**Case Study: Pond and Plug Restoration at the Perazzo Meadows in the Northern Sierra Nevadas**

*Berenice Gonzalez, Daria Kieffer, Christopher Kingsley, Beatriz Stambuk-Torres, Erina Szeto, & Advisor: Jennifer Natali*

## Abstract

Meadows in the Sierra Nevada mountain range are a valuable ecological and hydrological resource for native plant and animal species and provide important services such as the delivery, storage, and filtration of water (Viers et al., 2013). This document addresses processes that lead to meadow degradation, as well as the 'Pond and Plug' restoration strategy. Using the 2010 restoration of Upper and Middle Perazzo Meadows as a case study, we discuss whether the pond and plug restoration strategy can be considered a long term solution to the current environmental factors that intervene with the natural process in the meadows. The hydraulic function of these meadows has been interrupted over the last 100 years by livestock grazing and the construction of roads in key parts of the meadow. This interruption in hydraulic function has impacted the meadow's ecology through decreased connection connection between the channel and floodplain. We measured stream cross sections and performed pebble counts. We then compared them with measurements taken in 2008 and 2014 to understand the channel's geomorphic response to the 2010 restoration. We compared our observations to the specific goals laid out by the U.S. Forest Service (USFS) at the outset of the restoration project and discuss to what extent the restoration is currently accomplishing those goals. We interviewed Beth Christman (Truckee River Watershed Council) and Randy Westmoreland (USFS) to better understand the motivations and expected outcomes of the restoration project. Important observed 2018 morphological features include retreating head cuts in reactivated channels and formation of

stable streambanks. Based on our observations of cross sections and long profiles, as well as our understanding of the USFS restoration objectives, we consider Perazzo Meadows to be meeting most of the goals of the restoration in the short term, though the long term outcomes require further monitoring.

**Introduction**

Meadows have a high water table, within 1m of the surface, that create unique vegetative field habitats, and are occasionally located along river banks. They are considered to be the "most altered, at risk landscapes" within the Sierras (Viers et al., 2013). Perazzo Meadow, located a few miles north of Truckee, is just one of thousands of meadows in the Sierra Nevada mountain range. As of 2008, Perazzo Meadow was considered to be in a degraded state, as the stream channel had incised so that it no longer frequently overbanked onto its floodplain. To understand why this is important, we first need to explore the connections between a meadow's morphology and its ecology.

Morphologically, a meadow is characterized by shallow groundwater (about ~1 meter below the surface), finely textured soils, and vegetation dominated by herbaceous species (Viers et al., 2013). As wetlands, they filter fine sediments, attenuate floods, and provide fauna with refuge from high flows when inundated (Loheide et al., 2009). Another important characteristic of meadows is narrow-channeled streams with stable banks, and whose conveyance capacity is small resulting in floodplain connection by overbanking on an annual or biannual basis. This overbanking in turn promotes the persistence of hydrophilic meadow vegetation, which provide habitat for fauna.(Viers et al., 2013).

*Degradation of Perazzo Meadows*

In the case of Perazzo Meadows, the degraded state of the meadow was characterized by a wide, incised stream channel with unstable banks. The stream overbanked into the floodplain only once every 5 to 10 years, whereas more frequent annual floodplain inundation is necessary to support the aforementioned riparian ecosystems (USDA, 2008). More frequent overbanking supports a higher groundwater table that in turn supports the hydrophilic vegetation characteristic of a meadow. Because they are capable of carrying larger in-channel, incised, and faster flood flows, widened channels tend to further incise over time, a positive feedback that leads to an even larger channel that overbanks still less frequently (Viers et al., 2013).

This feedback loop of wider channels and less overbanking contributes to a lower water table by removing a primary mechanism for groundwater recharge (Viers et al., 2013). The hydrophilic vegetation that characterizes a meadow ecosystem is then unable to survive, and a shift towards xeric vegetation occurs. This shift also contributes to further widening and incision of stream channels, as the root systems of xeric plants are less dense and less capable of stabilizing soil (Schumm, Watson, & Harvey, 1984; Viers et al., 2013).

