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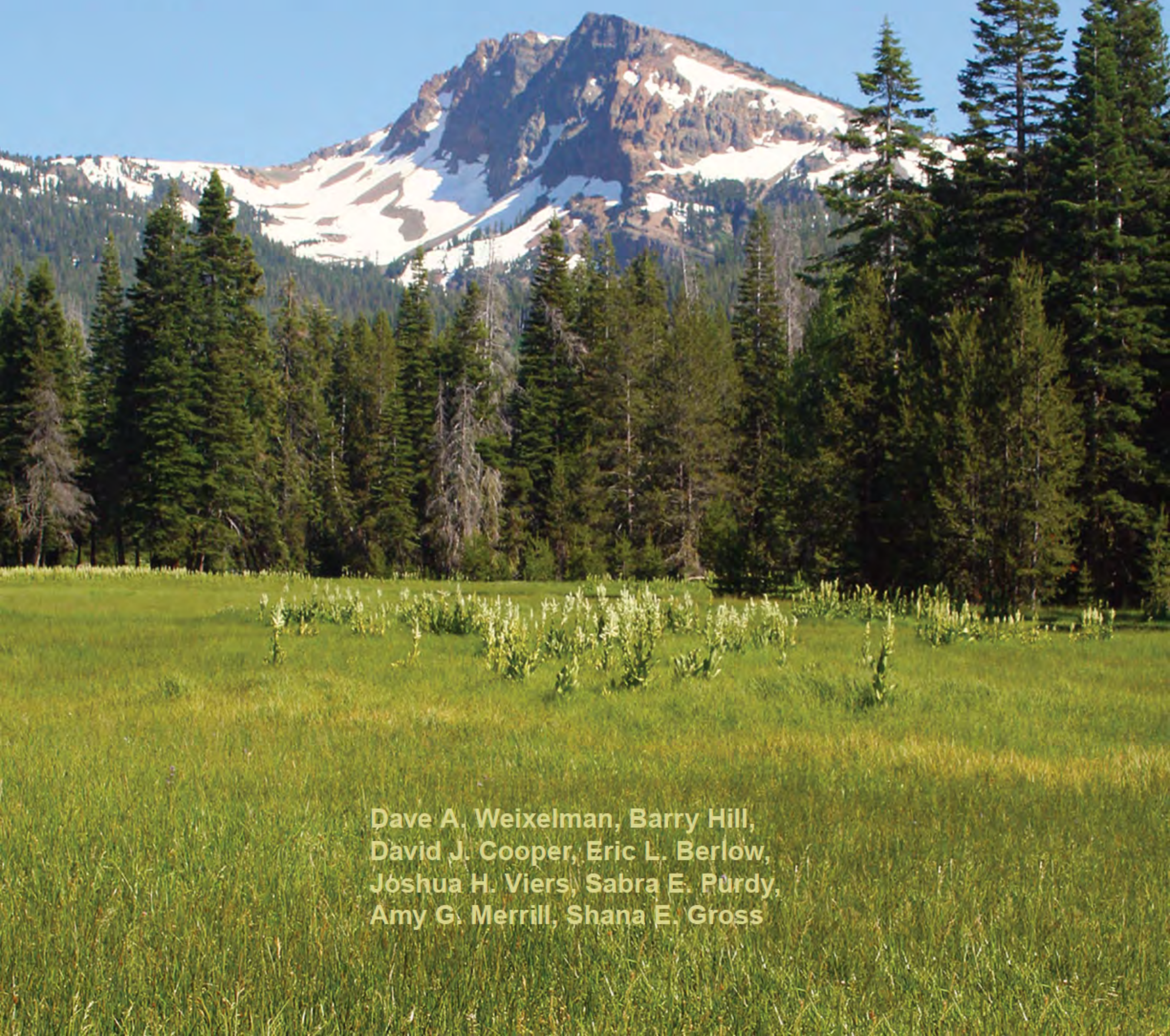
Meadow Hydrogeomorphic Types for the Sierra Nevada and Southern Cascade Ranges in California

A Field Key



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Abstract

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The purpose of this document is to provide a dichotomous key to meadow hydrogeomorphic types for the Sierra Nevada and Southern Cascades of California. This classification and field key uses both hydrology and geomorphology to identify fourteen meadow types. Strengths of the classification include its ability to clarify the relationship between hydrology and geomorphology and meadow function.

Meadows are extremely valuable to society and to the natural systems that support society. Meadows reduce peak water flow after storms and during runoff, recharge groundwater supplies as they release water into the ground, protect streambanks and shorelines, filter sediments, provide habitat for a wide variety of wildlife, and serve important recreational and cultural functions. Because of these multiple purposes, land managers face a special challenge to maintain, restore, and manage meadows. To aid in management, a classification of meadows is needed that uses both hydrology and geomorphology in identifying types and functioning of meadows. Potential uses for this classification include stratifying meadows for condition assessment and as an aid in mapping or delineating meadow features on the landscape.

Keywords: meadow, hydrology, hydrogeomorphology, geomorphology, wetland, Sierra Nevada

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INTRODUCTION

Meadows are extremely valuable to society and to the natural systems that support society. Meadows reduce peak water flow after storms and during runoff, recharge groundwater supplies as they release water into the ground, protect streambanks and shorelines, provide habitat for a wide variety of wildlife, and serve important recreational and cultural functions. In addition, meadows filter sediments from water of surrounding slopes reducing sedimentation in lakes and reservoirs, and helping to provide clean waters in streams and lakes. Meadows are highly productive in terms of number of species and biomass of individuals. Because of these multiple purposes, land managers face a special challenge to maintain, restore, and manage meadows. To aid in the management of meadows, classifications are needed that increase our understanding of the relationship of landform position of meadows and water inputs and outputs from meadows. This classification provides a framework for addressing condition and functioning of meadows, provides stratification for mapping meadows, and provides a common naming convention for addressing meadow types.

CHARACTERISTICS OF MEADOWS

In the simplest terms, meadows are defined by hydrology, vegetation, and soil characteristics. Meadows in the Sierra Nevada and Southern Cascades in California have these characteristics in common:

- ✓ **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).**
- ✓ **Woody vegetation, like trees or shrubs, may occur and be dense but are not dominant.**

Meadows are characterized by the existence of two fundamental abiotic conditions: (1) a shallow water table (usually less than 1 m) during the summer; and (2) surficial soil material that is fine-textured. Water tables are high and persistent enough to favor hydric herbaceous species and limit the establishment of trees and most shrubs. Hydrologic processes control the amount, source, and duration of water entering a meadow. Geomorphology (landform) controls where water comes from and whether it leaves the meadow system. Directional flow of water is also an important characteristic. Terms like outflow, inflow, and throughflow describe whether a meadow is a source, sink, or pass-through system respectively. Meadows perform different functions, depending on the gradient of the groundwater table and the topography of the land surface. The relationship of the groundwater table and the land surface dictates which function - groundwater recharge or discharge - a meadow performs. Groundwater recharge adds water to the groundwater system whereas groundwater discharge takes water from the groundwater system. Meadows may include areas that are wetland, but depending upon the wetland definition being used, not all areas within meadows will necessarily meet that definition's criteria. Therefore, when trying to determine if a meadow or part of a meadow is a wetland, the user must first decide on the wetland definition to be used, and then determine if the meadow or part of the meadow meets these criteria.

Meadows that develop on mineral soils can be separated from meadows that occur on organic soils (peatlands) where an accumulation of peat creates the substrate, influences groundwater conditions, selects for specialized vegetation, and modifies surface morphology of the wetland. Sources of water in meadows can be precipitation, groundwater, or surface flow, or a combination of these sources. Meadows that receive little groundwater inflow or surface water inputs are often precipitation and/or snowmelt dominated and become dry during summer. Sometimes these precipitation and/or snowmelt dominated meadows are located in depressions with an impervious layer which retains precipitation and prevents the discharge of groundwater. Precipitation dominated meadows can also occur on a number of different landforms and typically results in a dry meadow type.

Meadows also form in landscape positions where water actively discharges in the form of springs or seeps, particularly on hillslopes, at the base of hills and at the base of alluvial fans. These groundwater dominated meadows may also receive overland flow but they have a steady supply of water from groundwater. Most meadows in low points and in areas of valley fill (alluvium) are dominated by overland surface flow or a combination of surface and groundwater flow. Meadows that occur on alluvium or in valley bottoms or swales that lack a stream channel are often fed by subsurface groundwater without significant surface water inputs. Riparian meadows are found on floodplains and terraces associated with stream channels. Riparian meadow systems are fed both by surface water from flood events and by subsurface groundwater. The amount of lateral groundwater inflow from the hillslopes as compared to basal-groundwater inflow is often a key determinant of the type and pattern of meadow vegetation (Loheide et al. 2009). Further, groundwater inflow from the hillslope, to the hillslope/riparian interface, and ultimately to the riparian zone is strongly affected by bedrock permeability in granitic regions (Katsuyama and Ohte 2005).

