Appendix H: Ecological Restoration Planning for the Tuolumne Wild and Scenic River Comprehensive Management Plan

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Ecological Restoration Planning for the Tuolumne Wild and Scenic River Comprehensive Management Plan

Ecological Restoration Planning for the Tuolumne Wild and Scenic Comprehensive Management Plan

Division of Resources Management and Science

Yosemite National Park

WRITTEN BY

CHAPTER 1 - ECOLOGICAL RESTORATION PLANNING FOR THE GREATER TUOLUMNE MEADOWS AREA

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CHAPTER 2 - MITIGATION MEASURES TO PROTECT CULTURAL RESOURCES FOR THE GREAT SIERRA WAGON ROAD ECOLOGICAL RESTORATION PROJECT

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Cover Photos:

Upper - Photo taken from the west end of Tuolumne Meadows late 1800s

Lower – Photo taken from the west end of Tuolumne Meadows 2008

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INTRODUCTION

This report presents an ecological restoration plan to support the Tuolumne Wild and Scenic River Comprehensive Management Plan (Tuolumne River Plan). It provides a description of sites recommended for ecological restoration in the Tuolumne River area, incorporating analyses of the status and integrity of plant communities in Tuolumne Meadows, and a cultural landscape review of the Great Sierra Wagon Road.

The first chapter in this report describes recommended ecological restoration actions throughout the Tuolumne Meadows area and the justification and need for these proposed actions. This chapter focuses on restoration actions associated with the Tuolumne River, Tuolumne Meadows, roads, trails, campgrounds and lodging.

The second chapter in this report focuses on cultural resource protection of a portion of the Great Sierra Wagon Road. This chapter provides culturally sensitive recommendations for the ecological restoration efforts along the road. It establishes mitigation measures for ecological restoration of abandoned sections of the road, and maps the past alignment(s) of the Great Sierra Wagon Road relative to today's Tioga Road. Ongoing consultation with NPS cultural resources staff will accompany restoration efforts.

The third chapter presents design guidelines for any boardwalk or trail treatment to ensure protection of natural, cultural and scenic resources.

Two studies frequently cited in this document provide baseline data on hydrology and vegetation that directs ecological restoration efforts and priorities. Cooper et al. (2006) completed a study focusing on the effects of the Tioga Road on hydrologic processes and lodgepole pine invasion into Tuolumne Meadows. Researchers found incongruence between existing vegetation, hydrology and soils that requires further study. A second study (Ballenger and Acree 2008) focused on the biological integrity of Tuolumne Meadows north of the Tioga Road. Botanists compared vegetation and habitat attributes of Tuolumne Meadows with eight other subalpine meadows in the park with similar plant communities. This study focused on several measures of meadow integrity – community level plant diversity, forb:graminoid ratio, the percentage of areas without functioning vegetation (bare ground), and levels of small mammal activity.

CHAPTER 1. ECOLOGICAL RESTORATION PLANNING FOR THE GREATER TUOLUMNE MEADOWS AREA

By Monica Buhler, Sue Beatty and April Johnson

THE NEED FOR ECOLOGICAL RESTORATION

Meadow and riparian ecosystems are sites of exceptional ecological importance. While highly productive and diverse, riparian and aquatic systems (including meadows) are the most impacted areas in the Sierra Nevada (SNEP 1996). Declining spatial extent and degradation of riparian and wet meadow ecosystems is occurring throughout California at an alarming rate (SNEP 1996). While riparian and meadow ecosystems occupy relatively little land area in Yosemite National Park, they comprise the most biologically diverse areas and are priorities for ecological restoration (Hall 1997).

Tuolumne Meadows represents some of the most extensive subalpine meadow and riparian habitat in the Sierra Nevada (Weixelman, pers. comm. 2011). This meadow/riparian/river complex provides habitat for a diversity of plant and animal species including several special-status species [e.g., slender lupine *(Lupinus gracilentis)*, Yosemite bulrush *[Trichophorum clementis (Scirpis clementis)]*, Yosemite toad *(Bufo canorus)*, several species of bats, and migratory bird populations). In addition, Soda Springs, a natural alkaline spring, supports localized populations of special status plant species [e.g., Buxbaum's sedge (*Carex buxbaumii)* and marsh arrow-grass (*Triglochin spp.*)].

Natural processes such as hydrology continue to shape the landscape and the meadow and riparian complex that extends through Tuolumne Meadows, Dana Meadows, and Lyell Canyon. While productivity of these riparian and meadow areas remains relatively high, recent studies document changes in the ecological integrity, particularly in parts of Tuolumne Meadows, exemplified by expanding areas of barren ground, atypical plant species, conifer encroachment, and diminished willow cover along riverbanks (Cooper et al. 2006). Development such as buildings, roads, trails, and past land management practices (such as ditching) disrupt hydrology, discourage vegetation establishment, and reduce habitat function. Many undeveloped portions of the Tuolumne Meadows area also exhibit impacts from past and contemporary activities such as human trampling, old roadbeds, historic grazing, stock use, invasive plant introduction, vegetation loss, and alterations to river processes.

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER 2004). Through ecological restoration, processes that sustain natural ecosystems, such as hydrology, are restored to provide conditions ideal for the perpetuation of native flora and fauna.

Ecological restoration is also appropriate to restore natural conditions if facilities are removed, updated or relocated. This report describes potential ecological restoration actions for currently impacted areas in the Tuolumne Meadows area, including developed areas that will require restoration if infrastructure are moved or removed, as well as undeveloped areas that have directly or indirectly been altered by human activities. Areas outside of designated Wilderness will be the first priority for restoration. Any restoration actions in designated Wilderness will use the minimum tool necessary to accomplish the project, in accordance with the minimum requirements analysis

Important cultural resources are numerous in the Tuolumne Meadows area and in addition to specific mitigations outlined in Chapter 2, the following programmatic guidance and collaboration with cultural resource staff will ensure protection during ecological restoration. Archeological sites are fragile, nonrenewable resources and contain important information potential about past life ways and represent tangible heritage resources for park-associated American Indian peoples, as well as the visiting public. Where archeological sites are subject to ongoing impacts from social trails or visitor use, careful assessment for stabilization needs is necessary. Social trails will be removed and visitor use of these areas will be discouraged using techniques that retain the data potential of the resource while encouraging native plant establishment and growth. Where ecological restoration actions have the potential to affect archeological resources, actions will be designed to avoid impacts wherever feasible. If avoidance is not possible, employment of archeological site treatments such as controlled testing and data recovery excavations where necessary, will reduce the level of impact and minimize adverse effects. All treatments for pre-contact archeological sites will involve close consultation with park-associated American Indian tribes and groups to ensure these treatments incorporate native concerns, issues and perspectives.

Ecological Restoration Goals and Objectives

The goals and objectives of ecological restoration focus on restoring primary processes, particularly hydrology, to maintain the structure and function of a self-sustaining ecosystem. Overall goals of ecological restoration actions for the Tuolumne River are to promote sheet flow in meadows, maintain groundwater levels that reflect landforms without incised channels, and limit continued disruptions to natural hydrology, all of which are factors for maintaining native plant communities. In order to achieve these goals the following combination of restoration actions will provide the best avenue for achieving ecological restoration objectives:

- Protect, maintain and restore natural hydrologic function of the Tuolumne River and tributaries

- Protect, maintain and restore the hydrologic connectivity between the main river channel and the floodplain (meadows, ponds, wetlands, cutoff channels, oxbows) during regular high water flows
- Protect, maintain and restore naturally high ground water levels and sheet flow processes to support biotic communities in riparian and meadow plant communities
- Protect, maintain and restore the ability for the Tuolumne River channel to migrate and change course
- Improve and protect ecological integrity of Soda Springs
- Protect, maintain and restore the function, structure, diversity and productivity of native riparian and meadow plant communities and wildlife habitat
- Restore areas impacted by the removal or relocation of facilities to natural conditions

Fig. 1-1. Riverbank erosion

Fig. 1-2. Heavily browsed willow

THE TUOLUMNE RIVER

NPS staff and researchers observed apparent absence of willow and extensive riverbank erosion along the Tuolumne River as it flows through Tuolumne Meadows. This triggered a recent study (Cooper et al 2006) which found that the banks of the Tuolumne River are eroding on outside meanders without concomitant riparian vegetation recruitment on the complementary point bar, likely resulting in channel widening. Channel widening produces a shallower channel with a lower river stage for any given flow volume and a concurrent drop of the groundwater level associated with the river (Cooper et al. 2006). A wider, shallower channel also influences the magnitude and frequency of overbank flow. The low vegetation cover on riverbanks, perhaps exacerbated by human trampling, contributes to the rapid bank erosion.

RIVERBANK EROSION

In general, the riverbanks on the Tuolumne River (particularly on the northwest end of the meadows) have little to no vegetation, particularly willows *(Salix ssp.)* and are characterized by extensive erosion and riverbank loss (Figure 1-1). Willows typically occur in much greater density along the river and are very effective at anchoring soils, stabilizing eroding riverbanks and providing wildlife habitat (Cooper et al. 2006). Vegetation, particularly woody species such as willow, also slows the velocity of water and associated scour while promoting sediment accretion (Mitsch and Grosselink 2007).

Existing willows in Tuolumne Meadows are heavily browsed (Figure 1-2), precocious (flowering on the previous season stems), or have no reproductive structures at all (Cooper et al. 2006). Deer browsing suppresses the plants to heights of less than 0.5 m in species that are typically 1-2 m tall. Because deer prefer tender, young shoots, heavy browsing can also limit the extent and regeneration of willow stands. Willows also provide important nesting habitat for many birds and cover for other

Fig. 1-3. Trampled vegetation on riverbanks

wildlife. The lack of willow establishment on sandbars and riverbanks contributes to the net river channel widening. This absence of vegetation allows water to flow unimpeded, increasing velocity and altering scour and deposition relationships. Understanding of the causal factors of the absence of willows along the Tuolumne River is limited, but the current condition of the riverbanks indicates that this has been occurring for some time and may be a remnant impact from historic sheep grazing (Loheide et al. 2008).

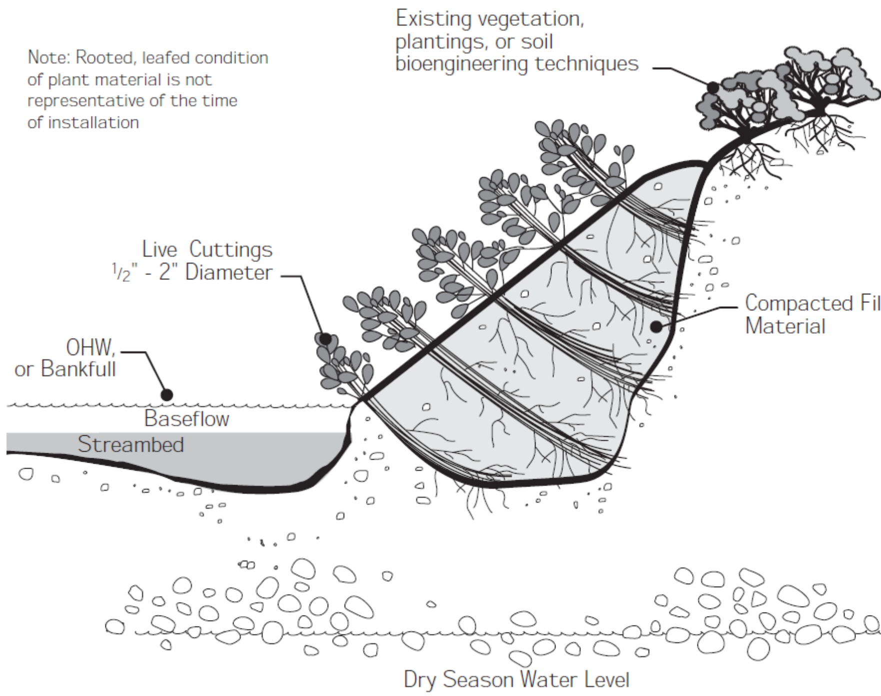
Human trampling can exacerbate vegetation loss and subsequent riverbank erosion (Milestone 1978, Madej et al. 1994), (Figure 1-3). Certain reaches of the Tuolumne River experience high levels of visitor use and are devoid of vegetation, facilitating more erosion. Protection of riverbanks in sensitive areas can help promote vegetation establishment and improve riverbank stability. If further studies indicate that current and past human actions impact riverbank conditions in the Tuolumne Meadows area, ecological restoration may be warranted.