*Natural and Social History of Perazzo Meadows*

The Perazzo Meadows consist of a series of wet meadow complexes that are part of the Little Truckee watershed in the Northern Sierra Nevada mountain range. The meadows lie east of of the Sierra Nevada Crest at an elevation of approximately 6,500 feet and are surrounded by peaks reaching over 8,000 feet. The basin in which the meadow lies was formed approximately 10,000 years ago as last major period of glaciation came to an end (Swanson, 2008).

The climate is characterized by dry, warm summers and cold, snowy winters. The rain shadow effect on the eastern slopes of the Sierra Nevadas leads to relatively little precipitation in the region, averaging 31 inches of rain equivalent annually. Most of this precipitation falls as snow, which averages 210 inches per year (McGraw et al., 2001). During a typical year, snow falls between November and April and melts between March and May. Though summer storms are occasionally intense enough to trigger flash floods, post-snowmelt summer stream flows are generally low and stem from subsurface flows and groundwater.

Henness Pass Road, the lowest path through the California Sierra, passes directly through the meadows. Though it is no longer an important transportation route, it was used extensively from the California Gold Rush through the early 1900's. As described by (Byrd, 1992), "For one period of time the use of the road was so great that it became necessary to regulate traffic with freight wagons running during the daylight hours and stages traveling at night". The extensive use of this road led to development of logging and cattle grazing along its length, which had significant impacts on the morphology of the Little Truckee River.

The Environmental Assessment report for the Restoration project postulates that cattle and sheep ranchers had dug a ditch in the channel that bypassed significant parts of the meadow in order to dry the meadows and make them more accessible for grazing in the summer (Swanson, 2008). As described by Randy Westmorland of the USFS, "the banks were raw and widening, and then I realized the banks weren't in the right place. They'd been moved. They had created a ditch to dry out the meadow. That was over 100 years ago, and the water had re-meandered it since then, making it hard to recognize the original ditch,"(R. Westmorland, personal communication, Nov. 27, 2018). This hypothesis is supported by aerial photographs

dating back to 1939 which show meander scars away from the then-active, straightened channel (Swanson, 2008).

