Section 2.4. Three Common Pathways of Meadow Degradation*, one potential stressor includes groundwater lowering through channel incision which can create dry soil conditions that favor sagebrush survival over more mesic graminoid plants. Other much more illusive mechanisms of progressive meadow drying can include climate-change related reductions in snowmelt and groundwater inputs. To this end, be aware of the recent water year types—are you in the middle of a 3- to 5-year drought? Or have recent years seen extensive precipitation—particularly snowfall? Information on water year type and April 1 snow water equivalents can be obtained from the USGS and Department of Water Resources. Other factors that can favor sagebrush invasion include frequent or extensive soil disturbance, for example from cattle and/or pocket gophers, that allows for sagebrush seed germination on bare mineral soils. Intensive grazing can create patches of bare mineral soil for seed germination and reduce competition from graminoids to support seedling survival and establishment. Clues on grazing intensity can usually be seen on-site, including frequency and age of cow paddies, stubble height, browse lines on riparian shrubs, and the frequency and density of hoof marks in the meadow soil. Information on grazing intensity over the past 5 to 10 years can also be obtained from the land owner and/or range manager.

3.5.2.2 Management objectives

Management objectives for a meadow subject to sagebrush conversion might include reduced sagebrush cover in invaded areas, reduced germination and survival of sagebrush seedlings within meadow boundaries, and recovery of a dense cover of native meadow vegetation that precludes sagebrush germination in the currently encroached areas. Characteristics of the restored meadow plant community need to be tailored to the particular meadow based on existing species composition in unimpaired areas or nearby reference sites and based on the expected range of physical conditions in the restored area. More specific objectives need to be developed, based on findings about the stressor affecting sagebrush conversion in the meadow, on reducing or eliminating that stressor so that physical site conditions are no longer conducive to sagebrush germination and survival. These might also include developing and maintaining a sufficiently dense herbaceous ground cover that precludes sagebrush germination and/or altering the range management regime so that grazers no longer create conditions conducive for sagebrush.

3.5.2.3 Level of manipulation required

Once you have developed an understanding (and/or hypotheses) about the stressors that facilitated sagebrush invasion, you will need to determine whether or not these stressors are on-going and at a sufficiently high level to support additional sagebrush conversion. If this is the case, then addressing these sources of stress will be a necessary part of meadow restoration.

3.5.2.4 Potential types of actions

Removal of existing sagebrush cover, through physical harvest or prescribed burns, will enable more rapid and intensive regeneration of a graminoid ground cover. If seed sources for native grasses are few or unavailable, consider planting an appropriate and locally native graminoid/forb mix to further support growth of a continuous ground cover. Grazing should be suspended until a graminoid/forb system is well established. For most native bunch grasses, this can take from 2 to 4 years. If a local and naturally occurring sagebrush seed source exists, prescribed burns might be required on a regular basis in some of the drier meadow areas, particularly those with higher cover of bare soil.

3.5.3 Conifer encroachment

3.5.3.1 Identifying sources of degradation

A first step in treating conifer encroachment in a meadow is to identify the extent and distribution of invasion in the meadow. Are the conifers only encroaching in the high and xeric soil areas, or only along one side of the meadow? What is the age of the encroaching conifers and how are the different cohorts distributed within and along side of the meadow? Coring a few trees of different sizes will help ensure the ages are not underestimated due to slower growth rates in the cold, wet meadow soil. If only older trees with no seedlings or saplings can be located within the meadow, then it can be inferred that the stressor that is enabling encroachment is no longer active. If you have a spatial stratification of tree age, with younger trees along the inner extents of conifer encroachment, then it is likely that encroachment is on-going. If a mix of tree ages can be found in the encroached area, then it is likely that encroachment is not continuing to extend into the meadow, but is intensifying in place. The age of the trees can also tell you how long the encroachment process has been underway. Understanding the timescale is important for interpreting likely sources of change that have facilitated encroachment.

If encroachment is actively increasing, look for the source of stress that is enabling encroachment based on your estimate of the time scale during which encroachment has been underway. As mentioned in *Section 2.4. Three Common Pathways of Meadow Degradation*, potential stressors include groundwater lowering through channel incision which can create drier soil conditions that favor conifer germination and survival. Other much more illusive mechanisms include climate-change related reductions in snowmelt and groundwater inputs. As mentioned above, information on annual water and snow inputs can be obtained from the USGS and the California Department of Water Resources.

3.5.3.2 Management objectives

Management objectives for a meadow subject to conifer encroachment might include reduction or elimination of conifer in invaded areas of the meadow, reductions in germination and survival of conifer seedlings within the meadow boundaries, and recovery of native meadow vegetation in the currently encroached area. Characteristics of the restored meadow plant community need to be tailored to the particular meadow based on existing species composition in unimpaired areas or reference sites and based on the expected range of physical conditions in the restored area. More specific objectives need to be developed, based on findings about the stressor affecting conifer encroachment in the meadow, and on reducing or eliminating that stressor so that physical site conditions are no longer conducive to conifer germination and survival. These might also include developing and maintaining a sufficiently dense herbaceous ground cover that precludes conifer germination.

3.5.3.3 Level of manipulation required

Once you have an understanding (and/or hypotheses) about the stressors facilitating conifer encroachment, you will need to estimate whether or not these stressors are increasing. If they are increasing, then restoration actions should address this stressor, if possible. For example, if conifer encroachment is on-going due groundwater lowering related to channel incision, then the first action must be to address the channel incision (*Section 3.5.1.Channel Incision*). It might not be possible to halt climate change related stressors; in these cases on-going management of conifer encroachment might be required.

3.5.3.4 Potential types of actions

In many cases, conifer encroachment can result in local changes to the soil conditions, which then fosters development of forest understory plant community. Trees can be mechanically removed from the meadow, leaving the formerly encroached area to return naturally—or by active planting—to meadow vegetation cover. In cases where forest litter has changed the surface soils and/or where many tree saplings and seedlings exist, prescribed burns might be effective for removing or reducing young trees and the surface litter layer.

4 RESTORATION AND MANAGEMENT ACTIONS

Now that you have done the research and carefully considered what you found and what you need to get done, it is time to choose the tools for implementation. As part of the approach development and conceptual planning phase, you weighted the pros and cons of a range of different options. The selected set of actions or management directions can be multifaceted, involving work at the meadow and watershed scale, and involving small changes in current management practices or large earth-moving projects such as channel realignment.

In the sections below, we describe some of the more common actions that can be taken to restore meadow processes at both the watershed and individual meadow scales. For each action or set of actions, we also suggest where the reader can find more in-depth information. A list of existing restoration projects in the Sierra Nevada (as of Fall 2010), the methods applied, and types of monitoring data collected is provided in Appendix B.

4.1 Actions at the Watershed Scale

Potential actions at the watershed scale include fuels and fire management; improvements on forest and ranch roads to control accelerated runoff, erosion, and sediment delivery. Control of invasive non-native species should also be considered at the watershed scale, since roads and streams are common conduits. Recommended actions to address invasive plant species can be found in *Section 4.2.2.2. Controlling Invasive Weed Species*.

4.1.1 Fuels and fire

Reducing high fuel loads, creating fire breaks, reducing fuel loads through manual removal and prescribed burns, as well as other fire and fuel management activities in the contributing watershed will help minimize the likelihood of catastrophic wildfire, which as discussed above, can result in high peak flows and sediment input to the meadow. Revegetation and erosion control can help minimize sediment inputs and erosion following wildfire.

For more information on fuels and fire, go to:

- Sugihara et al. 2006 (background information on fire in California).
- Forest Service Fire and Environmental Research Applications Team website (more in-depth information on management methods): http://www.fs.fed.us/pnw/fera/research/treatment/index.shtml

4.1.2 Roads and trails

Many different actions can be taken at the site and watershed scales to reduce accelerated runoff and sediment delivery from roads and trails. Problems associated with existing roads may be remedied by relocating roads and trails to a more stable alignment, reshaping the road prism (e.g., out sloping) to disperse surface runoff and improve road drainage, removing fill material at stream crossings, and improving the road surfacing. Drainage improvements may include installing cross drains and rolling dips, and removing improperly functioning or high risk culverts and replacing them with properly designed culverts or bridges. Many of these principles also apply to other types of construction related disturbances (e.g., trails and ski areas).

For more information on roads and trails, go to:

- Weaver and Hagens (1994) (the basic principles for planning, locating, designing, retrofitting, closing, and abandoning forest and ranch roads).

4.2 Actions at the Meadow Scale

Actions at the scale of an individual meadow include channel restoration (such as bank stabilization, installation of wood and rock structures, riffle augmentation, channel shaping, and channel realignment), vegetation management, range and wildlife habitat management. These actions are discussed in more detail in the following sections.

4.2.1 Channel restoration

Restoration and management actions that directly modify the meadow channel range from installation of bank stabilization and grade controls structures, to reconfiguration of existing channel geometry, to complete re-creation of the channel in a new alignment (e.g., Pond and Plug and other similar approaches).

Grade control structures (e.g., debris jams, boulder check dams, sod mats, and riffle augmentation) may be designed to limit further incision and/or raise the level of the channel bed to facilitate increased groundwater recharge and storage in the meadow. A combination of measures is typically required to rehabilitate severely incised channels. An example of a project where a combination of measures were used to rehabilitate an incised channel, including boulder vanes and "W" weirs, bank and floodplain shaping, channel re-alignment, and revegetation can be found at Guidici Ranch along Little Last Chance Creek in the Upper Feather River watershed (Plumas Corporation 2010).

For more information on channel restoration, go to:

- Brookes and Shields 1996 (excellent resource on the concepts behind channel restoration)
- Other sources on field methods in channel restoration include:
  - Zeedyk and Clothier 2009;
  - Wilcox et al. 2001; and
  - Rosgen 1997.

4.2.1.1 Instream structures

Log revetments, boulder vanes, and vortex rock weirs are often used in combination with woody vegetation plantings to stabilize the outer banks at bends, increase channel roughness, dissipate high flow velocities, and create hydraulic complexity, leading to local scour and deposition. Bank stabilization measures usually do not increase the risk of flooding, are typically site specific, and are focused in a smaller portion of the channel and floodplain area than other measures. Bank stabilization measures do not increase connectivity between the channel and floodplain, do not help elevate the groundwater table in the adjacent meadow, and can create flow patterns that lead to erosion in upstream and downstream channel reaches.

Log revetments are placed parallel or nearly parallel to the channel bank with a large portion of the log(s) anchored in the channel bank and/or bed. Since large wood eventually decays and breaks apart, log revetments are usually used as a temporary measure until riparian vegetation (e.g. rhizomatous sedges, alder or willow) can establish within the stable bank.

Vanes are comprised of a linear cluster of resistant materials (e.g., boulders or logs) oriented obliquely upstream from the bank into the channel. The crest of the structure typically slopes from a high point at the bank down to the channel bed, with the goal of slowing flow velocity near the bank to prevent erosion and promote sediment deposition while forcing higher velocity flow to the channel center.

Vortex rock weirs are V-shaped structures that span the channel, with the V pointing upstream and each end anchored in the banks. Like vanes, the highest elevations of the structure are at the banks, and the lowest elevations are near the middle of the channel. Vortex weirs focus flow to the center of the channel and away from the banks, scouring the bed immediately downstream. While vortex rock weirs are effective at dissipating stream energy, they are subject to jamming from debris and are less effective at transporting coarse bedload. In the Feather River, vortex weirs were used in Wolf Creek in 1991 and in Greenhorn Creek in 2001 (Wilcox et al. 2001), where weirs were installed at the crest (upstream) and tail (downstream) of each riffle in order to control the bed elevation. This approach, however, interfered with the natural tendency for channel adjustment of the location and length of riffles. In many cases the weirs were either destroyed or abandoned by shifts in channel planform. Vortex weirs appear to be more effective when placed only at the tail of riffles (Wilcox et al. 2001).

Woody debris structures and rock dams are measures commonly used to encourage coarse sediment deposition, raise channel bed elevations, and facilitate higher flood state heights capable of reintroducing overbank flow to the floodplain. Restoration projects in 1997 at Boulder Creek and Rowlands Creek within the Feather River Watershed (Wilcox et al. 2001) are examples of where a combination of woody debris structures and rock dams were installed to aggrade the channel by sediment deposition. Debris jams typically consist of multiple logs (usually with root wads) placed within and across the channel at various angles to increase roughness, trap sediment, and direct flow onto the floodplain. Debris jams may also be used in the vicinity of side channel junctions to facilitate connectivity by scouring the bed during high flows. Woody debris structures are typically more permeable than boulder dams, thereby minimizing lateral erosion of adjacent banks. This method is most effective where there is an abundant supply of mobile sediment during bankfull discharge and where the channel banks are relatively resistant to erosion. Debris jams are typically placed in straight reaches or riffles. Sod mats placed at the riffle crest serve a similar purpose in smaller, mildly- entrenched channels. It should be recognized that in large meadows, woody debris dams are clearly artificial devices in that it would be rare for such a structure to form naturally in the absence of adjacent forest.

4.2.1.2 Headcut and gully stabilization

Gullies and associated headcuts are one of the most common forms of meadow degradation and are often the most difficult to effectively treat. Gullies and associated headcuts may develop through surface erosion and/or groundwater sapping processes, particularly where stratified valley fill deposits lead to concentrated flow at the contacts between strata with contrasting permeability and hydraulic conductivity. Development of an effective treatment strategy requires an understanding of the stratigraphic and geomorphic setting, gully morphology, surface and groundwater hydrology, and erosion processes that are active at the site. Chambers and Miller (2011) summarize four general strategies for treating gullies:

- Use in-stream check dams and weirs to retain sediment and stabilize the channel at the local base level;
- Regrade and vegetate gully banks and headcuts to increase channel cross-sectional areas, reduce shear stress, and inhibit bank failure by mass wasting;
- Line headcuts with rock or other resistant material; and
- Spread and/or divert surface flow to reduce the amount of water entering gully.