Because of the dynamic nature of river processes and gaps in knowledge, it would be shortsighted to focus riverbank restoration in isolated areas. Therefore, a holistic approach to riverbank restoration and willow establishment is necessary for the entire stretch of the Tuolumne River including both the Dana and Lyell Forks, and as it flows through Tuolumne Meadows. Further research on willow establishment, recruitment and persistence, and sediment dynamics will refine restoration techniques. The following restoration actions are proposed to mitigate impacts and restore riverbanks and natural river processes:

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Protect, maintain and restore the function, structure, diversity and productivity of native riparian and meadow plant communities and wildlife habitat
- Apply bioengineering techniques (e.g. brush layering, anchor logs, intensive planting of vegetation) to stabilize riverbanks, promote sediment accretion, and minimize further riverbank loss
- Establish willows (using hydro-drilling techniques) along riverbanks
- Protect impacted riverbanks from further trampling using temporary fencing or natural obstructions, such as logs, so vegetation can establish
- Install temporary exclosures to protect willow regeneration from deer browsing
- De-compact, mulch, seed and plant to encourage vegetation establishment on denuded riverbanks

Examples of bioengineering techniques commonly used for riverbank restoration include willow hydro-drilling, brush layering (Figure 1-4), willow wattles and anchoring logs to stabilize soils and accrete sediment. To establish willow and prevent them from washing away during high water events, cuttings are cut from established plants and placed deeply into the soil. A hydro-drill (a pump with a high-powered stream of water) will be used where riverbank areas are rocky or compacted to create deep holes into which cuttings are placed. Willows may also be bundled and partially buried and anchored along riverbanks.

BRUSH LAYERING: FILL METHOD
(Not to scale)



Brush Layering

Brush layering is the technique of laying cuttings on horizontal benches that follow the contour of either an existing or filled bank (slope). Branches serve as tensile inclusions or earth-reinforcing units to provide shallow stability of slopes.

The cuttings are oriented more or less perpendicular to the slope face. The portion of the brush that protrudes from the slope face assists in retarding runoff and reducing surface erosion. When used on a fill slope, this technique is similar to vegetated geogrids without the geotextile fabric.

Applications and Effectiveness

- Breaks up the slope length into a series of shorter slopes separated by rows of brush layer.
- Dries excessively wet sites.
- Works where the toe is not disturbed.
- Works on a slump and as a patch.
- Reinforces the soil with the unrooted branch stems.
- Reinforces the soil as roots develop, adding significant resistance to sliding or shear displacement.
- Traps debris on the slope.
- Aids infiltration on dry sites.
- Adjusts the site's microclimate, aiding seed germination and natural regeneration.
- May cause flow to wash soil from between layers.
- Does not work on outside bends.

Construction Guidelines

Brush layering can be installed on an existing or filled slope. On an existing slope, a bench is cut 2- to 3-ft. deep and angled slightly down into the slope. On a fill slope, brush layers are laid into the bank as it is filled.

Live material

- Branch cuttings should be 0.5 to 2 in. in diameter and long enough to reach the back of the bench and still protrude from the bank.
- Side branches should remain intact.
- Mix easy-to-root species such as willow, dogwood, and poplar.

Fig. 1-4: From *A Soil Engineer's Guide* (Eubanks et al. 2006)

TUOLUMNE MEADOWS

Meadows and wetlands link the main Tuolumne River channel with neighboring terrestrial systems and regulate the entry of water, nutrients, and organic material into the river channel (Gregory et al. 1991). Humans have used the Tuolumne Meadows area for thousands of years, but in the last century the level and intensity of use has increased and changed dramatically. Human alterations in Tuolumne Meadows range from historic actions such as digging ditches to drain ponded areas of the meadow, building roads in the meadow, and extensive sheep grazing from 1860-1905, to contemporary impacts from trampling, development, and fragmentation. Other impacts result from parking area edge effect or parking creep leading to soil compaction, soil loss, and vegetation loss. Tuolumne Meadows is not only ecologically important but also is a treasured resource for visitors and highly valued by traditionally associated people because it contains sacred areas and provides traditionally used ecological resources. Efforts to sustain the integrity of the Tuolumne River ecosystem are likely to be more effective over the long term when considering the integrity of the meadow and associated riparian areas.

VEGETATION

Most of the greater Tuolumne Meadows comprises subalpine meadow vegetation with pockets of subalpine forest dominated by lodgepole pine *(Pinus contorta).* Existing plant communities are influenced by hydrologic and climatic conditions as well as past (intensive grazing, fire suppression, tree removal) and current (tree removal, infrastructure, fire suppression, trampling) human activities. Changes in hydrology from a variety of perturbations including ditching, road and trail building, water diversions, livestock grazing, visitor foot traffic, fire suppression, and imbalances in the mammal herbivore populations, have altered the plant and animal communities that once occupied the meadow (WRD 2010). These disturbances alter hydrologic conditions including water delivery (primarily through channelization rather than sheet flow), sediment dynamics, lowered groundwater levels, and changes in the amount and timing of ground and surface water availability for plants (Loheide et al. 2007).

A study completed in 2008 (Ballenger and Acree) compared several attributes of meadow integrity in Tuolumne Meadows with eight other subalpine meadows in Yosemite. All other meadows in the study have also experienced grazing or other perturbations and are not considered reference or pristine, but provide a range of meadow condition for comparison. Assessments focused on indicators of meadow function and structure including community level plant diversity, forb (flowering herbaceous plants):graminoid (grasses, sedges, rushes) ratio, the percentage of areas without functioning vegetation (bare ground), and levels of small mammal activity.

Tuolumne Meadows had a much greater proportion of plots with bare ground as well as a much higher occurrence of plots with bare ground cover greater than 50% when compared to other meadows. In addition, Tuolumne Meadows study plots had four to eight times the proportion of plots dominated by forbs (Ballenger and Acree 2008). In terms of the forb:graminoid ratio, study plots in Tuolumne Meadows had two to eight times the proportion of plots dominated by forbs compared to six of the other meadows (Ballenger and Acree 2008). Areas in Tuolumne Meadows that have a high forb:graminoid ratio are of particular importance, especially in areas with high organic matter content in the soil. Centuries of the accumulation of organic matter contributed from deep-rooted graminoids typically build and maintain high organic content levels in meadow soils (Cooper et al. 2006). Where soil organic matter content is high but no or few graminoids occur, it is likely that the floristic composition has changed from the time when these soils developed. Shallow- or tap-rooted forbs do not grow as densely as long-lived rhizomatous and clonal plants, and they do not grow into and reduce the areas of bare ground in the same manner as the graminoid species (Ballenger and Acree 2008). Because tap- or shallow-rooted forbs lack the soil stabilizing characteristics of graminoids and do not contribute significantly to soil organic matter, areas with a high proportion of forbs are also at higher risk of soil erosion and loss of soil organic matter (Cooper et al. 2006). Finally, areas with high forb:graminoid ratios and high cover of bare ground are not likely to re-vegetate on their own, and soils may be losing organic matter.

Tuolumne Meadows was the only meadow (of the eight surveyed) with areas dominated by big sagebrush (*Artemisia tridentata*) shrubs (Ballenger and Acree 2008). Related meadow studies found that expansion of sagebrush into meadows might be stemming from livestock grazing-related disturbances, which can compact soil, increase the aridity of soils, and cause changes in meadow hydrologic processes, such as stream incision (Vavra et al. 1994, Magilligan and McDowell 1997). Berlow et al. (2002) found that intact moist meadow vegetation effectively prevents sagebrush germination and subsequent seedling survival, while small disturbances (such as gopher activity) can decrease competition with other vegetation and promote sagebrush invasion (Burke and Grime 1996). The fact that Tuolumne Meadows has areas dominated by big sagebrush is another indication that the biological integrity of this meadow is in a compromised state (Ballenger and Acree 2008).

Mammal burrowing activity can influence plant communities but levels did not differ greatly between Tuolumne and the eight other meadows (Ballenger and Acree 2008). Although Tuolumne had proportionately more plots with high levels of mammal activity (excepting Lower Lyell - also a highly impacted meadow), the proportion of Tuolumne plots with any (low, moderate to high) burrow activity falls within the normal range of variability of the other meadows.

CONIFER ENCROACHMENT

Conifer encroachment into subalpine meadows has been observed and researched for nearly a century in the mountains of western North America. Several studies focused on the Sierra Nevada, including Tuolumne Meadows, indicate that conifer establishment is likely a response to climate change (Jakobus and Romme 1993, Cooper et al. 2006), reduction in fire frequency (DeBenedetti and Parsons 1979), high levels of bare ground and impacts from intensive grazing (Sharsmith 1959, Ratliff 1985, Miller and Halpern 1998, Millar et al. 2004, Cooper et al. 2006).

Conifer encroachment is widespread in Tuolumne Meadows. Lodgepole pines are more likely to establish on bare mineral soil (Lotan at el. 1985) and the high levels of bare ground observed in Tuolumne Meadows provide ideal conditions for germination. Conifer encroachment occurs nearly twice as often in drier meadow plant communities with higher cover of bare ground when compared with other plant communities in the meadow (Ballenger and Acree 2008). Periods of low precipitation and low year-to-year variability in moisture conditions appears to be related to lodgepole pine expansion into Tuolumne Meadows and follows recruitment patterns observed Sierra Nevada wide (Cooper et al. 2006). Because tree removal activities have occurred in Tuolumne Meadows since around1933, it is unknown if earlier tree establishment episodes would have survived in the absence of managed tree removal.

Despite aggressive tree removal over the past 80 years, lodgepole expansion into the meadow continues and is likely due to climatic and soil conditions. Studies of subalpine meadows in the Cascade Mountains indicate that soils in meadows and adjacent forests have different biochemical properties and that meadow soils rapidly assume forest soil characteristics as trees establish in the meadow (Griffith et al. 2005). Changes in the soil pH, extent of fungal mats, denitrification potential, and litter depth, favor continued establishment of conifers even after removal (Griffith et al. 2005). In particular, higher pH and the presence of extensive fungal mats that depend on conifers as their hosts, discourage establishment of meadow species. It is probable that conifer establishment will continue with the current soil, vegetation, and climate conditions and ecological restoration may not be appropriate or feasible for limiting conifer encroachment. However, where conifer encroachment can be attributed to bare ground resulting from human trampling or development, and/or research indicates that conifer encroachment is tied to anthropogenic impacts, ecological restoration that includes conifer removal to restore those plant communities may be appropriate. Clearing of conifers may also continue to maintain scenic vistas and the cultural landscape.

FIRE REGIME

Both natural and anthropogenic factors likely influenced the fire regime in Tuolumne Meadows. Lightning-ignited fires are documented in Yosemite National Park (van Wagtendonk 1993), but the spatial and temporal patterns in Tuolumne Meadows during the last 500 years are largely unknown. Prior to the 1850s, American Indians may have set fires in Tuolumne Meadows to modify vegetation

(Reynolds 1959, Gassaway 2005). During the early years of sheep grazing, sheepherders may have set fires in forested areas around Tuolumne Meadows in order to expand grasslands (Babalis et al. 2006). Fire suppression efforts in Tuolumne Meadows began after 1891 and natural fires have not occurred since at least 1921 (Cunha 1992, Cooper et al. 2006). However, it is unknown if natural or anthropogenic fires burned across Tuolumne Meadows or stopped at the forest/meadow margin.

Based on a limited study (Cooper et al. 2006) of fire scarred trees in the Tuolumne Meadows area, fire has not occurred in the Tuolumne Meadows area since at least the early 1900s, but may have been relatively frequent prior to the mid-1800s. More frequent fires may have modified the meadow environment or led to the mortality of lodgepole seedlings, thus greatly changing the prevalence of conifer establishment. A fire history study of lodgepole pine forests in the Sierra Nevada is in progress and may shed some light on the spatial and temporal patterns of previous fires.

Non-native species

Based on limited survey and incidental observations, there is a relatively low level of occurrence of non-native plant species in the Tuolumne area. Observed non-native species include common dandelion *(Taraxacum officionale),* cheat grass *(Bromus tectorum)* and yellow star thistle *(Centaurea solstitialis).* Reports of yellow toadflax *(Linaria vulgaris)* at 9,000 feet in elevation and spotted knapweed *(Centaurea maculosa)* at 7,500 feet in elevation in the Inyo National Forest along Tioga Road above 9,000 feet in elevation, indicate that high elevation areas are still vulnerable to the introduction of highly invasive plant species.