Riparian meadows can be further broken down based on slope steepness as low, middle, or high gradient. Stream gradient is correlated with riparian vegetation (Quistberg and Stringham 2009), flow velocity, substrate material, floodplain development, channel morphology and stream habitat types (pools, riffles, runs, etc.)(Rosgen 1994, Montgomery and Buffington 1997). Lacustrine fringe meadows are located along lake shores where the water elevation of the lake influences the water table of the adjacent meadow. These riparian (associated with a stream or river), and lacustrine (associated with a lake) meadows come in contact with, store, or release large quantities of water.

CLASSIFICATION OF MEADOWS

Efforts to classify meadows in the Sierra Nevada have used plant communities (Sumner 1941, Bennett 1965, Pemble 1970, Chabot and Billings 1972, Taylor 1976, Ratliff 1979 and 1982, Benedict and Major 1981, Jackson and Bliss 1982, Benedict 1983, Taylor 1984, Halpern 1985, Manning and Padgett 1995, Cheng 2004, Potter 2006, Barbour et al. 2007, Sawyer et al. 2009), general topography (Harkin and Schultz 1967, Benedict and Major 1982, Ratliff 1986), elevational range (Sharsmith 1959), site potential (Weixelman et al. 1999, Rundel et al. 2009), stratigraphy from the Holocene record (Wood 1975), moisture gradient as wet, moist, and dry (Klikoff 1965), and peatland types (Cooper and Wolf 2005, Weixelman and Cooper 2009, Sikes et al. 2010).

Figure 1*. The geographic extent (green shading) covered by the classification for the Sierra Nevada and Southern Cascade ranges in California.*

This classification and field key uses both hydrology and geomorphology to identify fourteen meadow hydrogeomorphic types and takes many concepts from Brinson (1993). The geographic extent where this classification has been used is shown in Figure 1. Plant nomenclature in this document follows Hickman (1993). Strengths of the classification include its ability to clarify the relationship between hydrology and geomorphology and meadow function. Landform features, water sources, and water flow directions are an integral part of this hydrogeomorphic classification. Patterns of landform occurrence, the source and amount of water in a meadow, and the path the water takes through the meadow have reoccurring characteristics that help identify and stratify meadows for management interpretations. The individual types in this classification, together with plant species information, would allow for a determination of ecological function based on the relationship between meadow type, ecological functioning, and plant functional groups.

USING THE KEY

Meadows, as defined above, may contain one or more hydrogeomorphic types depending on landscape position, water sources, and flow direction. The dichotomous key is designed to help the user identify these individual hydrogeomorphic types. In some cases, the meadow may be composed of only one hydrogeomorphic type, in other cases there will be two or more hydrogeomorphic types present. To use this key, start by locating a representative section of the meadow. The representative section should generally be consistent in soil moisture, and occur on a single dominant landform. Once this representative section of the meadow area has been located, the dichotomous key can be used to determine the hydrogeomorphic type. Definitions of terms used in the key can be found in Appendix A. If the meadow includes sites that are distinctly different in landscape position and/or soil moisture characteristics, those sites may need to be keyed separately. In that case there may be more than one hydrogeomorphic type present in the meadow.

An example of a meadow is shown in Figure 2. In this figure, there is a stream channel running the length of the meadow and the predominant landform is a floodplain adjacent to the stream channel. Representative sampling locations are marked by an "X." At these sampling locations, the dichotomous key was used to identify a hydrogeomorphic type. The dominant type was the *riparian low gradient*. Also present were two other hydrogeomorphic types within the meadow, a *discharge slope* type located on a toeslope and a *dry* type located on a terrace at the outer edge of the meadow. This example illustrates the concept of a meadow and component hydrogeomorphic types which make up the meadow.

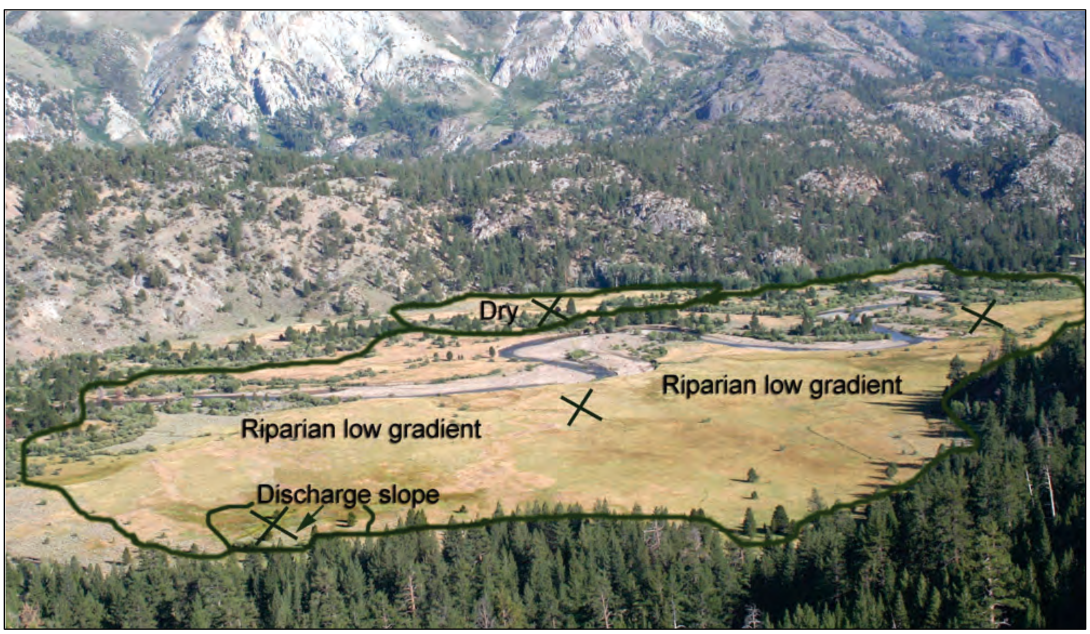

Figure 2. *Illustration of a meadow and the component hydrogeomorphic types which make up the meadow. Also shown are the representative locations (marked by X's) where the dichotomous key was used in the field to identify the component hydrogeomorphic types.*

FIELD KEY TO MEADOW HYDROGEOMORPHIC TYPES

Note: More than one hydrogeomorphic type may occur in a meadow area.

1a. **At least 20 cm** of organic soil material present in the top 40 cm of soil. Water table is typically within 20 cm of the surface for most of the summer, and clonal peat forming plant species are typically present (e.g. members of the Cyperaceae or Juncaceae)........2

2a. Occurs in a basin typically without inlets or outlets, or at the margins of lakes or ponds........**Basin peatland, page 8**

2b. Not as above. Not occurring in a basin or at the margin of a lake or pond. Fed by a spring or a series springs........3

3a. Occurs at the base of slopes, on toeslopes, or valley bottoms where peat has accumulated creating a mound. The mound is a result of a single, strong source of upwelling water (groundwater discharge) to the surface. There typically is a surface water outlet so they are not classified as basin peatlands........**Mound peatland, page 9**

3b. Not as above. Occurs on a hillslope, toeslope, or at the base of an alluvial fan where groundwater discharges to the surface and flows downslope in a gravity-driven system. No distinct mound structure is apparent........**Discharge slope peatland, page 10**

1b. Not as above. **Less than 20 cm** of organic soil material present in the top 40 cm of soil. Water table is within 20 cm of the surface for most of the summer or not, clonal peat forming species may be present or not........4

4a. Occurs in a topographic depression with a closed elevation contour that allows accumulation of surface water. If standing water is present, the water depth is less than (or is judged to be less than) 2 meters (6.6 feet) deep. The depression may have any combination of inlets and outlets or lack them completely. Water either does not flow through the depressional meadow or the flow is essentially imperceptible. Includes artificially created depressions due to impoundments, causeways, and roads. May or may not be surrounded by upland vegetation........5

5a. Has no standing water after late July during most years. Also includes vernal pools........**Depressional seasonal, page 11**

5b. Not as above. Has some amount of standing water after late July during most years........**Depressional perennial, page 12**

FIELD KEY TO MEADOW HYDROGEOMORPHIC TYPES (Cont'd.)

4b. Not as above. Not occurring in a topographic depression 6

6a. Occurs along a lake or reservoir or within its basin (i.e. on the relatively flat area contiguous to the lake or reservoir). Depth of water in the lake is greater than (or is judged to be greater than) 2 meters (6.6 feet) deep. Meadow is immediately adjacent to the waterbody, and nearly at the same elevation as the waterbody. The upper limit of the lacustrine fringe meadow is defined by the upstream influence of the lake which is approximated by the limits of the nearly flat or gently sloping lake margin .... **Lacustrine fringe, page 13**

6b. Not as above. Not occurring along the fringe of a lake or reservoir 7

7a. Dominated by perennial dryland grasses (*Poaceae* spp.), dryland sedges (*Carex* spp.), or herbaceous dicots adapted to drying conditions during summer, e.g. plants that have a wetland rating of Facultative Upland (FACU), Upland (UPL). Soil surface generally becomes dry by midsummer. Groundwater level (water table or zone of saturation) is usually below 1m during the growing season**.** Occurs at all elevations, from the foothills up into the alpine zone and occurs on many landforms such as stream terraces, benches, swales, drainageways and occurs on alluvial, colluvial, and lacustrine deposits. May occur adjacent to wetter meadow types that receive groundwater .... **Dry, page 14**

7b. Not as above. Not dominated by dryland plant species. Dominated by plant species indicative of a shallow water table and that have a wetland rating of Obligate (OBL), Facultative Wetland (FACW), or Facultative (FAC). Groundwater level (water table or zone of saturation) is at the surface or within 1 m during all or part of the growing season. Soil surface generally moist or wet after mid-summer. 8

8a. Dominant source of water is from groundwater that emerges at or near the meadow surface in the form of springs or seepage areas. This type occurs on hillsides, toeslopes, and at the bases of alluvial fans where groundwater discharge is a dominant source to the meadow surface. In some cases, the emerging groundwater flows downhill through very small channels .... **Discharge slope, page 15**

FIELD KEY TO MEADOW HYDROGEOMORPHIC TYPES (Cont'd.)