Effective treatment may require a combination of design components from the four strategies.

4.2.1.3 Riffle augmentation

Riffle augmentation is an approach that directly raises bed elevations by adding coarse sediment to riffles. In locations where suitable rock must be imported to a site, unit costs of this method are typically high. Riffle augmentation was effective at elevating groundwater levels and reducing erosion in the Upper Feather River watershed along Little Last Chance Creek in 2007 where floodplain development, drainage infrastructure, and downstream water rights issues limited other rehabilitation options (Wilcox et al. 2001; http://www.feather-river-crm.org/).

4.2.1.4 Channel shaping and realignment

Rather than treating an incised channel by installing structures that control headcuts and gullying, that stabilize the bed and banks or trap sediment, channel shaping and realignment methods address degradation problems by reconfiguring the existing channel geometry (longitudinal and in cross-section) or by diverting flow into a new channel with stable hydraulic geometry and planform.

An existing incised channel can be reshaped to increase cross-sectional area, modify channel morphology, control avulsion potential, or change base level. Channel realignment is a large-scale approach that involves directing flow away from an incised channel and into a newly constructed stable channel. The approach is potentially applicable where broad meadows contain inactive channels that formerly conveyed all or part of the streamflow prior to incision of another main channel. These former channels may be suitable for redirecting streamflow away from the incised channel. In some cases, realignment requires excavating an entirely new channel.

In the “Pond and Plug” approach (Wilcox et al. 2001), all streamflow is redirected through a new or existing abandoned channel and the former incised channel is stabilized with alternating “ponds” and “plugs.” The “plugs” are constructed with fill excavated during construction of a new channel and/or by excavating pond segments within the now abandoned incised channel. The surface of the plugs are typically dressed with salvaged topsoil and vegetated. Mounded topography may be used to direct overland flow away from the abandoned channel, and a control structure may be required to prevent erosion at the downstream point where the new stream channel meets the former degraded channel. There are several examples of channel realignment and pond and plug approaches in the Feather River watershed (e.g., Red Clover/McReynolds meadow in 2006, Clarks Creek in 2001, Bagley Creek in1996, Big Flat on Cottonwood Creek 1995, Boulder Creek in 2008; see http://www.feather-river-crm.org/). Some of these projects have required follow-up modifications to stabilize the new channel (Wilcox et al. 2001).

Many factors must be considered in constructing a stable channel or in excavating ponds within a meadow. Channel realignment approaches that require excavating alluvial valley fill have the potential to dramatically alter hydrology by breaching confining statigraphic units that control surface and subsurface flow patterns critical to the meadow ecosystem. These approaches require expertise of professionals with appropriate experience in hydrology, hydraulic engineering, fluvial geomorphology, erosion and sediment control, and aquatic ecology.

4.2.2 Vegetation management

Ensuring that meadow plant communities recover in response to a changing physical template is a key step in meadow restoration. In some cases, very little action will be necessary because native meadow species will volunteer into the newly created or reformed surfaces. In other cases, active planting, weed management or tree and shrub removal are necessary in order to ensure that the meadow plant community composition develops along the targeted trajectory. Active revegetation along reconstructed banks or other structures can also be important for bank stabilization and reduced erosion. Ongoing monitoring and adaptive management of vegetation is a critical part of any restoration plan.

4.2.2.1 Passive and active revegetation

Passive revegetation, in which a restored area with exposed soils is left unplanted so that it seeds in from surrounding sources, can be an excellent option if the composition of the surrounding vegetation is appropriate for the restored areas and time to revegetate is not critical. In many cases, passive revegetation can occur through vegetative expansion of adjacent plants, sending in tillers, rhizomes or stolons to occupy the newly opened soil. Local sources of seeds can also rain onto the open mineral soil to emerge the next growing season. The composition of soil seed banks, a product of recent to long-past plant species composition, can also affect a recovering plant community composition, although the importance of the seedbank in determining the composition of the recovering plant community is variable (Lang and Halpern 2007). Long-term viability of native species seeds, soil conditions, and the composition of other species raining seeds and propagules from the surrounding area affect the relative importance of seed bank contributions to a recovering plant community not subjected to active revegetation.

Active planting might be needed if there are large sources of invasive weeds in the area, if few nearby sources of appropriate plant species exist, or where high plant density is needed within the first year. High plant density can be an important strategy for precluding establishment of invasive non-native or native (e.g. sagebrush) species and high plant density along channel banks can be an important erosion control strategy. Active revegetation involves planting seeds or plants in the restoration area. Sourcing propagules, such as willow cuttings, blocks of sedge-laden sod, and harvested seeds from adjacent vegetation or reference sites and planting these in the restored area is an inexpensive and relatively easy method for revegetating a site with local native plants. Alternatively, native plants can be purchased from local native nurseries; for large orders, you will need to submit your orders during the preceding fall to allow time for seed collection.

Plant seed mixes can be purchased and applied (there are multiple methods for applying seeds); or whole plants can be purchased and planted at the site. The species, number of individual plants, and plant container sizes all need to be provided to a native nursery supplier. Planting density (distances between installed plants, or number of plants per acre) should also be determined based on plant size, site capacity and restoration needs. A common mistake is to "over plant"—thereby creating excessively crowded beds that eventually require thinning. Moreover, once established many plant species will seed in and/or spread by vegetative propagation. Many rhizomatous species and perennial bunch grasses require two to three years to become well established. During this period, weeds need to be controlled and grazing precluded or tightly controlled in the restored area. In some cases, properly timed mowing (usually spring) or light grazing can be an effective way of favoring native perennial grasses over non-native annuals. However, high spring soil moisture will make this difficult in many mountain meadows. Many of these details can be incorporated into a planting plan, in which target species mixes and locations are presented along with planting, irrigation, and weed management instructions, as well as a planting palette which details planting methods, spacing, densities (pounds of seed per acre or plants per acre), and recommended container sizes per species.

For more information on revegetation, go to:

- Dortner, J. 2002;
- Vallentine 1989;
- TAdN (Team Arundo del Norte). 1999;
- California Native Grassland Association (workshops, excellent archives of relevant articles and documents on grassland restoration and management, and other reources) http://www.cnga.org/
- California Native Plant Society program for Growing Natives (library of resources, planting recommendations, etc.). http://www.cnps.org/cnps/grownative/
- University of Californa Cooperative Extension Sonoma County Office. Riparian Revegetation Evalution. Available at: http://cesonoma.ucdavis.edu/Watershed_Management923/Program_Research_-_Extension_Efforts/Riparian_Revegetation_Evaluation/

4.2.2.2 Controlling invasive weed species

A first step in addressing invasive plants in a meadow restoration project is to identify what weeds are present through a site inventory. This should be done with local lists of potential and known invasive plants. The Cal IPC 2011 report on invasive plants in the Sierra should be the first resource to check. This document (available on-line) provides a list of priority weeds for the entire mountain range as well as more localized lists for 14 subregions. Other weed lists should also be obtained from a local natural lands management office (such as the local USDA Forest Service Ranger District). If you are in the Cascade, Klamath or Warner mountains (not covered in Cal IPC 2011 report), check the Invasive Plants Council website list for the appropriate region (http://www.cal-ipc.org/ip/inventory/weedlist.php). Within these lists, species habitats are usually described. Identify those species that can occur in the habitats available in and around the meadow (e.g., conifer forests, grasslands, riparian forest). Each species is given an overall invasiveness rating. Depending on the size of the project area and scope of the project, you may want to limit the target list to those species with an inventory category of high or moderate.

Map the location and extent of each population of listed weed species found within or nearby the meadow and report these occurrences at the Cal Weed Mapper website, hosted by Cal Flora (http://calweedmapper.calflora.org/). Include as precise location and species name information as possible; also report your name, the date and whether or not the plants are flowering or in seed. Once you have identified, mapped and reported the weeds at your site, determine whether or not all can or need to be managed and what the management options are for each species. There is a wealth of species-specific control and eradication information at the Cal IPC website and at many other on-line locations. Some of these are listed below. In developing the weed management plan, be sure to consider the effects of other restoration activities on habitat conditions for each weed.

General categories of treatment methods for managing invasive weeds include the following:

- Manual and mechanical—hand pulling with various tools, mowing, cutting, and burning. These treatments are often the most labor intensive and commonly the most successful for smaller infestations.
- Biological—approved use of biological control agents such as insects and fungi that damage or kill the host plant, or the grazing by sheep, cows, horses, or goats. Biological control agents, if proven successful, can be applied to a large infested area. Grazing can also be applied to both small and large infestations. Disadvantages of grazing may be the effect (i.e., trampling or eating) on native species, including special interest species at a particular site.
- Chemical—treatment with a variety of chemicals approved for use in designated habitats. Chemical treatment is often the quickest and lowest cost response to an infestation. However, there are potential detrimental effects on habitat quality when herbicides are used. For instance, herbicides applied adjacent to stream corridors can affect water quality and habitat for fish and macroinvertebrates. Herbicide use on Forest Service lands is currently restricted by Forest Service policy. Future changes to Forest Service herbicide use policy may allow the use of certain herbicides in certain areas.
- Integrative—treatment that combines categories of treatment; for example, mowing or cutting followed by herbicide application. Integrative treatments are often the most creative and can be the most effective, though results may vary from site to site, depending on site characteristics.

As in all management and restoration plans, monitoring and adaptive management should be applied to ensure that the weed(s) remain under control.

For more information on invasive weed species, go to:

- California Invasive Plant Council (Cal IPC) 2011;

- California Invasive Plant Council website: http://www.cal-ipc.org/
- CDFA: http://www.cdfa.ca.gov/plant/ipc/weeds/weeds_hp.htm
- Bay Area Early Detection Network: http://baedn.org/
- Managing Invasive Plants: Concepts, Principles, and Practices by the USFWS National Wildlife Refuge System. 2009. Available at: http://www.fws.gov/invasives/staffTrainingModule/index.html

4.2.2.3 Prescribed burns, shrub and tree removal.

Conifer and sagebrush shrub encroachment in meadows has been traditionally controlled with fire by Native Americans (Vale 1981, Teensma 1987) and then by the early European settlers and ranchers (DeBenedetti and Parson 1979, 1984; Parsons 1981). After seventy or more years of fire suppression, land management agencies are experimenting with reintroducing the practice of burning to control conifer and shrub encroachment in meadows of the Sierra Nevada. Results from several wildfires in which wet and moist meadows burned during the 1960s and 1970s highlighted several basic points about fire in meadows (Ratliff 1985; DeBenedetti and Parson 1979, 1984; Parsons 1981):

1. There is little fire effect on vegetation when the fire occurs while meadow soils are wet;
2. Meadow fire intensity is also affected by the fuel load such that fires in meadows that have been heavily grazed were not as intense as those with high remaining above ground biomass;
3. High intensity wildfires can have long-lasting damage on meadow soils and vegetation, particularly in meadows with peat soils which can burn for extended periods and represents loss of an irreplaceable resource on the human time-scale;
4. The balance between burning at sufficient intensity to kill encroaching conifers and shrubs while not damaging native meadow plants and soils can be difficult, at times impossible, to achieve.

Recently, a combination of tree removal and scattering (by hand or with machines on snow) and prescribed burning was performed on meadows in Oregon (Swanson et al. 2007) and in the Sierra Nevada (Van Vleck Meadows in Eldorado National Forest). Reports on these projects, as well as a time-series tree encroachment study in the Cascades (Haugo and Halpern 2007) provide insights on how prescribed burns might best be applied to control conifer encroachment. Swanson et al. (2007) report high recovery rates of meadow herbaceous species with tree removal, regardless of whether or not tree removal was followed by a prescribed burn. They also report that encroachment in the Oregon Cascade meadows is initiated by lodgepole pine, which by altering soil conditions, then facilitates establishment of Grand fir (*Abies grandis*) as well as forest rather than meadow ground cover species. Thus, conifer encroachment that is treated early in the process, for example when lodgepole pine invasion is young, could be more easily reversed than conifer encroachment that is decades old and in which soil conditions and the soil seed bank have been largely altered. In the latter cases, recovery of native herbaceous meadow cover might require active revegetation due to both the seedbank depletion and altered soil conditions (Haugo and Halpern 2007; Swanson et al. 2007).

In Van Vleck meadows, a large subalpine meadow complex experiencing conifer encroachment on the Eldorado National Forest, 183 acres are being treated with a combination of tree removal and prescribed burn. In the fall of 2007, roughly 4,000 conifers were hand felled and scattered; moderately large conifers (over 8” dbh) growing within an aspen stand were girdled to reduce competition on the aspen (ENF October 7, 2009 News Release, Forest and Rangelands 2008). In October 2009, 168 acres were treated with prescribed burning, timed for the driest time of year at the driest time of day to produce a light and fast burning fire that would consume decadent brush and conifer (red fir and lodgepole pine) seedlings while stimulating native meadow forb and graminoid cover through creation of open mineral soil patches (California Forest Stewardship Program 2011). The fire was directed away from willow thickets, which are vulnerable to fire damage. Post-fire monitoring revealed that the low to high intensity mosaic burn did not kill off the conifer seedlings as hoped but did result in greater above ground production and diversity in the burned compared to the unburned areas (California Forest Stewardship Program 2011). The Eldorado Forest plans to perform similar burns at least every ten years from now into the future. Pre and post treatment monitoring from more projects like the Van Vleck meadow site will provide important practical information on managing meadows and conifer encroachment through prescribed fire and tree removal.