Survey and treatment of common dandelion began in 2010 but no treatment of cheat grass currently occurs. Plans for expanding non-native plant survey of the Tuolumne area will provide managers a better idea of the extent and number of non-native plant species and lead to recommendations for effective treatment. Survey and treatment methods will follow those outlined in Yosemite’s Invasive Plant Management Plan Update (NPS 2010).

Summary

These findings support the importance of further investigation into the causes of differing vegetation and habitat features in Tuolumne Meadows. High levels of bare ground in areas that likely have rich organic soil suggest that the dense deep-rooted sedges and grasses that formed these soils over centuries of time may not be self-sustaining, and these areas may even be losing organic matter. When coupled with high forb:graminoid ratios, revegetation may not occur on its own. Research into the root causes of vegetation differences, the make-up of historic vegetation, and whether carbon is being lost in the soil, could confirm these hypotheses (Ballenger and Acree 2008). Meadow integrity is reflected in biotic elements and the processes that generate and maintain those elements such as groundwater levels (Angermeier and Karr 2005). For example, where high groundwater levels persist during the growing season yet conifer encroachment, high levels of bare ground cover or other indications of impaired meadow integrity are observed, other causal factors are likely (Ballenger and Acree 2008).

SOILS

Based on initial assessments of soils in Tuolumne Meadows completed by the National Resources Conservation Service (NRCS), meadow soils are comprised of sandy loams, loamy sands and silt loams, with some component of volcanic ash or glacial till (Jones and Stokes 2001). A hydric soils list is not available for the Tuolumne Meadows area, but redoximorphic features (those indicating prolonged inundation or saturation during the growing season) occur in many areas.

A 2006 study (Cooper et al.) of the organic matter in soils found that content ranged from 12-18% in wet meadow plant communities and approximately 7% in upland and border areas dominated by lodgepole pine and upland herbaceous plant species. Initial investigations indicate that the high organic content of these soils and the low below-ground plant production may suggest that the existing vegetation did not form the existing soils (Cooper et al. 2006). Further investigations are needed to determine if ecological restoration actions are feasible and warranted.

Fig. 1-5. Trails and channels can interrupt or channelize sheet water flows

HYDROLOGIC PROCESSES

Sheet flow is very important in maintaining meadow ecosystems by providing water via surface flow at low velocities and depositing sediment that provides nutrients to meadow biota. Channel incision resulting from downcutting, vegetation loss and headcuts has altered sheet flow processes in the meadow, leading to concentrated flows and a lower groundwater level. Ponding associated with culverts further concentrates water and limits sheet flow.

The conditions of the riverbanks along the Tuolumne River, as well as the shallower and wider channel, also influence sheet flow processes and groundwater levels. According to recent assessments of the hydrologic regime in Tuolumne Meadows, most sediment transport occurs during spring or summer rainstorms (Roche, personal comm). During heavy downpours associated with thunderstorms, water flows off adjacent granite domes at high velocity in sheets that typically flow into lower lying areas such as meadows. Small streams quickly become bank full and redeposit sediment transported by the high velocity water sheeting off of landforms such as granite domes. However, when water reaches trail ruts, incised channels, bare or sparsely vegetated areas, flows are concentrated in these channels rather than sheeting across the meadow (Figure 1-5). Sediment accumulated during these storms is deposited in concentrated areas rather than dispersing throughout the meadow, limiting the distribution of nutrients. Flow concentration and channelization limit infiltration of storm water and snow melt, affecting soil moisture and groundwater.

Fig. 1-6. Headcut near Delaney Creek

Fig. 1-7. Headcut on Budd Creek

Fig. 1-8. Diffuse headcut

Fig. 1-9. Healthy transition between vegetation types

HEADCUTS

Numerous headcuts associated with trails, culvert ditches and natural water channels (such as incised sections of Budd Creek) occur throughout Tuolumne Meadows (Figure 1-6, 1-7). Headcuts occur when water flow is concentrated and channeled at high velocity, increasing scour and altering sedimentation dynamics. Headcuts lower the adjacent groundwater level, expose soils, and limit sheet flow across the meadow. With a lower groundwater level, the upper soil levels dry sooner in the year, potentially changing wetland plant communities to upland plant dominated communities with less anchoring roots. Headcuts are most commonly due to some perturbation such as vegetation loss, concentration of water flow, increase in flow or increase in slope. While these perturbations can occur naturally, most headcuts observed in Tuolumne Meadows result from artificial (human-caused) changes to hydrology.

Incipient headcuts are more diffuse and characterized by an abrupt transition between different vegetation types (Figure 1-8, 1-9). These types of headcuts occur below Pothole Dome where surface water flows off the dome at high velocity and is channeled onto informal trails. The abrupt slope transition from the relatively flat and vegetated surface of the meadow to the unvegetated trail surface erodes the trail margin, progressively incising the meadow surface upslope from the trail. With water flow concentrated by the trail, sediment is channeled to discrete deposition points rather than deposited over larger areas of the meadow.

To mitigate downcutting, headcutting, and other disruptions to hydrologic flow, it is important to understand and address the source of the problem. Because headcutting is a result of channeling (often in trail ruts or incised streambeds), simply filling in the deep gouges does not address the cause of the headcut and it will likely continue. Mitigation of the source or cause of the high velocity and concentrated flow is necessary to limit the development and enlargement of headcuts. To restore the hydrologic conditions to limit further headcutting, the following actions are proposed:

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Determine source of problem (channeling of water from culvert ditches, trails, bare ground etc.) and mitigate to decrease velocity, slope and concentration of flow
- Fill in deep headcuts with local native soil to discourage continued channeling
- Apply bioengineering techniques (such as hydro-drilling of willows, brush layering, installing of woody debris, plant material, and erosion control structures such as wattles or blankets) to divert and disperse runoff, promote deposition and limit scour
- Re-contour surrounding area to natural landform
- Mulch, seed and plant to re-vegetate with native species and minimize bare ground cover, sediment loss and continued erosion

Fig. 1-10. Incised channel near Pothole Dome

DITCHES AND INCISED CHANNELS

There are several ditches and incised channels throughout Tuolumne Meadows associated with perennial and intermittent streams, trails, culverts and historic draining efforts (Figure 1-10). The most prevalent ditches are those adjacent to a section of the Great Sierra Wagon Road that serves as a trail between the Visitor Center and Soda Springs. Other, more subtle ditches are likely remnants of draining efforts of potholes (kettle tarns) and ponding associated with culverts for mosquito abatement (Figure 1-11). There is also extensive channel incision associated with perennial and intermittent streams throughout the meadows that may be attributed to poor or inadequate culverts and bare ground.

Fig. 1-11. Ditch draining kettle pond

Ditches and incised channels alter the hydrologic regime by channeling and concentrating water flow, intercepting surface and groundwater, cutting off flow to downstream areas and altering the timing, velocity, depth and direction of groundwater flow. The resulting concentrated flow and velocity leads to further downcutting. Mitigation of the source in upstream areas and any conditions that have led to channel incision is also necessary. To restore the landform from past ditching and channel incision, the following actions are proposed:

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Determine source of problem and mitigate to decrease velocity, slope and concentration of flow
- Fill in ditches and incised channels with local native soil to discourage continued channeling
- Apply woody debris, native mulch, and plant material (willows using hydro-drilling techniques) to divert and disperse runoff, promote deposition and limit scour
- Re-contour surrounding area to natural landform
- Mulch, seed and plant to re- vegetate with native species and minimize bare ground, sediment loss and continued erosion

Fig. 1-12. Bare area adjacent to shuttle bus stop

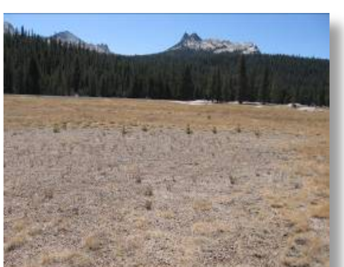


Fig. 1-13. Bare area with lodgepole seedlings

TRAMPLING

Several areas experience high levels of human trampling resulting in vegetation loss, soil compaction and impacted meadow habitat. Several of these areas are adjacent to trailhead parking, shuttle bus stops and visitor facilities such as the Visitor Center, Tuolumne Meadows Store and Grill and Gas Station. The meadow adjacent to these high use areas is characterized by a high proportion of bare ground, different vegetation communities than observed in undisturbed portions of the meadow (e.g. dominated by big sagebrush), dead or damaged vegetation, compacted soils, and disrupted hydrologic function such as headcutting (Figure 1-12). Because of the high level of visitor use in the Tuolumne Meadows area, allowing dispersed use only increases the area of vegetation damage. Human trampling may also, via soil compaction and bare soil exposure, contribute to the lodgepole pine encroachment apparent in Tuolumne Meadows (Vale and Vale 1994), (Figure 1-13). Based on a recent study of the effects of tramping on subalpine meadow habitat, Tuolumne Meadows is very sensitive to trampling impacts and is very slow to recover from damage and degradation (Holmquist 2008). Several methods are recommended to minimize these impacts and the following actions are proposed:

Fig. 1-14. Parking lot creep

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Protect sensitive areas using closure signs, fencing, and/or other natural barriers such as rocks and logs as deterrents
- Focus use by delineating trails, signs and other means of concentrating visitor use to more sustainable areas
- Assess visitor flow associated with trailheads, shuttle bus stops and facilities and focus use to more appropriate areas
- Delineate parking areas adjacent to meadow
- Delineate trailhead areas and the beginnings of trails to reduce informal trail density and minimize area of impact
- Consider shuttle bus stop locations in respect to impacts on vegetation

PARKING AND TRAILHEADS

Limited parking for visitors to the Tuolumne Meadows area puts enormous pressure on the existing parking areas. These areas exhibit parking lot "creep" (Figure 1-14) and continue to expand as more and more visitors try to find parking. Areas around the parking areas exhibit damaged vegetation, bare ground and many informal trails. This also impacts cultural resources and archeological sites. The most impacted areas include the Cathedral Meadow Trailhead (Figure 1-15), the Soda Springs trailhead and the Lembert Dome/Glen Aulin Trailhead. Issues and design for the trailheads along the entire Tioga Road will be addressed in a separate environmental assessment. Depending on the preferred alternative for parking determined in the Tuolumne Meadows Plan, the following actions are proposed to maximize natural and cultural resource protection:

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Delineate parking areas with rocks, logs, or other obstructions to discourage creep (expansion)
- Ensure that parking areas are flat to minimize erosion and runoff
- Organize parking areas and trail access to minimize the tendency for informal trails
- Focus parking areas away from meadow habitat or sensitive cultural areas
- Re-vegetate damaged areas by de-compacting soils, mulching, seeding and planting
- Protect newly restored areas from further impact with closure signs, fencing, and/or other natural barriers such as rocks and logs

Fig. 1-15. Impacted vegetation adjacent to Cathedral Lakes Trailhead

Cathedral Lakes Trailhead

The Cathedral Lakes and Cathedral Peak trailhead is one of the most popular in the Tuolumne Meadows area. Over decades, the roadside parking area has expanded further west and east along the road and further out into vegetated areas, particularly on the north side where parking is immediately adjacent to the meadow. The impacts extend beyond the parking as visitors walk further out into the meadow, trampling vegetation and promoting more bare ground. Because parking is limited, visitors annually increase the parking area by squeezing their cars between trees, boulders or directly onto meadow vegetation. Roadside parking in this fragile meadow ecosystem is neither sustainable nor appropriate. To restore this heavily impacted area after parking is removed, the following actions are recommended:

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Close area to parking with fencing, boulders or other obstructions
- In forested areas, de-compact, mulch and seed the area
- In meadow areas, re-contour, de-compact, mulch, seed, and plant to restore natural meadow topography and vegetation
- Collect seed and grow native vegetation in a nursery to plant the area
- Address any hydrologic diversions or channeling to limit erosion and facilitate sheet flow

ROADS

TIOGA ROAD

Highway 120 (Tioga Road), runs east to west along the southern edge of Tuolumne Meadows and surface water flowing from the southern slopes is channeled through 35 culverts. In 2006, culverts clogged with vegetation and sediment were observed in 12 locations and signs of ponding water south of the road were observed in 23 locations (Cooper et al. 2006), (Figure 1-16). In most places, water is diverted to run parallel to the road at a distance less than 10 meters before a culvert allows water conveyance under the road and into the meadow (Cooper et al. 2006). Ponding is much more frequent near the east end of the meadow, where culverts are spaced further apart. The campground, gas station, store, and other infrastructure, coupled with lower gradient surface slopes, further interrupt water flow. The Tuolumne River is spanned by a bridge on the east end of the meadows that impacts the free-flow of the river.

