GEOMORPHIC, HYDROLOGIC AND ECOLOGICAL EFFECTS OF THE BEAR CREEK MEADOW RESTORATION PROJECT: A LAYMAN'S REVIEW

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Introduction

Rivers and their floodplains throughout the world have been degraded by human uses including water extraction, river engineering, dam and levee building, and watershed land use changes. Two common causes of river degradation are overgrazing and the channelization of naturally flowing watercourses. Channelization is often performed in land reclamation activities or as a flood control measure. The combination of channelization and overgrazing is particularly destructive because it alters the functions of a riverine/floodplain wetland by impacting the hydrology, hydraulics, biogeochemistry, geomorphology, riparian ecology and aquatic ecology of the system. The growing recognition of the numerous functions and services that rivers and their floodplain wetlands provide, and the societal values placed on these functions, has prompted the restoration and rehabilitation of many of these degraded ecosystems in California, the United States and throughout the world. As several recent prominent publications have noted, it has been difficult to demonstrate 1) whether these ambitious and numerous restoration efforts have led to significant improvements in river functions and services and 2) which strategies have proven most effective. A dearth of rigorous pre- and post-project monitoring information and evaluations inhibits our ability to adaptively learn from projects and to improve and guide future restoration efforts.

This report describes an unusually well-documented stream restoration project on Bear Creek, a tributary to the Fall River in Shasta County, California. Extensive pre- and post-project information provides the opportunity to evaluate the response of Bear Creek ground water, surface water, geomorphology and wetland ecology to restoration of a 2.2-mile stream reach located on Thousand Springs Ranch. The methodology of the restoration is described, followed by a discussion of the geomorphic, hydrologic and ecologic effects observed during the comprehensive monitoring of the restoration project. The findings in this report indicate that efforts to restore ecosystem function within the Bear Creek Meadow by re-establishing the necessary geomorphic and hydrologic conditions have been successful with a concomitant range of ancillary downstream benefits.

Background

Bear Creek Meadow lies at the base of the 84 square mile Bear Creek watershed, immediately upstream of the confluence with the spring fed Fall River (Figure 1). The watershed is underlain entirely by Tertiary and Quaternary volcanic rocks with a mixture of conifer forests, sagebrush scrub and, along the valley bottom, multiple meadows. Bear Creek Meadow on Thousand Springs Ranch is approximately two miles long and one mile wide and is flanked to the west by steep slopes, to the north and east by the low relief Medicine Lake Highlands, and to the southeast by the Fall River Valley. Located at the intersection of the Cascade Mountain Range and the Modoc Plateau, the vegetation surrounding the meadow is primarily Ponderosa pine forest interspersed with Black oaks and a shrub understory. The head of the meadow lies at the base of a relatively steep, heavily forested bedrock reach.

There is limited information available that indicates the conditions of Bear Creek Meadow prior to land use changes. A combination of historical aerial photographs, an undisturbed nearby "reference" meadow, and inspection of the relict undisturbed channels provide the best indications of pre-disturbance conditions.

Bear Creek Meadow was, and remains, a low-gradient meadow with a broad floodplain. The cohesive soils of the meadow indicate long-term accumulation of fine sediment associated with seasonal flooding. Radiocarbon dating of soil horizons in the center of the meadow indicate that this fine sediment deposition has been taking place for more than 2,800 years, reflecting long-term stability of the meadow system.

Analysis of historical aerial photographs and surveys of relict channels on Bear Creek Meadow show a complex pattern of channel development prior to human disturbances that included channel modification, grazing, dewatering and the introduction of invasive annual plant species. At the head of the meadow, where the confined bedrock channel transitions to a low-gradient alluvial valley, flows spread laterally into multiple, sinuous distributary channels that carried water and sediment across the meadow. During low flow periods, much of the creek's water flowed through one or two of these channels. However, during high rainfall or snowmelt periods each of the normally dry secondary channels "connected" to the primary channels. As the creek continued to swell with floodwaters, the many small channels would become full and the floodwaters would flow out of the creek's banks, inundating the meadow surface, Bear Creek's floodplain. During moderate to high flows, distributary channels would periodically be abandoned while new channels formed, typically due to large wood debris jams or sediment deposition. The channels of the meadow were all relatively shallow and many were lined with Oregon ash.

Although there is no direct evidence, it is apparent that Bear Creek Meadow played an important role in regulating the amount of sediment that Bear Creek discharged into the Fall River. Compared to the higher gradient, more confined upstream reaches of Bear Creek, the wide, low-gradient floodplain and channels of the meadow reduced the stream's ability to transport sediment immediately upstream of the Fall River. This reduction in sediment transport was due to the decrease in water depth and velocity as water spread out across the meadow. Anecdotal evidence suggests that the meadow historically "decanted" sediment that would have damaged spawning habitat in the spring-fed Fall River. This was especially important as human modification of the watershed upstream increased the stream's sediment load.

Although there has been logging, fire, grazing, road and railroad construction within the Bear Creek watershed for much of the last century, there is no information that would suggest a significant change in hydrologic conditions. The hydrology of Bear Creek is greatly influenced by the permeable soils that formed on top of the volcanic rocks throughout the watershed. Most precipitation, whether as rainfall or snow, reaches Bear Creek by first passing through the soils and rocks, rather than flowing across the surface. The transport of water through the subsurface prior to entering the creek acts like a shock absorber, causing the water to rise and fall slowly in response to typical storm or snowmelt events. The flood flows on Bear Creek are associated with intense rain-on-snow events in the winter and spring snowmelt events. During late spring and summer, flows on the creek steadily decline, usually stopping by June or July, which results in the drying out of portions of the meadow channel.

The combination of Bear Creek's shallow channels and extensive alluvial deposits overlying low permeability ancient lake deposits formed a very large, shallow aquifer. The aquifer was recharged every winter and spring by flows through and across the meadow along with minor inflow from the hills that surround the meadow. The shallow aquifer that existed within the meadow supported a lush wetland during the winter, spring and early summer, in turn supporting a complex mix of riparian, grassland and wetland vegetation. This mosaic of vegetation communities created an important feedback in the meadow. The dense vegetation slowed the velocity of water as it flowed across the meadow during floods, further enhancing the ability of the meadow to retain Bear Creek sediment, keeping it from Fall River.