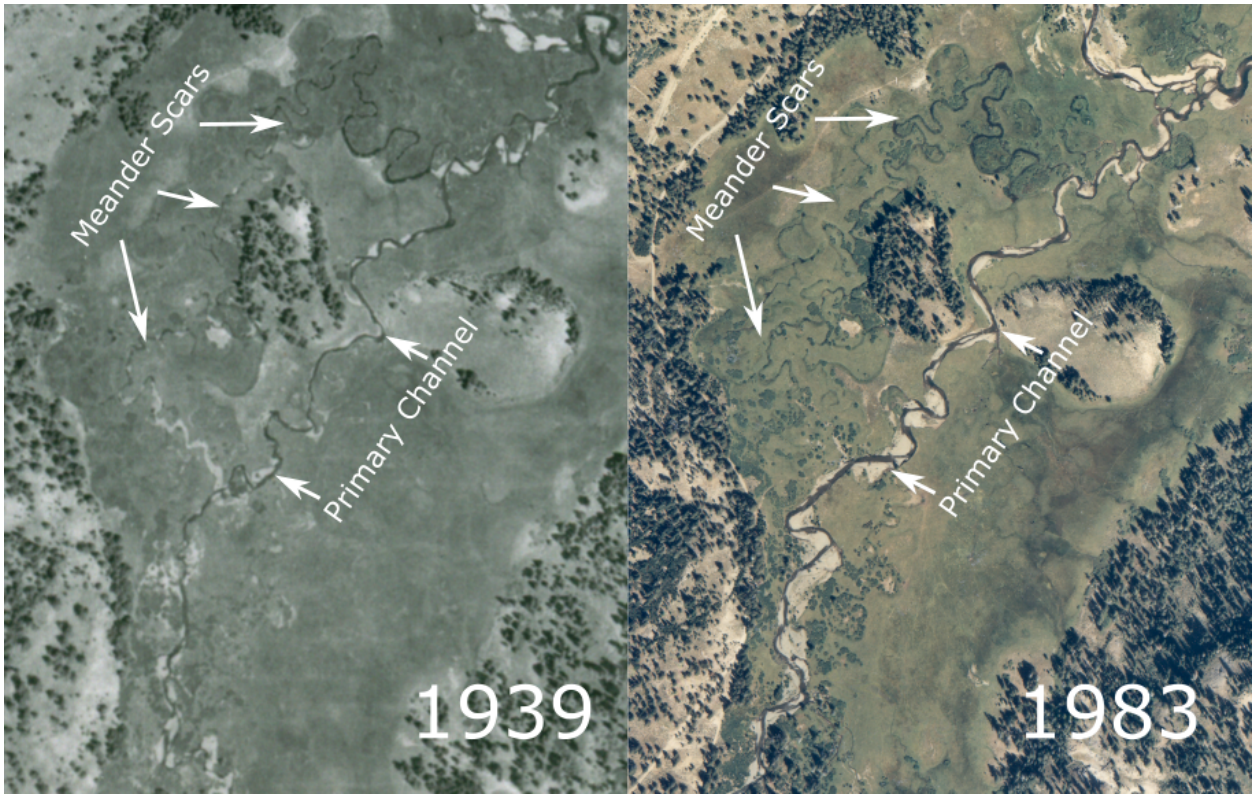



*Figure 1: Aerial photographs of Upper Perazzo Meadows from both 1939 and 1983 show meander scars outside of the primary channel. There is also a noticeable increase in sediment around the primary channel, evidence of channel widening and incision*

It is thought that this intentional change to meadow's morphology was the primary trigger for the meadow's further degradation. More recent construction of a low water crossing over the Little Truckee River has further exacerbated channel incision by inhibiting the function of the alluvial fan at the confluence with the Little Truckee River in the Middle Perazzo Meadow (USDA, 2008). In addition to these more direct contributors, the USFS also acknowledges that overgrazing in adjacent areas, a modified fire regime, road building on hillslopes above the meadow, and disturbances in the upper watershed are all factors that contributed to the degradation of the meadows (USDA, 2008).

**Perazzo Meadows Restoration**

In the early 2000s, the Truckee River Watershed Council (TRWC) and the USFS began developing a plan to restore the ecological and hydrological function of Perazzo Meadow. In 2008, Swanson Hydrology conducted a hydrologic and geomorphic assessment of the meadows in order to document past and current conditions and, ultimately, to develop restoration design recommendations. The following are the goals proposed by the USFS to restore the functions of the Perazzo meadows.