Culverts

Fig. 1-16. Partially blocked culvert

Because culverts force previously dispersed runoff into localized channels, downcutting has occurred downstream of many of the culverts, particularly in the west end of the meadow. This downcutting results in levee formation and accumulations of soils with greater permeability than surrounding meadow soils. These areas experience isolated prolonged inundation (in the channel) surrounded by higher elevation areas with little to no inundation. Surface water inflows, in particularly Unicorn and Budd Creek, provide groundwater recharge to the meadows, resulting in locally higher water levels near the streams. Downcutting may decrease recharge from surface water to meadow groundwater since it lowers the water table in the downcut streams and limits overbank flow (Cooper et al. 2006).

Fig. 1-17. Culvert set too low in meadow

In addition, many of the culverts along Tioga Road are lower or higher than the surface level of the meadow (Figure 1-17). This increases downcutting, headcutting, and ponding, producing lower water availability and concomitant changes in species composition.

A single culvert conveys the majority of Budd Creek under the Tioga Road and does not effectively accommodate high spring flows. As a result, upstream incision on the south side of the road has deepened the channel and reduced overbank flow. A secondary culvert and associated channel accommodates Budd Creek during very high flows but channel incision and decreased overbank flow from the main stem limits this function (Figures 1-18, 1-19).

An assessment of the placement, number and size of existing culverts helps identify where replacement or modification can improve the hydrologic connectivity between the surface flow from the south side of the road and Tuolumne Meadows,. In general, additional, larger and better-placed culverts could mitigate many of the observed impacts. Placement of culverts should depend on surface levels of the meadow to minimize downcutting, headcutting and ponding effects. In particular, culverts conveying water from Budd Creek and Unicorn Creek need to be much larger and numerous to accommodate peak spring runoff, some channel migration and "flashy floods" from summer thunderstorms. Many of these culverts have been identified as contributing features to the historic Tioga Road. Suggested mitigations are discussed further in Chapter 2

Fig. 1-18. Ponding at culvert below Budd Creek

Once culverts are enhanced and replaced, work to restore the contours adjacent to existing culverts would help reduce the impacts and likelihood of further downcutting, channeling and ponding on the meadow vegetation and groundwater level. To lessen impacts of the existing culverts on meadow hydrology, the following restoration actions are proposed:

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Fill in ditches associated with culverts with native soil
- Apply woody debris, native mulch, and plant material (willows using hydro-drilling techniques) to divert and disperse runoff, promote deposition and limit scour
- Place rocks to disperse outflow energy and prevent downcutting
- Re-contour slope and landform to natural conditions to encourage sheet flow
- Re-vegetate areas adjacent to and downslope of culverts with native species to slow velocity of water flowing into the meadow, encouraging sheet flow and sediment deposition

Fig. 1-19. Budd Creek culvert

TIOGA ROAD BRIDGE

The Tioga Road Bridge, west of the Lembert Dome parking area, has a 400-foot length of fill on the northeast approach to the bridge that acts as a levee, bisecting the wetland floodplain into two separate areas. Transfer of water downstream across the right bank floodplain is impeded, forcing overbank flows back through the constricted bridge opening that increases hydraulic pressure on the bridge. This condition also erodes the riverbank, alters the composition of wetland soils in the area, and compromises the structural integrity of the bridge. To reestablish a hydrologic connection between the floodplain on either side of the fill and allow water to transfer under the approach road, one of the following actions are recommended:

- Install a series of large culverts placed on grade under the road or
- Increase span of bridge to a greater width, including more of the river and floodplain.

Little Blue Slide

Little Blue Slide is an unstable road cut east of Tuolumne Meadows along Tioga Road. Continuous sloughing of silt and boulder-sized material from the road cut impacts water quality, park operations, and safety. Stabilization of the site would require development of an engineering and revegetation strategy followed by extensive manipulation of the cut slope above the road and the fill slope below the road.

Mitigation of impacts due to the Little Blue Slide road cut should consist of two components: 1) a low guard wall at the base of the slope next to the road to intercept boulders and sediment before they hit the road and 2) stabilization of the remaining cut slope using a proven bioengineering approach. The guard wall may be 6-10 feet in height and engineered for impacts of large boulders tumbling from the top of the cut slope. The proposed bioengineering approach consists of cutting benches in the slope and backfilling each bench with blue slide sediments ameliorated with organic materials. The fill will be planted with local plant species capable of withstanding the harsh climate and creating substantial root masses that can stabilize the slope. While these measures will not eliminate fine sediment flux from the slope, they will reduce it to levels of other steep natural slopes nearby.

- Engineer benches backfilled with soil with adequate rooting depth for plants to stabilize the surface layer, facilitating infiltration and providing cover
- Construct a small retaining wall at the base of the slope on the road
- Re-vegetate the slope by planting, seeding and mulching

Historic Roads

In 1883, the Great Sierra Consolidated Silver Mining Company built the Great Sierra Wagon Road (GSWR) to access the company's mines east of Tuolumne Meadows. In 1915, the road became a public highway and was officially renamed the Tioga Road and a segment was rerouted through Tuolumne Meadow to cross the river (referred to as the Old Tioga Road), (Figure 1-20). Today, some sections of the original Great Sierra Wagon Road and Old Tioga Road are well-defined and serve as a trail or access road. Other sections of the Great Sierra Wagon Road lie under the footprint of the present Tioga Road, while some sections are barely discernible. The western portion of the Great Sierra Wagon Road is listed in the National Register of Historic Places, with other sections likely eligible to be listed. This Great Sierra Wagon Road, and other historic roads in the Tuolumne Meadows area, are also contributing features to the Tuolumne Meadow Historic District and are subject to considerations of the National Historic Preservation Act (NHPA).

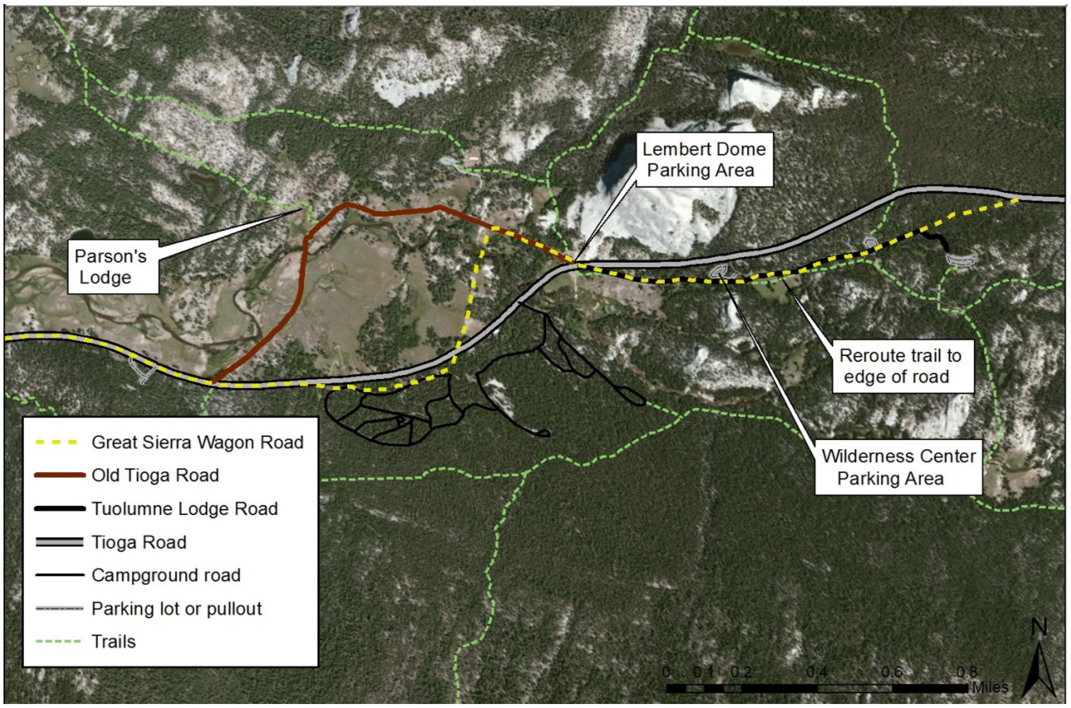


Figure 1-20: The Great Sierra Wagon Road and Old Tioga Road alignment

There are remnants of these old roadbeds along the northern and southern edges of Tuolumne Meadows (Figure 1-21, 1-22). Many sections of the roads are difficult to detect, while other sections are obvious and characterized by sparse vegetation, multiple ruts, and conifer encroachment. While these roadbeds have historic value, they also impact meadow integrity in a number of ways including channeling water, altering vegetation composition, retaining compacted soils, and disrupting hydrologic connectivity (ponding upslope and drying downslope areas).

Fig. 1-21. Old roadbed north of the Visitor Center

As part of larger efforts to restore meadow health, the most ecologically-damaging aspects of these historic resources may be addressed through ecological restoration. Since these actions are likely represent an adverse impact under NHPA, historic preservation mitigation measures are discussed in Chapter 2. Two sections of old roadbed currently used as trails require special attention due to the impacts on ecological processes in the adjacent meadow and are described in more detail below. The following general restoration actions are proposed for other abandoned sections of road:

- Re-contour, de-compact, mulch and seed to restore to natural conditions
- Remove associated fill or infrastructure such as culverts
- Ensure documentation of historic resources before removal

Chapter 2 in this report provides a cultural resource analysis with design recommendations and mitigations required to minimize adverse effects to the contributing structures and the historic district should ecological restoration take place. Following are general objectives for historic roads:

Fig. 1-22. Old roadbed near Delaney Creek

- Document the Great Sierra Wagon Road and Old Tioga Road through Tuolumne Meadows
- Retain alignments of all trails along historic road segments
- Retain first (southernmost) 174 meters (570 feet) of the Old Tioga Road roadbed and stretches of the Great Sierra Wagon Road near the Tioga Road that are minimally impacting meadow hydrology (e.g. across from the Visitor Center)
- Conduct archeological monitoring during any operations that require soil disturbance

The sections below provide more detail on the specific restoration actions that are proposed by each section of old roadway.

Fig. 1-23. Headcut and downcutting

SECTION 1: LEMBERT DOME PARKING AREA TO TUOLUMNE LODGE

The Great Sierra Wagon Road crosses the Tuolumne River just south of Dog Creek, continues to the south across from the present day Lembert Dome Parking area and through meadow habitat towards the Tuolumne Lodge. A section of this portion of the Great Sierra Wagon Road now serves as a trail between Lembert Dome Parking area to the Wilderness Center. This section of trail is heavily used by stock coming from the NPS stables towards the Glen Aulin trail. Due to heavy use and erosion, some sections of the trail are up to 3 feet below the grade of the meadow and up to 12 feet wide; significantly impacting meadow hydrology by lowering groundwater levels and channeling surface flow. Culverts on the nearby Tioga Road concentrate surface flow coming off Lembert Dome (particularly during heavy thunderstorms) that previously sheet flowed to the meadow into the trail corridor, leading to extensive erosion, headcuts and sediment transport into the river. This concentration of sheet flow in the trail corridor diverts water from the meadow areas, lowers groundwater levels, increases erosion and alters plant communities (Figure 1-23). Because this section of trail is so deep and sandy, it is difficult to walk on so visitors and pack stock walk on the edge next to the trail, causing more vegetation loss and further widening (Figure 1-24). There are also several informal trails leading to the main trail, further exacerbating channeling effects. In order to mitigate impacts to the meadow, prevent sediment from going into the Tuolumne River, retain the trail for foot and pack stock traffic, and minimize any adverse effect to the historic character of the Great Sierra Wagon Road, the following actions are proposed. Project implementation will require the utilization of heavy equipment including an excavator, dozer, skid steer, and dump truck over up to 10 weeks in late summer/early fall when river and groundwater levels have dropped.