Application of prescribed fire to control sagebrush and encourage greater graminoid cover in dry meadows has been broadly applied, particularly in the intermountain west (Van Dyke and Darragh 2006, Wyoming Interagency Vegetation Committee 2002).

For more information on prescribed burns, shrub and tree removal, go to:

- Holechek, J.L., R. D. Pieper and C. H. Herbel. 2010;
- Vallentine 1989; and
- Swanson et al. 2007.

4.2.3 Rangeland management

As a general rule, livestock should be kept out of a restored meadow area for at least three years after implementation to allow for site recovery. If the area is to be used again as rangeland, then appropriate timing, duration, and grazing density are important issues to address in the range management plan. Other key considerations include management of sensitive areas, such as the channel-riparian areas, special wildlife habitat features, and nesting and rearing seasons for sensitive bird and wildlife species that use the meadows (see next section). Fencing, placement of salt blocks and alternative water sources along the forest edge rather than near the channel can help keep livestock from damaging channel banks and overgrazing streamside vegetation. As mentioned above, in some cases grazing can be targeted at certain areas and times in order to help control weeds.

For more information on rangeland management go to:

- Holechek, J.L., R. D. Pieper and C. H. Herbel. 2010.
- Bush, L. 2004
- Vavra, M., W. A. Laycock and R. D. Pieper. 1994.
- Vallentine 1989

4.2.4 Wildlife habitat management

Managing and restoring riparian meadows to create excellent bird habitat should include these key bird habitat features (PRBO and USDA Forest Service no date):

- Dense patches of willow/alder
- Lush tall herbaceous layer

- Large area to perimeter ratio
- Soil moisture/standing water

Managing meadows for both range and wildlife habitat requires careful planning, implementation and monitoring. Heavy or inappropriately timed and located grazing can negatively impact meadow dependent birds by reducing vegetative cover and making habitat unsuitable for many riparian bird species that are sensitive to changes in vegetation complexity and structure.

Key Sierra Nevada meadow bird species include (Siegel and DeSante 1999):

- sandhill crane
- Wilson's snipe
- calliope hummingbird
- red-breasted sapsucker
- warbling vireo
- willow flycatcher
- swainson's thrush
- yellow warbler
- Wilson's warbler
- Macgillivray's warbler
- Lincoln's sparrow

For more information on managing and restoring meadows for birds and wildlife go to:

- The Sierra Nevada Bird Observatory: http://www.birdpop.org/sierra.htm
- Riparian & Sierra Nevada Bird Conservation Plans http://www.prbo.org/calpif/plans.html
- Siegel and DeSante 1999

5 MONITORING AND ADAPTIVE MANAGEMENT

Ongoing monitoring and adaptive management is an important part of any restoration plan since few if any restoration or enhancement projects require no management adjustments once the initial actions are complete. Monitoring provides the critical information on which adaptive management decisions can be made. Without such information, management becomes a combination of educated guesses and "seat of the pants" actions, which can backfire. One of the main purposes of monitoring is to provide an early warning for negative or unexpected changes in the meadow and to help identify when ecological thresholds are going to be crossed, sending the meadow into an alternative state. Identifying and incorporating these thresholds in a monitoring program makes it possible for the manager to track when such thresholds are being approached, and thus to take early, preventative actions.

It is important to think through the monitoring design several years prior to implementation so that pre-implementation field measurements that directly parallel post-implementation measurements can be made during one or multiple seasons prior to implementation. These data will be extremely valuable for demonstrating meadow response to changes in management. The more years of pre-implementation data collected, the stronger the case for assigning meadow response to the management change rather than other time-related variables (e.g., climate).

Meadow restoration goals, defined early in the project planning process, should be the starting point for development of any monitoring and adaptive management plan. Project goals for increased or decreased process rates or structural characteristics need to be translated into metrics with specific thresholds for action. If monitoring results indicate that meadow processes are not changing in the targeted direction, then alternative management strategies can be applied. If monitoring indicates that meadow processes are moving in the target direction, then there is no change in management, but continued monitoring and assessment. The overall process of developing project goals, selecting appropriate management/restoration or enhancement methods, and tailoring the pre- and post-implementation monitoring plan to those goals and methods with "iteration loops" for on-going monitoring and adaptive response, is depicted in Figure 9.

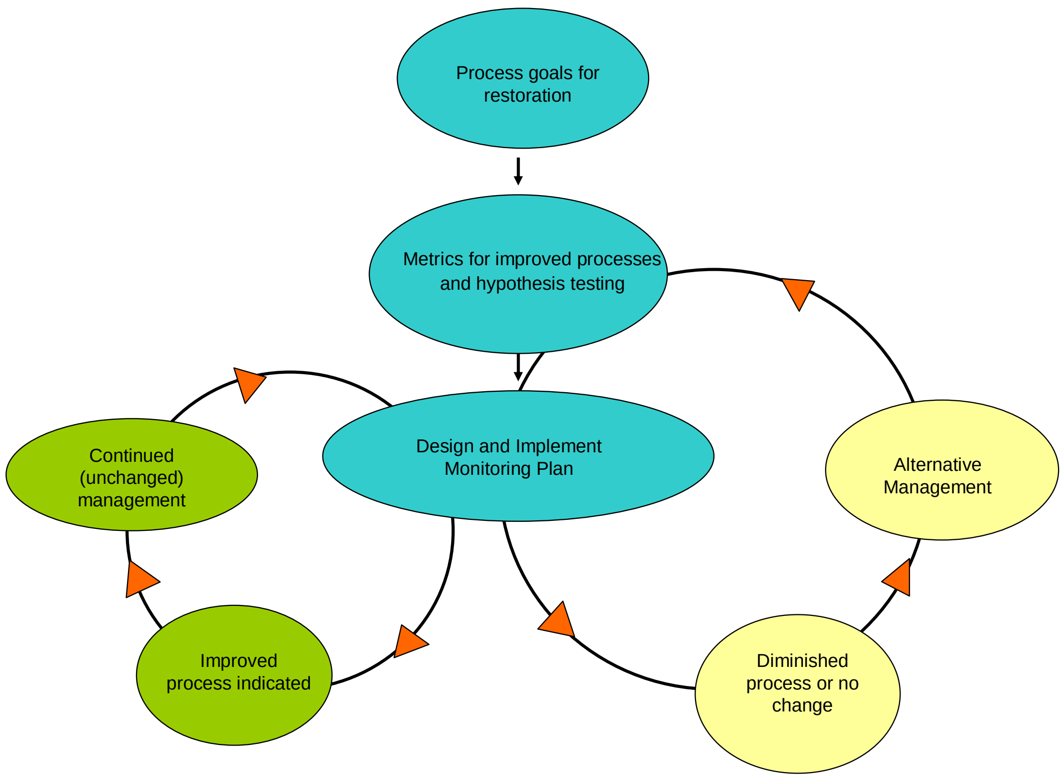

Figure 9. Process-directed monitoring goals and metrics are used to monitor restoration or enhancement effects. Iterative loops of continued monitoring occur when indicators reflect desired responses; whereas adaptive management is performed when indicators reflect undesired process responses.

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Appendices

Appendix A

List of Common Meadow Plant Species with Wetland Indicator Status and USFS R5 Functional Group Information

SPECIES	SCIENTIFIC NAME	WETLAND	WET	MOIST	DRY	FUNCTION	N FIXER	GRASS	GRASSLIKE	FORB	WOODY	LIFEHIST	ROOT	HT	LATERALS
ABCO	Abies contorta	APL	E	E	E	WOODYDRY	0	0	0	0	1	2	10	100	2
ABMA	Abies magnfica	FACU	E	E	E	woodydry	0	0	0	0	1	2	15	100	2
ACMI2	Achillea millefolium	FACU	E	E	E	rhizforbdry	0	0	0	1	0	2	15	4	4
ACHNA	Achnatherum	FACU	E	M	L	gramupl	0	1	0	0	0	2	10	5	2
ACLE	Achnatherum lettermanii	FACU	E	M	L	gramupl	0	1	0	0	0	2	4	5	2
ACLE8	Achnatherum lettermanii	FACU	E	M	L	gramupl	0	1	0	0	0	2	4	5	2
ACLE9	Achnatherum lettermanii	FACU	E	E	L	gramupl	0	1	0	0	0	2	12		
ACNE9	Achnatherum nelsonii	UPL	E	M	L	gramupl	0	1	0	0	0	2	7	5	2
ACCO4	Aconitum columbianum	FACW	L	L	L	taprootwet	0	0	0	1	0	2	18	5	2
AGAU2	Agoseris aurantiaca	FACU	E	M	M	taprootdry	0	0	0	1	0	2	11	4	2
AGGL	Agoseris glauca	FACU	E	E	E	taprootdry	0	0	0	1	0	2	5	4	2
AGGR	AGOSERIS GRANDIFLORA	FAC	E	E	E	taprootdry	0	0	0	1	0	2	7	4	2
AGHE2	Agoseris heterophylla	FAC	E	E	E	taprootdry	0	0	0	1	0	1	8	4	1
AGOSE	Agoseris sp.	FAC	E	E	E	taprootdry	0	0	0	1	0	2	13	4	2
AGIN2	AGROPYRON INTERMEDIUM	UPL	E	E	E	gramdry	0	1	0	0	0	2	4	3	4
AGEX	Agrostis exarata	FACW	E	E	L	gramshallow	0	1	0	0	0	2	14	4	4
AGGI2	Agrostis gigantea	FAC	E	E	M	gramshallow	0	1	0	0	0	2	12	4	4
AGHA2	Agrostis hallii	FACW	E	E	E	gramshallow	0	1	0	0	0	2	5	4	5
AGTH2	Agrostis humilis	FACW	M	M	L	gramshallow	0	1	0	0	0	2	14	4	4
AGID	Agrostis idahoensis	FACW	L	L	L	gramshallow	0	1	0	0	0	2	24	4	3
AGOR	Agrostis oregonensis	FACW	L	L	L	gramshallow	0	1	0	0	0	2	11	4	2
AGDI	Agrostis pallens	FACW	L	L	L	gramshallow	0	1	0	0	0	2	14	4	4
AGPA8	Agrostis pallens	FACW	L	L	L	gramshallow	0	1	0	0	0	2	14	4	4
AGSC	Agrostis scabra	FAC	E	E	E	gramshallow	0	1	0	0	0	2	19	4	3
AGSC5	Agrostis scabra	FAC	E	E	E	gramshallow	0	1	0	0	0	2	19	4	3
AGROS	Agrostis sp.	FAC	E	E	L	gramshallow	0	1	0	0	0	2	20	4	2
AGST	Agrostis stolonifera	FACW	E	E	E	gramshallow	0	1	0	0	0	2	15	4	5
AGST2	Agrostis stolonifera	FACW	E	E	E	gramshallow	0	1	0	0	0	2	15	4	5
AGST8	Agrostis stolonifera	FACW	E	E	E	gramshallow	0	1	0	0	0	2	13	4	5
AGTH	Agrostis thurberiana	OBL	M	M	L	gramshallow	0	1	0	0	0	2	12		
AGVA	Agrostis variabilis	FACW	L	L	L	gramshallow	0	1	0	0	0	2	10	4	4
AICA	Aira caryophyllea	FAC	E	E	E	annual	0	1	0	0	0	1	1	4	1
AIRA	Aira sp.	FAC	E	E	E	annual	0	1	0	0	0	1	1	4	1
ALLIU	Allium sp.	FAC	L	L	M	taprootdry	0	0	0	1	0	2	9	4	3
ALAE	Alopecurus aequalis	OBL	E	E	E	gramshallow	0	1	0	0	0	2	8	5	2
ALOPE	Alopecurus sp.	FAC	E	E	L	gramshallow	0	1	0	0	0	2	8	5	2
AMPS	Ambrosia psilostachya	FACU	E	E	E	taprootdry	0	0	0	1	0	1	6	4	1
ANAR	Anagallis arvensis	FAC	E	E	E	taprootdry	0	0	0	1	0	1	6	2	1
ANDE3	ANEMONE DELTOIDEAE	UPL	E	E	E	taprootdry	0	0	0	1	0	2	3	1	2
ANCA10	ANEMOPSIS CALIFORNICA	OBL	M	M	M	rhizforbwet	0	0	0	1	0	2	4	1.5	4
ANCO	Antennaria corymbosa	FAC	E	E	M	taprootdry	0	0	0	1	0	2	8	3	3