Inspection of the aerial photographs and historical accounts, indicate that by 1960, the Soil Conservation Service and the landowner had realigned Bear Creek and cleared some vegetation to “reclaim” the meadow for the purpose of enhanced grazing and agriculture. These reclamation activities concentrated the many channels into one main channel and one secondary channel, which were partially straightened and located on the sides of the meadow. This was done to expedite floods across the meadow and to dry the meadow out. Physically, this realignment made Bear Creek follow a shorter path from the top of the meadow to the bottom, increasing the creek’s slope in this reach. By increasing the channel’s slope and eliminating the baffling effect of vegetation, the creek’s “stream power,” or the ability of the stream to erode, was also increased. In this altered state, the increased power of Bear Creek initiated an extended period of incision within the meadow.

First cutting down, the creek became deeper and deeper, which allowed it to convey more and more water within its banks rather than gently across the floodplain. Subsequently, its ability to erode also continued to increase. As it eroded, Bear Creek became progressively disconnected from its floodplain in all but the largest of floods. By 1999 the channels had incised up to 15 feet into the alluvium. This incision led to the near complete loss of in-stream spawning habitat, a significant lowering of the ground water table, and the loss of riparian and meadow plant communities. Channel incision not only eliminated the meadow’s ability to trap sediment, but led to substantial increases in the amount of sediment delivered to the Fall River by channel erosion.

Prior to channel realignment, the ground water table was very close (0-3 ft deep) to the meadow surface during the spring and early summer. Once Bear Creek incised, the ground water table was much deeper (3-5+ ft deep) in spring and early summer. Consequently the water dependent wetland plant species, which historically created a riparian corridor lining and stabilizing the banks of Bear Creek, were no longer able to persist and gave way to annual grasses characteristic of much drier upland habitats.

As the stream channel incised and lowered the ground water table, the stream banks progressively grew very tall and steep, and unable to support much vegetation which lead to increased instability of the stream banks (Figure 2). This instability initiated a cycle of lateral erosion of the banks, widening the channel. This lateral channel enlargement confined more water within the channel and contributed even more sediment to the Fall River. Bear Creek’s once numerous shallow, vegetated, and meandering channels had degraded into what are best described as two unstable, erosive gullies (Figure 2).

By the 1990's Bear Creek's main channel through the meadow, the gully, continued to erode vertically and laterally. According to pre-restoration project sediment flux monitoring conducted by Rick Poore, the meadow was delivering copious quantities of sediment downstream to the Fall River. In addition, the historic ecological processes that sustained the meadow were fundamentally altered. The Oregon ash trees, which lined portions of the undisturbed channels, existed in a state of poor health. New ash trees ceased to regenerate. The multitude of native wetland plant species, including various species of sedges and rushes, were present in very limited amounts. Exotic annual grasses like Japanese brome, bulbous bluegrass and Kentucky bluegrass, common in upland (non-wetland) environments dominated what little vegetation was present on the meadow surface. In addition, due to the very wide nature of the channel, fish passage through the meadow was limited only to periods of higher discharge.

Details of the Restoration

Driven by a desire to improve the degraded creek and meadow and to reduce impacts on the Fall River, the landowner, Peter Stent, undertook a multi-year program to restore the historic geomorphic, hydrologic and ecologic processes that sustain healthy meadow and creek ecosystems. The founder of modern fluvial geomorphology, Luna Leopold, and a highly experienced stream restorationist, Dave Rosgen, were recruited to participate in the planning of the restoration. Together, Leopold and Rosgen prescribed a four year pre-project research plan which included monitoring aspects of hydrology and sediment transport along with geomorphic surveys at the project site and a reference site. This pre-project data collection began in 1994, five years before the actual restoration was undertaken. Both Peter Stent, the Thousand Springs Ranch owner, and Rick Poore, the Thousand Springs Ranch manager, attended many of Dave Rosgen's stream restoration courses. Rick Poore used the Bear Creek Meadow Restoration as his design project throughout the series of restoration courses. During the design process, Dave Rosgen visited the site, reviewed the plan and utilized his extensive experience to suggest any concerns or potential modifications.

A wide variety of analyses were conducted to provide a vision for the restored channel. Briefly described below, this list is by no means complete or all-inclusive. Historical aerial photographs were collected and analyzed. Natural (undisturbed) channels, which remained in the Bear Creek Meadow, were surveyed to assess their geometry and discharge capacity. A "reference reach," located several miles upstream in a relatively undisturbed meadow was analyzed, and various data collected. In addition, creek discharge and sediment load were measured at the top and bottom of the meadow. As these data were collected and analyzed, a vision of Bear Creek in its restored state began to emerge. Following completion of the design for restoration, a panel of experts reviewed it and recommended its implementation.

The creek and meadow restoration construction began in the early summer of 1999. The project employed a popular methodology (frequently used by Rosgen and his trained stream restoration practitioners) known as "pond and plug." Discrete sections of the disturbed channel or gully were plugged with soil while a new channel was constructed nearby. If the plugs were not placed in the old channel, the restored channel might show a tendency to be abandoned as flow returned to the older channel during high flow events. The fill material needed to create these plugs was derived from nearby floodplain deposits, creating several large ponds within the meadow. The restored channel was constructed using remnant channel reaches where available and practical, and the remaining reaches were sculpted with heavy machinery in the size and shape of the historic meadow channels (Figure 3). Based upon the recommendation of the expert panel, gravels were added to the restored channel to enhance fish spawning habitat and to reduce bed erosion. Upon the completion of the project, 2.2 miles of restored stream, and 42 acres of new ponds, almost ten percent of the meadow area, existed in the Bear Creek Meadow (Figure 4). These ponds consisted of two types: large ponds created by the need for fill material, and smaller linear ponds, which are remnants of the old gullies.