Fig. 1-24. Wide deep rut with trail on side

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Bring trail ruts up to the same elevation as the adjacent meadow (fill with soil, rocks and/or gravel) – heavy equipment such as skid steer and excavator may be used

Fig. 1-25. Ditches adjacent to old roadbed

- Apply woody debris, plant material, and erosion control structures such as wattles or erosion blankets to divert and disperse runoff, promote deposition and limit scour
- Establish native vegetation (locally gather seed, grow out seeds in a nursery setting and plant, transplant salvaged plants and mulch) to slow water velocity
- Narrow roadbed to width recommended by cultural resource specialists, while minimizing impacts to natural resources
- Increase the number and size, and improve the placement of culverts conveying water flowing off of Lembert Dome (north of the road) to reduce channeling, downcutting, headcutting, and velocity, and encourage sheet flow
- Stabilize existing headcut – completely fill and plant appropriate native plants and install a series of properly designed checkdam structures to encourage sediment accretion
- Relocate a section of trail that diverges from the historic GSWR alignment out of the meadow across from the Tuolumne Ranger Station to the edge of the road and restore the meadow to natural conditions
- Improve signage to encourage visitors to stay on the trail

SECTION 2: TIOGA ROAD TO PARSON'S LODGE AND SODA SPRINGS

The section of the Old Tioga Road that begins east of the Visitor Center from the current Tioga Road to Parson's Lodge now serves as the main foot and stock trail to the lodge and the Soda Springs area. Constructed in 1915, the roadbed was elevated above the meadow level with soil dug from the sides of the road (Figure 1-25). Today, the road averages 12 feet wide, and the roadside ditches channel water laterally alongside the roadbed into one of four culverts (one of which conveys Unicorn Creek). These roadside channels, along with the damming effect of the roadbed, alter surface flow ultimately changing plant communities. Where the road crosses Unicorn Creek and another small drainage, inadequate culverts have caused significant scour and headcutting downstream of the roadbed (Figure 1-26). A bridge across the Tuolumne River brings visitors to the lodge and these bridge abutments constructed on the riverbanks alter natural river processes and sediment deposition and scour. In addition, conifer encroachment on the roadbed (Figure 1-27) detracts from scenic views of the meadow.

Fig. 1-26. Scour downstream of culvert on Unicorn Creek

In order to mitigate impacts on hydrology and meadow vegetation, retain the trail for foot and pack stock traffic, retain the historic alignment of this road and address impacts of the bridge over the Tuolumne River, the following actions are proposed. Treatment will vary depending on the expected surface water flow, level and the best opportunity for restoration of meadow hydrology. Project implementation will require the utilization of heavy equipment including an excavator, dozer, skid steer, and dump truck over up to 10 weeks in late summer/early fall when river and groundwater levels have dropped.

Figure 1-27. Multiple trail ruts on old roadbed

Historic road:

- Conduct archeological monitoring prior to and during implementation
- Salvage plants in ditches or on roadbed prior to restoration work and replant them to encourage plant reestablishment and to limit erosion
- Promote surface water connectivity utilizing a range of the following actions (further described in Chapter 3), (Figure 1-28):
  - Install box culverts under the trail to provide surface water connectivity for drainages (such as Unicorn Creek) and areas of ponding water
  - Lower roadbed and use that material to fill in ditches (specifically those parallel to the roadbed), headcuts, borrow pits and/or incised channels to restore natural meadow topography
  - Install boardwalk (i.e. wood, metal or concrete) or other trail surface through wet and saturated areas to maintain sheet flow and protect vegetation from trampling
  - Construct low crossings for stock and stepping stones for visitors in areas with intermittent flow to allow for surface water connectivity during spring runoff
- Narrow or maintain trail corridor to approximate historic road width to retain historic character (determine by cultural resource specialists)and minimize impacts to cultural and natural resources
- Gather and spread local native seed to encourage plant establishment
- Remove conifers that have established in response to the drier conditions on the roadbed
- Apply woody debris, plant material, and erosion control structures such as wattles or blankets to divert and disperse runoff, promote deposition and limit scour

- Improve signage to encourage visitors to stay on the designated trail
- Avoid impacting archeological site on northern end near the Tuolumne River (south of the bridge)

Tuolumne River Bridge area:

- Install two low spans up to the southern abutment to increase flow capacity of the side channel currently cut off from the river by road fill
- Consider bridge redesign If impacts on the Tuolumne River continue: focusing on improving bank abutments (abutment in the middle of the river is built on natural boulder and has less impact)

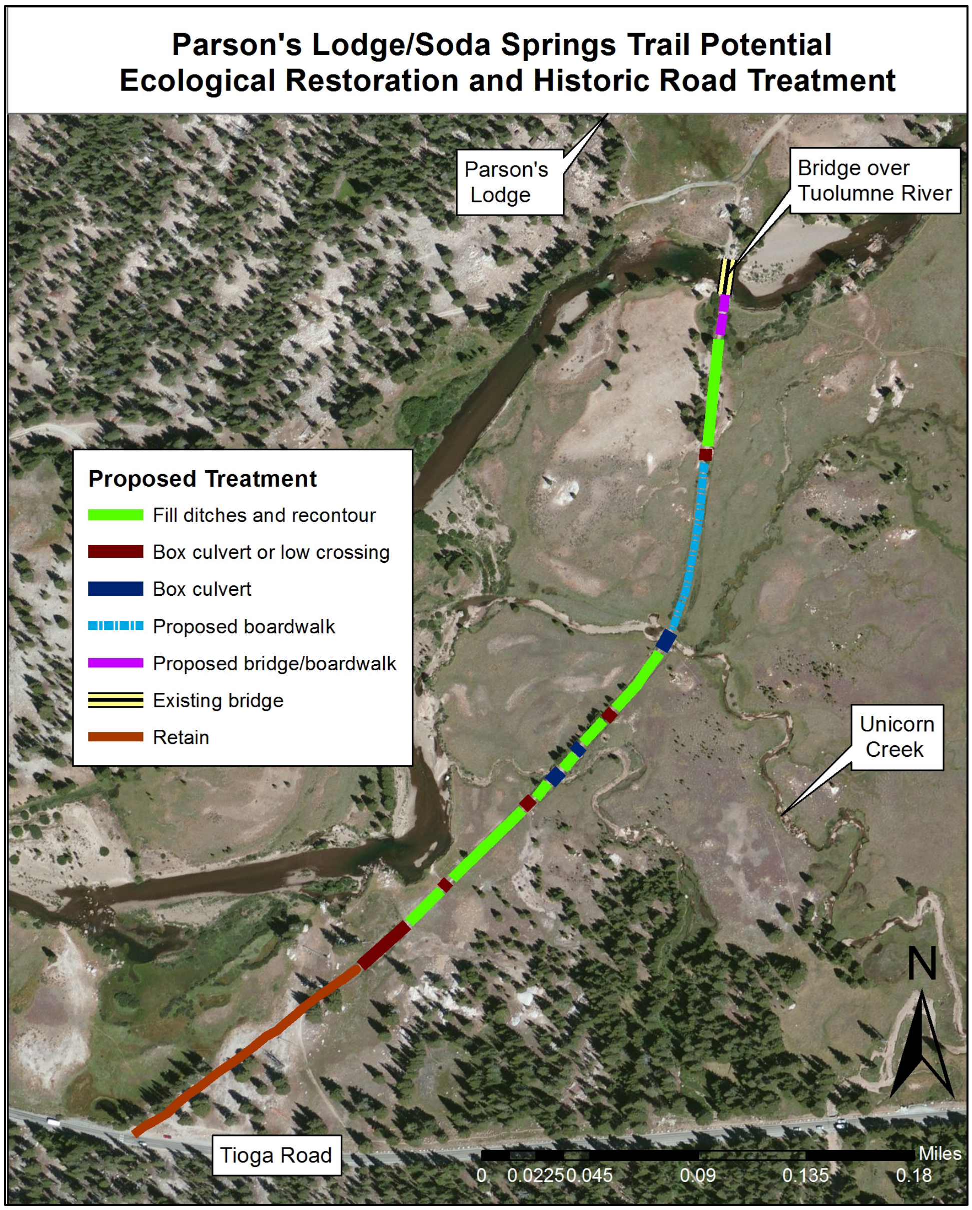


Figure 1-28. Proposed treatment for the old road to Parson's Lodge

TRAILS

There are miles of both formal and informal trails throughout the Tuolumne Meadows area. Trails through meadows can affect hydrology, compact soils, reduce vegetation cover and impact scenic views. In general, multiple rutted trails are common in meadows because as the ruts deepen they are subject to more saturation and inundation, causing visitors to move to drier areas adjacent to the trail, thus creating a new trail that also will become rutted (Figure 1-27). In some areas of frequent saturation, the trail may be built up to keep the tread dry but this impacts hydrology by obstructing sheet flow by acting as a dam. Most of the formal trails in the Tuolumne Meadows area lie within the footprint of the Great Sierra Wagon Road and are described in that section. There are also heavily used trails along the Dana and Lyell Forks of the Tuolumne River. Sections of these trails also exhibit braiding, rutting and widening. To mitigate impacts of both formal and informal trails, particularly multiple, rutted trails, the following restoration actions are proposed:

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Reroute trails out of meadows to drier, more resilient areas in collaboration with Trails, Wilderness, and RMS staff
- Remove any non-native fill, salvage native fill and vegetation
- Restore multiple ruts to natural conditions by re-contouring, de-compacting, mulching, seeding and re-vegetating
- Improve sheet flow disrupted by existing trails by improving or adding causeways
- Lower trail sections that act as dams
- Fill ditches that channel water with native soil
- Apply woody debris, plant material, and erosion control structures such as wattles or blankets to divert and disperse runoff, promote deposition and limit scour
- Install boardwalks or other trail types in very wet sections to promote sheet flow, protect vegetation and discourage multiple trail ruts
- Assess site appropriateness for formal trails considering wetland status, duration and depth of flooding/saturation, impacts of installing boardwalks or elevated trails and recovery of subalpine vegetation
- Delineate trails with natural materials and improve signage to encourage visitors to stay on the designated trail
- Narrow trails where appropriate (considering historic character)

INFORMAL TRAILS

Fig. 1-29. Wilderness sign at informal trail

Informal hiking trails are common throughout Tuolumne Meadows. Some of these trails exhibit heavier use just in the past decade, as they become more defined from constant traffic. Informal trail conditions vary depending on the level of use. Deep multiple ruts characterize some informal trails while others only exhibit trampled vegetation. A restoration project at Pothole Dome in the 1990's addressed multiple informal trails and proved effective in protecting the central part of the meadow. In addition, fencing was installed to guide visitors to walk along the edge of the meadow. In recent years, an informal trail originating from parking just east of Pothole Dome and extending to the Tuolumne River has become much more prominent, particularly after an "Entering Yosemite Wilderness" sign was placed at the edge of the road (Figure 1-29). The sign is an indication to visitors that it is a formal trail and subsequently, use has increased. High concentrations of informal trails exist adjacent to the Tuolumne Store and Grill, at the Soda Springs trailhead, around the Soda Springs area, along the Cathedral Peak parking area and along the banks of the Tuolumne River. Many of these informal trails also affect cultural resources and merit removal. To minimize the extent and impact of informal trails, the following actions are proposed:

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Restore informal trails to natural conditions through re-contouring, de-compacting, mulching, seeding and re-vegetating
- Direct visitors to established trails
- Limit off-trail hiking in the meadow to protect sensitive areas
- Install temporary deterrents to protect sensitive areas from further impact
- Allow dispersed use in more resilient and less popular areas

Fig. 1-30. Riprap along river in Tuolumne Campground

TUOLUMNE MEADOWS CAMPGROUND

The Tuolumne Meadows Campground has seven loops and 304 campsites. While most of the campground is within lodgepole pine forest, the A loop is very close to the riparian corridor of the Lyell Fork of the Tuolumne River. This loop road experiences ponding and flooding in the early part of the season. At the end of the A loop, flooding in 1997 washed out some of the road, prompting park mangers to lay riprap to harden the riverbank (Figure 1-30). Riprap can be effective in protecting infrastructure from further flood exposure, but it decreases the free flow of the river, compromising channel morphology and altering scour and deposition dynamics. There are many informal trails along this section of riverbank as well. The access road, campsites and other hardened areas concentrate water flow and sediment movement. To restore the free flowing character of the Tuolumne River and to protect and restore riverbanks and the riparian corridor, the following actions are proposed:

Fig. 1-31. Employee housing next to river

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Remove the A loop access road, informal trails and infrastructure to protect the riverbanks from further impact and to allow free flow of the Tuolumne River
- Remove riprap and any other erosion control structures
- Remove asphalt, re-contour, de-compact, mulch, seed and re-vegetate impacted areas
- Reroute the road entering the campground further away from the river out of the floodplain
- Re-vegetate and re-contour disturbed areas adjacent to the reroute
- Salvage any soil or vegetation that is removed for any new road development
- Apply bioengineering techniques (e.g. brush layering, anchor logs, intensive planting of vegetation) to stabilize riverbanks, promote sediment accretion, and minimize further riverbank loss
- Minimize the extent and concentration of informal trails by focusing access to more resilient areas and restore impacted areas to natural conditions