SPECIES	SCIENTIFIC NAME	WETLAND	WET	MOIST	DRY	FUNCTION	N FIXER	GRASS	GRASSLIKE	FORB	WOODY	LIFEHIST	ROOT	HT	LATERALS
ANDI2	Antennaria dimorpha	FAC	E	E	M	taprootdry	0	0	0	1	0	2	12	3	3
ANME2	Antennaria media	FAC	E	E	M	taprootdry	0	0	0	1	0	2	10	3	3
ANRO2	Antennaria rosea	FAC	E	E	E	taprootdry	0	0	0	1	0	2	8	3	3
ANTEN	Antennaria sp.	FAC	E	E	M	taprootdry	0	0	0	1	0	2	6	3	3
ANTENNARIA	Antennaria sp.	FAC	E	E	M	taprootdry	0	0	0	1	0	2	8	3	3
ARABI	Arabis sp.	FAC	E	E	M	taprootdry	0	0	0	1	0	2	6	3	2
ARENA	Arenaria sp.	FAC	E	E	M	taprootdry	0	0	0	1	0	2	6	3	3
ARAM2	Arnica amplexicaulis	FAC	E	E	M	rhizforbdry	0	0	0	1	0	2	17	4	5
ARCH3	ARNICA CHAMISSONIS	FAC	E	E	M	rhizforbdry	0	0	0	1	0	2	16	4	5
ARCHF	ARNICA CHAMISSONIS	FAC	E	E	M	rhizforbdry	0	0	0	1	0	2	16	4	5
ARLO6	Arnica longifolia	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	12	4	5
ARMO	Arnica mollis	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	9	4	5
ARMO4	Arnica mollis	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	9	4	5
ARMO4	Arnica mollis	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	9	4	5
ARNE3	ARNICA NEVADENSIS	UPL	E	E	E	rhizforbdry	0	0	0	1	0	2	12	4	5
ARSO2	ARNICA SORORIA	UPL	E	E	E	taprootdry									
ARNIC	Arnica sp.	FAC	M	M	M	rhizforbdry	0	0	0	1	0	2	12	4	5
ARTRT	Artemesia tridentata	FACU	E	E	E	taprootdry	0	0	0	1	0	2	5	5	3
ARCA13	Artemisia cana	FAC	E	E	M	rhizforbdry	0	0	0	1	0	2	16	4	5
ARDO3	Artemisia douglasiana	FAC	E	M	M	taprootdry	0	0	0	1	0	2	5	4	3
ARLU	Artemisia ludoviciana	FACU	E	E	E	rhizforbdry	0	0	0	1	0	2	5	4	4
ARTEM	ARTEMISIA SP.	FACU	E	E	E	taprootdry	0	0	0	1	1	2	3	6	3
ARTR2	ARTEMISIA TRIDENTATA	FACU	E	E	E	taprootdry	0	0	0	1	1	2	3	6	3
ARTRV	Artemisia tridentata vaseyana	FACU	E	E	E	taprootdry	0	0	0	1	1	2	1	6	3
ASAL	Aster alpigenus ssp. andersonii	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	12	1	4
ASAL2	Aster alpigenus ssp. andersonii	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	12	1	4
ASALA	Aster alpigenus ssp. andersonii	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	14	4	4
ASALA2	Aster alpigenus ssp. andersonii	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	12	1	4
ASALA3	Aster alpigenus ssp. andersonii	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	12	1	4
ASFO	Aster foliaceous	FAC	E	E	E	rhizforbdry	0	0	0	1	0	2	16	4	4
ASOC	Aster occidentalis	FAC	E	E	E	rhizforbdry	0	0	0	1	0	2	14	4	4
ASTER	ASTER SP.	FAC	E	E	E	rhizforbdry	0	0	0	1	0	2	12	4	4
BOCR	Botrychium crenulatum	FAC	L	L	L	taprootdry	0	0	0	1	0	2	13	2	2
BOPI	Botrychium PINNATUM	FAC	L	L	L	taprootdry	0	0	0	1	0	2	19	2	2
BOSI	Botrychium simplex	FAC	L	L	L	taprootdry	0	0	0	1	0	2	19	2	2
BOTRY	Botrychium SP.	FAC	L	L	L	taprootdry	0	0	0	1	0	2	19	2	2
BRASS	Brassica sp.	FAC	E	E	M	taprootdry	0	0	0	1	0	2	12	4	2
BRODI	Brodiaea sp.	FAC	E	E	M	taprootdry	0	0	0	1	0	2	12	4	3
BRCA5	Bromus carinatus	FAC	E	M	L	gramupl	0	1	0	0	0	2	8	5	2
BRDI3	BROMUS DIANDRUS	UPL	E	E	E	annual	0	1	0	0	0	1	0	2	1
BRHO2	BROMUS HORDACEOUS	UPL	E	E	E	annual									
BRIN2	Bromus inermis	FAC	E	E	M	gramupl	0	1	0	0	0	2	6	5	5
BRJA	BROMUS JAPONICUS	FACU	E	E	E	annual	0	1	0	0	0	1	1	1	1
BRMA	BROMUS MADRITENSIS	UPL	E	E	E	annual									
BROMUS	BROMUS SP.	FACU	E	M	L	gramupl									
BRSU2	Bromus suksdorfii	FAC	E	M	L	gramupl	0	1	0	0	0	2	8	5	2
BRTE	Bromus tectorum	UPL	E	E	E	gramupl	0	1	0	0	0	1	1	4	1
CACA4	Calamagrostis canadensis	FACW	L	L	L	gramdeep	0	1	0	0	0	2	15	5	4
CASI7	CALOCHORTUS SIMULANS	UPL	E	E	E	taprootdry	0	0	0	1	0	2	2	1	2
CALE4	Caltha leptosepala	FACW	L	L	L	taprootwet	0	0	0	1	0	2	17	4	2
CALTH	CALTHA SP.	FACW	L	L	L	taprootwet	0	0	0	1	0	2	22	4	2
CALYP	Calyptridium umbellatum	UPL	E	E	E	taprootdry	0	0	0	1	0	2	2	1	2

SPECIES	SCIENTIFIC NAME	WETLAND	WET	MOIST	DRY	FUNCTION	N FIXER	GRASS	GRASSLIKE	FORB	WOODY	LIFEHIST	ROOT	HT	LATERALS
CAUM2	Calyptridium umbellatum	UPL	E	E	E	taprootdry	0	0	0	1	0	2	2	1	2
CALAM	CAMAGROSTIS SP.	FAC	L	L	L	gramdeep									
CAQU2	Camassia quamash	FACW	L	L	L	taprootwet	0	0	0	1	0	2	22	4	2
CARDU	Carduus sp.	FACU		E	E	taprootdry	0	0	0	1	0	2	3	4	2
CAAB	Carex abrupta	FACW	L	L	L	gramdeep	0	0	1	0	0	2	16	4	3
CAAQ	Carex aquatilis	OBL	L	L	L	gramdeep	0	0	1	0	0	2	25	5	3
CASI3	Carex aquatilis	OBL	L	L	L	gramdeep	0	0	1	0	0	2	25	5	3
CAAT3	Carex athrostachya	FACW	L	L	L	gramdeep	0	0	1	0	0	2	17	4	3
CAAU	Carex aurea	OBL	L	L	L	gramdeep	0	0	1	0	0	2	16	3	4
CAAU3	Carex aurea	OBL	L	L	L	gramdeep	0	0	1	0	0	2	16	3	4
CABO2	Carex bolanderi	FACW	L	L	L	gramshallow	0	0	1	0	0	2	13	4	3
CACA13	Carex capitata	OBL	L	L	L	gramdeep	0	0	1	0	0	2	36	3	3
CADE8	Carex densa	OBL	L	L	L	gramdeep	0	0	1	0	0	2	15	4	3
CADO	Carex douglasii	FACU	E	M	M	gramupl	0	0	1	0	0	2	12	3	4
CADO2	Carex douglasii	FACU	E	M	M	gramupl	0	0	1	0	0	2	12	3	4
CAEC	Carex echinata	OBL	L	L	L	gramdeep	0	0	1	0	0	2	39	4	3
CAECE	Carex echinata ssp. echinata	OBL	L	L	L	gramdeep	0	0	1	0	0	2	17	4	3
CAEL2	CAREX ELEOCHARIS	OBL	L	L	L	gramdeep	0	0	1	0	0	2	17	4	3
CAFE4	Carex feta	OBL	L	L	L	gramshallow	0	0	1	0	0	2	11	5	3
CAFI	Carex filofolia	FACW	L	L	L	gramshallow	0	0	1	0	0	2	9	4	3
CAFI2	Carex fissuricola	FACW	L	L	L	gramdeep	0	0	1	0	0	2	15	5	3
CAHE8	Carex heteroneura	FACW	L	L	L	gramdeep	0	0	1	0	0	2	15	5	3
CAIL	Carex illota	OBL	L	L	L	gamdeep	0	0	1	0	0	2	15	5	3
CAIN10	Carex integra	FACW	L	L	L	gramdeep	0	0	1	0	0	2	17	4	3
CAJO	Carex jonesii	FACW	L	L	L	gramdeep	0	0	1	0	0	2	17	4	5
CALA30	Carex lanuginosa	OBL	L	L	L	gramdeep	0	0	1	0	0	2	22	5	5
CALE6	CAREX LEAVENWORTHII	FACW	L	L	L	taprootwet	0	0	0	1	0	2	17	4	2
CALE	Carex lemmonii	OBL	L	L	L	gramshallow	0	0	1	0	0	2	13	5	3
CALE7	Carex lemmonii	OBL	L	L	L	gramshallow	0	0	1	0	0	2	13	5	3
CALE8	Carex lenicularis	OBL	L	L	L	gramdeep	0	0	1	0	0	2	27	5	3
CALU6	Carex luzulifolia	OBL	L	L	L	gramdeep	0	0	1	0	0	2	16	5	3
CALU7	Carex luzulina	OBL	L	L	L	gramdeep	0	0	1	0	0	2	22	5	3
CAMA13	Carex mariposana	FACU	L	L	L	gramdeep	0	0	1	0	0	2	15	2	3
CAMI7	Carex microptera	FACW	M	M	L	gramshallow	0	0	1	0	0	2	13	4	3
CAMU6	Carex multicostata	FAC	M	L	L	gramdeep	0	0	1	0	0	2	15	4	3
CANE	Carex nebrascensis	OBL	L	L	L	gramdeep	0	0	1	0	0	2	17	5	5
CANE2	Carex nebrascensis	OBL	L	L	L	gramdeep	0	0	1	0	0	2	17	5	5
CANE5	Carex nervina	FACW	L	L	L	gramdeep	0	0	1	0	0	2	23	5	3
CANU5	CAREX NUDATA	FACW	L	L	L	gramdeep	0	0	1	0	0	2	18	2	4
CAPA14	CAREX PACHYSTACHYA	FACW	L	L	L	gramdeep	0	0	1	0	0	2	16	2	3
CAPR	Carex praegracilis	FACW	L	L	L	gramshallow	0	0	1	0	0	2	13	4	5
CAPR5	Carex praegracilis	FACW	L	L	L	gramshallow	0	0	1	0	0	2	13	4	5
CARA6	Carex raynoldsii	FACW	L	L	L	gramdeep	0	0	1	0	0	2	16	2	3
CASC12	Carex scopulorum	OBL	L	L	L	gramdeep	0	0	1	0	0	2	24	4	5
CASC13	Carex scopulorum	OBL	L	L	L	gramdeep	0	0	1	0	0	2	24	4	5
CASI2	Carex simulata	OBL	L	L	L	gramdeep	0	0	1	0	0	2	19	4	5
CAREX	Carex sp.	FACW	L	L	L	gramdeep	0	0	1	0	0	2	15	2	4
CASU6	Carex subfusca	FAC	L	L	L	gramdeep	0	0	1	0	0	2	12	5	3
CASU7	Carex subnigricans	FACW	L	L	L	gramdeep	0	0	1	0	0	2	15	3	5

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CAUN3	CAREX UNILATERALIS	FACW	L	L	L	gramdeep									
CAUT	Carex utriculata	OBL	L	L	L	gramdeep	0	0	1	0	0	2	29	5	5
CAVE5	Carex vernacula	FACW	L	L	L	gramshallow	0	0	1	0	0	2	13	5	5
CAVE	Carex vesicaria	OBL	L	L	L	gramdeep	0	0	1	0	0	2	20	5	5
CAVE6	Carex vesicaria	OBL	L	L	L	gramdeep	0	0	1	0	0	2	20	5	5
CALE18	Castilleja lemmonii	FACW	L	L	L	gramdeep	0								
CESO3	Centaura solstitialis	FACU	E	E	E	taprootdry	0	0	0	1	0	1	12	4	1
CEAR4	Cerastium arvense	FACU	E	E	E	taprootdry	0	0	0	1	0	2	12	4	2
CEBE2	Cerastium beeringianum	FACU	E	E	E	taprootdry	0	0	0	1	0	2	20	4	2
CERAS	Cerastium sp.	FACU	E	E	E	taprootdry	0	0	0	1	0	2	17	4	2
CHENO	Chenopodium sp.	UPL	E	E	E	taprootdry									
CHNA2	Chrysothamnus nauseosa	FACU	E	E	E	taprootdry	0	0	0	1	1	2	4	6	3
CIAR4	CIRSIUM ARVENSE	FACU	E	E	E	taprootdry	0	0	0	1	0	2	10	4	2
CIOC	Cirsium occidentale	FACU	E	E	E	taprootdry	0	0	0	1	0	2	6	4	2
CISC2	Cirsium scariosum	FACU	E	E	E	taprootdry	0	0	0	1	0	2	4	4	2
CIRSI	Cirsium sp.	FACU	E	E	E	taprootdry	0	0	0	1	0	2	10	4	2
CLAYT	Clatonia sp.	FACW	M	M	M	taprootwet	0	0	0	1	0	2	12	4	2
CLPE	Claytonia perfoliata	FACW	M	M	M	taprootwet	0	0	0	1	0	2	0	3	2
COPA3	COLLINSIA PARVIFLORA	UPL	E	E	E	annual									
COLLI	Collinsia sp.	FACU	E	E	E	taprootdry	0	0	0	1	0	1	0	3	1
COLI2	Collomia linearis	FACU	E	E	E	taprootdry	0	0	0	1	0	1	7	3	1
COAR4	CONVOLVULUS ARVENSIS	UPL	E	E	E										
CREPI	Crepis sp.	FACU	E	E	E	taprootdry	0	0	0	1	0	2	17	4	2
CYEC	CYNOSURUS ECHINATUS	UPL	E	E	E	annual									
DAGL	Dactylis glomerata	FACU	E	E	M	gramupl	0	1	0	0	0	2	12	5	4
DAUN	Danhtonia unispicata	FAC	M	M	M	gramshallow	0	1	0	0	0	2	7	4	2
DACA	Danthonia californica	FAC	M	M	L	gramshallow	0	1	0	0	0	2	14	4	2
DACA3	Danthonia californica	FAC	M	M	L	gramshallow	0	1	0	0	0	2	14	4	2
DAIN	Danthonia intermedia	FACU	M	M	L	gramupl	0	1	0	0	0	2	16	4	2
DANTH	Danthonia intermedia	FACU	M	M	L	gramupl	0	1	0	0	0	2	16	4	2
DACA5	Darlingtonia californica	OBL	L	L	L	taprootwet	0	0	0	1	0	2	21	4	3
DENU2	Delphinium nuttallianum	FACW	M	M	M	taprootwet	0	0	0	1	0	2	14	4	2
DECA	DESCHAMPSIA CESPITOSA	FACW	L	L	L	gramshallow	0	1	0	0	0	2	15	5	2
DECE	DESCHAMPSIA CESPITOSA	FACW	L	L	L	gramshallow	0	1	0	0	0	2	15	5	2
DEDA	Deschampsia danthonioides	FACW	E	E	E	annual	0	1	0	0	0	1	7	4	2
DEEL	Deschampsia elongata	FACW	E	E	L	gramshallow	0	1	0	0	0	2	9	4	2
DESCH	Deschampsia sp.	FACW	L	L	L	gramshallow	0	1	0	0	0	2	15	5	2
DEPI	Descurainia pinnata	FACU	E	E	E	taprootdry	0	0	0	1	0	1	2	4	1
DESO2	Descurainia sophia	FACU	E	E	E	taprootdry	0	0	0	1	0	1	2	4	1
DISP	Distichlis spicata	FAC	M	L	L	gramshallow	0	1	0	0	0	2	3	3	4
DOAL	Dodecatheon alpinum	OBL	L	L	L	taprootwet	0	0	0	1	0	2	21	4	3
DOCO	Dodecatheon conjugens	FAC	M	M	M	taprootdry	0	0	0	1	0	2	21	4	3
DOJE	Dodecatheon jeffreyi	FACW	M	M	M	taprootwet	0	0	0	1	0	2	27	4	3
DRRO	Drosera rotundifolia	OBL	L	L	L	taprootwet	0	0	0	1	0	2	8	2	2
DUHO	Dugaldia hoopsii	FACU	E	E	E	taprootdry	0	0	0	1	0	2	5	4	2
ELAC	Eleocharis acicularis	OBL	M	M	M	annual	0	0	1	0	0	1	12	3	1
ELBE	Eleocharis bella	FACW	E	E	E	annual	0	0	1	0	0	1	2	2	1
ELMA5	ELEOCHARIS MACROSTACHY/	OBL	M	M	M	gramdeep	0	0	1	0	0	2	24	4	4
ELPA4	ELEOCHARIS PARISHII	FACW	M	M	M	gramshallow									