Immediately following the sculpting of a restored reach, it was heavily planted with a variety of wetland plants (grasses, sedges, rushes, willows, and various tree and shrub species), to resist erosion, and accelerate the recovery of the riparian corridor. Once planted, these plantings were irrigated to encourage root growth and successful establishment. Nearly all of the genetic material for planted vegetation was collected from the meadow in the years preceding the earthwork. Plants were generated and grown off site at Cornflower Farms, a nursery specializing in native vegetation restoration projects. By the fall of 1999, prior to arrival of winter rains and flow through the newly constructed channel, over 109,000 native herbaceous plants (mostly sedge and rush species) and 4,500 native trees and shrubs had been planted in the meadow.

Effects of the Restoration

The goal of the restoration of Bear Creek Meadow was to set the meadow ecosystem on a trajectory where the natural hydrologic, geomorphic and ecologic processes could sustain the ecosystem without the need for frequent intervention. In the six years following the restoration, many elements of the creek and meadow have been monitored. Monitoring information has been collected by Streamwise, Inc., the Center for Watershed Sciences at the University of California, Davis, CalTrout, California Department of Fish and Game, Cornflower Farms and Point Reyes Bird Observatory. It is arguably one of the best-monitored private stream restoration projects in the United States. The discussion below provides a partial synopsis and an assessment of the effects of the restoration on the geomorphic, hydrologic and ecologic processes in the meadow.

The conceptual foundation of the restoration project centered on the assumption that recreating natural geomorphic functions of the floodplain and channel would lead to restoration of desired ecologic conditions. These functions included 1) development of a sinuous meadow channel with the proper size and geometry to contain and convey low to moderate flows without excessive erosion or sedimentation, 2) promotion of frequent overbank flooding of the meadow in order to support meadow wetland and riparian communities, reduce the erosive effects of high flows on the channel, and trap sediment on the floodplain, and 3) establishment of a channel geometry that enhances connection and interaction between surface water flows and ground water in the meadow, restoring shallow ground water conditions. This effort ultimately seeks to restore a condition of "dynamic equilibrium," where the size, shape and adjustments of the channel are in balance with the sediment and water supplied to the meadow by the watershed.

Geomorphic Response

The plugging of the old, over-sized channel and creation of the new, small main channel for Bear Creek re-established the geomorphic processes typical of a meadow. Based on annual surveys of more than 20 channel cross sections (Figure 5), the sinuous, shallow channel has remained relatively stable in the period since completion of the restoration project. Rapid channel adjustments involving incision or significant lateral migration have not been widespread although minor redistribution of sediment has been observed. The causes of this sediment redistribution are under investigation by UC Davis and Streamwise, Inc., but appear to involve local excessive slope or flow confinement. The few instabilities have been addressed by Streamwise, Inc. through a variety of bank stabilization techniques.

The relatively shallow, low gradient channel of the restored meadow has played an important role in regulating sediment flux into Fall River. In the years immediately following completion of the project, widespread deposition of silt and sand was noted on the floodplain in the lower reaches of the project. Under pre-project conditions, this fine sediment would have been confined to the main channel and transported directly to the Fall River. The restored meadow appears to be effectively trapping large volumes of sediment that would normally have impaired the Fall River. This stems from the ability of the channel to maintain high enough turbulence to keep sediment in suspension as flows leave the channel and move onto the floodplain. Once flows move onto the floodplain, wetland and riparian vegetation slow the flows, allowing sediment to settle. Over the course of the spring and summer, vegetation establishes on the newly deposited sediment, trapping it on the floodplain. Sediment flows into, and out of, the meadow have been closely monitored. During the high flows of 2005, sediment concentrations entering the meadow were four times greater than those exiting the meadow, indicating the exceptional benefit that the restoration project provides to the Fall River.

Hydrologic Response

The restoration of the Bear Creek channel has profoundly impacted the hydrology of the meadow. By reducing the channel slope and size, the creek discharges water onto the floodplain with much greater frequency. Under pre-project conditions, overbank flooding occurred only when inflows to the meadow were greater than 1,200 to 1,500 cfs. In the post-project condition, floodplain inundation begins when inflows exceed 130 cfs. This order of magnitude difference has significantly changed the frequency of flooding.

As floodplain inundation occurs, floodwaters are slowed and temporarily stored on the meadow surface before either flowing back into the channel at a downstream location, or infiltrating into the meadow, recharging the ground water table (Figure 6). One effect of this restored connection between the channel and the floodplain has been that downstream flood peaks, or the elevation of floods, have been significantly reduced. In addition, due to temporary storage of floodwaters on the floodplain, the length of time that it takes for a flood pulse to move through the meadow increased substantially, enhancing the amount of recharge to shallow ground water. Therefore, while softening the impact of floods, the restored channel-floodplain connection has also greatly enhanced ground water conditions. Quantifying the magnitude of these changes is the subject on going research by UC Davis researchers; however some preliminary results illuminate some anticipated trends (Figure 7).

In the pre-project state, the deeply incised gully intercepted the ground water table and effectively drained it (Figure 8). The ground water surface sloped toward the gully and, during low flow conditions; ground water would discharge into the gully and be carried into the Fall River. Plugging the gully with soil eliminated this ground water drain, allowing the ground water table throughout the meadow to recover. This coupled with the frequent flooding of the floodplain and recharge of the meadow aquifer through the relatively shallow restored channel has restored ground water throughout the meadow to conditions that are roughly similar to those prior to channelization. Preliminary calculations indicate that currently during the spring, the meadow stores 195 acre-feet of water more than it did during pre-project conditions (an acre-foot is 325,851 gallons of water, roughly equivalent to the water necessary for a single household for one year).

Ecologic Response

The restoration of channel geomorphology and surface water-ground water connections has provided the physical processes necessary for the recovery of the meadow's plant and animal communities. The complexity and extent of ecologic recovery of the meadow is beyond the scope of this report and is the focus of on-going study by UC Davis researchers. Several key elements of the recovering meadow and stream ecology have been chosen for this discussion. Passive elements are emphasized, because in many ways the meadow is restoring itself now that the historic physical processes have been reestablished.