Tuolumne Meadows Lodge

The Tuolumne Meadows Lodge is a historic resource and provides overnight accommodation for visitors and housing for employees. Several structures, particularly the lodge and employee housing, are located within 10 meters of the Dana Fork of the Tuolumne River (Figure 1-31). These areas exhibit compacted soils, vegetation loss, exposed roots and riverbank erosion. Having structures so close to the river can also affect water quality. If any structures are removed, the following are proposed:

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Remove all above and below ground infrastructure (including pipes or any utilities)
- Re-contour the area to natural landform
- De-compact, mulch, seed and plant to promote native plant establishment
- Protect newly restored areas from further impact with closure signs, fencing, and/or other natural barriers such as rocks and logs

SODA SPRINGS AND PARSON'S LODGE

Soda Springs is a natural alkaline spring, unusual in the high Sierra Nevada, which provides habitat for many special status plant species. Soda Springs is not only ecologically valuable but is also an important American Indian historic resource. Parsons Lodge is listed on the National Register of Historic Places and is designated a National Historic Landmark. It is currently used for workshops and as a starting point for interpretive walks and talks. This area experiences high levels of use, with most people accessing the site via the trail from the Visitor Center. Additionally, the road to the sewage treatment ponds, the Glen Aulin trail, and many informal trails provide access to this very popular area. The Glen Aulin trail, heavily used by stock, passes very closely to the springs and the associated manure and dust has potential to contaminate the springs. To improve the ecological integrity of the site, the following actions are proposed:

- Consult with park-associated American Indian tribes and groups to develop restoration strategies, ensuring that treatments incorporate native concerns, issues, and perspectives
- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Improve delineation of trails
- Improve signage
- Remove informal trails and restore to natural conditions
- Direct visitors to use established trails
- Reroute the Glen Aulin trail further away from the springs
- Establish monitoring of vegetation and hydrology

STABLES

To provide supplies to the High Sierra Camps, day rides for visitors, and park management operations in wilderness, stock is housed in one of two corrals in the Tuolumne area. Issues associated with the corrals include soil loss from erosion and dust, potential water quality issues, water diversions for water supply, and vegetation loss. For alternatives of the Tuolumne Meadows Plan that propose to relocate, remove or consolidate stock staging areas, the following ecological restoration actions are recommended to minimize continued impacts:

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document any cultural resources
- Re-contour impacted area to natural landform if stables are consolidated and/or removed
- De-compact, mulch, seed and plant to re-vegetate with native species
- Restore hydrologic processes to minimize erosion, eliminate water diversions and address water quality issues

- Remove and restore associated trails that would no longer be needed to natural conditions
- Where stables are retained, ensure that water quality issues are addressed
- Where stables are retained, minimize footprint
- Protect newly restored areas from further impact with closure signs, fencing, and/or other natural barriers such as rocks and logs

General Removal or Relocation of Facilities

There are several facilities providing visitor and park management services in the Tuolumne Meadows area including roads, trails, employee housing, maintenance facilities (including stock operations, water collection and wastewater treatment facilities, and storage and staging areas), the Tuolumne Meadows Visitor Center, Tuolumne Meadows Campground, Tuolumne Meadows Lodge, Store, Grill, Mountaineering Shop and Gas Station, and Glen Aulin High Sierra Camp. Day use, overnight parking areas, and utilities are also associated with these facilities.

Depending on the preferred alternative, any plans to remove or relocate facilities must consider minimizing impacts to natural and cultural resources. If facilities, utilities, and/or associated infrastructure are removed, the following actions are proposed to restore areas to natural conditions:

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document cultural resources
- Restore wetland function impacted by infrastructure (e.g. housing area behind the gas station)
- Remove all above and below ground infrastructure impacting hydrologic conditions (pipes, asphalt, water diversion etc.)
- Crush, fill (slurry), or remove all abandoned underground utilities
- Re-contour area to natural landform
- Restore primary ecosystem processes, primarily hydrology and wetland function
- Salvage any soil or vegetation impacted by removal
- De-compact, mulch, seed and re-vegetate impacted area
- Minimize impacts to surrounding vegetation by limiting size and development of staging and construction areas
- Minimize impacts to hydrology
- Minimize impacts to wildlife
- Ensure that all equipment and materials are weed seed free
- Ensure that new construction or demolition does not impact the surrounding area (e.g. changes in drainage patterns), specifically wetland, riparian or riverine ecosystems or any primary ecological processes
- Protect restoration areas from further impacts with fencing or appropriate deterrents

Fig. 1-32. Sewage Treatment Pond

Fig. 1-33. Pump station associated with treatment pond

WASTEWATER TREATMENT

Wastewater from Tuolumne Meadows facilities is currently conveyed through pipes to two sewage ponds and spray fields north of Parsons Lodge (Figure 1-32). If the preferred alternative is to move wastewater treatment facilities to another location, significant restoration of the existing site is needed. Any site chosen for new wastewater treatment facilities or associated infrastructure would require an impact analysis for natural and cultural resources. The following actions are proposed to ecologically restore the existing site as well as associated access routes (including roads) to the site:

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document cultural resources
- Restore natural contours which match the surrounding landscape using heavy equipment (excavator, bulldozer, loader, dump trucks)
- Fill in pond sites (potentially using fill material left from the construction of the ponds)
- Remove asphalt, de-compact, re-contour, re-vegetate and restore to natural conditions
- Remove pump station and restore area to natural conditions (Figure 1-33)
- Remove and properly dispose of any toxic substances associated with the wastewater treatment
- Remove or crush all pipes and underground infrastructure associated with wastewater treatment
- Remove riprap and re-contour mounds from the construction of the ponds
- Re-contour ditched areas associated with the spray field and restore area to natural conditions
- Remove sections of non-historic road and restore to natural conditions; narrow sections of historic roads to retain historic character

WILDERNESS

Any restoration actions in designated Wilderness will use the minimum tool necessary to accomplish the project, in accordance with the minimum requirements analysis. For actions not covered under Yosemite's Programmatic Minimum Requirement Analysis for Ecological Restoration, a separate MRA will be completed.

GLEN AULIN HIGH SIERRA CAMP

The Glen Aulin High Sierra Camp is a historic resource and provides overnight lodging six miles into the wilderness. A wetland delineation of the area completed in 2006 documented areas of fragmented wetlands, a heavily used trail through a wetland and areas in need of ecological restoration. Denuded riverbanks also occur in the area. Ecological restoration is necessary to mitigate current impacts to wetlands and riverbanks and will vary in extent depending on whether the camp remains, is reduced in size, or is completely removed, Because Glen Aulin is located in a Potential Wilderness Addition, extra sensitivity to natural and cultural resources and wilderness character is necessary. For any structures or utilities that are removed or altered, the actions outlined in this plan under "Removal or Relocation of Facilities" apply. In addition, the following restoration actions are recommended:

- Survey for rare or sensitive plant and animal species and ensure protection
- Protect and document cultural resources
- Remove any impacts to wetlands and restore currently impacted areas to natural conditions
- Reroute the heavily used trail out of the fragmented wetland to a less sensitive upland area
- Salvage plants in reroute area and transplant to obstruct old trail
- Remove trail in wetland by de-compacting soils, filling in ruts, re-contouring natural meadow topography, seeding and mulching to promote plant establishment
- Obstruct old trail with natural materials to encourage visitors to use the new route
- Restore the natural drainage that was filled in and flattened to natural conditions, thereby improving access to toilets
- De-compact, mulch and seed to revegetate the historic corral on the granite bench that once was an extension of a delineated wetland
- Re-vegetate, stabilize and protect denuded riverbanks on the Tuolumne River

Lyell Canyon

The Pacific Crest Trail and John Muir Trail travels along the Lyell Fork of the Tuolumne River for approximately nine miles. Where the trail passes through wet meadow habitat, multiple ruts and muddy hiking conditions are common. Ongoing work by National Park Service staff to reroute these sections of the trail to upland areas and restore the meadow to more natural conditions protects these sensitive habitats.

Research

Additional research is needed to quantify the condition of meadow plant communities and the Tuolumne River, and the relationships to past and current land management practices. In particular, more research is needed to determine historic vegetation communities in these areas of concern, the most efficient and effective techniques for restoration, and the feasibility or appropriateness of ecological restoration. Research into the composition of historic vegetation is likely to entail analysis of soil seed banks, plant macrofossils and phytoliths (microscopic pieces of plants that are resistant to decay and can identify historic plant species). Analyses of organic matter content, soil carbon, carbon cycling, and plant productivity may also be included. Ecological restoration techniques to actively restore meadow plant communities, if feasible or appropriate, are likely to involve planting, seeding and mulching with temporary closure to foot traffic as vegetation re-establishes. These data may also provide information on the conditions that increase the rate and extent of conifer seedling establishment as related to past land use (i.e. intensive grazing). All of these studies would address the potential influence of climatic conditions and consider those interactions.

Cooper et al. (2006) recommended a detailed study of willows in order to understand the factors that limit establishment and persistence as well as the relationship between willow growth and riverbank stability. Research may also focus on mammalian herbivory (pocket gophers, voles and deer) and the effects on establishment and growth of perennial plants typical of wet meadows. This research may require installation of temporary experimental plots that eliminate entry of small mammals. The effects of deer browsing would be assessed by protecting individual willows from grazing by small exclosures and comparing willow height, productivity, and catkin/seed production of those willows not protected. These research plots would be located outside of designated Wilderness. If research indicates that vegetation communities are in an altered state due to anthropogenic influence (such as historic sheep grazing), restoration actions to restore these plant communities may be desired and appropriate.

MONITORING AND LONG-TERM MAINTENANCE

Tuolumne Meadows and the Tuolumne River corridor comprise diverse and dynamic ecosystems. Any alterations can effect cascading changes to the complex physical, chemical and biological interactions and conditions. Monitoring the efficacy of restoration efforts and the conditions stemming from those actions can feed into adaptive management and help avoid unwanted results.

Successful ecological restoration should also include continued protection and management of the project site into the indefinite future (Clewell et al. 2005). Frequently, ecological restoration projects are not funded for subsequent management that may be required to prevent recurrent degradation of restored ecosystems. To ensure success and to facilitate adaptive management, it is critical to include monitoring in ecological restoration planning.

Monitoring can help to determine the efficacy of the restoration efforts and provide guidance for future restoration projects in similar environments. Monitoring methods may include vegetation transects, quadrats or ocular estimations of vegetation cover, temporary exclosures, groundwater monitoring wells, and photo point establishment.

Ecological restoration is a long-term process and future intervention may be necessary. Future ecological restoration actions and monitoring will also be guided by research as understanding meadow systems increases. Future monitoring and adaptive management of restoration actions will be dependent on the ability of Park staff to secure funding through proposal processes.

CHAPTER 2. MITIGATION MEASURES TO PROTECT THE GREAT SIERRA WAGON ROAD

By Daniel Schaible, Historical Landscape Architect

HISTORIC OVERVIEW OF THE GREAT SIERRA WAGON ROAD

The Great Sierra Wagon Road was built in 1883 by the Great Sierra Consolidated Silver Mining Company to access the company's mines on Tioga Hill east of Tuolumne Meadows. This road was unpaved, built to a maximum grade of 10% and was 10-20 feet wide. In 1915, it was acquired by Stephen Mather and donated to the Department of the Interior as a public highway serving motor tourism in the area. At that time the road was officially renamed the Tioga Road, although it had been referred to by that name for some time earlier. A segment of the wagon road was rerouted through the meadow from east of the Visitors Center to the area of Parsons Lodge in 1915.

In the early 1930s, the National Park Service decided to reconstruct the Tioga Road in three phases. The first involved rebuilding the road from the east, from Tioga Pass to Cathedral Creek, the second from the west, from Crane Flat to White Wolf, and the third segment, begun about twenty years later, completed the remainder of the current road alignment. Although the first two segments were constructed on schedule, the third section of roadway, having been stalled following the U.S. entering into World War II, was not completed until 1958. The "new" Tioga Road was built to contemporary Forest Highway Standards, as defined by the Bureau of Public Roads, and was 26-28 feet wide with a maximum grade of 6%. Although following a similar route in some locations, the new Tioga Road deviated from the alignment of the original road in many stretches. Today, many remnants of the original alignment of the Great Sierra Wagon Road are still present, some of which are currently used as foot and stock trails.