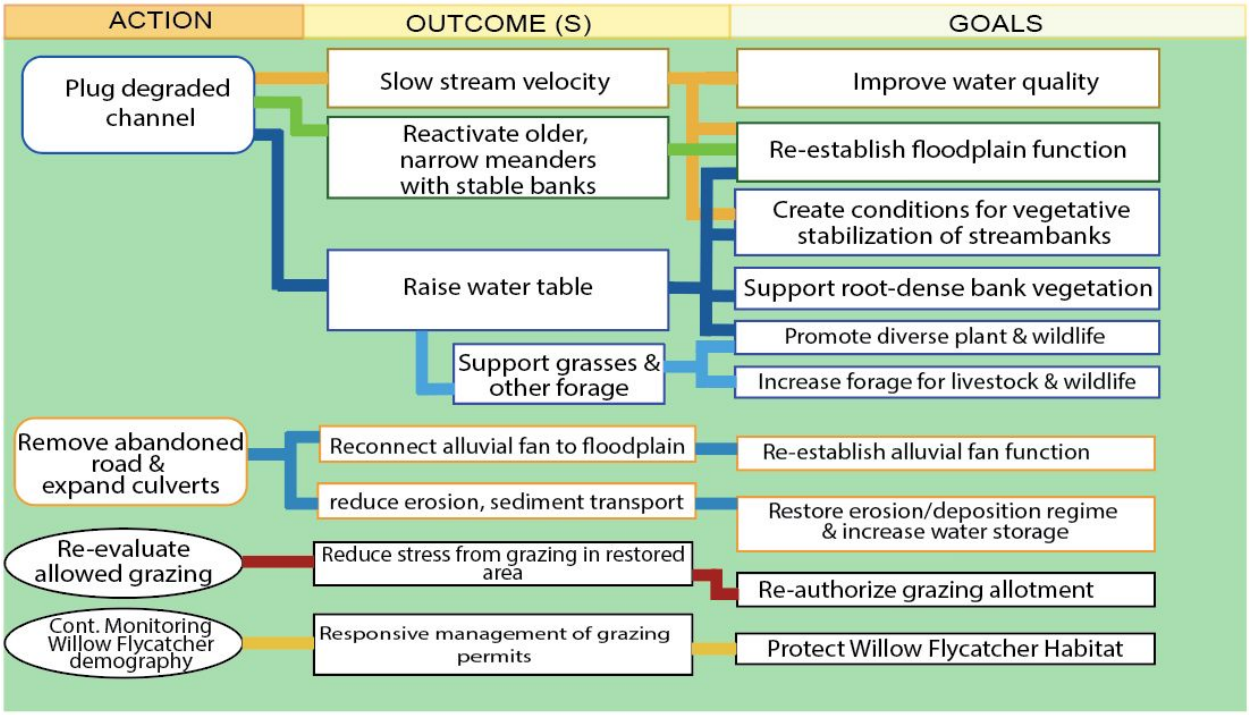



*Table 1: Theory of change for Perazzo Meadows Restoration. Adapted from Environmental Assessment report (USDA, 2008).*

Among the various goals and outcomes detailed by USFS, raising the water table is a common desired outcome of the pond-and plug approach. In an interview, TRWC has identified

reconnection of the stream with the floodplain, and subsequent raising of the water table, as the most important outcome of the project (B. Christman, personal communication, Nov. 27, 2018).

**Goals of our Study**

Our report aims to integrate data from the Perazzo Meadows Geomorphic Assessment (Swanson 2008), data from previous site surveys, as well as 2018 data collected by our group. The previous surveys were done in 2014, Jennifer Natali, PhD candidate at the Departments of Landscape Architecture and Environmental Planning, University of California, Berkeley. By combining these data and inspecting available satellite imagery of Perazzo, both before and following the restoration, we formulated an image of the area prior to the restoration and how the morphology of the stream has responded to the restoration. The key assessment we want to make with this information is if the current morphology is consistent with the USFS goals, and if the morphology is on a trajectory to continue meeting those goals in the near future.

**Methods**

*Overview*

Some of the perspectives used in this paper come from Forest Service Managers, the Truckee River Watershed Council, Truckee Donner Land Trust, and the layout of our analysis is based on multiple literature references, including those by Swanson et al., 2008 and McGraw et al., 2001.

The team visited and surveyed Perazzo Meadows on two weekends in Fall 2018. On the first weekend, we took stream cross sections, long profiles and pebble counts at Restoration Site 1 in Upper Perazzo Meadows. On the second weekend, we collected similar data at Restoration Site 4. We interviewed the groups and individuals responsible for the project and park area in

order to gain an understanding of socioeconomic factors and influences in person in late November 2018.

*Topographic Surveys*

At each site, we conducted two kinds of surveys: long profiles of Perazzo Canyon Stream, and cross-sectional profiles at key points in the stream. Long profiles were taken along the thalweg of reaches of the stream that had been surveyed before. Similarly, we took cross-sections as close as possible to where previous cross-sections had been taken. Unfortunately, benchmarks from previous surveys could not be located, so our cross sections do not line up perfectly between years.

Using a Nikon DTM-324 Total Station and handheld target we created topographic surveys. Where not previously monumented, we drove a rebar stake into the ground to designate endpoints of each cross section to support repeatable measurement and comparison over time.

Pebble counts have been shown to be a useful, rapid method for characterizing a streambed and its recent flow history (Wolman, 1954). We did pebble counts at key sites that appeared to have been recently deposited

*Stakeholder Interviews*

In order to better understand the history of Perazzo and the goals of the various stakeholders in the project, we interviewed Beth Christman, TRWC Director of Restoration projects, and Randy Westmorland, USFS lead on the project. These interviews were semi-structured, with topic and open-ended questions based on our outside research. The goal of the interview was to better understand the motivations and goals of key stakeholders in the project whose views may not have been adequately captured in the literature.