SPECIES	SCIENTIFIC NAME	WETLAND	WET	MOIST	DRY	FUNCTION	N FIXER	GRASS	GRASSLIKE	FORB	WOODY	LIFEHIST	ROOT	HT	LATERALS
ELPA6	Eleocharis pauciflora	OBL	M	M	M	gramdeep	0	0	1	0	0	2	17	3	4
ELQU2	Eleocharis quinqueflora	FACW	M	M	M	gramshallow	0	0	1	0	0	2	5	3	4
ELEOC	Eleocharis SP.	FACW	M	M	M	gramshallow	0	0	1	0	0	2	12	3	4
ELEL	ELYMUS ELYMOIDES	FACU	E	M	M	gramupl	0	1	0	0	0	2	5	4	3
ELEL5	ELYMUS ELYMOIDES	FACU	E	M	M	gramupl	0	1	0	0	0	2	5	4	3
ELGL	Elymus glaucus	FACU	E	M	M	gramupl	0	1	0	0	0	2	15	5	4
ELTR7	Elymus trachycaulus	FAC	M	M	L	gramshallow	0	1	0	0	0	2	14	5	2
ELTRT	Elymus trachycaulus ssp. trachyc	FAC	M	L	L	gramshallow	0	1	0	0	0	2	14	5	2
AGTR	Elymus trachycaulus ssp. trachyc	FAC	M	L	L	gramshallow	0	1	0	0	0	2	14	5	2
EPBR	EPILOBIUM BRACHYCARPUM	UPL	E	E	E	annual	0	0	0	1	0	1	2	2	1
EPBR3	EPILOBIUM BRACHYCARPUM	UPL	E	E	E	annual	0	0	0	1	0	1	2	2	1
EPCI	Epilobium ciliatum	OBL	M	M	M	taprootwet	0	0	0	1	0	2	20	4	2
EPDE	Epilobium ciliatum	OBL	M	M	M	taprootwet	0	0	0	1	0	2	20	4	2
EPCIC	Epilobium ciliatum ciliatum	OBL	M	M	M	taprootwet	0	0	0	1	0	2	12	4	2
EPCIG	Epilobium ciliatum glandulosum	OBL	M	M	M	taprootwet	0	0	0	1	0	2	19	4	2
EPGL	Epilobium glaberrimum	OBL	M	M	M	taprootwet	0	0	0	1	0	2	13	4	2
EPHA	Epilobium halleanum	FACW	M	M	M	taprootwet	0	0	0	1	0	2	23	4	2
EPMI	Epilobium minutum	FACW	E	E	E	taprootwet	0	0	0	1	0	1	2	3	1
EPOR	Epilobium oreganum	OBL	M	M	E	taprootwet	0	0	0	1	0	2	5	3	2
EPOR2	Epilobium oregonense	OBL	M	E	E	taprootwet	0	0	0	1	0	2	18	3	2
EPILO	Epilobium sp.	FACW	M	M	M	taprootwet	0	0	0	1	0	2	20	4	2
EPILOBIUM	Epilobium sp.	FACW	M	M	M	taprootwet	0	0	0	1	0	2	20	4	2
BOST	Epilobium torreyi	FACW	E	E	E	annual	0	0	0	1	0	1	1	1	1
EPIL	Epliobium sp.	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	9	3	
EQAR	Equisetum arvense	FACW	E	E	E	rhizforbwet	0	0	0	1	0	2	18	4	4
EQUIS	Equisetum sp.	FACW	E	E	E	taprootwet	0	0	0	1	0	2	7	4	2
EQUISETUM	Equisetum sp.	FACW	E	E	E	taprootwet	0	0	0	1	0	2	7	4	2
ERSE	Eragrostis secundiflora	FACU	E	E	E	taprootdry	0	0	0	1	0	1	3	3	1
HAGR6	ERICAMERIA GREENII	UPL	E	E	E	woodydry									
ERIGE	Erigeron sp.	FAC	M	M	M	taprootdry	0	0	0	1	0	2	14	4	2
ERIOG	Eriogonum sp.	FACU	E	E	E	taprootdry	0	0	0	1	0	2	10	4	2
ERCR4	Eriophorum crinigerum	OBL	L	L	L	gramdeep	0	0	1	0	0	2	43	4	4
ERBO	Erodium botrys	FAC	E	E	E	taprootdry	0	0	0	1	0	1	2	3	1
ERCI6	ERODIUM CICUTARIUM	FACU	E	E	E	taprootdry	0	0	0	1	0	1	4	2	1
ERCIC	ERODIUM CICUTARIUM	UPL	E	E	E	annual	0	0	0	1	0	1	1	1	1
ERAR11	Eryngium aristulatum	FAC	E	E	E	taprootdry	0	0	0	1	0	2	2	2	2
ERYSI	Erysimum sp.	FAC	E	E	M	taprootdry	0	0	0	1	0	2	21	4	2
FEID	Festuca idahoensis	FACU	E	E	L	gramupl	0	1	0	0	0	2	19	5	3
FEOVV	Festuca ovina	FACU	M	M	M	gramupl	0	1	0	0	0	2	15	5	3
FERU2	Festuca rubra	FACU	M	M	M	gramupl	0	1	0	0	0	2	15	5	4
FESTU	Festuca sp.	FACU	E	E	L	gramupl	0	1	0	0	0	2	3	3	3
FESTUCA	Festuca sp.	FACU	E	E	L	gramupl	0	1	0	0	0	2	3	3	3
FRVI	Fragaria virginiana	FAC	E	E	E	rhizforbdry	0	0	0	1	0	2	5	4	4
FRSP	FRASERA SPECIOSA	UPL	E	E	E	taprootdry	0	0	0	1	0	2	2	4	3
GALIU	Galium sp.	FAC	M	M	M	taprootdry	0	0	0	1	0	1	12	3	2
GATR	Galium trifidum	FACW	M	M	M	taprootwet	0	0	0	1	0	2	15	3	2
GATR2	Galium trifidum	FACW	M	M	M	taprootwet	0	0	0	1	0	2	15	3	2
GATR3	Galium triflorum	FACU	E	E	E	taprootdry	0	0	0	1	0	2	5	1	3
GARA2	Gayophytum ramosissimum	FACU	E	E	E	taprootdry	0	0	0	1	0	1	3	3	1

SPECIES	SCIENTIFIC NAME	WETLAND	WET	MOIST	DRY	FUNCTION	N FIXER	GRASS	GRASSLIKE	FORB	WOODY	LIFEHIST	ROOT	HT	LATERALS
GAYOP	Gayophytum sp.	FACU	E	E	E	taprootdry	0	0	0	1	0	1	11	3	1
GADI2	GAYPHYTUM DIFFUSUM	FAC	E	E	E	taprootdry	0	0	0	1	0	1	3	3	1
GADID	GAYPHYTUM DIFFUSUM	FAC	E	E	E	taprootdry	0	0	0	1	0	1	3	3	1
GADIP	GAYPHYTUM DIFFUSUM	FAC	E	E	E	taprootdry	0	0	0	1	0	1	3	3	1
GENE	Gentiana newberryi	FACW	M	M	M	taprootwet	0	0	0	1	0	2	15	3	3
GENTI	Gentiana sp.	FACW	M	M	M	taprootwet	0	0	0	1	0	2	16	3	3
GEHO3	Gentianopsis holopetala	OBL	M	M	M	taprootwet	0	0	0	1	0	2	11	3	3
GESI3	Gentianopsis simplex	OBL	M	M	M	taprootwet	0	0	0	1	0	1	3	3	1
GERAN	Geranium sp.	FAC	E	E	M	taprootdry	0	0	0	1	0	2	3	3	3
GEVI2	Geranium viscosissimum	FAC	E	M	M	taprootdry	0	0	0	1	0	1	5	4	3
GEMA4	Geum macrophyllum	FACW	E	M	M	taprootwet	0	0	0	1	0	2	5	4	2
GEUM	Geum sp.	FAC	M	M	M	taprootdry	0	0	0	1	0	2	14	4	2
GETR	Geum triflorum	FAC	M	M	M	rhizforbdry	0	0	0	1	0	2	5	4	4
GLBO	Glyceria borealis	OBL	L	L	L	gramdeep	0	1	0	0	0	2	34	5	4
GLEL	Glyceria elata	OBL	L	L	L	gramdeep	0	1	0	0	0	2	25	5	4
GLYCERIA	Glyceria sp.	OBL	L	L	L	gramdeep									
GNPA	Gnaphalium palustre	FAC	E	E	E	taprootdry	0	0	0	1	0	1	1	3	1
GRIND	Grindelia sp.	FACU	E	E	E	taprootdry	0	0	0	1	0	2	2	4	3
HAFL2	Hackelia floribunda	FAC	E	E	M	taprootdry	0	0	0	1	0	2	6	4	3
HASE2	Hastingia serpentinicola	FAC	E	E	M	taprootdry	0	0	0	1	0	2	14	4	3
HEBI	Helenium bigelovii	FACW	M	M	M	taprootwet	0	0	0	1	0	2	8	4	3
HEHO5	Helenium bigelovii	FACW	M	M	M	taprootwet	0	0	0	1	0	2	8	4	3
HELENIUM	Helenium sp.	FACW	M	M	M	taprootwet	0	0	0	1	0	2	8	4	3
HOLA	Holcus lanatus	FACW	E	E	M	gramshallow	0	1	0	0	0	2	12	4	2
HOBR2	Hordeum brachyantherum	FACW	E	M	M	gramshallow	0	1	0	0	0	2	15	5	2
HOJU	Hordeum jubatum	FAC	E	E	E	gramshallow	0	1	0	0	0	2	7	4	2
HORDE	Hordeum sp.	FACW	E	M	M	gramshallow	0	1	0	0	0	2	14	5	2
HOVU	HORDEUM VULGARE	UPL	E	E	E	annual									
HOCA3	Horkelia californica	FAC	E	E	M	taprootdry	0	0	0	1	0	2	9	4	3
HOCL	Horkelia clevelandii	FAC	E	E	M	taprootdry	0	0	0	1	0	2	3	4	3
HOFU	Horkelia fusca	FAC	E	E	E	taprootdry	0	0	0	1	0	2	13	4	3
HYAN2	Hypericum anagalloides	FACW	E	E	E	taprootwet	0	0	0	1	0	1	2	3	1
HYPE	Hypericum perforatum	FACW	M	M	M	taprootwet	0	0	0	1	0	2	16	3	2
HYFOS	Hypericum scouleri	FACW	M	M	M	taprootwet	0	0	0	1	0	2	12	3	2
IRCH	IRIS CHRYSOPYLLA	FAC	E	E	E	taprootdry	0	0	0	1	0	2	14	3	3
IRMI	Iris missouriensis	FAC	E	E	E	taprootdry	0	0	0	1	0	2	14	3	3
IVAPA	Ivesia aperta	FAC	E	E	M	taprootdry	0	0	0	1	0	2	3	3	2
IVCA2	Ivesia campestris	FACW	E	E	E	taprootwet	0	0	0	1	0	2	12	3	2
IVLY	Ivesia lycopodioides	FACW	M	M	M	taprootwet	0	0	0	1	0	2	13	3	2
IVSE	Ivesia sericoleuca	FAC	M	M	M	taprootdry	0	0	0	1	0	2	3	3	2
IVUN	Ivesia unguiculata	FACW	M	E	E	taprootwet	0	0	0	1	0	2	13	3	2
JUAC	JUNCUS ACUMINATUS	OBL	L	L	L	gramdeep	0	0	1	0	0	2	12	2	3
JUBA	Juncus balticus	OBL	M	M	M	gramdeep	0	0	1	0	0	2	16	4	5
JUBU	Juncus bufonius	OBL	E	E	E	annual	0	0	1	0	0	1	3	2	3
JUCO2	Juncus confusus	FACW	M	M	M	gramshallow	0	0	1	0	0	2	10	3	3
JUDR	Juncus drummondii	FACW	M	M	L	gramdeep	0	0	1	0	0	2	15	1	3
JUDU	Juncus dubius	FACW	L	L	L	gramdeep	0	0	1	0	0	2	19	3	4
JUEF	Juncus effusus	OBL	L	L	L	gramshallow	0	0	1	0	0	2	11	3	3
JUEN	Juncus ensifolius	OBL	L	L	L	gramdeep	0	0	1	0	0	2	27	4	5