The western portion of the Great Sierra Wagon Road, from the area near Aspen Valley to White Wolf, (which is far outside of the proposed ecological restoration project area) was listed in the National Register of Historic Places in 1978 with local significance within the fields of transportation, industry and engineering. Later, the remnant section of the Great Sierra Wagon Road that passes through the project study area was evaluated and determined to be a contributing feature within the Tuolumne Meadow Historic District, as defined in the 2007 Tuolumne Meadows Cultural Landscape Inventory .

PROJECT OVERVIEW

The goal of this project is to restore natural hydrological functions, and address erosion and trampling of native vegetation within Tuolumne Meadow. It is important to note that Tuolumne Meadow itself is also a cultural resource as the central character defining feature of the Tuolumne Meadow Historic District, and an important cultural landscape for many people.

A component of this project will regrade and narrow segments of the Great Sierra Wagon Road (1883) that are now used as foot and equestrian trails in the Tuolumne Meadows area. These modifications are necessary because the roadbed disrupts natural hydrologic flow, and the roadside swales in the meadow have become deeply incised n many locations. The section of the road that crosses the meadow to Parson's Lodge and Soda Springs was likely built on fill excavated from meadow soils alongside the roadway. There are currently an inadequate culverts resulting in disrupted surface water flow and increased erosion. Furthermore, the trail itself is deeply rutted and "braided" in some locations, resulting in multiple parallel pathways, unsecure walking surfaces, difficult wayfinding, all of which result in further widening the trail.

The following actions are recommended in conjunction with actions to recreate ecological processes within Tuolumne Meadows:

- Narrow stretches of the historic roadbed to an appropriate historic width of approximately 10 feet.
- Remove fill and reduce the profile of the historic roadbed.
- Add fill and raise the profile of eroded sections of the historic road.
- Add or enlarge culverts or construct footbridges over stream channels along the Great Sierra Wagon Road roadbed.
- Fill in and/or re-contour the swales that run parallel to the historic road.
- Remove vegetation that has grown on the historic roadbed, particularly lodgepole pine.
- Remove non-historic social trails that parallel the historic road and restore to natural conditions.

Mitigation Measures to Minimize Adverse Effects on Historic Landscape Resources within Tuolumne Meadows

In order to minimize impacts to cultural resources, the following guidelines should be followed during the ecological restoration work in Tuolumne Meadows: When narrowing the roadbed (which is wider than historically and excessively braided in some locations) maintain a minimum width of 10 feet in order to convey the corridors historic use as a wagon road.

- Before any actions take place, historic resources must be researched and existing conditions documented in the field by qualified staff.
- When narrowing the roadbed (which is wider than historically and excessively braided in some locations) maintain a minimum width of 10 feet in order to convey the corridors historic use as a wagon road.
- Maintain the current alignment of historic remnants of the Great Sierra Wagon Road.
- If modifications are necessary to historic culverts and their associated headwalls, efforts should be undertaken to ensure that modifications meet the Secretary of the Interior’s Standards for Treatment of Historic Properties. Measures can include retaining materials, construction style, and workmanship that matches the historic character. These efforts should be combined with photo-documentation, contracting with a qualified stonemason, numbering headwall stones for reconstruction and locating granite that matches the color and texture of the existing stone masonry granite.
- New culverts (if added) should be built to complement historic culverts along the roadway, with simple, understated stone masonry headwalls with discrete, low profiles. The stone used in the headwalls should match, as closely as possible, the color, texture and dimensions of the stone found in other historic culvert headwalls found at Tuolumne Meadows.
- Once the work is completed, the historic road should be documented to capture the changes.
- It is acceptable to remove woody vegetation from the roadside shoulders, as these features were not present during the historical period.
- The ditches that lead from and drain many of the area’s kettle ponds are not documented as historic features and should be investigated and documented before filling and regrading.
- Major reroutes of historic trails in the area, particularly iconic trails such as the John Muir Trail and the Pacific Crest Trail, will likely constitute an adverse effect on potential historic properties. If any such actions are proposed, their possible historical significance should be investigated. Depending on the outcome of any such investigations, further discussions should occur

Figure 2-1. U.S. Geological Survey map of Yosemite National Park from 1910, 1:125,000. The alignment of the Tioga Road is traced in black.

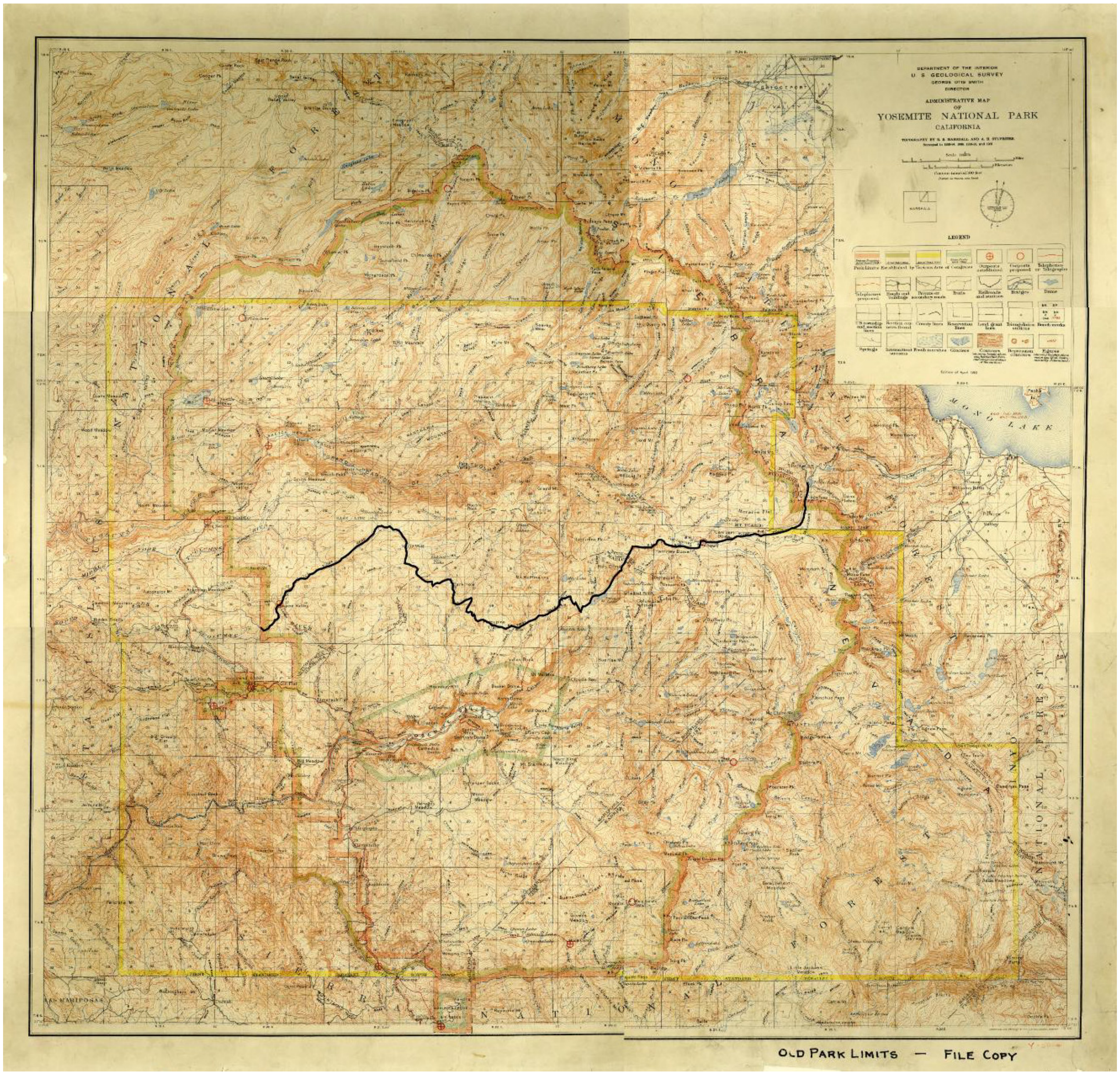


Figure 2-2. U. S. Geological Survey map of Yosemite National Park from 1958, 1:125,000. The alignment of the Tioga Road is traced in red.

Figure 2-3. Map showing the 1910 alignment of the Tioga Road (black) overlaid with the 1958 alignment of the Tioga Road (red). Notice that the alignment is profoundly different, particularly along the western stretches of the road

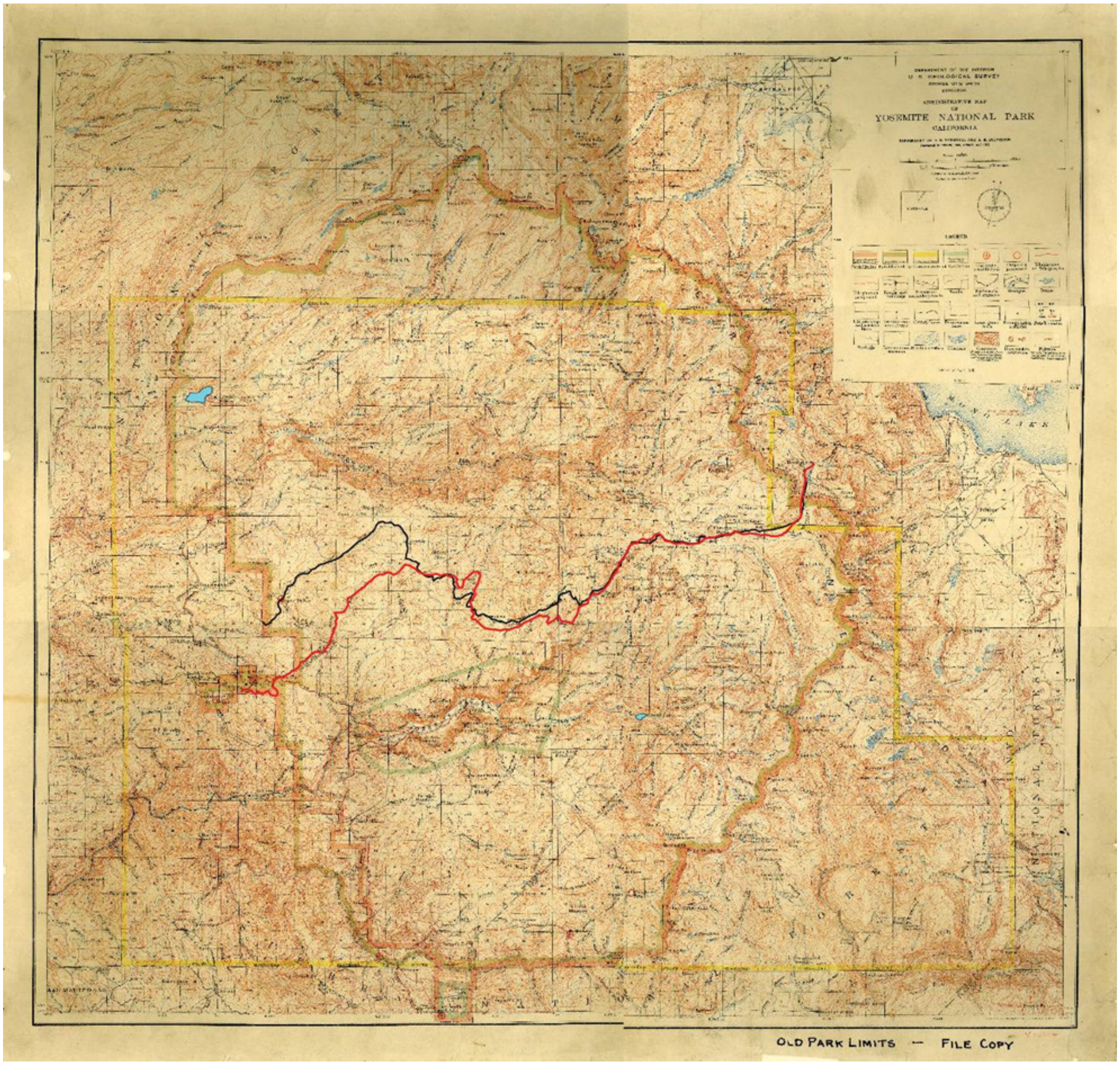


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Figure 2-4. Map showing a detail of the 1910 (black) and 1958 (red) alignments of the Tioga Road as it passes through Tuolumne Meadows. Although the alignments are quite close for this stretch of the road, the arrow points to the section of the 1910 road that used to cross Tuolumne Meadows out towards Soda Springs, but, since the 1930s, now runs along the meadows perimeter. Most of the ecological restoration work will take place on this stretch of the historic roadway

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CHAPTER 3. DESIGN GUIDELINES FOR TRAILS

Overall, the goal is to create a trail for visitors that lessens the ecological impact on the meadow, retains the meadow's visual beauty, and reflects the historic and cultural importance of the meadow. These goals can be achieved by matching the surrounding native colors, using similar materials, maintaining a trail height and horizontal line that is close to the natural grade as possible, retaining an alignment that reflects that of the historic road, and using existing structures as a model. The following list provides more detail on these objectives.