**Results**

*Aerial Photo Comparison*

Aerial photos obtained from Swanson et al. (2008) and Google Earth (2018) for both survey sites show a marked change in the character of the stream channel and the meadow. Photos from before the restoration show a wide, gravelly channel with less dense vegetation in the meadow. Current aerial imagery shows a small channel with few very few gravel bars and more dense grassy vegetation in the meadow overall.

*Figure 1. Aerial photo comparison of Site 1: 1982 (Swanson, 2008) and 2018 (Google earth)*

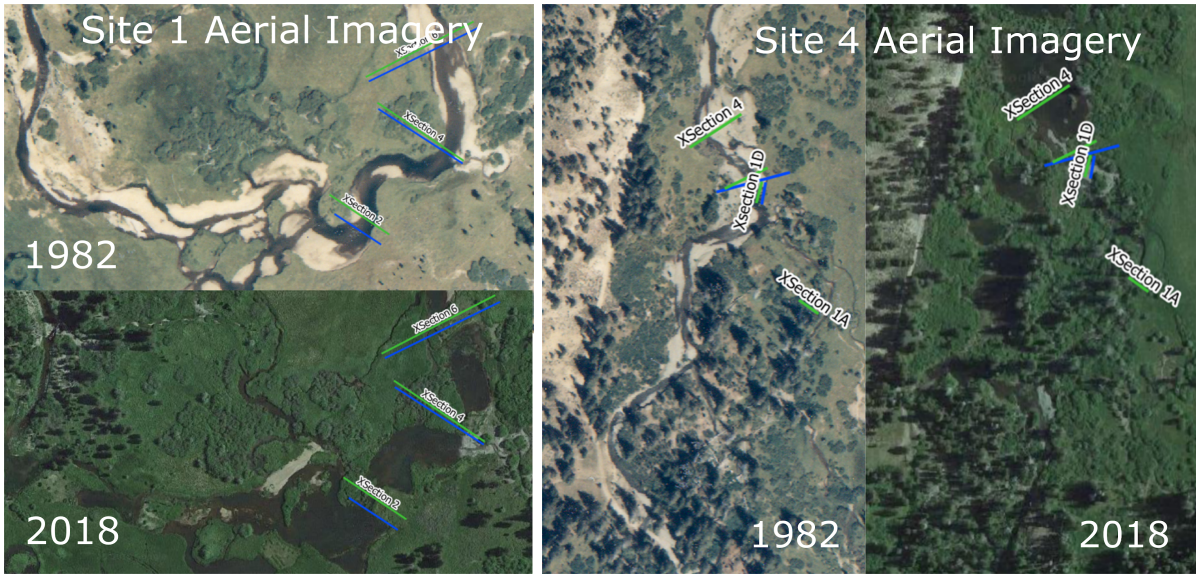
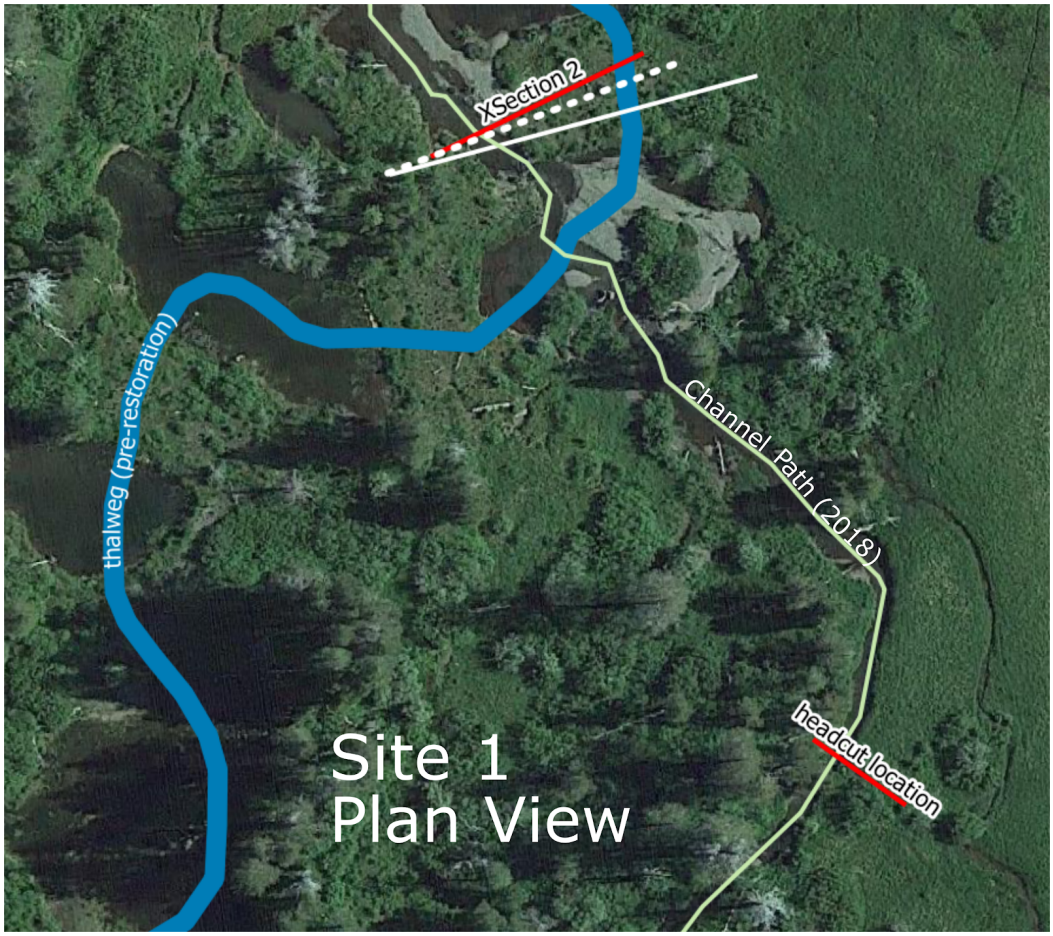