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JUEN2	Juncus ensifolius	OBL	L	L	L	gramdeep	0	0	1	0	0	2	27	4	5
JULO	Juncus longistylis	FACW	L	L	L	gramshallow	0	0	1	0	0	2	8	4	4
JUME3	Juncus mertensianus	OBL	L	L	L	gramshallow	0	0	1	0	0	2	6	3	4
JUME	Juncus mexicanus	FACW	M	M	M	gramdeep	0	0	1	0	0	2	18	4	4
JUME4	Juncus mexicanus	FACW	M	M	M	gramdeep	0	0	1	0	0	2	18	4	4
JUNE	Juncus nevadensis	FACW	L	L	L	gramdeep	0	0	1	0	0	2	22	4	4
JUOR	Juncus orthophyllus	FACW	M	M	L	gramdeep	0	0	1	0	0	2	17	4	3
JUOX	Juncus oxymeris	FACW	L	L	L	gramdeep	0	0	1	0	0	2	19	4	3
JUPA	Juncus parryi	FACU	E	E	M	gramdry	0	0	1	0	0	2	4	4	3
JUPA2	Juncus patens	FACW	M	M	L	gramshallow	0	0	1	0	0	2	11	4	3
JUPH	Juncus phaeocephalus	FACW	L	L	L	gramdeep	0	0	1	0	0	2	15	4	5
JUNCU	JUNCUS SP.	FACW	L	L	L	gramdeep	0	0	1	0	0	2	15	3	4
JUNCUS	JUNCUS SP.	FACW	L	L	L	gramdeep	0	0	1	0	0	2	15	3	4
JUTE	JUNUS TENUIS	FACW	M	M	M	gramshallow	0	0	1	0	0	2	2	1	
KAPO	KALMIA POLIFOLIA	FACW	L	L	L	rhizforbwet	0	0	0	1	1	2	17	3	4
KAPOM3	KALMIA POLIFOLIA	FACW	L	L	L	rhizforbwet	0	0	0	1	1	2	17	3	4
LASE	Lactuca serriola	FACU	E	E	E	taprootdry	0	0	0	1	0	1	2	3	1
LEPID	Lepidium sp.	FACU	E	E	E	taprootdry	0	0	0	1	0	1	10	3	1
LESSI	LESSINGIA SP.	FAC	E	E	M										
LENE5	Lewisia nevadensis	FACU	L	L	L	taprootdry	0	0	0	1	0	2	7	3	3
ELTR3	Leymus triticoides	FAC	M	M	L	gramshallow	0	1	0	0	0	2	8	5	5
LETR5	LEYMUS TRITICOIDES	FAC	M	M	L	gramshallow	0	1	0	0	0	2	14	5	2
LIHA	Linanthus harknessii	FACU	E	E	E	taprootdry	0	0	0	1	0	1	4	2	1
LICI	Linathus ciliatus	FACU	E	E	E	taprootdry	0	0	0	1	0	1	5	2	1
LINAN	Linathus sp.	FACU	E	E	E	taprootdry	0	0	0	1	0	1	2	3	1
LILE3	Linum lewisii	FACU	E	E	E	taprootdry	0	0	0	1	0	2	12	3	3
LOMU	LOLIUM PERENNE	UPL	E	E	E	annual									
LOMAT	Lomatium sp.	FACU	E	E	E	taprootdry	0	0	0	1	0	2	1	3	3
LOCO6	Lotus corniculatus	FAC	E	E	M	taprootdry	0	0	0	1	0	2	7	3	2
LOOB	Lotus oblongifolius	FACW	E	E	M	taprootwet	0	0	0	1	0	2	3	3	2
LOOB2	Lotus oblongifolius	FACW	E	E	M	taprootwet	0	0	0	1	0	2	3	3	2
LOPI2	Lotus pinnatus	FACW	E	E	M	taprootwet	0	0	0	1	0	2	4	3	2
LOPU3	Lotus purshianus	FAC	E	E	E	taprootdry	0	0	0	1	0	1	10	3	1
LOTUS	Lotus sp.	FAC	E	E	E	taprootdry	0	0	0	1	0	1	13	3	1
LOST4	Lotus strigosus	FAC	E	E	E	taprootdry	0	0	0	1	0	1	1	3	1
LUAR3	Lupinus argenteus	FACU	E	E	E	taprootdry	0	0	0	1	0	2	6	3	3
LUBI	Lupinus bicolor	FACU	E	E	E	taprootdry	0	0	0	1	0	1	3	3	1
LUCA	LUPINUS CAUDATUS	UPL	E	E	E	taprootdry	0	0	0	1	0	2	2	2	3
LULES2	Lupinus lepidus var. sellulus	UPL	E	E	M	taprootdry	0	0	0	1	0	2	4	1	3
LUPO2	Lupinus polyphyllus	FACW	M	M	M	taprootwet	0	0	0	1	0	2	4	5	3
LUPIN	Lupinus sp.	FACU	E	E	E	taprootdry	0	0	0	1	0	2	9	3	3
LUCO6	Luzula comosa	FACW	L	L	L	gramshallow	0	0	1	0	0	2	10	4	4
LUOR4	Luzula orestera	OBL	L	L	L	gramshallow	0	0	1	0	0	2	7	4	4
LUPA4	Luzula parviflora	FAC	E	E	M	gramshallow	0	0	1	0	0	2	15	4	4
LUZUL	Luzula sp.	FAC	L	L	L	gramshallow	0	0	1	0	0	2	16	4	4
LUSU7	Luzula subongesta	FAC	E	L	L	gramshallow	0	0	1	0	0	2	22	4	4
MAGL2	Madia glomerata	FACU	E	E	E	taprootdry	0	0	0	1	0	1	5	3	1
MAMI	Madia minima	FACU	E	E	E	taprootdry	0	0	0	1	0	1	0	3	1
MADIA	Madia sp.	FACU	E	E	E	taprootdry	0	0	0	1	0	1	2	3	1

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MELU	Medicago lupulina	FAC	E	E	E	taprootdry	0	0	0	1	0	1	2	3	2
MEDIC	Medicago sp.	FAC	E	E	E	taprootdry	0	0	0	1	0	1	3	3	1
MEBU	Melica bulbosa	UPL	E	E	E	gramupl	0	1	0	0	0	2	14	4	3
MEAR4	Mentha arvensis	FACW	E	E		taprootwet	0	0	0	1	0	2	7	3	2
MECI3	Mertensia ciliata	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	3	3	4
MIGU	Mimulus guttatus	OBL	M	M	M	rhizforbwet	0	0	0	1	0	2	12	3	4
MIMO3	Mimulus moschatus	OBL	M	M	M	taprootwet	0	0	0	1	0	2	5	3	2
MIPR	Mimulus primuloides	OBL	M	M	M	rhizforbwet	0	0	0	1	0	2	19	3	4
MIPRL	Mimulus primuloides	OBL	M	M	M	rhizforbwet	0	0	0	1	0	2	19	3	4
MOOD	Monardella odoratissima	FACW	M	M	M	taprootwet	0	0	0	1	0	2	8	3	2
MOCH	Montia chamissoi	OBL	M	M	M	rhizforbwet	0	0	0	1	0	2	15	3	4
MOLI4	Montia linearis	OBL	E	E	E	taprootwet	0	0	0	1	0	1	14	3	1
MUAS	Muhlenbergia asperifolia	FACW	M	E	M	gramshallow	0	1	0	0	0	2	18	4	4
MUFI	Muhlenbergia filiformis	OBL	M	M	M	annual	0	1	0	0	0	1	18	3	1
MUFI2	Muhlenbergia filiformis	OBL	M	M	M	annual	0	1	0	0	0	1	18	3	1
MURI	Muhlenbergia richardsonis	FAC	E	M	M	gramshallow	0	1	0	0	0	2	14	3	4
MURI2	Muhlenbergia rigens	FAC	E	M	L	gamshallow	0	1	0	0	0	2	10	5	3
NABR	Navarretia breweri	FACU	E	E	E	taprootdry	0	0	0	1	0	1	2	3	1
NAIN2	Navarretia intertexta	FACU	E	E	E	taprootdry	0	0	0	1	0	1	7	3	1
NALE	Navarretia leucocephala	OBL	E	E	E	taprootwet	0	0	0	1	0	1	10	3	1
NAVAR	Navarretia sp.	FACU	E	E	E	taprootdry	0	0	0	1	0	1	17	3	1
NEPE	Nemophila pedunculata	FAC	E	E	E	taprootdry	0	0	0	1	0	1	14	3	1
NEMOP	Nemophila sp.	FACW	E	E	E	taprootwet	0	0	0	1	0	1	11	3	1
ORLU2	Orthocarpus luteus	FACU	E	E	E	taprootdry	0	0	0	1	0	1	0	3	2
ORTHO	Orthocarpus sp.	FAC	E	E	E	taprootdry	0	0	0	1	0	1	13	3	1
OXOC	Oxypolis occidentalis	FACW	L	L	L	taprootwet	0	0	0	1	0	2	15	3	2
PANIC	Panicum sp.	FAC	M	M	M	taprootdry	0	0	0	1	0	2	14	3	2
PEAT	Pedicularis attollens	OBL	L	L	L	taprootwet	0	0	0	1	0	2	15	4	3
PEGR2	Pedicularis groenlandica	OBL	L	L	L	taprootwet	0	0	0	1	0	2	8	4	2
PEDIC	Pedicularis sp.	FACW	L	L	L	taprootwet	0	0	0	1	0	2	12	4	3
PEHE2	Penstemon herterodoxus	FAC	E	E	M	taprootdry	0	0	0	1	0	2	22	3	2
PELA7	Penstemon laetus	FAC	E	E	M	taprootdry	0	0	0	1	0	2	10	3	2
PEPR2	Penstemon procerus	FAC	E	E	M	taprootdry	0	0	0	1	0	2	7	3	2
PERY	Penstemon rydbergii	FAC	M	M	M	taprootdry	0	0	0	1	0	2	16	3	2
PERYO	Penstemon rydbergii	FAC	M	M	M	taprootdry	0	0	0	1	0	2	10	3	2
PENST	Penstemon sp.	FAC	M	M	M	taprootdry	0	0	0	1	0	2	25	3	2
PERID	Perderidia sp.	FAC	M	M	M	taprootdry	0	0	0	1	0	2	14	4	2
PELE5	Perideridia lemmonii	FAC	E	E	M	taprootdry	0	0	0	1	0	2	26	4	2
PEPA21	Perideridia parishii	FACW	E	E	M	taprootwet	0	0	0	1	0	2	15	4	2
PEPAL	Perideridia parishii	UPL	E	E	M	taprootdry	0	0	0	1	0	2	10	2	2
PHBO	Phalacroseris bolanderi	FACW	M	M	M	taprootwet	0	0	0	1	0	2	16	3	3
PHBO2	Phalacroseris bolanderi	FACW	M	M	M	taprootwet	0	0	0	1	0	2	16	3	3
PHAQ	Phalaris aquatica	FACW	E	E	E	gramshallow	0	1	0	0	0	2	15	5	4
PHAL2	Phleum alpinum	FACW	L	L	L	gramshallow	0	1	0	0	0	2	20	4	3
PHPR3	Phleum pratense	FAC	E	E	M	gramshallow	0	1	0	0	0	2	18	5	3
PHLEU	Phleum sp.	FACU	E	E	E	gramupl	0	1	0	0	0	2	17	5	3
PHGR16	Phlox gracilis	UPL	E	E	E	taprootdry	0	0	0	1	0	2	2	1	2
PICO	PINUS CONTORTA	FAC	M	M	L	woodymesic	0	0	0	1	1	2	17	6	3
PICOM	PINUS CONTORTA	FAC	M	M	L	woodymesic	0	0	0	1	1	2	17	6	3

