

# Yuba Headwaters Meadow Restoration Monitoring Report

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## Executive Summary

Mountain meadows in the Sierra Nevada provide multiple ecosystem services. As natural water retention basins, meadows attenuate floods, sustain stream baseflows, improve water quality and support vegetation that stabilizes stream channels and promotes biodiversity. In addition, mountain meadows provide natural storage of atmospheric carbon (Xu 2003). Historic landuse and management activities, along with impacts of climate change, have degraded Sierra Nevada meadows by altering meadow conditions, resulting in a disturbance to surface water and groundwater dynamics.

The main objective of this project was to determine the effects of restoration implementation on hydrologic and ecosystem function at Loney Meadow. We leaned on the assumption that re-establishing hydrological connectivity between the stream channel, remnant channels, and the meadow floodplain would increase groundwater levels and surface inundation resulting in a shift towards wetter plant communities and an increase in net carbon sequestration. We implemented a BACI experimental design, utilizing two nearby reference meadows as controls to validate our findings at Loney Meadow. The experimental design provided us with more explanatory power to: 1) evaluate the restoration response in context with annual changes in the hydrologic regime and 2) determine how and whether the restoration project impacted conditions exclusively at Loney compared with other meadows in the same geographic vicinity. This experimental design allows us state with a fair amount of certainty that the restoration of Loney Meadow did result in wetter habitat conditions. The results of our hydrologic, vegetation, and carbon monitoring efforts quantify and support this finding.

## Introduction

The South Yuba River Citizens League (SYRCL), in collaboration with the Sierra Meadow Restoration Research Partnership (SMRRP) and the Tahoe National Forest, led the Yuba Headwaters Meadow Restoration Project which restored over 149 acres within three meadows across the Sierra Nevada. Additionally, the Yuba Headwaters Meadow Restoration Project quantified the impact of restoration on carbon sequestration, greenhouse gas exchange, streamflow, groundwater levels, and vegetation change within the Loney Meadow complex (Loney, Upper Loney, and Lower Deer meadows), and sampled two proxy meadows (Beartrap and Freeman) to use in a model being developed by the SMRRP. SYRCL's project was unique among the projects funded in the 2014 California Department of Fish and Wildlife greenhouse gas reduction grant round because it established a before, after, control, impact study in the Loney Meadow complex with both reference and degraded control meadows in close proximity (less than 0.7 km) to the restoration/impact meadow, allowing for finer scale comparisons of change over time and as a result of restoration implementation. The project objectives are:

### Carbon/GHG Objectives:

- Help meet the goals of AB 32 by achieving net GHG emission reductions through the restoration of mountain meadows;
- Improve the understanding of greenhouse gas emissions from mountain meadows; and
- Support the development of a predictive model that will allow for the use of proxy variables (e.g., depth and duration of saturation, soil texture and carbon content, plant community type, and length of growing season) to estimate carbon sequestration and GHG emissions in mountain meadows

### Co-benefit Objectives:

- Restore and expand habitat for native plants, fish, and wildlife;
- Restore and enhance the connectivity of associated wetland and riparian communities;
- Increase late-season flows in meadow streams;
- Reduce and delay peak flows in meadow streams;
- Decrease sedimentation downstream of mountain meadows;
- Improve water quantity and quality for native fish and wildlife;
- Increase water storage capacity in mountain meadows; and
- Protect climate refugia in meadows, such as aspen communities and floodplain habitat.

It is estimated that over 60% of meadows in the Sierra Nevada are considered degraded, and many of those meadows are degraded due to loss of hydrologic function caused by historic impacts, like overgrazing, road-building, mining, fire suppression and/or development has resulted in localized stream incision, and partial conversion from wet to dry meadow conditions (Ratliff 1985; Dwire et al. 2004; Freitas et al. 2014). Climate change impacts, such as shifting precipitation regimes, have led to further degradation of meadows, resulting in accelerated channel erosion and depletion of groundwater. All of these impacts have the potential to decrease carbon sequestration and greenhouse gas (GHG) uptake in montane meadows (Blankinship and Hart 2014; Reed et al. 2017), reduce groundwater recharge (Hammersmark et al. 2008; Loheide et al. 2007), alter hydrologic streamflow regimes (Hunt et al. 2018), decrease wetland plant communities or plant community heterogeneity (Dwire et al 2006; Hammersmark et al. 2008), and shift meadows from overall wetter to drier conditions. Impacted meadows have slowly become drier, and shorter, warmer winters are expected to result in accelerated wetland vegetation loss,

aquatic and terrestrial species habitat depletion, the mineralization of soil organic matter, and an increase in GHG emissions.

Restoration efforts have the potential to create functioning groundwater retention basins that may increase summer baseflow (Hunt et al. 2018; Tague et al. 2008; Lohide et al. 2007; Hammersmark et al. 2008) and improve a myriad of other co-benefits that are indicative of a healthy, functioning meadow (Lal 2003). Restoring mountain meadows has the potential to increase water retention (Tague et al. 2008; Hammersmark et al. 2008; Hunt et al. 2018) and soil organic carbon sequestration (Blankinship and Hart 2014), creating a Sierra Nevada region-wide water and carbon sink that will help supply summer water demands and offset CO<sub>2</sub> emissions from fossil fuel use.