*Figure .2 Cross Sections and Stream Incision at Site 1*

Stream cross sections taken at Site 1 indicate that the width and depth of the post-restoration channel have remained relatively constant since the 2010 restoration (Figure 3). The channel has also re-routed into a remnant meander scar to the east of the pre-restoration thalweg. A small (6 inch) headcut was observe 130m upstream of cross-section 2.

*Figure 2. Site 1 plan view and cross sections*



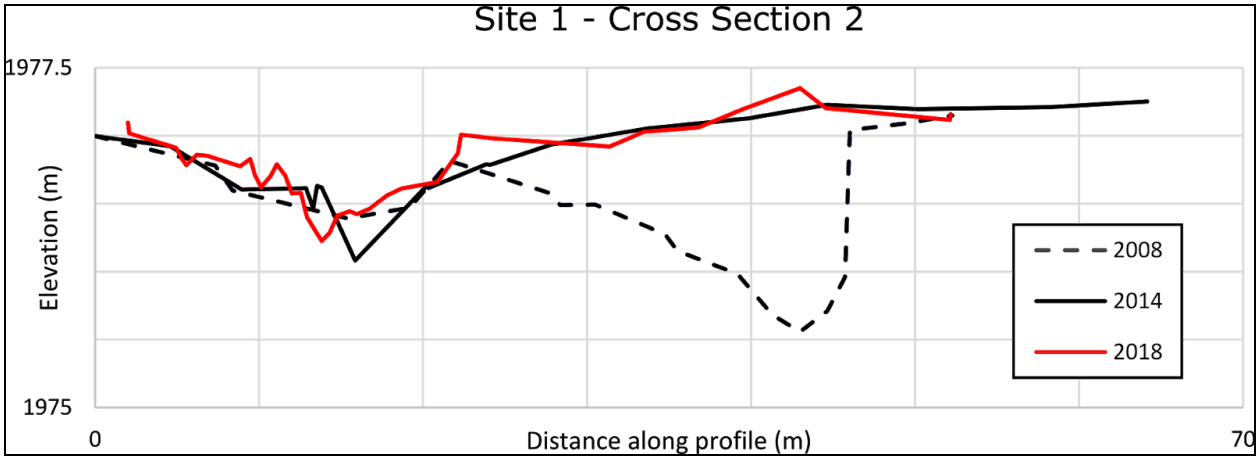




*Figure 3. Cross section 2 side view shown in the lower graph, referring to the top most red line in the aerial imagery in the above image.*