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PICOM4	PINUS CONTORTA	FAC	M	M	L	woodymesic	0	0	0	1	1	2	24	6	3
PIJE	Pinus jeffreyi	FACU	E	E	E	woodydry	0	0	0	1	1	2	10	6	3
PLAGI	PLAGIOBOTHRYS SP.	FACU	E	E	M	gramdry									
PLMA2	Plantago major	FACU	E	E	E	taprootdry	0	0	0	1	0	2	8	3	2
PLLE5	Plantanthera dilatata	FAC	E	E	M	taprootdry	0	0	0	1	0	2	28	4	3
PLANT	Plantanthera sp.	FACW	E	E	E	taprootwet	0	0	0	1	0	2	0	3	3
PLHY2	Platanthera hyperborea	FACW	L	L	L	taprootwet	0	0	0	1	0	2	12	4	3
POA	POA	FACU	E	E	M	gramupl									
POAN	Poa annua	FAC	E	E	E	gramshallow	0	1	0	0	0	2	1	2	3
POBU	Poa bulbosa	FACU	E	E	E	gramupl	0	1	0	0	0	2	6	3	3
POCO	Poa compressa	FAC	E	E	M	gramshallow	0	1	0	0	0	2	3	3	4
POCU3	Poa cusickii	FACW	L	L	L	gramshallow	0	1	0	0	0	2	4	3	3
POCUE2	Poa cusickii eplis	FACW	L	L	L	gramshallow	0	1	0	0	0	2	10	3	3
POPR	Poa pratensis	FACU	E	M	L	gramupl	0	1	0	0	0	2	16	4	4
PONE3	Poa secunda	FACU	M	L	L	gramupl	0	1	0	0	0	2	12	4	3
POSE	Poa secunda	FACU	M	L	L	gramupl	0	1	0	0	0	2	12	4	3
POSEJ	Poa secunda juncifolia	FACU	M	L	L	gramupl	0	1	0	0	0	2	15	4	3
POSES	Poa secunda secunda	FACU	M	L	L	gramupl	0	1	0	0	0	2	12	4	3
POST11	Poa stebbinsii	FACW	M	L	L	gramshallow	0	1	0	0	0	2	11	4	3
POWH2	Poa wheeleri	FACU	E	E	L	gramupl	0	1	0	0	0	2	19	5	4
POBI	Polygonum bistortoides	OBL	M	M	M	rhizforbwet	0	0	0	1	0	2	12	2	4
POBI6	Polygonum bistortoides	OBL	M	M	M	rhizforbwet	0	0	0	1	0	2	15	4	4
PODA	Polygonum davisiae	UPL	E	E	E	taprootdry									
PODO	Polygonum douglasii	FACU	E	E	E	taprootdry	0	0	0	1	0	1	8	3	1
PODO4	Polygonum douglasii	FACU	E	E	E	taprootdry	0	0	0	1	0	1	8	3	1
POMI2	Polygonum minimum	FAC	E	E	E	taprootdry	0	0	0	1	0	1	14	3	1
POPO4	Polygonum polygaloides ssp. kell	FAC	E	E	E	taprootdry	0	0	0	1	0	1	4	2	1
POPOK	Polygonum polygaloides ssp. kell	FAC	E	E	E	taprootdry	0	0	0	1	0	1	4	2	1
POLYG	Polygonum sp.	FACU	E	E	E	rhizforbdry	0	0	0	1	0	2	8	3	4
POAN5	Potentilla anserina	FACW	E	E	E	rhizforbwet	0	0	0	1	0	2	17	2	4
POBI7	Potentilla biennis	FACW	E	E	E	taprootwet	0	0	0	1	0	1	4	2	1
PODR	Potentilla drummondii	FACW	M	M	M	taprootwet	0	0	0	1	0	2	16	3	3
POFL	Potentilla floribunda	FAC	E	E	M	taprootdry	0	0	0	1	0	2	13	3	3
POFL3	Potentilla floribunda	FAC	E	M	M	taprootdry	0	0	0	1	0	2	13	3	3
POGL9	Potentilla glandulosa	FAC	E	E	E	taprootdry	0	0	0	1	0	2	17	3	3
POGR9	Potentilla gracilis	FACW	E	E	E	rhizforbwet	0	0	0	1	0	2	14	3	4
POTEN	Potentilla sp.	FAC	E	E	E	taprootdry	0	0	0	1	1	2	22	6	3
LOPUP	Potus purshianus	FAC	E	E	E	taprootdry	0	0	0	1	0	1	8	3	1
PRVU	Prunella vulgaris	FACW	M	M	M	taprootwet	0	0	0	1	0	2	4	3	2
PSJA2	Pseudostellaria jamesiana	FACU	M	L	E	taprootdry	0	0	0	1	0	2	10	3	2
PEBOB	Pteridia bolanderi	FACW	L	L	L	taprootwet	0	0	0	1	0	2	10	4	2
PTKI	PTILIGROSTIS KINII	FACU	L	L	L	gramupl									
PUCCI	Puccinellia sp.	OBL	L	L	L	gramshallow	0	1	0	0	0	2	12	4	4
PYAP2	Pyrrocoma apargioides	FACW	E	E	E	taprootwet	0	0	0	1	0	2	11	3	2
PYUN2	PYRROCOMA UNIFLORA	FACW	M	M	M	taprootwet									
RAAL	Ranunculus alismifolius	FACW	E	E	E	taprootwet	0	0	0	1	0	2	17	3	2
RAAL2	Ranunculus alismifolius	FACW	E	E	E	taprootwet	0	0	0	1	0	2	17	3	2
RACA2	Ranunculus californicus	FAC	E	E	M	taprootdry	0	0	0	1	0	2	16	3	2
RAFL2	RANUNCULUS FLAMMULA	FACW	M	M	M	rhizforbwet									

SPECIES	SCIENTIFIC NAME	WETLAND	WET	MOIST	DRY	FUNCTION	N FIXER	GRASS	GRASSLIKE	FORB	WOODY	LIFEHIST	ROOT	HT	LATERALS
RAOC	Ranunculus occidentalis	FACW	E	E	E	taprootwet	0	0	0	1	0	2	11	3	2
RAOR3	Ranunculus orthorhynchus	FACW	E	E	E	taprootwet	0	0	0	1	0	2	16	3	2
RANUN	Ranunculus sp.	FACW	E	E	M	taprootwet	0	0	0	1	0	2	20	3	2
RIAU	Ribes aureum	FACW	L	L	L	rhizforbwet	0	0	0	1	1	2	3	6	4
RICE	Ribes cereum	FACU	E	E	E	taprootdry	0	0	0	1	1	2	1	6	3
RIIN2	Ribes inerme	FACW	L	L	L	taprootwet	0	0	0	1	1	2	2	6	3
RIMO2	Ribes montigenum	FACW	L	L	L	taprootwet	0	0	0	1	1	2	2	6	3
ROCU	Rorippa curvisiliqua	OBL	E	E	E	taprootwet	0	0	0	1	0	1	1	3	1
RONA2	Rorippa nasturtium-aquaticum	OBL	E	E	E	taprootwet	0	0	0	1	0	2	13	3	2
RORIPPA	Rorippa sp.	OBL	M	M	M	taprootwet	0	0	0	1	0	2	13	3	2
ROWOU	Rosa woodsii	FAC	M	L	L	woodymesic	0	0	0	1	1	2	2	6	4
RUFU5	RUBUS WHEELERI	UPL	E	E	E	woodydry									
RUDBE	Rudbeckia sp.	FACU	E	E	E	rhizforbdry	0	0	0	1	0	2	4	3	4
RUAC3	Rumex acetosella	FACW	E	E	M	taprootwet	0	0	0	1	0	2	12	3	3
RUCR	Rumex crispus	FACW	E	E	E	taprootwet	0	0	0	1	0	2	12	3	3
RUPA6	Rumex paucifolius	OBL	E	E	E	taprootwet	0	0	0	1	0	2	7	3	3
RUMEX	Rumex sp.	FACW	E	E	E	taprootwet	0	0	0	1	0	2	3	3	3
SASA	Sagina saginoides	FACW	E	E	E	taprootwet	0	0	0	1	0	2	0	2	2
SAGE2	Salix geyeriana	FACW	L	L	L	woodywet	0	0	0	1	1	2	10	6	3
SALE	Salix lemmonii	FACW	L	L	L	woodywet	0	0	0	1	1	2	15	6	3
SAOR	Salix orestera	FACW	L	L	L	woodywet	0	0	0	1	1	2	15	6	3
SAPL	Salix planifolia	FACW	L	L	L	wodywet	0	0	0	1	1	2	2	6	3
SAOR2	Saxifraga oregana	OBL	M	M	M	taprootwet	0	0	0	1	0	2	12	4	2
SAXIF	Saxifraga sp.	FACW	M	M	M	taprootwet	0	0	0	1	0	2	12	3	2
SCCL	Scirpus clemantis	FACW	L	L	L	gramshallow	0	0	1	0	0	2	10	2	4
SCCO	Scirpus congdonii	OBL	L	L	L	gramdeep	0	0	1	0	0	2	22	4	4
SCMI	Scirpus microcarpus	OBL	L	L	L	gramdeep	0	0	1	0	0	2	20	4	5
SCMI2	Scirpus microcarpus	OBL	L	L	L	gramdeep	0	0	1	0	0	2	20	4	5
SCIRP	Scirpus sp.	OBL	L	L	L	gramdeep	0	0	1	0	0	2	15	4	5
SCIRPUS	Scirpus SP.	OBL	L	L	L	gramdeep	0	0	1	0	0	2	20	4	5
SESES	Senecia serra	OBL	M	E	M	taprootwet	0	0	0	1	0	2	12	5	2
SEHY2	Senecio hydrophilus	OBL	M	M	M	taprootwet	0	0	0	1	0	2	14	5	2
SECA2	Senecio serra	FACW	M	M	M	taprootwet	0	0	0	1	0	2	2	4	2
SETR	Senecio triangularis	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	18	5	4
SIPR	Sibbaldia procumbens	FAC	E	L	L	taprootdry	0	0	0	1	0	2	11	2	2
SIMA2	Sidalcea malviflora	FAC	E	E	M	taprootdry	0	0	0	1	0	2	5	3	2
SIOR	Sidalcea oregana	OBL	E	E	E	taprootwet	0	0	0	1	0	2	5	4	2
SIRA	Sidalcea ranunculacea	OBL	E	E	E	taprootwet	0	0	0	1	0	2	3	4	2
SIRE	Sidalcea reptans	OBL	E	E	E	taprootwet	0	0	0	1	0	2	15	4	2
SIDAL	Sidalcea sp.	FACW	E	E	E	taprootwet	0	0	0	1	0	2	5	3	2
SILEN	Silene sp.	FAC	E	E	M	taprootdry	0	0	0	1	0	2	22	4	2
SISYM	Sisymbrium sp.	FACW	M	M	M	taprootwet	0	0	0	1	0	2	1	4	2
SIID	Sisyrinchium idahoense	FACW	M	M	M	taprootwet	0	0	0	1	0	2	10	4	2
SISYR	Sisyrinchium sp.	FAC	E	E	M	taprootdry	0	0	0	1	0	2	15	4	2
SOCA5	Solidaga canadensis	FAC	E	E	M	taprootdry	0	0	0	1	0	2	10	4	3
SOCAE	Solidaga canadensis	FAC	E	E	E	taprootdry	0	0	0	1	0	2	11	4	3
SOMU	Solidago multiradiata	FACU	E	E	E	taprootdry	0	0	0	1	0	2	20	4	3
SOLID	Solidatgo californica	FAC	E	E	E	taprootdry	0	0	0	1	0	2	22	4	3
SPAR	Spergula arvensis	UPL	E	E	E	taprootdry	0	0	0	1	0	1	9	3	1