8b. Not as above. Dominant source of water is not from a spring or seep. Meadow receives surface water from a channel (perennial or intermittent, stream or river) above the meadow. Inflow and outflow channels are visible at the top end of the meadow and bottom end of the meadow. The meadow itself may or may not have a channel (intermittent or perennial, stream or river) running through it. 9

9a. Meadow contains a channel or multiple channels (perennial or intermittent, stream or river) for a majority of its length and the meadow occurs on a floodplain or terrace adjacent to a stream or river. Channel may occur to one side of the meadow. Note: if a side-valley tributary meadow occurs adjacent to the main axial valley, include the meadow part of the side valley up to the base of the main axial valley hillslope. 10

10a. Stream gradient is less than 2 % .... **Riparian low gradient, page 16**

10b. Not as above, stream gradient is 2 % or more 11

11a. Stream gradient is 2 % to 4 % .... **Riparian middle gradient, page 17**

11b. Stream gradient is greater than 4 % .... **Riparian high gradient, page 18**

9b. Not as above. Does not contain a channel (perennial or intermittent, stream or river) for a majority of the meadow length. A stream or river (perennial or intermittent) may enter or exit this type of meadow but it does not flow through it as a channel. May have rills or ditches. Found on a variety of gradients from nearly flat to sloping. Note: if a side-valley tributary meadow occurs adjacent to the main axial valley, include the meadow part of the side valley up to the base of the main axial valley hillslope 12

12a. Downvalley slope is less than 2 % .... **Subsurface low gradient, page 19**

12b. Not as above, downvalley slope is 2 % or more 13

13a. Downvalley is slope is 2 % to 4 % .... **Subsurface middle gradient, page 20**

13a. Downvalley slope is greater than 4 % .... **Subsurface high gradient, page 21**

Basin Peatland

Setting

Basin peatlands occur on a horizontal surface, have a flat water table, are found in basins typically with no inlets or outlets, or on the fringes of lakes or ponds. The basin peatland type may also occur as small patches within the *lacustrine fringe* meadow type. There is at least 20 cm of organic soil in the top 40 cm of soil. This definition departs from a true histosol, which requires 40 cm of organic soil material in the top 1 m. Organic soil material that occurs within the rooting zone of herbaceous species is a key factor in describing peatlands in the Sierra Nevada, thus the emphasis on the upper soil layer. Organic soil material is composed primarily of dead plant parts in various stages of decomposition and accumulates in meadows and wetlands as a result of anaerobic conditions created by poorly drained conditions. By feel, organic soil material is dark in color, generally contains fibers, and feels greasy when rubbed.

Hydrology

Basin peatlands, also called topogenous peatlands (Mitsch and Gosselink 2000), are supported by surface runoff from the basin edges and/or surface water and/or groundwater inflow from an adjacent water body such as a lake or pond. Water levels in this type tend to be very stable, and some basin peatlands develop a unique feature-- a floating peat mat on the margins of open water.

Vegetation

Peatlands are typically dominated by obligate or facultative wetland graminoid and moss species that are peat forming. Scattered shrubs or coniferous trees may be present. The vegetation of peatlands varies widely and appears to be controlled by the hydrologic regime (water depth, water inflow rates), as well as water chemistry (pH, cation, anion, and nutrient concentrations) (Cooper and Wolf 2005).

Figure 3. *Photo of a basin peatland located on the margin of a lake on the Modoc National Forest.*

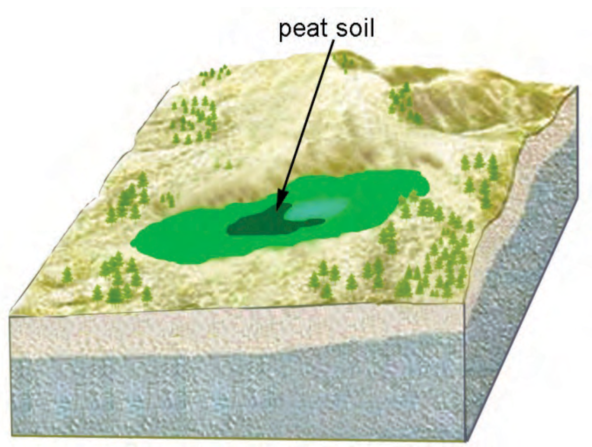

Figure 4. *Illustration showing a basin peatland type occurring as a floating mat at the edge of open water.*

Mound Peatland

Setting

This type often occurs at the base of slopes associated with sloping fens or on valley bottoms where there is a strong upwelling of groundwater discharge. This strong upwelling source of water helps create a mound of peat. There is at least 20 cm of organic soil material in the top 40 cm of soil. This definition departs from a true histosol, which requires 40 cm of organic soil in the top 1 m. An organic soil layer present within the rooting zone of herbaceous species is a key factor in describing peatlands in the Sierra, thus the emphasis on the upper soil layer. Organic soil material is composed primarily of the remains of plants in various stages of decomposition and accumulates in meadows and wetlands as a result of anaerobic conditions created by poorly drained conditions. By feel, organic soil material is dark in color, generally contains fibers, and feels greasy when rubbed. The mound peatland type may also occur as small patches within the *discharge slope* meadow type.

Hydrology

Mound peatlands are raised areas where peat has accumulated due to a single strong source of upwelling of water. There typically is a surface water outlet and thus these sites are not classified as basin peatlands.

Vegetation

Peatlands are typically dominated by obligate or facultative wetland graminoid and moss species that are peat forming. Scattered shrubs or coniferous trees may be present. The types and concentration of nutrients present in the peatland have a strong influence over the type of vegetation that occurs. Peatlands are often classified along a chemical gradient and the gradient is typically as follows: a peatland that is "poor" is characterized by low pH and low cation concentration, whereas "intermediate" and "rich" peatlands are characterized by higher pH and higher cation concentration. Most peatlands in the Sierra Nevada are considered "intermediate" or "rich."

Figure 5. *Photo of a mound peatland at the base of a toeslope and fed by upwelling ground water. Located on the Tahoe National Forest.*

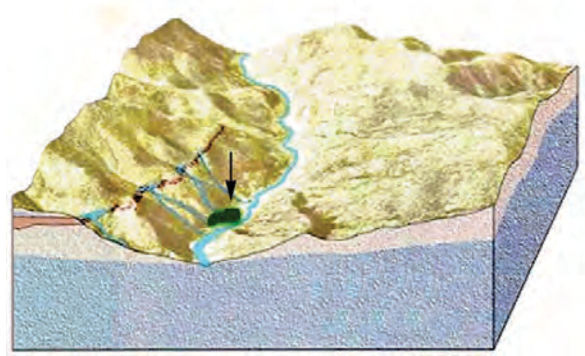

Figure 6. *Illustration showing the position of a mound peatland type occurring on a toeslope.*

Discharge Slope Peatland

Setting

Discharge slope peatlands, also called soligeneous peatlands (Mitsch and Gosselink 2000), are the most common type of peatland in the Sierra Nevada and southern Cascades. They occur over peat soils on hillslopes, toeslopes, at the base of alluvial fans, and at slope breaks on terraces. The discharge slope peatland type may also occur as small patches within the *discharge slope* meadow type. There is at least 20 cm of organic soil material in the top 40 cm of soil. This definition departs from a true histosol, which requires 40 cm of organic rich soil in the top 1 m. Organic soil material within the rooting zone of herbaceous species is a key factor in describing peatlands in the Sierra, thus the emphasis on the upper soil layer. Organic soil material will be very dark in color, contain fibers, and will feel greasy when rubbed.

Hydrology

Discharge slope peatlands are commonly fed by springs, or a complex of springs, where groundwater discharges at the surface. A discharge slope peatland is an outflow system, where there is a continuous outflowing of groundwater and/or surface water in a gravity-driven sloping system.

Vegetation

Peatlands are typically dominated by obligate or facultative wetland graminoid and moss species that are peat forming. Scattered shrubs or coniferous trees may be present. The types and concentration of nutrients present in the peatland have a strong influence over the type of vegetation that occurs. Peatlands are often classified along a chemical gradient and the gradient is typically as follows: a peatland that is "poor" is characterized by low pH and low cation concentration, whereas "intermediate" and "rich" peatlands are characterized by higher pH and higher cation concentration. Most peatlands in the Sierra Nevada are considered "intermediate" or "rich."