Our observations of cross sections from Survey site 4, specifically at cross sections 2 and 4, show that the channel remains less incised than it was before the restoration. Cross section 2, however, appears to be in the process of incising, based on the dipping red data line (2018) vs the more elevated solid black data line (2014) (Fig. 3.) Cross sections 4 and 6 appear to be remaining stable over time due to their similarity over the many years (Fig. 4). Cross section 2 is the closest to the confluence with the Little Truckee River, and thus may be seeing more scour and incision from higher velocity flow.

At cross section 4, a number of smaller channels appear to be forming around the plug. This is not the case at cross section 2, just a hundred meters upstream, where it appears that the channel has nearly incised to its pre-restoration depth, though it is not nearly as wide (Fig. 4)..

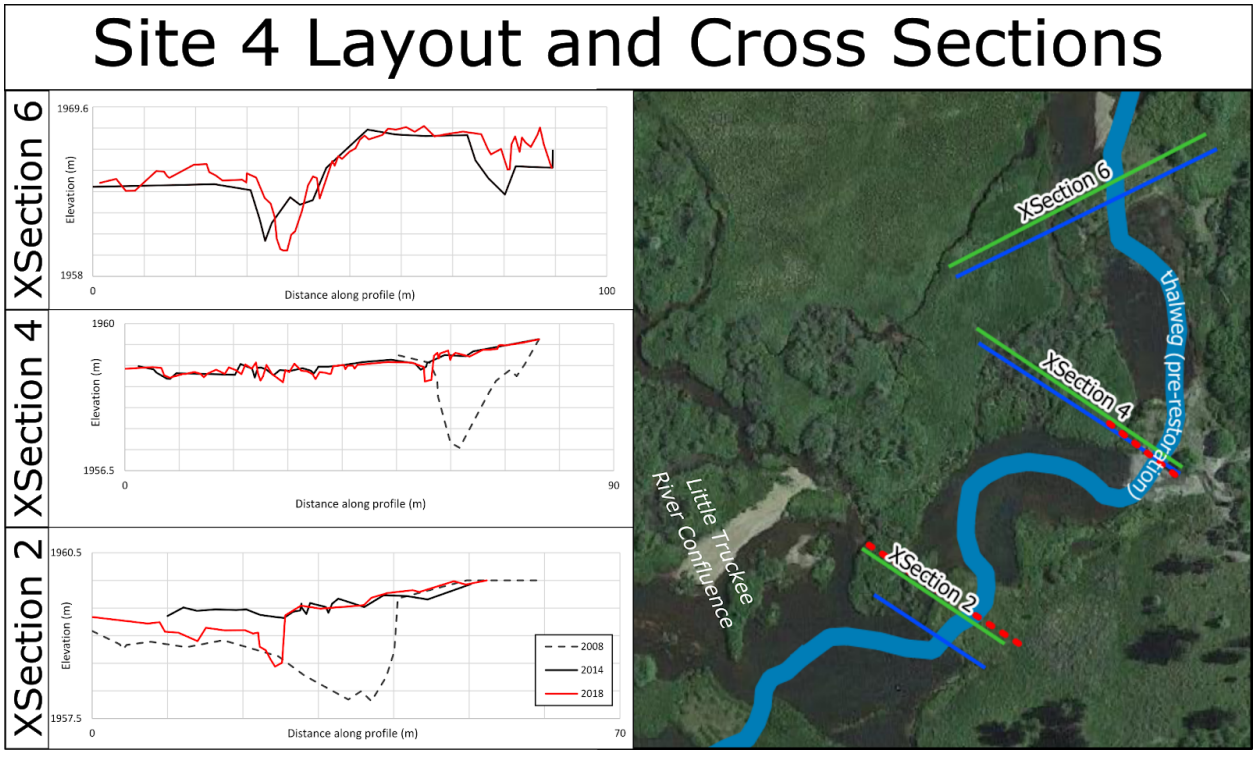



*Figure 4. Cross sections 2, 4, and 6 shown by depths from the years 2008-2018. Included next to them is an aerial image showing their positions relative to each other.*