While extensive planting occurred along the stream corridor in 1999 for immediate post-construction stabilization, the effects of the restoration of physical processes that extend throughout the meadow go far beyond the planting zones. These vegetation effects can be separated into those of woody plants and those of herbaceous plants. The ribbons of Oregon ash trees, which lined portions of the historic channels, have regained their vigor and produced large quantities of seeds in the years following the restoration. Many young ash trees have recruited naturally within the riparian zone, and have survived through their first few crucial years of life. The vast majority of willows that were planted have grown quite successfully. Willows also have grown from plant material washed downstream and deposited on the floodplain as floodwaters recede. Many new willow individuals have been observed throughout the meadow, the result of beaver activity upstream. It will take many years before the woody plants have grown enough to provide habitat and forage for the variety of animals, which utilize them, but the trajectory observed over the past six years is encouraging. In addition, xeric (dry) woody plants (i.e. great basin sage) that had colonized the driest upper portion of the meadow have died from the frequent flooding and shallow ground water conditions.

Herbaceous (non-woody) plants have responded dramatically to the restoration activities. A vast seed bank existed throughout most of the meadow, allowing most historic species to propagate themselves given the restored water regime. Vast areas previously consisting of scarce quantities of exotic annual grasses have been reclaimed by native wetland plant species. Through many of the wetter areas of the meadow, sedges, rushes and native wet meadow grasses dominate at high biomass levels. In addition, species common to vernally wet places (i.e. vernal pools and depressions) are found in great abundance in some areas. This is a direct result of the reconnection of Bear Creek to its floodplain. The impacts of this restoration on herbaceous plants are best seen in early June when an exceptional display of a variety of native wildflowers occurs due to the increased soil moisture (Figure 9).

The aquatic ecosystem has also rebounded, with a diverse range of aquatic animal species utilizing the restored ecosystem. Several native fish species, including Sacramento sucker, rainbow trout and Sacramento pike minnow (previously known as squawfish) have been observed in large numbers within the restored channel. No systematic spawning surveys have been recorded, however the physical conditions (combination of depth, velocity, substrate size, and permeability) in many of the restored reaches are ideal for the spawning of suckers and trout. The fish are regularly observed using the restored reach as a corridor to migrate upstream for spawning. Fish are best observed in the creek in early June as juvenile trout migrate downstream to the Fall River as Bear Creek's flow declines.

The ponds, created by channel plugging and excavation for fill material, have added an additional seasonal lentic type of aquatic habitat not historically abundant on the Bear Creek Meadow. It is not known whether the introduction of these new ecosystem elements has a positive or negative impact on the overall meadow ecosystem. In all, 42 acres of ponds are found in the meadow, existing in a variety of shapes, sizes and depths. In late summer, all but a few of these ponds are totally dry, reflecting the seasonal draw down of ground water in the meadow. As the creek begins to flow in late fall/early winter these ponds begin to fill as the shallow ground water table starts to rise. These seasonal ponds provide habitat for several native amphibian species including Pacific treefrogs and Western toads. The ponds are ephemeral, however they remain wet long enough for treefrogs to hatch from their eggs and metamorphose into froglets. In fact, the ephemeral nature of the ponds is an advantage for the treefrogs because if water was permanently present, then predators (bullfrogs and fish) would also be present. In early summer, treefrogs are conspicuously abundant around the perimeters of many of the created ponds. As the ponds dry up, the frogs appear to move into the neighboring ribbons of ash trees to live their adult lives.

The created ponds and surrounding wet meadow areas also provide seasonal habitat to large numbers of waterfowl as they migrate through the area. Mallards, Wood Ducks, Cinnamon Teal, Gadwalls, American Widgeons, Mergansers and Canada Geese have all been observed using the ponds. Waterfowl are not the only birds found in the restored meadow. Wilson's Snipe, a shorebird associated with very wet meadows, was found in high numbers by a Point Reyes Bird Observatory (PRBO) survey conducted in June of 2005. Typically they probe into the mud for invertebrates and nest just off the ground in thick herbaceous vegetation (primarily sedges). In addition, Song Sparrows, which are associated with sedges and other dense herbaceous vegetation along creeks in this region, were found to be increasing in abundance following completion of the restoration. While the meadow still falls behind undisturbed meadows surveyed by PRBO in the nearby Lassen National Forest, increases in both relative abundance and species richness have been documented following the restoration. It should be noted, that the meadow's woody vegetation is still considered immature, as it takes in excess of ten years for riparian tree and shrub species to reach the structural diversity observed in undisturbed meadows. It is expected that relative abundance and species richness will continue to increase as the existing woody vegetation matures, new willow clusters are planted, and new tree and shrub individuals are naturally recruited, which will increase the structural diversity of habitat available to birds.

Ecological effects of the restoration extend beyond those discussed above. Although it has not been documented, the lush restored meadow also provides important terrestrial habitat to many animal species including elk, deer, coyotes, bobcats, mountain lions, in addition to Sandhill Cranes and several species of raptors.

Conclusion

The foundation of the Bear Creek Meadow Restoration Project was to restore the geomorphic and hydrologic conditions necessary to recover and sustain plant and animal communities typically associated with wet meadows and to reduce the impacts of channel erosion on the Fall River, downstream of the project. The plugging of the incised gullies and the construction of a shallow, sinuous meadow channel in 1999 appears to have initiated a significant and rapid recovery of the meadow. Based on study of the meadow over the past six years, the following have been well-documented:

- significant reduction in sediment supplied to Fall River by incised gully erosion
- increased effectiveness of sediment trapping by the floodplain, further reducing sediment loads to the Fall River
- increased frequency and duration of seasonal meadow flooding
- restoration of shallow ground water conditions with significant increases in soil moisture
- recovery of woody vegetation along historic and restored channels and decline of invasive, dry-meadow woody vegetation
- dramatic recovery of herbaceous plants, particularly native wetland plant species
- increases in use of the meadow by birds, including species common to wet meadows

Less well-documented but generally observed responses include:

- improved native fish rearing habitat and connection to the upper watershed
- significant increase in habitat for native amphibians and waterfowl

The extensive monitoring of the Bear Creek Meadow Restoration Project provides a rare opportunity to evaluate the effectiveness of restoration efforts of this type. The results of the monitoring effort and a complete assessment of the impacts of the project are currently being prepared by Christopher Hammersmark of the UC Davis Center for Watershed Sciences. This effort, funded by the David and Lucile Packard Foundation, the Peter and Nora Stent Foundation, and the University of California Center for Water Resources, should be completed in 2007.