SPECIES	SCIENTIFIC NAME	WETLAND	WET	MOIST	DRY	FUNCTION	N FIXER	GRASS	GRASSLIKE	FORB	WOODY	LIFEHIST	ROOT	HT	LATERALS
SPRU	Spergularia rubra	FAC	E	E	E	taprootdry	0	0	0	1	0	1	10	3	1
SPCA5	Sphenosciadium capitellatum	OBL	L	L	L	taprootwet	0	0	0	1	0	2	12	4	2
SPRO	Spiranthes romanzoffiana	OBL	L	L	L	taprootwet	0	0	0	1	0	2	21	4	2
STBU	Stachys bullata	FAC	E	E	M	taprootdry	0	0	0	1	0	2	27	4	2
STAJR	Stachys rigida	FAC	E	E	M	taprootdry	0	0	0	1	0	2	10	4	2
STLO	Stellaria longipes	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	17	4	4
STLO2	Stellaria longipes	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	17	4	4
STLOL5	Stellaria longipes	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	17	4	4
STELL	Stellaria sp.	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	27	4	4
ASAD6	Symphyotrichum ascendens	FAC	E	E	E	rhizforbdry	0	0	0	1	0	2	12	4	4
TACA8	TAENIATHERUM CAPUT-MEDU	UPL	E	E	E	annual									
TAOF	Taraxacum officinale	FACW	E	E	E	taprootwet	0	0	0	1	0	2	4	3	2
TARAX	Taraxacum sp.	FACW	E	E	E	taprootwet	0	0	0	1	0	2	4	3	2
THFE	THALICTRUM FENDERLIANA	FACU	E	E	E	taprootdry	0	0	0	1	0	2	2	3	3
TOGLO2	TOFIELDIA	OBL	L	L	L	taprootwet									
TRAL5	Triantha occidentalis	FAC	E	E	E	taprootdry	0	0	0	1	0	1	1	3	1
TROB	Trichostema oblongum	FACW	E	E	E	Nfix		0	0	1	0	1	2	4	1
TRHI4	Tridolium hirtum	FACU	E	E	E	taprootdry	1	0	0	1	0	1	2	3	2
TRBO	Trifolium bolanderi	OBL	M	M	M	Nfix	1	0	0	1	0	1	3	1	1
TRBO3	Trifolium bolanderi	OBL	E	E	E	Nfix	1	0	0	1	0	1	12	3	2
TRCY	Trifolium cyathiferum	FACW	E	E	E	Nfix	1	0	0	1	0	1	2	3	1
TRER2	TRIFOLIUM ERIOCEPHALUM	FAC	M	M	M	Nfix									
TRLE2	Trifolium lemmonii	FACW	M	M	M	Nfix	1	0	0	1	0	2	6	3	2
TRLO	Trifolium longipes	FACW	M	M	M	Nfix	1	0	0	1	0	2	12	3	4
TRMI4	Trifolium microcephalum	FACW	E	E	E	Nfix	1	0	0	1	0	1	9	3	1
TRMI5	TRIFOLIUM MOICRODON	UPL	E	E	E	Nfix									
TRMO	Trifolium monanthum	FACW	M	M	M	Nfix	1	0	0	1	0	2	12	3	2
TRMO2	Trifolium monanthum	FACW	M	M	M	Nfix	1	0	0	1	0	2	12	3	2
TRRE	Trifolium repens	FAC	E	E	E	Nfix	1	0	0	1	0	2	3	3	4
TRRE3	Trifolium repens	FAC	E	E	E	Nfix	1	0	0	1	0	2	3	3	4
TRIFO	Trifolium TRIFOLIUM	FACW	M	M	M	Nfix	1	0	0	1	0	2	2	5	2
TRVA	Trifolium variegatum	FACW	M	M	M	taprootwet	1	0	0	1	0	1	8	3	1
TRWI3	Trifolium wildenovii	FACW	E	E	E	taprootwet	1	0	0	1	0	1	1	3	1
TRWO	Trifolium wormskioldii	OBL	M	M	M	Nfix	1	0	0	1	0	2	16	3	4
TRSP2	Trisetum spicatum	FACW	L	L	L	gramshallow	0	1	0	0	0	2	11	4	3
TRWO3	Trisetum wolfii	FACW	L	L	L	gramshallow	0	1	0	0	0	2	12	4	3
TRHY3	Triteleia hyacinthina	FACW	E	M	M	taprootwet	1	0	0	1	0	2	10	3	3
2GRAM	UNK graminoid	FAC	E	M	L	gramupl									
URDI	Urtica dioica	FACW	E	E	E	taprootwet	0	0	0	1	0	2	2	4	1
URTIC	Urtica sp.	FACW	E	E	E	rhizforbwet	0	0	0	1	0	2	13	4	4
VACA	VACCINIUM CESPITOSUM	FACW	L	L	L	taprootwet	0	0	0	1	1	2	12	5	3
VACE	VACCINIUM CESPITOSUM	FACW	L	L	L	taprootwet	0	0	0	1	1	2	12	5	3
VACCI	VACCINIUM SP.	FACW	L	L	L	taprootwet	0	0	0	1	1	2	12	5	3
VAUL	VACCINIUM ULIGINOSUM	FACW	L	L	L	taprootwet	0	0	0	1	1	2	12	5	3
VAULO	VACCINIUM ULIGINOSUM	FACW	L	L	L	taprootwet	0	0	0	1	1	2	12	5	3
DEPA12	Vahlodia atropurpurea	FACW	L	L	L	taprootwet	0	1	0	0	0	2	12	3	
VECA2	Veratrum californicum	OBL	M	M	M	rhizforbwet	0	0	0	1	0	2	12	6	4
VECAC	Veratrum californicum	OBL	M	M	M	rhizforbwet	0	0	0	1	0	2	12	6	4
VETH	Verbascum thapsus	FAC	E	E	E	taprootdry	0	0	0	1	0	2	3	6	2

SPECIES	SCIENTIFIC NAME	WETLAND	WET	MOIST	DRY	FUNCTION	N FIXER	GRASS	GRASSLIKE	FORB	WOODY	LIFEHIST	ROOT	HT	LATERALS
VELA	Verbena lasiostachys	FAC	E	E	E	taprootdry	0	0	0	1	0	2	16	4	2
VEAM2	Veronica americana	OBL	M	M	M	rhizforbwet	0	0	0	1	0	2	20	3	4
VEAR	Veronica arvensis*	FAC	E	E	M	taprootdry	0	0	0	1	0	1	7	1	3
VECH	VERONICA CHAMAEDRYS	UPL	E	E	E	taprootdry									
VESC2	Veronica scutellata	OBL	M	M	M	taprootwet	0	0	0	1	0	2	17	3	2
VERON	Veronica sp.	FAC	M	M	M	taprootdry	0	0	0	1	0	1	14	3	2
VEWO2	Veronica wormskjoldii	FACW	M	M	M	rhizforbwet	0	0	0	1	0	2	4	1	4
VIAM	Vicia americana	FAC	E	E	M	rhizforbdry	0	0	0	1	0	2	6	4	4
VICIA	Vicia sp.	FAC	E	E	E	taprootdry	0	0	0	1	0	2	2	3	2
VIAD	Viola adunca	FAC	M	M	M	taprootdry	0	0	0	1	0	2	5	3	2
VIGL	Viola glabella	FACW	M	M	M	taprootwet	0	0	0	1	0	2	22	3	2
VIMA	Viola macloskeyi	OBL	M	M	M	taprootwet	0	0	0	1	0	2	17	3	2
VIMA2	Viola macloskeyi	OBL	M	M	M	taprootwet	0	0	0	1	0	2	17	3	2
VIOLA	Viola sp.	FACW	M	M	M	taprootwet	0	0	0	1	0	2	21	3	2
VUMY	VUPLIA MYUROS	UPL	E	E	E	annual	0	0	0	1	0	1	1	1	1
VUOC	VUPLIA OCTOFLORA	UPL	E	E	E	annual	0	0	0	1	0	1	1	1	1
VULPIA	VUPLIA SP.	UPL	E	E	E	annual	0	0	0	1	0	1	1	1	1
WYOV	Wyethia ovina	FACU	E	E	E	taprootdry	0	0	0	1	0	2	2	3	2
WYETH	Wyethis ap.	FACU	E	E	E	taprootdry	0	0	0	1	0	2	2	4	3
DODEC		FACW	M	M	M	taprootwet	0	0	0	1	0	2	11	4	3

APPENDIX B

List of Example Restoration Projects in the Sierra

Table B.1. This table presents examples of meadow restoration projects in the Sierra Nevada which involve channel reconstruction through in-channel treatments (CR) and Pond and Plug (P&P) methods; database populated and compiled by American Rivers.

Project Name	Watershed	Years	Project Location	Technique Code*	Technique Description	Ownership	Watershed	Monitoring Data
Angora Creek and Washoe Meadows Wildlife Habitat Enhancement	Upper Truckee River	1997-2002	Upper Truckee River, CA	CR	Channel Reconstruction - Maintenance of Hydraulic Connections & Stream Meander Restoration	California State Parks	Upper Truckee River	Stream Geomorphology and Stability, Surface and Groundwater, Vegetation, Aquatic Invertebrates, Photography
Cook's Meadow Restoration	Merced	1998-2006	Yosemite National Park, CA	CR	Channel Reconstruction - Maintenance of Hydraulic Connections, Best Management Practices - Forestland, Fow Regime Enhancement - Culvert Realignment	National Park Service: Yosemite National Park	Merced	Vegetation, Surface and Groundwater (NPS)
Evans Meadow Improvement Project	North Fork Kaweah River, CA		North Fork Kaweah River, CA	CR	Instream Practices - Grade Control Measures, Streambank Treatment - Fiber Roll, Stream Corridor Measures - Livestock Exclusion or Management	USFS Sequoia National Forest		Unknown
Greenhorn Creek	Indian Creek	1991-1992	Feather River, CA	CR	Channel Reconstruction; Streambank Treatment - Vegetation, Instream Practices - Grade Control Measures, Best Management Practices - Forestland	Private	Indian Creek	Stream Conditions and wildlife (NRCS, USFS, CDFG)
Lower Red River Meadow	Red River	1994 - 2004	Lower Red River, ID	CR	Channel Reconstruction, Streambank Treatment - Vegetation & Rock, Instream Practices - Grade Control Measures	Idaho Department of Fish and Game	Red River	Channel Geometry, Surface and Groundwater Hydrology, Riparian and Fish Habitat, Wildlife and Fish Populations
Restoration Plan for Upper Halstead Meadow		2006	Sequoia National Forest, CA	CR	Grading, Gully Fill, Revegetation	USFS Sequoia National Forest		Hydrology, vegetation, water table depth for 3 yrs

* CR refers to in-channel channel reconstruction techniques (see sections 4.2.1.1 through 4.2.1.3)
P&P refers to the Pond and Plug method of channel realignment (see section 4.2.1.4)

Project Name	Watershed	Years	Project Location	Technique Code	Technique Description	Ownership	Watershed	Monitoring Data
Big Flat Meadow Re-watering Project (1995) Big Flat Modification (2004)	Cottonwood Creek	1994-2004	Feather River, CA	P&P	Pond & Plug, Instream Practices - Grade Control Measures, Channel Reconstruction, Streambank Treatment - Vegetation, Stream Corridor Measures - Livestock Exclusion or Management	96% USFS Plumas National Forest - 4% Private	Cottonwood Creek	Fish Population, Stream Flow, Groundwater, Vegetation, Channel Stability and Structure
Big Meadows Creek Restoration Project	Big Meadows Creek	2004-2009	Sequoia National Forest, Giant Sequoia National Monument, Hume Lake Ranger District, Tulare County, CA	P&P	Pond & Plug, Large Woody Debris Installation, Grade Control Measures, Re-vegetation	USFS Sequoia National Forest	Big Meadows Creek	Groundwater, Benthic Macroiverterbrates, Water Temp in Ponds, Avian Studies, Hydrology of unknown composition (irregularities in data prevented report from being published), Stream Condition Inventory and Range Plot Inventory (Sequoia National Forest)
Clarks Creek	Clarks Creek	1998-2008	Feather River, CA	P&P	Pond & Plug, Streambank Treatment - Vegetation, Stream Corridor Measures - Livestock Exclusion or Management	USFS Plumas National Forest	Clarks Creek	Fish and Wildlife (DWR), Groundwater, Vegetation (FR-CRM), aerial and ground photography
Dooley Creek/Downing Meadow	Last Chance	2004 - 2005	Feather River, CA	P&P	Pond & Plug, Streambank Treatment - Vegetation & Rock, Stream Corridor Measures - Livestock Exclusion and Management, Flow Regime Enhancement - Culvert Removal	Private - within the Plumas National Forest Beckwourth RD	Last Chance	Vegetation, Surface Flows (FRCRM)
Hosselkus Creek Stream Restoration	Indian Creek	2002 (Phase 1), 2006 (Phase 2)	Plumas National Forest, Mount Hough Ranger District, Last Chance Creek Watershed Management Aera (29), CA: Phase II	P&P	Plug & Pond, Grazing Management, Re-Vegetation,	Public: Plumas National Forest Private: Neff Family	Indian Creek	Groundwater, Vegetation, Photo (FRCRM)
Carmen Creek Watershed Restoration Project		Unknown	Tahoe National Forest, Sierraville Ranger District, Carmen Creek Watershed, Sierra County, CA	P&P	Plug & Pond, Floodplain & Hillslope Re-Contouring			Unknown

* CR refers to in-channel channel reconstruction techniques (see sections 4.2.1.1 through 4.2.1.3)
P&P refers to the Pond and Plug method of channel realignment (see section 4.2.1.4)

Project Name	Watershed	Years	Project Location	Technique Code*	Technique Description	Ownership	Watershed	Monitoring Data
Perazzo Meadow Watershed Restoration Project and Grazing Allotment Management		2008 - Ongoing	Tahoe National Forest, Sierraville Ranger District, Sierra County, CA	P&P	Pond & Plug, Grade Control Measures, Grazing Management, Access Road Decomissioning, Culvert Installation	Tahoe National Forest		Photo Documentation, Stream Channel Cross-Sections, R5 Range Long Term Monitoring Project (Weixelman), Willow Flycatcher Habitat, PFC assessment (3-5 yrs), Vegetation, Soil Conditions, Groundwater
Boulder Creek Restoration Project or Raap-Guidici Creek Floodplain Project	Sulphur Creek	2007-2008	Approximately 3 miles southwest of Clio, CA within Whitehawk Ranch off Hwy. 89	P&P	Pond & Plug, Grade Control Measures, Streambank Treatment - Vegetation	Private: Ron Rapp & Mike Murray	Sulphur Creek	Photo Documentation, Water Tempreture, Suspended Sediment, Riparian and Noxious Vegetation, Groundwater Recharge, Fish
Red Clover / McReynolds Creek Restoration Project	Red Clover	2006	Plumas National Forest, Beckworth Ranger District, Red Clover Creek Management Area (36) Plumas County, CA	P&P	Pond & Plug, Exclusion Fencing (within meadow and access road), Grade Control Measures, Revegetation, Grazing Management	Private - 715 ac, Plumas National Forest - 60 ac	Red Clover	Surface Water and Groundwater Hydrology, Water Quality, Precipitation, Fish and Wildlife, Vegetation, Photographs.
Davies / Merrill Watershed Restoration Project		2003	Tahoe National Forest, Sierraville Ranger District, Sierra County, CA	P&P	Plug & Pond, Floodplain & Hillslope Re-Contouring, Culvert Installation, Re-Vegetation	Tahoe National Forest		
Red Clover / McReynolds Creek Restoration Project	Red Clover	2003	Plumas National Forest, Beckwourth Ranger District, Clover Creek Management Area, Plumas County, CA	P&P	Plug & Pond, Grade Control Measures, Aquatic Life Management, Re-vegetation, Grazing Management, Noxious Week Management, Streamflow Management / Water Rights	715 Acres - Private, 60 Acres - USFS Plumas National Forest	Red Clover	Water Temperature, Vegetative Cover, Species and Vigor to Monitor Groundwater Levels, Forage and Erosion Rates, Fish and Wildlife Populations, Channel Morphology. Also a separate study on portions of private land looking at Groundwater using Stable Isotope Analysis.

* CR refers to in-channel channel reconstruction techniques (see sections 4.2.1.1 through 4.2.1.3)
P&P refers to the Pond and Plug method of channel realignment (see section 4.2.1.4)