Alignment: Maintain the historic alignment of the road
Width: Restrict to 10 feet to maintain approximate historic road width and to accommodate high levels of visitor use
Surface: Install sections of boardwalk (possible materials outlined below) or durable trail surface such as logs, stepping stones, lowered trail profile that allows for surface flow.
Support: Use helicals, piers and small abutments to support the boardwalk surface to minimize disruption to hydrologic flow
Height: Retain at the minimum necessary rise above meadow grade. This will typically be less than 18". If railing is required, select low profile to match design and style of bridges
Color: Use pale brown to blend into the landscape
Maintenance: Design for low maintenance requirements as future funding is not secured.
Stock use: Design for heavy stock use. If wood products are used, a wear strip or center section that can be replaced without deconstructing the whole boardwalk is recommended to reduce replacement costs and time. Consider redirecting stock to new trail south of Tioga Road.
Bridges**:** Construct any new bridges or stream crossings using similar materials and patterns found in the existing Tuolumne River Bridge. These do not need to be duplicates, but reflect the design that successfully blends with the surrounding area.

BOARDWALKS

Boardwalks may be constructed of wood, pressed wood, silica infused wood, plastics, concrete, steel or a combination of these materials (Figure 3 provides a matrix of different products). A series of piers (placing, size and depth depend on the type of decking and the substrate) typically supports the beams and decking (Figure 1). The use of tall and extended beams to support the decking creates a large profile and can disrupt water flow during flooding. The use of helicals and piers along with shorter and narrower beams can provide a stable footing yet require minimal ground disturbance. An ideal solution will balance these requirements.

In areas of heavy snowpack such as the Tuolumne Meadows area, the strength of the boardwalk must be sufficient to support snow weight. Boardwalks can require high maintenance costs and labor, particularly in high elevation areas that receive heavy snowpack or that flood regularly. Over time, boardwalks can begin to sag where the wood is weakening and connections loosen. Freeze/thaw is also an issue for some composite products and some products can be very slippery when frosty. Other parks like Glacier and Yellowstone have successfully constructed, and continue to maintain, boardwalks in such climates. Following is a brief description of several products that may be used, with uses in these two parks discussed as appropriate.

Figure 3-1: Cook's Meadow boardwalk in Yosemite Valley. Constructed of recycled plastic, a material commonly used in Yellowstone National Park, where a roughened surface is used to provide traction on frosty mornings. However, Yosemite managers have found that this product does not last and requires frequent maintenance.

TIMBERSIL®:

TimberSIL® wood is infused with a microscopic layer of amorphous glass that provides an effective permanent barrier to rot, decay and other common wood problems. The wood is non-toxic, odorless and nonvolatile, is not corrosive to fasteners, does not cause excessive wear on tools, and has a natural clear color. The company that produces this material claims that TimberSIL® Glass Wood is stronger and longer lasting than natural or composite wood / lumber, does not burn and is guaranteed not to rot or decay for 40 years. This product looks like natural wood and is being used at Tenaya Lake (Figure 3-2). Yosemite staff working with this product found that it is somewhat difficult to work with as the boards are warped and require a sealing epoxy on the ends. In addition, further investigation is required to ensure that this product could accommodate stock.

Figure 3-2: Newly installed TimberSIL® boardwalk at Tenaya Lake 2012

PERMATRAK®:

Permatrak® is a precast concrete boardwalk system for elevated trails (Figure 3-3). This trail material is primarily supported by piers and footings, is less susceptible to freeze/thaw damage than treated wood, and will not float away during high water events. Components are precast and can be assembled and installed on site with a relatively low level of impact. There are standard and custom colors available and it can be finished to resemble a wood texture (Figure 3-4). A slip resistant surface is also available, like a standard concrete walkway.

Figure 3-3: Boardwalk Estate, Melbourne Australia: Permatrak® boardwalk with pier supports allows water flow underneath the structure

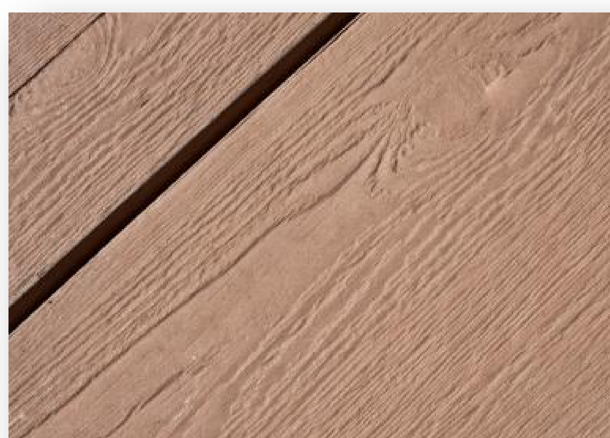

Figure 3-4: Permatrak® wood finish

STEEL GRATING:

This boardwalk material is used extensively in Glacier National Park (Figures 3-5 - 3-8) and other areas with heavy snowpack. It is typically supported by a series of crossbeams but piers may also be an option. Benefits include allowing light to penetrate through the tread and allow some plants to grow underneath the trail. It is also less susceptible to flooding impacts and heavy snow load. In frosty conditions, the surface can become slippery but surface traction can be added. Maintenance requirements are generally less than wooden boardwalks. There are several different types of steel grating with varying gap size and strength. Gap sizes must be less than ¼" to be American Disability Act (ADA) compliant and must be of sufficient strength and gap size to withstand stock traffic.

Figure 3- 5: plants growing beneath grate

Figure – 3-6: Metal grate boardwalk in Australia

Figure 3-7 and 3-8: Metal grate boardwalk in Glacier National Park

Other Trail Surfaces and Treatments

Stabilizer®:

This product stabilizes soils with the crushed seeds of a native plant that is activated by water. The powder is blended into the soil and works its way into the pore spaces. The swelling action triggered by the addition of water, pulls the particles and binds them together and depending on the aggregate used, can provide a very hard to relatively flexible surface. When the stabilizer is saturated, excess water drains and the soil remains stable without becoming muddy because the stabilizer keeps the soil particles bonded. It is uncertain how this product performs in seasonally wet areas but it could be used in sections of trail that are rarely or only intermittently saturated. Stabilizer® was most recently used in Yosemite on the Tenaya Lake east beach access trail (Figures 3-9 and 3-10).

Figures 3- 9 and 3-10: Stabilizer® trail at Tenaya Lake 2012

Geosynthetics:

Geosynthetics help create stable trail surfaces in wet areas saturated by subsurface moisture and precipitation (Groenier et al. 2008). Geosynthetics such as geotextiles, geonets and geocoposites (sheet drains) keep saturated, weak native soils from intermixing with stronger, load-bearing trail surface materials. These products also allow subsurface drainage and lessen saturation and weakening of the trail tread. In addition, they also provide some degree of tread reinforcement and load distribution.

Most geotextiles are made from some sort of polymer and are typically black, although tan, green or other colors with no heavy metal content are also available.

Typical life expectancy is 10 years when used with a porous trail tread material such as coarse sand, gravel or small rock (Groenier et al. 2008).

Low Crossings

Low stream crossings or fords are effective for providing some surface water connectivity and work well in areas experiencing flow or saturation for short periods of time. To construct a low crossing, the roadbed fill would be used to fill in side ditches and re-contoured to allow for surface water connectivity. The crossings are typically covered with rocks or cobble large enough to remain stable during any flow.

Where this treatment may be applied, stepping stones placed to one side can provide a dry surface for visitors during times of saturation or flooding, while still allowing surface water connectivity.

Box Culverts:

Box culverts allow for surface water transport under a trail or road structure while providing a dry and stable walking surface. Box culverts are typically constructed of steel enforced concrete and may be custom designed to an appropriate height and width for a given expected flow and area. When box culverts are installed at the meadow surface, this low profile decreases visibility yet surface water transport is maintained. Box culverts can accommodate high surface flows (such as Unicorn creek) or can just provide connectivity for standing surface water.

Rockwork to support and frame the box culvert and delineate the trail surface decreases visibility and provides a more rustic appearance (Figure 3-11). Surfacing on a box culvert may be native soil overlying an aggregate that improves stability yet maintains the appearance of a trail.

Figure 3-11 Road box culvert in Yosemite Valley (trail would be lower profile)

Bridges or Spans:

To allow for flow in the side channel along the southern abutment of the bridge over the Tuolumne River, two spans of boardwalk are proposed. These would be similar in structure and appearance to the bridge over the Tuolumne River (Figure 3-12). This surface may be wooden or match the material of the trail surface in other sections (e.g. steel grate or concrete). Where steel girders are required, they will be narrow, located above the stream crossing, only cover short runs (to avoid damming effects) to limit impacts to hydrologic connectivity.

The width of the spans will be 10 feet to match the trail and bridge width and would not be substantially higher than meadow grade (18 inches). If railing were required, style would be similar to the 8x8 foot beams on the bridge over the Tuolumne River.

Figure 3-12: Bridge over the Tuolumne River

Figures

Figure 3- 1: Boardwalk in Cook's Meadow NPS photo
Figure 3-2: Timberwil at Tenaya Lake - Suzy Hasty 2012
Figure 3-3: Permatrak: http://www.permatrak.com/#!prettyPhoto[home]/1/
Figure 3-4: Permatrak: http://www.permatrak.com/features-benefits/tread-surfaces-and-color-palette/#!prettyPhoto[profile]/1/
Figure 3-5: Steel grating at Glacier National Park - Lou Summerfield 2012
Figure 3-6: Steel grating in Australia - http://www.wildwalks.com/bushwalking-and-hiking-in-nsw/kosciuszko-np-south/thredbo-to-the-eagles-nest-via-dead-horse-gap.html
Figure 3-7 and 3-8: Steel Grating at Glacier National Park - Monica Buhler 2009
Figure 3-9 and 3-10: Stabilizer at Tenaya Lake - Monica Buhler 2012
Figure 3-11: Box culvert in Yosemite Valley - Daniel Boughtner 2013
Figure 3-12: Bridge over the Tuolumne River - Monica Buhler 2012

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Table 3-1: Matrix of different boardwalk materials available

Product	Raw Material Cost for 2 x 6 (per linear ft)	Sustainability	Safety for employees to install	Lifespan (years)	Maintenance requirements	Performance in Freeze/Thaw and heavy snow load environment	Aesthetics
Pressure Treated Douglas fir	$1.16	N: Sustainably harvested but, is treated with chemicals	N: chemicals used to treat wood are toxic	10-20	High	Good	Good: Consistent with well established Yosemite rustic trail aesthetic, although "slits" detract from the visual appearance
Timbersil	$3.08	Y	?: Requires toxic sealant epoxy on cut ends	40-year warranty	Unknown: manufacture claims Low	Good, performs slightly better than wood because it is completely dry (according to sales rep)	Good: May be on the light side when compared to pressure treated wood, although could be stained. Supposedly weathers like real wood (turns grey).
Steel grating	$11.35	Y	Y	100+	Low	Great	Fair: May have urban, industrial feel. Departure from Yosemite rustic style but used in other NP.
Western red cedar	$5.55	N: Sustainably harvested but requires long transport	Y	10-20	High	Good	Good: Consistent with well established Yosemite rustic trail aesthetic
DreamDex	$6.94	Y	Y	25-year warranty	Moderate	Good, expansion/ contraction is less than wood because polymer is infused in product	Good: From website, looks like normal wood.
Plastic Lumber	$4.63	Y	Y	10-year warranty	High	Poor, significant expansion/contraction observed in Yosemite	Fair: Inconsistent with Yosemite rustic bridge and boardwalk – although has been used in Cook's Meadow
Permatrak	$17-3 per sq. foot (includes entire system; planking, footing etc.)	Y	Y: Precast: reduces time to install	40- year warranty	Low	Unknown but manufacture claims great - concrete in general is not impacted by freeze/thaw	Good: From website looks like wood and texture and color can be modified with added aggregate
Stabilizer	$1.50	Y	Y	Unknown	Frequent but low cost and time	Unknown	Looks like soil but when very compacted or with large aggregate, may resemble asphalt