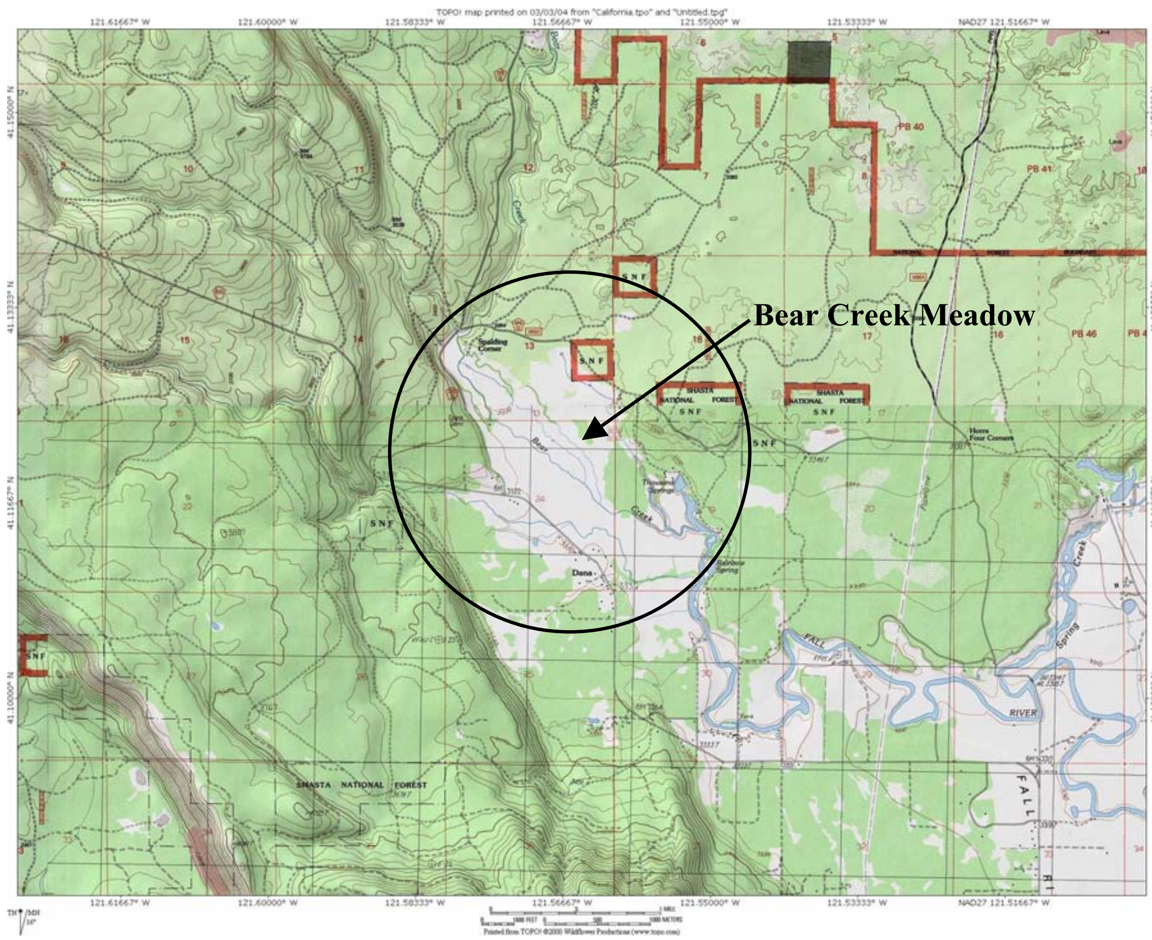

Figure 1 – Bear Creek Meadow location map. The 2.2 mile restored reach is just upstream of the Bear Creek-Fall River confluence in northeastern Shasta County, California.

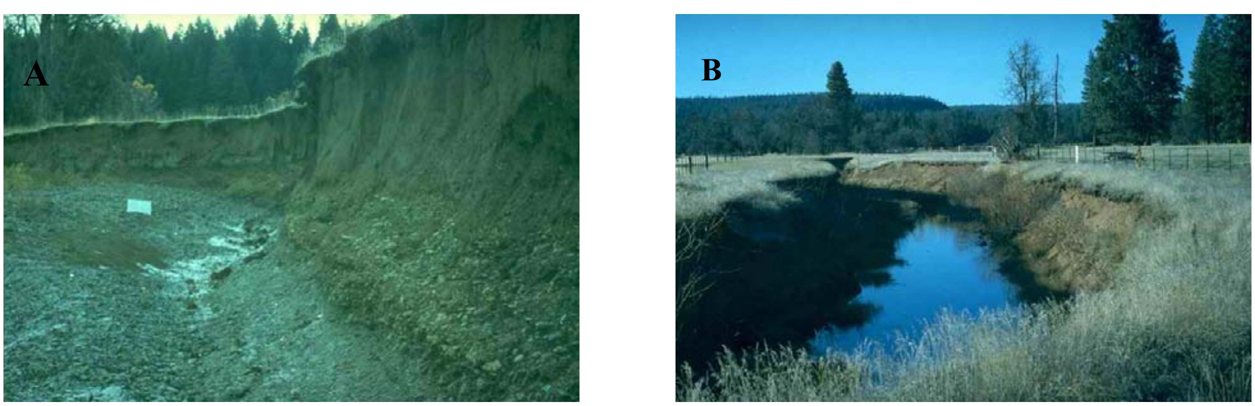

Figure 2 – A) Tall, near vertical unvegetated banks of the pre-restored Bear Creek channel. **B)** Prior to restoration, Bear Creek was best described as a gully (Photos: Rick Poore).