***Figure** 7. Photo of a discharge slope peatland on the Tahoe National Forest.*

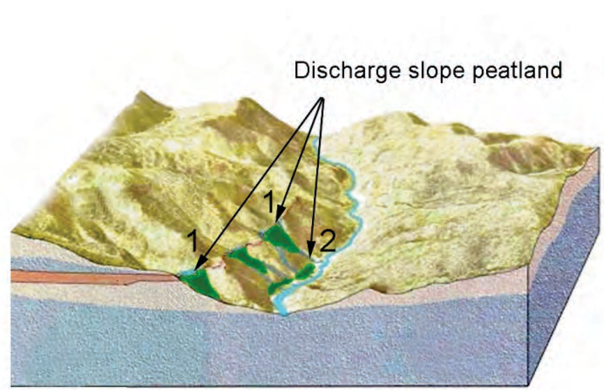

***Figure 8**. Illustration showing a discharge slope peatland type occurring on: 1) a hillslope fed by ground water discharge springs; and 2) the base of an alluvial fan.*

Depressional Seasonal

Setting

Depressional meadows are places where runoff accumulates in a topographic depression. Water either does not flow through the meadow or the flow is essentially imperceptible. Depressional basins are less than 2 meters (6.6 feet) in depth. Depressional landforms may be either manmade (e.g. stock ponds, irrigation ponds, road impoundments), or natural.

Hydrology

Depressional seasonal meadows have no standing water or the standing water dries up before August in most years. Depressional seasonal meadows are characterized by irregular hydroperiods; many fill with water only occasionally and dry quickly. Direct precipitation appears to be the primary water source but overland runoff and groundwater in seasonal perched water tables may also be important. Dominant hydrodynamics are vertical fluctuations (rise and fall of water levels), which is primarily seasonal.

Vegetation

Fluctuations in water availability often promote diverse herbaceous plant growth, but the communities that develop will be shaped by the timing and length of inundation or dryness. Often, the center of the depression will have a longer hydroperiod resulting in a stratification of plant communities. The vegetation of these sites is so variable temporally and spatially (Holland & Jain 1984, Barbour et al. 2003) that it is difficult to identify indicator species to characterize these seasonal depressional habitats. Plant genera that are common in these habitats include *Eleocharis*, *Madia*, *Navarretia*, *Danthonia*, *Plagiobothrys*, *Juncus*, and *Carex*.

***Figure 9**. Photo of Depressional seasonal meadow on the Plumas National Forest.*

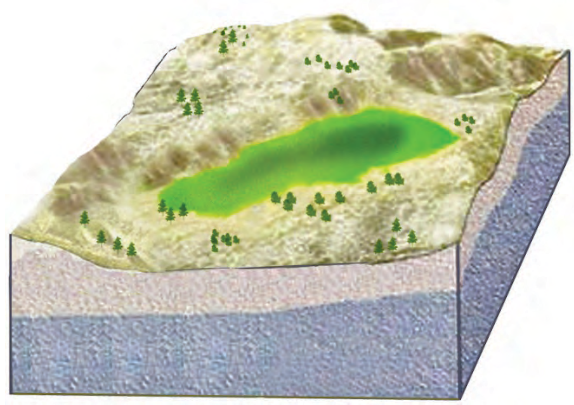

***Figure 10.** Illustration showing a depressional seasonal meadow located in a topographic depression.*

Depressional Perennial

Setting

Depressional meadows are places where runoff accumulates in a topographic depression. Water either does not flow through the meadow or the flow is essentially imperceptible. Depressional basins are smaller than lakes and are less than 2 meters (6.6 feet) in depth. Depressional features can be natural or manmade. Stock ponds, irrigation ponds, and road impoundments are examples of manmade depressional features.

Hydrology

Depressional perennial meadows have standing water all year or late into the growing season in most years. Dominant sources of water are precipitation, groundwater inputs, and interflow from adjacent uplands. The direction of water movement is normally from the surrounding uplands toward the center of the depression. Depressional perennial meadows are separated from basin peatlands by the absence of a peat layer.

Vegetation

Depressional perennial meadows are characterized by more stable hydroperiods than the depressional seasonal meadow type. These meadows are often dominated at their centers by wetland vegetation (obligate and facultative wetland plant species) that requires saturation near the surface and/or late season moisture. Plant communities may reflect a strong zonation due to changes in flooding depth from center to edge.

Figure 11*. Photo of depressional perennial meadow on the Plumas National Forest.*

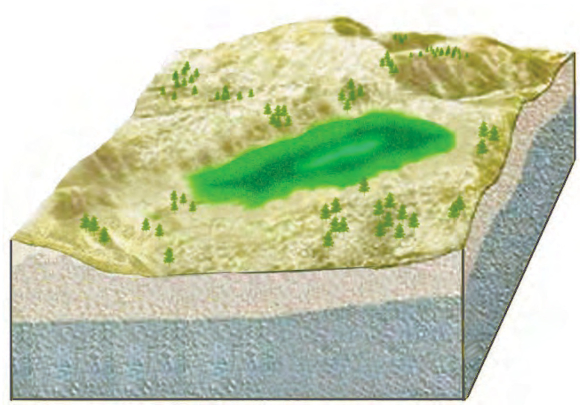

Figure 12*. Typical landscape position for the depressional perennial meadow occurring in a topographic depression.*

Lacustrine Fringe

Setting

Lacustrine fringe meadows occur along a lake or reservoir or within a lake basin (i.e. on the relatively flat area contiguous to the lake, or reservoir). This meadow type is immediately adjacent to the lake and is at the same (approximate) elevation as the lake. The upper limit of the lacustrine fringe meadow is defined by the upstream influence of the lake which is approximated by the limits of the flat or gently sloping lake margin. A lake is defined as being greater than (or judged to be greater than) 2 meters (6.6 feet) deep. In some cases, these meadows consist of a floating mat attached to land.

Hydrology

The primary water input in the lacustrine fringe type is generally inflow from the lake adjacent to the meadow. Additional sources of water are precipitation and groundwater discharge, the latter dominating where lacustrine fringe meadows intergrade with *slope discharge* meadows or either riparian or subsurface throughflow meadows. Lacustrine fringe meadows lose water by surface and subsurface flow returning to the lake and also by evapotranspiration. Organic matter may accumulate in areas sufficiently protected from shoreline wave erosion.

Vegetation

Vegetation is generally dominated by hydric meadow graminoid species (obligate and facultative wetland plant species) with scattered riparian shrubs including willow (*Salix* spp.) or alder (*Alnus* spp.). Plant communities may reflect a strong zonation due to changes in water inputs going from the lake or pond edge toward the uplands.

Figure 13. *Photo of a lacustrine fringe meadow occurring on the edge or fringe of Mono Lake, CA.*

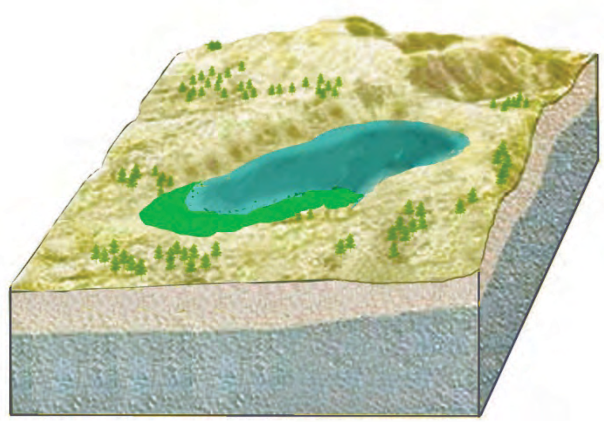

Figure 14. *Landscape position of a lacustrine fringe meadow occurring on the edge of a lake.*

Dry

Setting

Dry meadows occur where the main source of water is precipitation or runoff. Dry meadows are located on benches, swales, drainways, terraces, slopes, and gentle summit ridges where soil has become relatively stabilized. Groundwater is generally deeper than 1 m for most or all of the growing season. They may occur adjacent to a wetter meadow that receives groundwater. These sites may resemble the *depressional seasonal* meadow type in general appearance, but are differentiated by not being located on a depressional landform.

Hydrology

Dry meadows occur at all elevations and on a variety of landforms. Dry meadows occur on sites where water from rains, snow, or snowmelt is concentrated near the soil surface and provides early season moisture sufficient for establishment of perennial graminoids and herbaceous dicots. They lose water by evapotranspiration, overland flow, and seepage to the underlying groundwater. At higher elevations, dry meadows are common where cool temperatures and snowmelt allow soil moisture to linger long enough for graminoid species and herbaceous dicots to flower and reproduce before the dry season comes. This type may mix with other meadow, forest and woodland types at a fine scale. Above treeline, this type may intergrade with alpine fell field communities in areas with decreasing levels of soil development.