**Discussion**

Meadow restoration is a new practice. This means that everything must be seen as an experiment to be tried and tested (B. Christman, personal communication, R. Westmoreland, Nov. 27, 2018). Because the upper, middle, and lower sites of the Perazzo Meadows will be completed in succession, there has been ample opportunity to learn lessons from the first projects and apply them to subsequent ones. In this case, lesson learned from the Upper and Middle Perazzo Meadows Projects (2010) manifested themselves both in slight structural changes and community-process changes, to be implemented in and the Lower Perazzo Meadows Project (in process for 2020).

There are some minor tweaks proposed to the way plugs should be constructed. Over all, the pond and plug approach does seem to be holding together. Our measurements indicate that, at least in the sections surveyed, channel incision and width has not returned to pre-restoration levels, and does not appear to have been increasing since the 2014 measurements were taken. This indicates that the channel has, at least temporarily in these areas, found a stable profile that is not leading back towards the degraded state. However, some of the plugs have blown through partially or completely. We concluded that it would be helpful to include more fine sediments in the plugs. This would give vegetation more to hold on to, thus creating a more robust root network to hold together the plug even when water flows are strong. In addition, there was one area in which three plugs had been breached and required repairs. The hypothesis is that the beaver dam immediately upstream could have created more pressure on these plugs than others

(Perazzo Meadows Project Evaluation Form, 2011) . The repairs to the plugs included tapering the plug and armoring it with rock to prevent a head cut from going through the plug.

In addition, the community process has been improved throughout the restoration of the Upper, Middle, and Lower Meadows. During the first restoration project in the Upper Perazzo Meadows, plugs were so effective in refilling the water table in the meadows that downstream users in Sierraville actually stopped receiving usual water flow for a little while. This caused concern in Sierraville, where many people rely on this water for the cattle industry based there, among other things. Although a report had been published, the community did not feel sufficiently forewarned. Since then, monitoring has been implemented to ensure that downstream Sierraville does not risk long-term water losses. The lessons learned from this site will be applied to the Lower Perazzo Meadows restoration project, to be implemented in 2020. For example, there has been a new community engagement process that includes the creation of stakeholder group of invested and committed members, that supplements the project with opinions and ideas. Beth Christman said, "It was absolutely beneficial ... Having engineers and biologists on the team helped us drill down on the details of the project, too. Sometimes it wasn't pleasant, but we built trust as it went on, and it got better and better. People asked for the analysis, and we did it. So, it started from necessity, but then became useful." ( personal communication, Nov. 27, 2018).

**Conclusion**

Outside of the results that we have discussed above, it is obvious that there is a need for long-term monitoring of projects like the one in Perazzo. Every watershed is unique, and it is impossible to accurately predict a river's long-term response to any given restoration project.

The pond-and-plug approach to restoration is still a relatively new approach to restoration  As such, its long-term effects are poorly understood. This paper contributes a better understanding of this restoration approach, as our observation in Site 1 demonstrates, the Meadows are continuing to respond to the restoration and further study is needed to understand that response.

With regard to the goals laid out by USFS many of the short-term goals have been achieved.  Continued groundwater monitoring by Shaw et al. (Shaw, 2016) has shown strong evidence of a consistently higher water table and more consistent stream discharge.  The meadow's response to the project, however, is ongoing and it remains to be seen whether it will persist in the longer term.

TRWC's Director of Restoration Programs, Beth Christman, has stated that, "In Perazzo, we're getting pretty close [to the pre-disturbance state]." (personal communication, Nov. 27, 2018)  TRWC's primary goal for the restoration was to reconnect the stream with the floodplain, which it sees as crucial for all other functions of the stream.

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