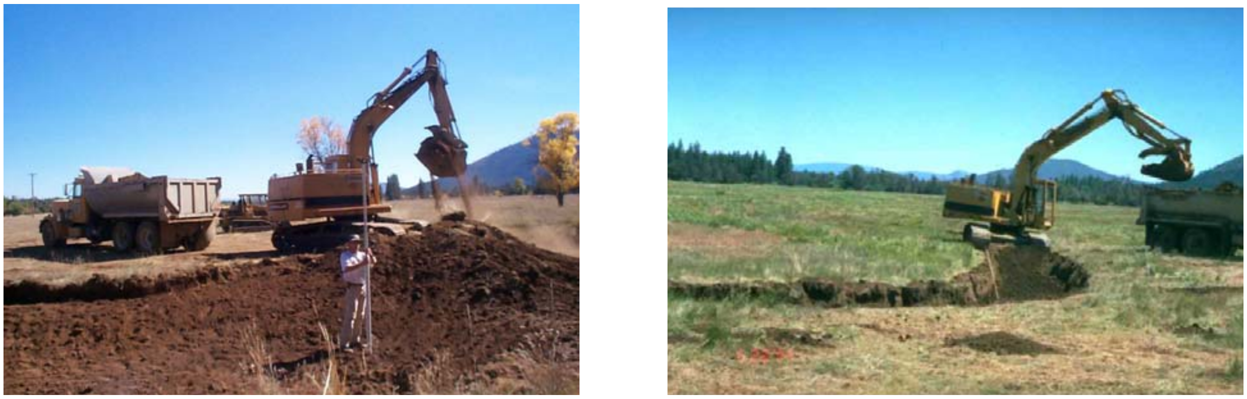

Figure 3 – Sculpting the restored channel in the summer of 1999 (Photos: Rick Poore).

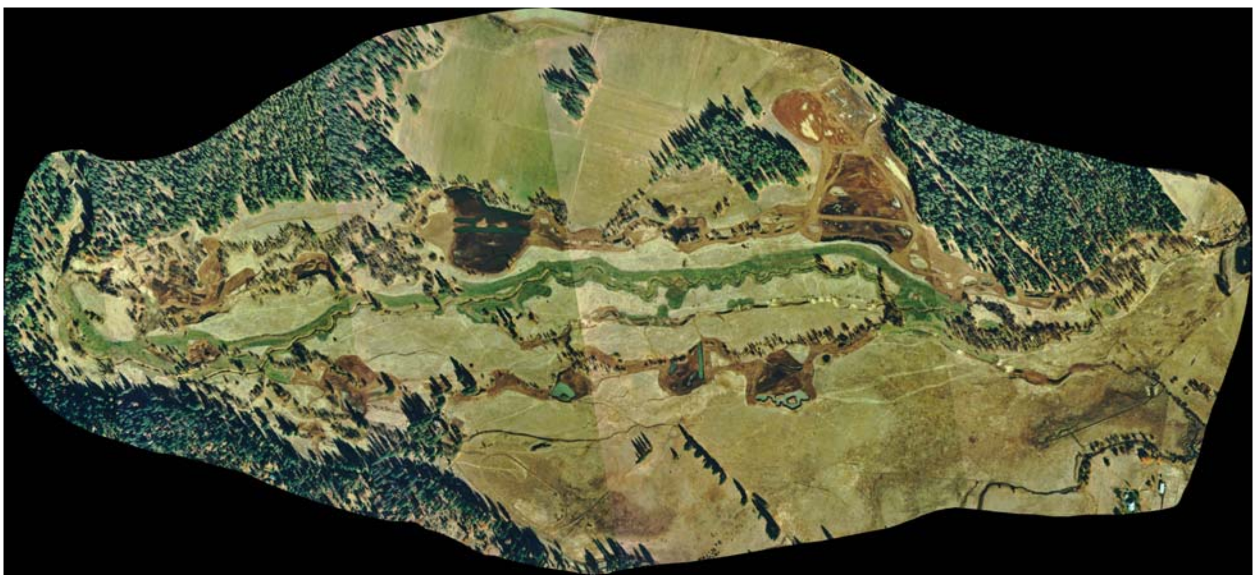

Figure 4 – Aerial view of the Bear Creek Meadow taken in the fall of 1999, months after the construction portion of the restoration was completed. The green irrigated strip running through the middle of the meadow highlights the restored channel. The "plugged" main and secondary channels, and source ponds are distinguished by the brown color of their unvegetated earth (Photo: Hodges Aerial Photos).