Vegetation

Dry meadow vegetation is generally dominated by grasses (*Poaceae* family), dryland sedges (*Carex* spp.), or dryland rushes (*Juncus* spp.). This type includes a very broad range of moisture conditions from low elevation stream terraces and swales to subalpine and alpine areas on gravelly slopes. High elevation sites on gravelly soils may be dominated by shorthair sedge (*Carex exserta*) or Parry's rush (*Juncus Parryi*). High elevation sites that are saturated early in the season may be dominated by shorthair reedgrass (*Calamagrostis breweri*) or Sierra ricegrass (*Ptilagrostis kingii*).

Figure 15. *Photo of a dry meadow type occurring on a stream terrace on the Stanislaus National Forest.*

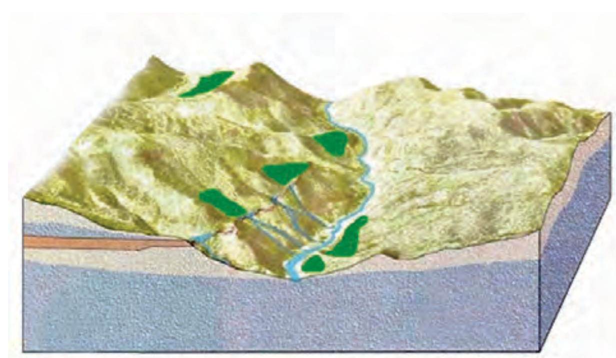

Figure 16. *Typical landscape positions for the dry meadow type.*

Discharge Slope

Setting

Discharge slope meadows are found in association with the discharge of groundwater to the land surface, or near surface in the form of springs or a complex of springs or seeps, or at sites with saturated overland flow with no channel formation. They normally occur on hillslopes, toeslopes, or the bases of alluvial fans on gradients ranging from very gentle to steep. The discharge slope type is distinguished from the *discharge slope peatland* type by the absence of a peat layer. However, a discharge slope type may have small areas of *discharge slope peatlands* within it.

Hydrology

Discharge slope peatlands are commonly fed by springs, or a complex of springs, where groundwater discharges at the surface. Direct precipitation is often a secondary contributing source of water. Hydrodynamics are dominated by downslope unidirectional water flow. This meadow type may develop channels, but the channels serve only to convey water away from the discharge area. Discharge slope meadows are distinguished from depressional meadows by the lack of a closed topographic depression, and the predominance of the groundwater/interflow water source.

Vegetation

Vegetation is generally dominated by hydric meadow graminoid species that are obligate or facultative wetland species and occasionally with scattered riparian shrubs including willows (*Salix* spp.). Hydric vegetation may be restricted to the immediate boundaries of the groundwater discharge, or it may extend outward where surface and/or groundwater flows outward and moistens soil.

Figure 17*. Photo of a series of discharge slope meadows occurring on a toeslope above a riparian low gradient meadow system, Modoc National Forest.*

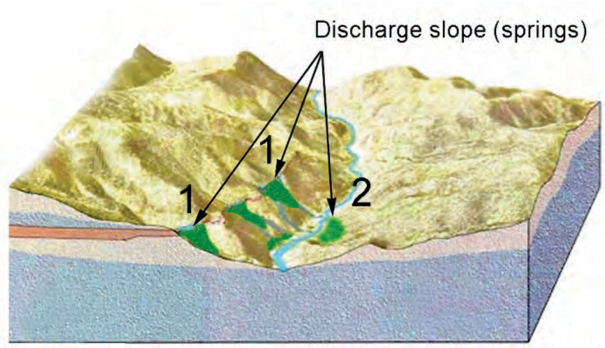

Figure 18*. The discharge slope type occurring on two different settings: 1) hillslopes; and 2) at a toeslope. The discharge slope type is distinguished from the discharge slope peatland type by the absence of a peat layer.*

Riparian Low Gradient

Setting

The riparian low gradient meadow type is associated with a stream or river channel where the average stream or river gradient is less than 2 percent. Streams in this type have a riffle-pool morphology composed of migrating pools and point bars, are sinuous, and have well developed floodplains. To qualify as a riparian type, a majority of the meadow length must contain a stream channel with a discernable bed and bank morphology. This distinguishes them from the subsurface meadow type where a majority of the meadow does not contain a stream channel with a definite bed and bank morphology.

Hydrology

Riparian meadow types are throughflow meadows; there is an inflow channel (perennial or intermittent) at the top of the meadow and an outflow channel at the bottom. Water inputs include overbank flow from the channel, subsurface hydraulic connections between the stream channel and meadow, and groundwater inputs from the hillslopes. Additional water sources may be interflow or occasional overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flows down the floodplain may dominate hydrodynamics.

Vegetation

Vegetation is generally dominated by hydric meadow graminoid species (obligate and facultative wetland plant species) and occasionally with scattered riparian shrubs including willows (*Salix* spp.) or alders (*Alnus* spp.). Steeper gradients have a higher probability of shrubby occurrence. At sites where there is little groundwater input from the adjacent uplands, or where terracing occurs, there may be a strong zonation from hydric to drier soils going from the streambank toward the uplands.

Figure 19. *Photo of a riparian low gradient meadow occurring on the Modoc National Forest.*

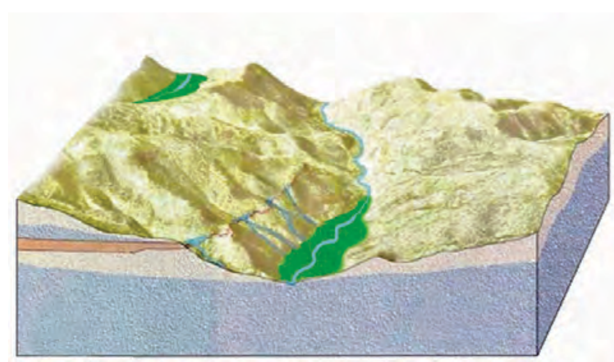

Figure 20*. Landscape position for a riparian low gradient meadow occurring on alluvium in low gradient valley bottoms.*

Riparian Middle Gradient

Setting

The riparian middle gradient meadow type is associated with a stream or river channel where the average stream gradient is 2 percent to 4 percent. In these streams, rapids predominate with occasional pools; have less developed floodplains than in the low gradient type, and generally low rates of aggradation and streambank erosion. Riparian types are distinct from subsurface types by having a majority of the meadow length contain a stream channel with a discernable bed and bank morphology. The channel may be perennial or intermittent. Near headwaters and first-order streams, as drainages consolidate (moving downstream) into defined channels and floodplains, *discharge slop*e meadows often intergrade with *riparian middle gradient* and *riparian high gradient* meadows.

Hydrology

Water inputs include overbank flow from the channel, subsurface hydraulic connections between the stream channel and meadow, and groundwater inputs from the hillslopes. Additional water sources may be interflow or occasional overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flows down the floodplain may dominate hydrodynamics.

Vegetation

Vegetation is generally dominated by hydric meadow graminoid species that have an obligate or facultative wetland rating. Scattered riparian shrubs including willows (*Salix* spp.) or alders (*Alnus* spp.) are often prominent and may be locally dominant. At sites where there is little groundwater input from the adjacent uplands, there may be a strong zonation from hydric to drier soils going from the streambank toward the uplands.

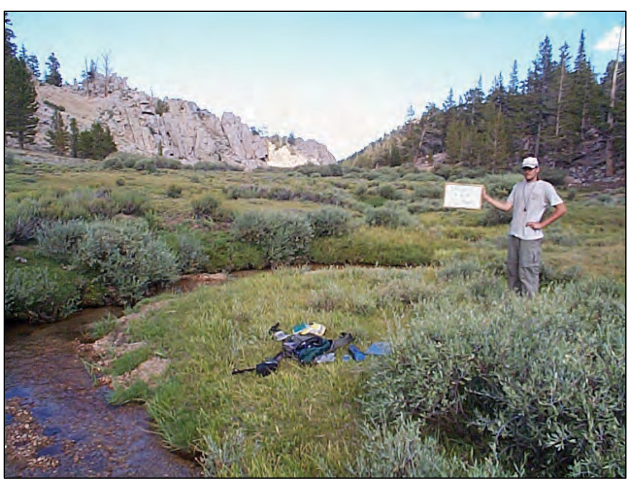

Figure 21. *Photo of a riparian middle gradient meadow occurring on the Inyo National Forest.*

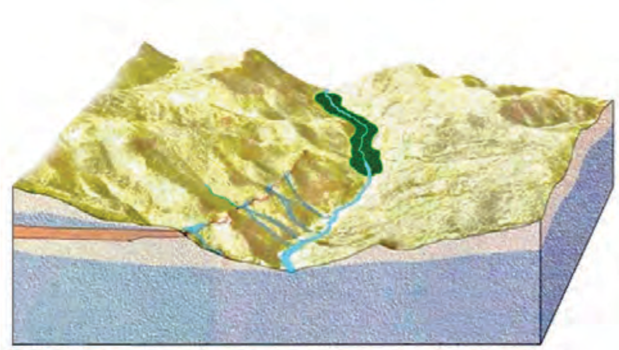

Figure 22*.* *Landscape position of a riparian middle gradient meadow occurring on a sloping valley with a gradient of 2percent to 4percent.*

Riparian High Gradient

Setting

The riparian high gradient meadow type is associated with a stream or river channel where the average stream gradient is greater than 4 percent. A majority of the meadow length contains a stream channel with a discernable bed and bank morphology, which distinguishes the riparian types from the subsurface meadow types. Riparian high gradient meadows are often associated with headwaters and low-order streams. Streams in this region have a sequence of step-pools which are composed of channel-spanning pools and boulder/cobble steps. They have little floodplain development, and have nearly straight channels. The channel may be perennial or intermittent. Near headwaters and first-order streams, *discharge slope* meadows often intergrade (moving down in elevation) with *riparian high gradient* meadows.