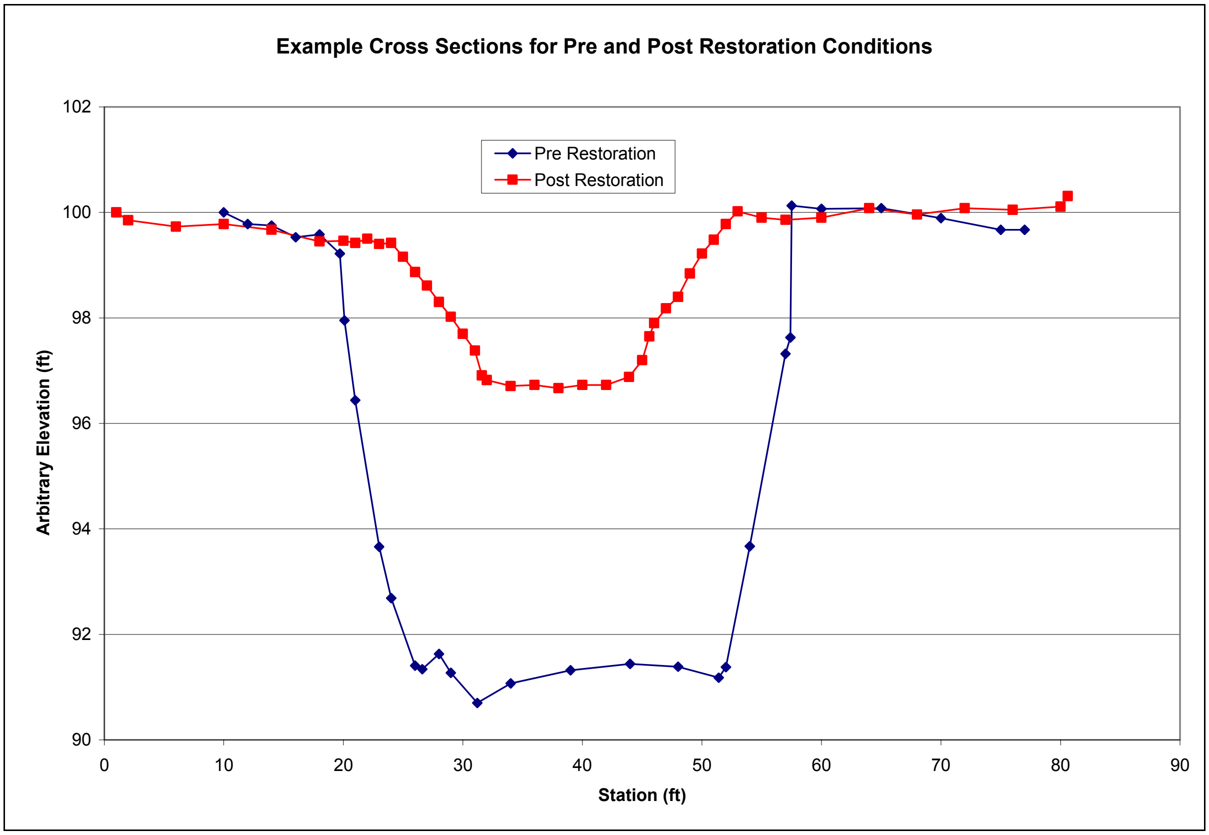

Figure 5 – Representative cross sections of Bear Creek in the pre restoration (blue with diamonds) and post restoration (red with squares) project conditions. Notice how much larger (deeper and wider) the pre restoration channel is when compared to the restored channel.

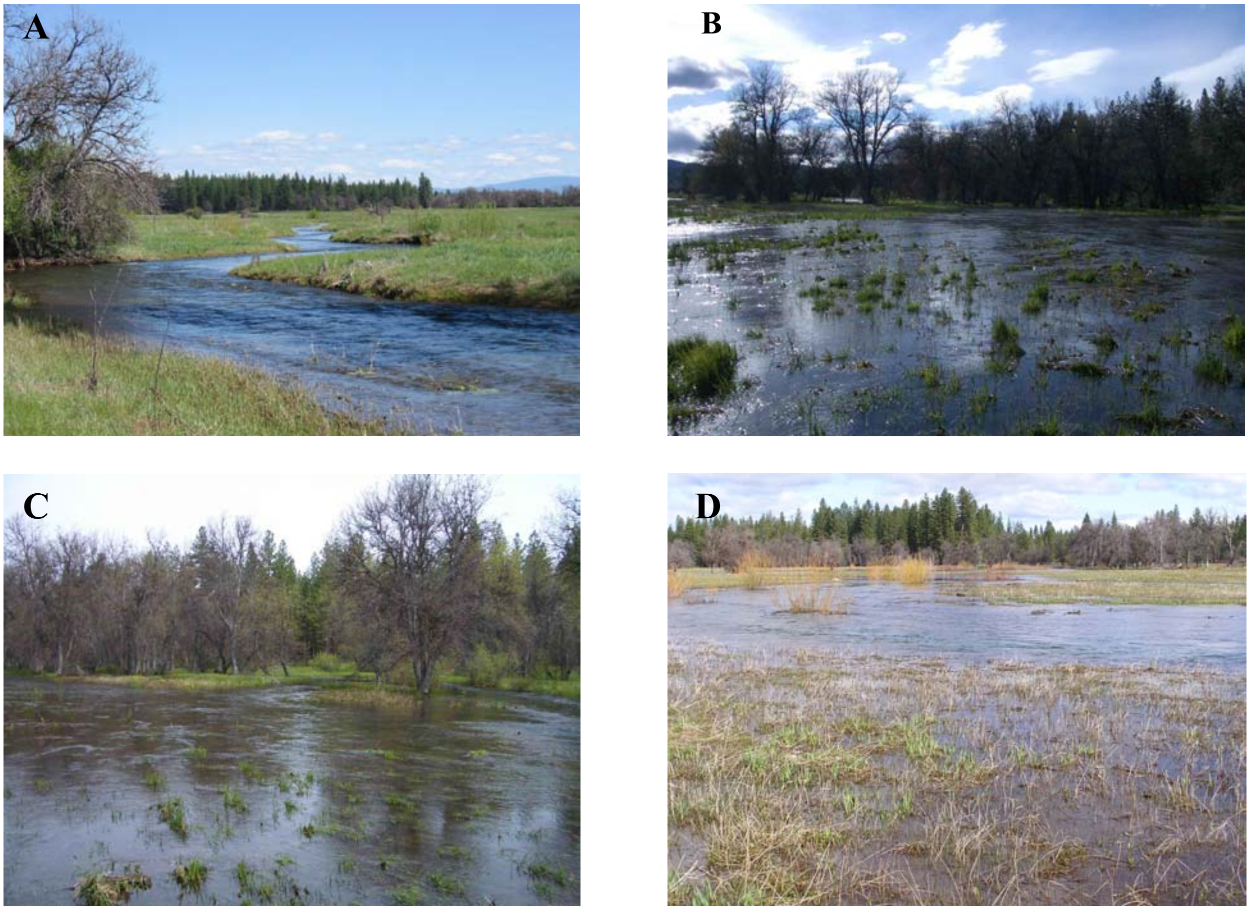

Figure 6 – A) The restored Bear Creek channel flowing just below bankfull. If discharge in the creek increased, the creek would flow out of banks and begin to inundate the floodplain (Photo: Steve Winter). **B-D)** The restored Bear Creek channel during flood conditions. In the restored state, floodwaters are able to frequently inundate the floodplain, dissipating energy, depositing fine sediment and recharging the shallow water table (Photos: Chris Hammmersmark).