Hydrology

Water inputs include overbank flow from the channel, subsurface hydraulic connections between the stream channel and meadow, and groundwater inputs from the hillslopes. Additional water sources may be interflow or occasional overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flows down the floodplain may dominate hydrodynamics.

Vegetation

Vegetation is generally dominated by hydric meadow graminoid species that are obligate or facultative wetland plant species and by tall herbaceous dicots such as California corn lily (*Veratrum californicum*), and lupine (*Lupinus* spp.). Riparian shrubs including willows (*Salix* spp.) or alders (*Alnus* sp.) are prominent and may be locally dominant. At sites where there is little groundwater input from the adjacent uplands, there may be a strong zonation from hydric to drier soils going from the streambank toward the uplands.

Figure 23. *Photo of a riparian high gradient meadow occurring on the Humboldt-Toiyabe National Forest.*

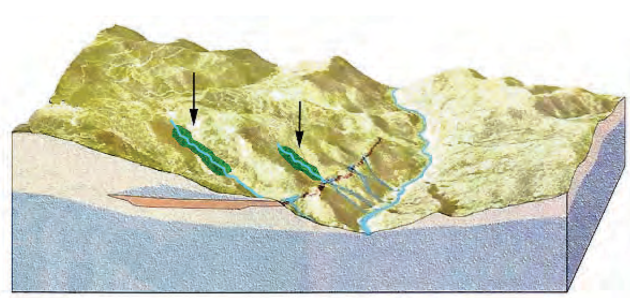

***Figure 24**. Landscape positions for riparian high gradient meadows occurring on sloping valleys with a gradient of more than 4percent.*

Subsurface Low Gradient

Setting

Subsurface low gradient meadows contain no stream or river channel, or a majority of the meadow does not contain a stream or river channel with a discernable bed and bank morphology. Ditches or rills may be present. This meadow type occurs on alluvium or colluvium and typically is connected to a distinct topographic flow line (perennial or intermittent channel) above and below the meadow. This type occurs where the down valley slope averages less than 2 percent.

Hydrology

The dominant water sources are surface water and groundwater throughflow. Additional water sources are groundwater inputs or overland flow from surrounding uplands, tributary inflow, and precipitation. Inflow and outflow stream channels (perennial or intermittent) are typically visible at the top end of the meadow and bottom end of the meadow. Subsurface low gradient types are distinguished from the groundwater discharge type by being a throughflow groundwater/interflow system with a water source (surface or subsurface) at a higher elevation and outflow (surface and/or subsurface) at the bottom of the meadow.

Vegetation

Vegetation is generally dominated by hydric meadow graminoid species (obligate and facultative wetland plant species). Occasionally scattered riparian shrubs including willows (*Salix* spp.) and coniferous tree species are present. Sites often exhibit a strong zonation from hydric to drier soils going from the center of the meadow toward the uplands.

Figure 25. *Photo of a subsurface low gradient meadow occurring on the Stanislaus National Forest.*

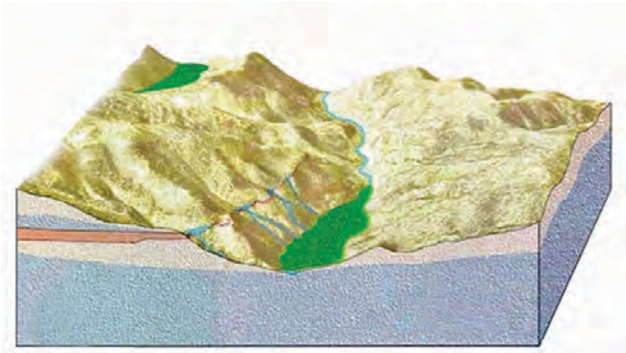

Figure 26. *Typical landscape positions for subsurface low gradient meadows occurring in low gradient valleys.*

Subsurface Middle Gradient

Setting

Subsurface middle gradient meadows contain no stream or river channel, or a majority of the meadow does not contain a stream or river channel with a discernable bed and bank morphology. Ditches or rills may be present. This meadow type occurs on alluvium or colluvium and typically is connected to a distinct topographic flow line (perennial or intermittent channel) above and below the meadow. This type occurs where the down valley slope is 2 percent to 4 percent.

Hydrology

The dominant water sources are surface water and groundwater throughflow. Additional water sources are groundwater inputs or overland flow from surrounding uplands, tributary inflow, and precipitation. Inflow and outflow stream channels (perennial or intermittent) are typically visible at the top end of the meadow and bottom end of the meadow. Subsurface low gradient types are distinguished from the groundwater discharge type by being a throughflow groundwater/interflow system with a water source (surface or subsurface) at a higher elevation and outflow (surface and/or subsurface) at the bottom of the meadow.

Vegetation

Scattered riparian shrubs including willows (*Salix* spp.) and coniferous tree species are often present. Sites often exhibit a strong zonation from hydric to drier soils going from the center of the meadow toward the uplands.

Figure 27*. Photo of a subsurface middle gradient meadow occurring on the Stanislaus National Forest.*

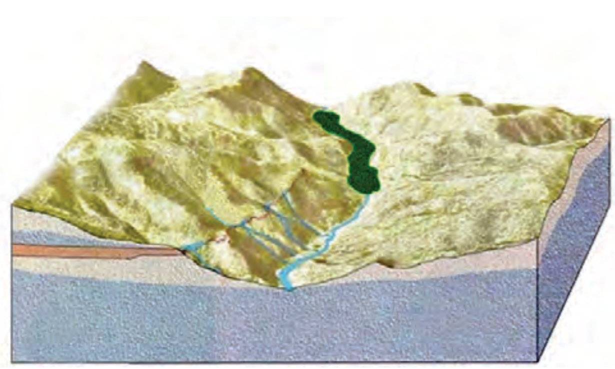

Figure 28. *Typical landscape position of a subsurface middle gradient meadow occurring on a slope of 2 percent to 4 percent.*

Subsurface High Gradient

Setting

Subsurface high gradient meadow types contain no stream or river channel or a majority of the meadow does not contain a stream or river channel with a discernable bed and bank morphology. Ditches or rills may be present. This meadow type occurs on alluvium or colluvium and typically is connected to a distinct topographic flow line (channel, drainway, or swale) above and below the meadow. Downvalley slope averages greater than 4 percent. Near headwaters and first-order streams, *discharge slope* meadows often intergrade (moving down in elevation) with *subsurface high gradient* meadows.

Hydrology

The dominant water sources are surface water and groundwater throughflow. Additional water sources are groundwater inputs or overland flow from surrounding uplands, tributary inflow, and precipitation. Inflow and outflow stream channels (perennial or intermittent) are typically visible at the top end of the meadow and bottom end of the meadow. Subsurface high gradient types are distinguished from the *discharge slope* meadow type by being a throughflow groundwater/interflow system with a water source (surface or subsurface) at a higher elevation and outflow (surface and/or subsurface) at the bottom of the meadow.

Vegetation

Vegetation is generally dominated by hydric meadow graminoid species that are obligate or facultative wetland plant species and by tall herbaceous dicots such as California corn lily (*Veratrum californicum*), and lupine (*Lupinus* spp.). Riparian shrubs including willows (*Salix* spp.) and conifer tree species are typically present, and may be locally dominant. At sites where there is little groundwater input from the adjacent uplands, there may be a strong zonation from hydric to drier soils going from the center of the meadow toward the uplands.

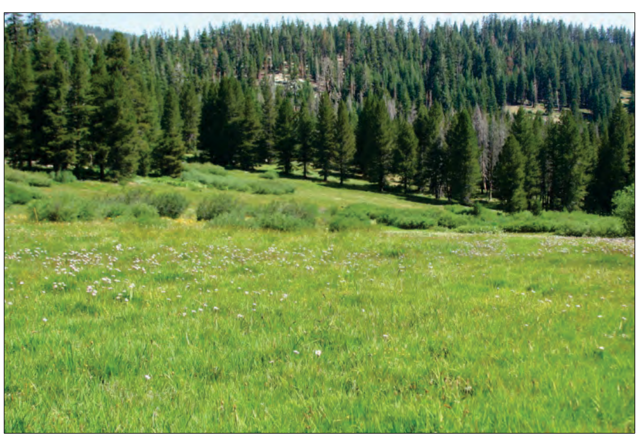

Figure 29. *Photo of a subsurface high gradient meadow near headwaters on the Sequoia National Forest.*

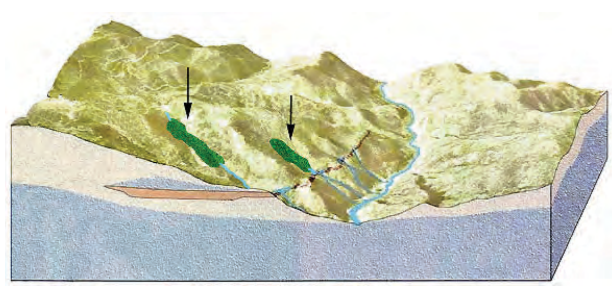

Figure 30. *Typical landscape positions for subsurface high gradient meadows occurring in sloping valleys.*

POTENTIAL USES FOR THIS CLASSIFICATION

1. **Condition assessment**: there is a need for condition assessment of meadows across the Sierra Nevada and southern Cascades in California. Meadow ecological functions, plant communities, response to various disturbances, and wildlife habitat characteristics vary by geomorphic setting and hydrologic inputs and outputs. This classification can provide a means of stratifying meadows for assessment of these characteristics. Protocols for assessing condition and functionality for each of the hydrogeomorphic types in this classification would provide a framework allowing meadow managers the ability to report on the overall distribution, abundance, and condition of meadows within watersheds or regions across the Sierra Nevada.

2. **Mapping**: A fundamental requirement of any meadow management program is the inclusion of comprehensive information about the distribution of meadows and wetlands, mapped and classified at an appropriate scale, with sufficient detail to allow management actions to be implemented or for further mapping and inventory work to be undertaken. This hydrogeomorphic classification can provide the physical and hydrologic settings for meadow types. Vegetation composition of these types can then be described and mapped using, for example, plant groupings at the alliance or community levels currently being developed (Sawyer et al. 2009).

   There are a number of techniques to map meadows. Examples are surveying with a high-grade GPS in the field, digitizing aerial photographs, and remote sensing. Appropriate attribution (hydrogeopmorphic or vegetation composition for example), even if provisional, can be followed up or accompanied by field validation. An example of a mapping project for delineating meadow hydrogeomorphic types is shown in Figure 31. As part of a mapping exercise, meadows larger than 0.5 acre were delineated on an aerial photo at a scale of 1:18,000. In the field, the hydrogeomorphic types were determined using field reconnaissance and the dichotomous key to meadow hydrogeomorphic types. The dominant hydrogeomorphic type in this drainage area was the *riparian low gradient* hydrogeomorphic type. This example illustrates the concept of a meadow and component hydrogeomorphic types which make up the meadow. In practice, after the meadow has been identified on an aerial photo or in the field, the key will help the user identify the component hydrogeomorphic type(s) in the meadow. In some cases, the transitions or boundaries between types can be indistinct due to subtle hydrologic gradients, or where microtopography causes meadows to be interspersed with uplands or other meadow hydrogeomorphic types at fine scales. For these situations, changes in plant community, landform, and/or changes in soil moisture as determined by ground-truthing can be used to draw boundaries between hydrogeomorphic types.

3. **Restoration**: A majority of meadows in the Sierra Nevada have been in the past, and continue to be impacted by tree encroachment, changes in water table due to stream incision, overgrazed areas, recreational use, hydrologic alteration including stream diversions, climate change, and fire suppression. Restoration attempts are being made to improve ecological functioning in meadows that have been degraded. This hydrogeomorphic classification can potentially link restoration methods to geomorphic setting and hydrologic characteristics of a meadow. Questions exist on restoration methods

and application of methods. For example, which hydrogeomorphic meadow types are most vulnerable to the above stressors, and further, what types of restoration measures are most appropriate for the different meadow hydrogeomorphic types. While restoration of meadows in the Sierra Nevada has been undertaken for decades, there is little guidance on appropriate restoration methods for different meadow types. At a time when climate change is putting unprecedented pressure on water supplies with less snowpack and earlier snowmelt being predicted, restoring mountain meadows has become even more of a priority (Null et al. 2010).

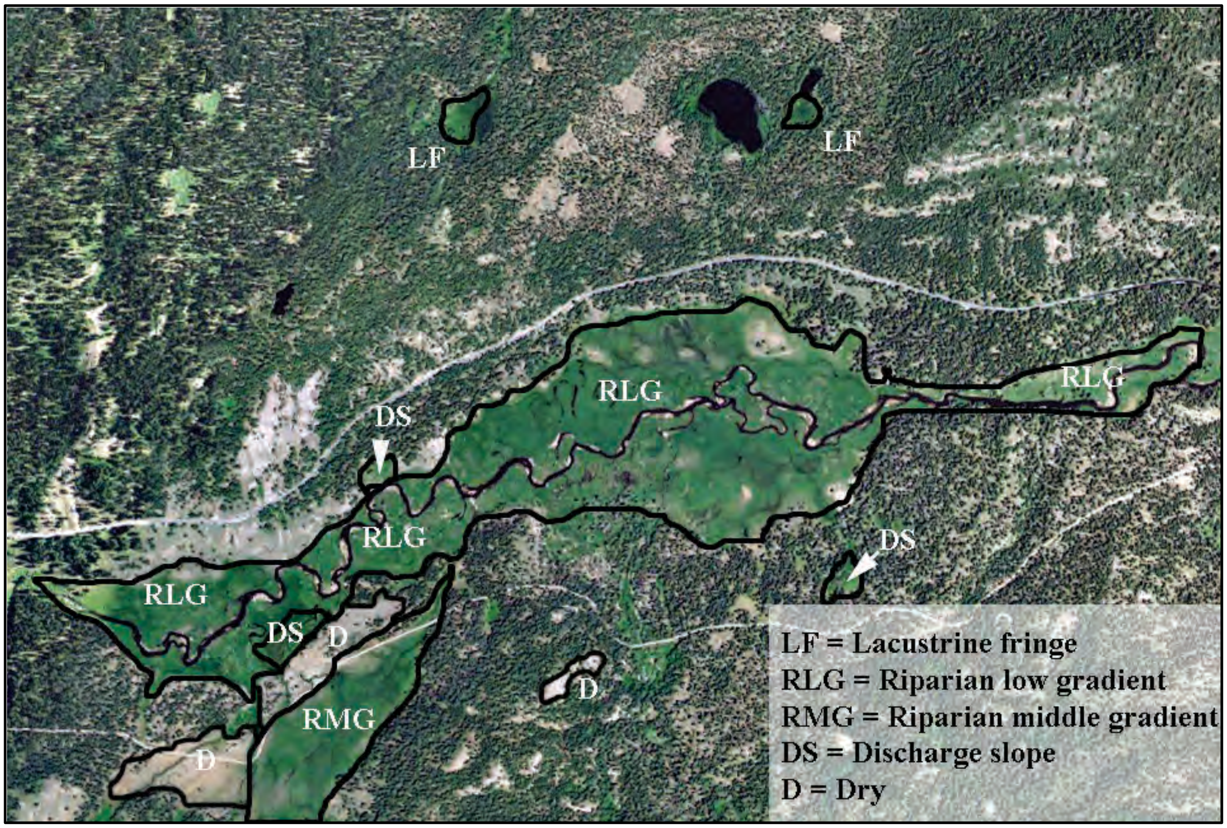

***Figure 31**. Map of hydrogeomorphic meadow types on the Tahoe National Forest.*

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Appendix A. Definitions.

Alluvial fan - a fan-shaped deposit of fluvial sand and gravel, usually located at the mouth of a tributary valley.

Alluvium - sediment deposited by flowing water, as in a floodplain, terrace, streambed, or riverbed.

Colluvium - a loose deposit of rock debris or soil accumulated through the action of rainwash or gravity at the base of a gently sloping cliff or slope.

Depression - Any relatively sunken part of the Earth's surface; especially a low-lying area surrounded by higher ground. A closed depression has no natural outlet for surface drainage (e.g. a sinkhole). An open depression has a natural outlet for surface drainage. A depression, for the purposes of this document, is less than 6.6 ft. (2 meters) deep.

Ditch - 'Ditch or canal' means a man-made channel other than a modified natural stream constructed for drainage purposes.. A ditch or canal may have flows that are perennial, intermittent, or ephemeral and may exhibit hydrological and biological characteristics similar to perennial or intermittent streams.

Down-valley gradient - down-valley axis represented by a hypothetical straight channel down the central axis of the valley. The down-valley gradient is usually steeper than the stream gradient because meanders develop, which lengthen the course of the stream, decreasing the gradient.

Drainageway - areas that convey surface water runoff from single storm events, or flows from highly localized snow melt, or flows from man-made drainage devices that intercept ground water. Similar to a swale.

Fellfield - "rock field" or "stone field" which is alpine land that is 35 percent to 50 percent rock-covered and which supports lichens, mosses, and cushion plants. Boulder fields are similar to fellfields except with larger rocks. The typical alpine landscape is a checkerboard-like arrangement of alpine meadow interspersed with fellfields and boulder fields.

Floodplain - level or very gently sloping surface bordering a river that has been formed by river erosion and deposition; it is usually subject to flooding and is underlain by fluvial sediments; similar to alluvial plain.

Graminoid - members of the grass (family Gramineae or Poaceae) and grasslike plants such as sedges (family Cyperaceae) and rushes (family Juncaceae).