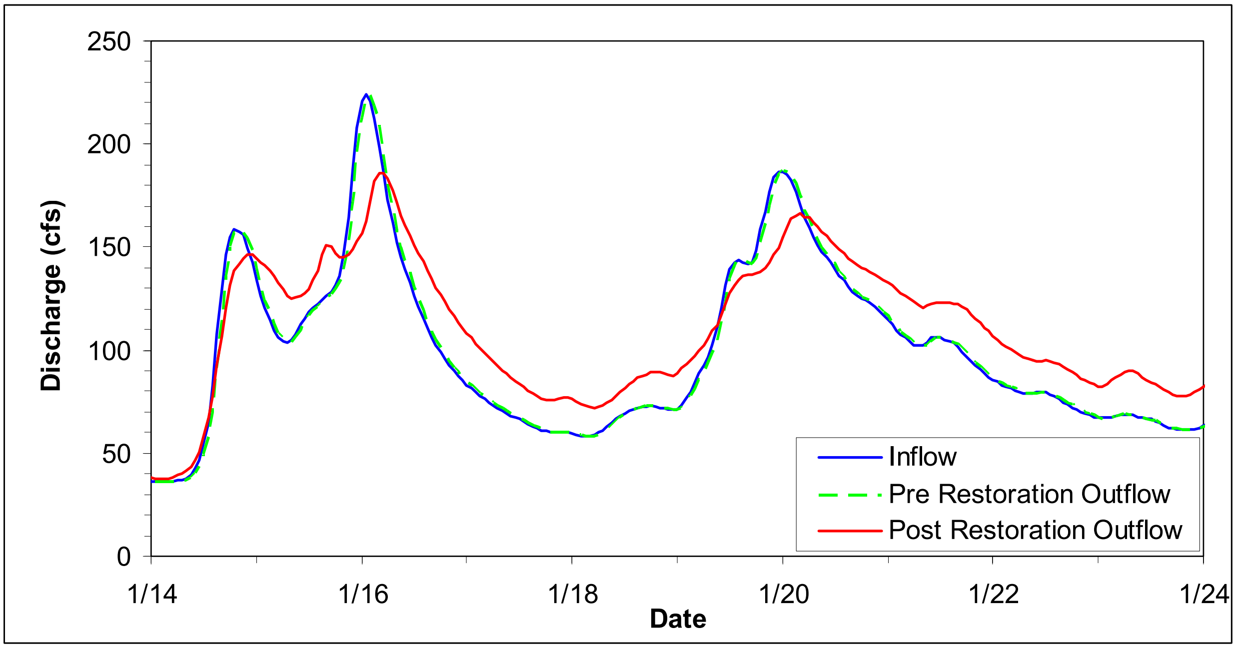

Figure 7 – Preliminary hydraulic modeling results reveal the effect of the channel restoration on the movement of several flood pulses through the meadow. In the pre-project incised condition (green dashed line) each flood pulse travels through the meadow relatively unchanged. In this case the meadow outflow (green dashed line) is very similar to the meadow inflow (blue solid line). Due to a lack of floodplain connectivity in the incised condition, flood peaks maintain their magnitude and travel through the meadow rather quickly. In the post-project, restored condition, significant attenuation and peak reduction are observed in the meadow outflow (red solid line). As water leaves the main channel and inundates the floodplain, it is slowed and temporarily stored. While some of this water flows back to the channel downstream after flowing across the floodplain, some of the water infiltrates into the meadow surface and recharges the shallow water table.

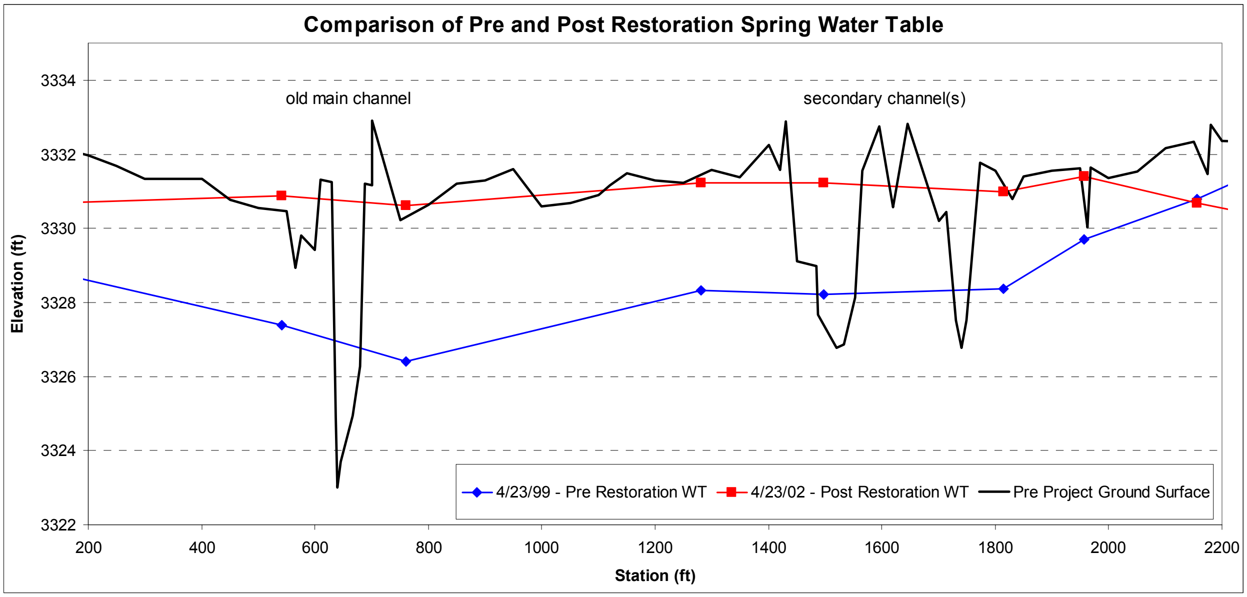

Figure 8 – Comparison of pre- (blue line) and post-restoration (red line) water table elevations in late April for ground water transect B. Transect B traverses the valley roughly half way down the meadow. The pre-restoration ground surface is provided to show the locations of old main channel and secondary channels, in addition to allowing the comparison of the restoration's influence on the depth to the water table. Note that the pre-restoration water table slopes toward the old main channel, as it acted as a drain for the meadow's ground water.

Figure 9 – A selection of native wildflowers found in the meadow. Clockwise from top left *Mimulus tricolor* (tri-colored monkey flower), *Camassia quamash* (camas), *Sisyrinchium bellum* (blue-eyed grass), *Iris missouriensis* (western blue flag) with butterfly (Photos: Chris Hammersmark).