Groundwater - Water that collects or flows beneath the Earth's surface, filling the porous spaces in soil, sediment, and rocks. Groundwater originates from rain and from melting snow and ice and is the source of water for aquifers, springs, and wells. The upper surface of groundwater is the water table.

Groundwater discharge - is the movement of water out of an area of saturated soil.

Herbaceous dicot (= forb) - a flowering plant lacking a permanent woody stem, and having flower parts in multiples of four or five. The leaf veins are reticulate in pattern and not parallel in pattern. These plants are the common wildflowers seen in meadows.

Hillslope - the inclined surface of a hill above the toeslope.

Histosol - soils that contain a minimum of 40 cm of organic horizons within the upper 80 cm of the soil profile. The organic horizons contain at least 12 – 18% organic carbon content by dry weight, depending upon the percent clay in the mineral fraction.

Hydric - of, relating to, formed in, living in, or growing in soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part.

Hydroperiod - the period of time during which a meadow or wetland is covered by water.

Hydrodynamics - the movement and action of water in a meadow or wetland.

Interflow - The water, derived from precipitation, that infiltrates the soil surface and then moves laterally through the upper layers of soil above the water table.

Lacustrine - of, relating to, formed in, living in, or growing in lakes.

Organic soil material - soil that contains a minimum of 12 percent organic carbon when no clay is present or a minimum of 18 percent organic carbon when clay content is 60 percent or greater.

Paludification - the process by which expansion of peat soil occurs over mineral soil.

Peat - a term that sometimes is applied to organic soils. A soil that contains a minimum of 12 percent organic carbon when no clay is present or a minimum of 18 percent organic carbon when clay content is 60 percent or greater.

Peatland - a type of ecosystem, also referred to as a mire, in which organic matter is produced faster than it is decomposed, resulting in the accumulation of partially decomposed vegetative material termed peat. Must contain at least 20 cm thickness of peat in the top 40 cm of soil.

Riffle - the sections of the streambed with the steepest slopes and shallowest depths at flows below bankfull, i.e. areas of a distinct change in gradient where flowing water can be observed. Riffles typically have a poorly defined thalweg.

Rill - A rill is a very small channel of water, caused mainly by runoff water that has eroded the soil. In this process, sediment particles on the soil surface are detached in the interrill areas and move to the rills by the processes of splash as the result of raindrop impact, and by suspension in overland flow.

Riparian - pertaining to the boundary between water and land. Normally represents the streamside zone and the zone of influence of the stream toward the upland.

Soligenous peatland - peatland that is maintained by slow lateral gravitational seepage of water through the substrate or the peat.

Stream channel - the physical confine of a stream (or river) consisting of a bed and more or less defined stream banks. The bed of a stream or river is the physical confine of the normal water flow. The lateral constraints (channel margins) during all but flood stage are the stream banks. Usually the bed is kept clear of terrestrial vegetation, whereas the banks are subjected to water flow only during unusual or infrequent high water stages, and therefore can support vegetation much of the time

Stream_terrace - one of a series of level surfaces on a stream valley flanking and parallel to a stream channel and above the stream level, representing the uneroded remnant of an abandoned floodplain or stream bed. Also known as river terrace.

Subsurface_Flow - water leaves via groundwater.

Surface_water - is water collecting on the ground or in a stream, river, lake, wetland, or ocean.

Swale - a shallow, open depression in unconsolidated materials which lacks a defined channel but can funnel overland or subsurface flow into a drainageway.

Terrene meadow- meadows surrounded or nearly so by uplands and lacking a channelized outlet stream.

Throughflow - water entering and exiting, passing through; a throughflow meadow receives significant surface or groundwater which passes through the meadow and is discharged to a stream, wetland or other waterbody at a lower elevation; throughflow may be perennial, intermittent, or associated with an entrenched stream.

Toeslope - the base of an inclined surface of a hill.

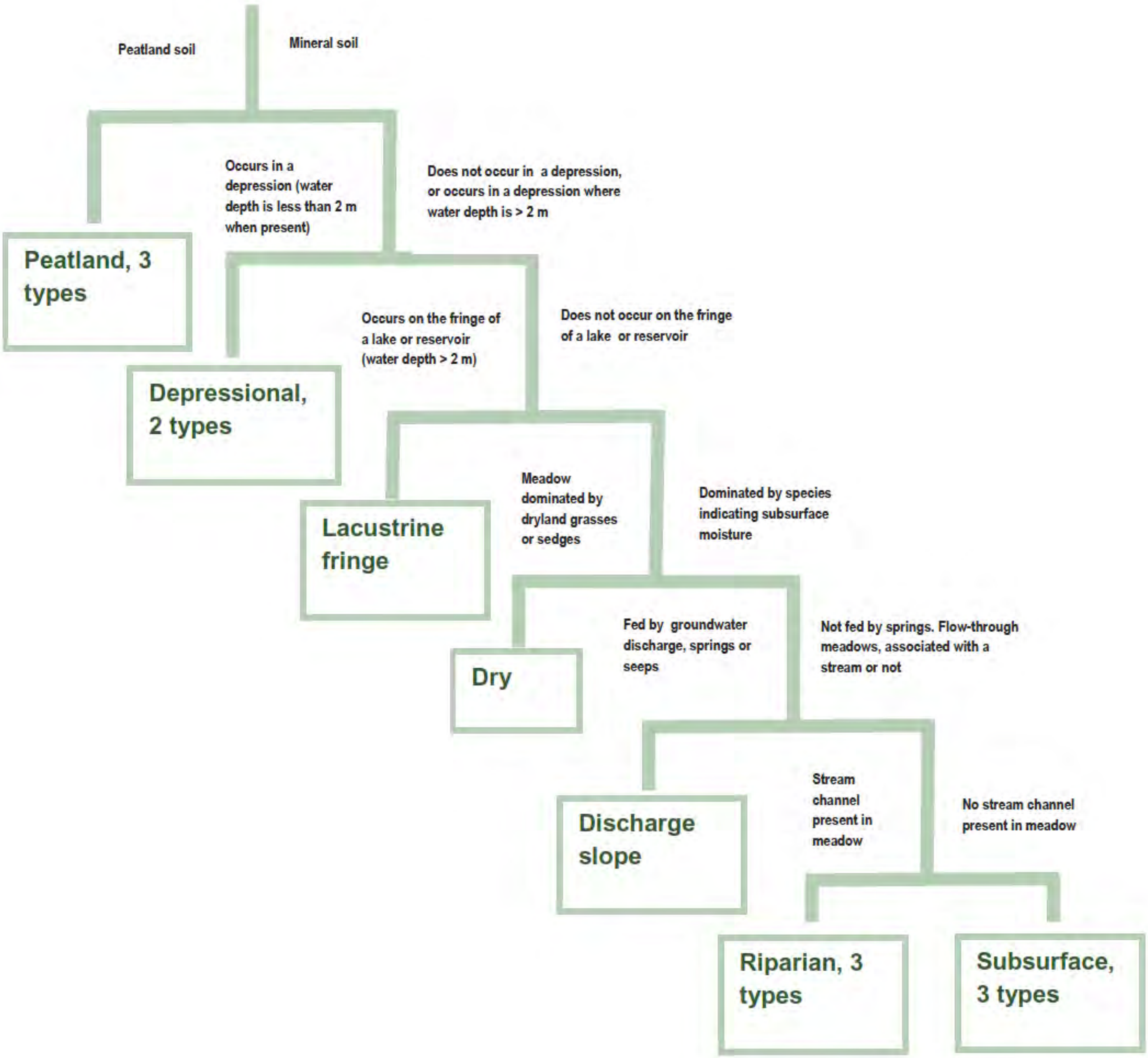
Topogenous_peatland - peatlands that develop in topographic depressions or horizontal surfaces with at least some regional groundwater flow.

Vernal_pool - a temporarily flooded basin or depression. These pools are surrounded by upland vegetation and are usually flooded from winter through early summer

Wetland rating (plant categories) - five categories are used to describe the likelihood of a particular plant species occurring in a wetland area:

- *OBL*: obligate wetland, Occurs almost always (estimated probability 99%) under natural conditions in wetlands.
- *FACW*: facultative wetland, Usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.
- *FAC*: facultative, Equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).
- *FACU*: facultative upland, Usually occurs in non-wetlands (estimated probability 67%-99%), but occasionally found on wetlands (estimated probability 1%-33%).
- *UPL*: obligate upland, occurs almost always (estimated probability 99%) under natural conditions in non-wetlands in the regions specified

Appendix B. Dendrogram of major meadow hydrogeomorphic types



Appendix C. Examples of meadow hydrogeomorphic types

Riparian middle gradient type on the Modoc National Forest

Subsurface low gradient type on the Plumas National Forest

Depressional perennial type located in Mt. Lassen Volcanic National Park.

Riparian middle gradient type on the Modoc National Forest.

Appendix C (cont'd.) Examples of meadow hydrogeomorphic types

Dry meadow type on a bench near treeline on the Inyo National Forest. This photo shows dry meadow areas intermixed with alpine fellfields.

Lacustrine fringe meadow type located in Mt. Lassen Volcanic National Park.

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