Improving stream channel conditions and flow path connectivity is critical to the improvement of meadow ecosystem function, including streamflow and groundwater hydrology, GHG emissions and carbon sequestration, and the stability of wetland plant communities. With the exception of Upper Loney Meadow, which represents a fairly stable undisturbed meadow state, all the meadows in this study are all in some stage of degradation, driven by impaired hydrology, land use history, and now earlier snowmelt as a result of climate change. To meet our project objectives, this project tested the hypotheses that re-establishing hydrological connectivity within a degraded mountain meadow system will: (1) increase net carbon sequestration, (2) increase groundwater levels, (3) improve late season streamflow, (4) improve water quality, (5) improve amphibian habitat, and (6) shift meadow vegetation to more wetland dominated vegetation communities, when compared to non-restored and reference conditions. To test these hypotheses, we utilized a before, after, control, impact (BACI) method and measured change in carbon stocks, groundwater levels, streamflow, and vegetation at three mountain meadows Loney Meadow, Lower Deer Meadow, and Upper Loney Meadow.

In addition, this project is part of a collaborative effort among many agencies and organizations in the Sierra Nevada, called the Sierra Meadow Restoration Research Partnership (SMRRP), which is developing an accredited proxy protocol for GHG sequestration in Sierra Meadows. A registered protocol has the potential to incentivize restoration actions in all of the Sierra Nevada's 17,000 meadows and the SMRRP's goal is to share data and provide a robust and coordinated regional response to the historic opportunity that AB 32 presents. SYRCL has participated in this effort and has provided all data associated with this project to the SMRRP Technical Advisory Committee (SMRRP TAC) for landscape scale analysis. This unprecedented effort by the SMRRP partners will advance the understanding of carbon and GHG dynamics in Sierra Nevada meadows, climate change impacts, and address the meadow restoration needs prioritized in the CA State Water Action Plan. The SMRRP TAC provided standardized field sampling protocols, lab methodologies, and data analysis procedures for this project, allowing for a comparative analysis of participating meadows across the Sierra Nevada.

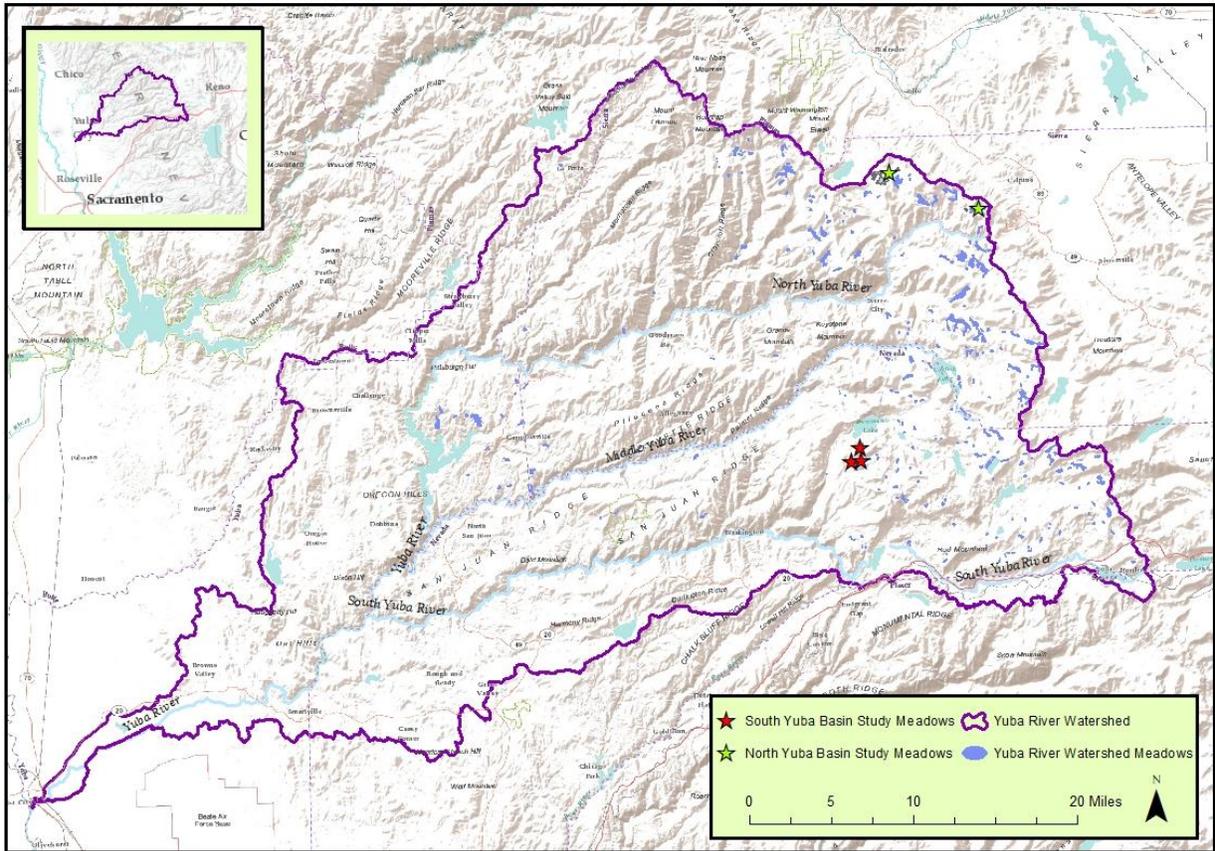
## Methods

### Study Area

The headwaters of the Yuba River watershed are generally characterized as being above 5,000 feet in elevation in the Sierra Nevada mountains and spans the north, middle, and south forks of the 1300 square mile Yuba River watershed. Within this headwaters region, there are about 315 meadows (Map 1) that are identified by the US Forest Service Pacific Northwest Region 5 and UC Davis meadows mapping layer. For this study and restoration project, meadows in the headwaters of the South Fork Yuba River (Loney, Upper Loney and Deer meadows) and the headwaters of the North Fork Yuba River (Beartrap and

Freeman meadows) were used as either restoration/impact meadows, reference control meadows, or degraded control meadows (Maps 2 and 3).

### Study Meadows within the Yuba Watershed



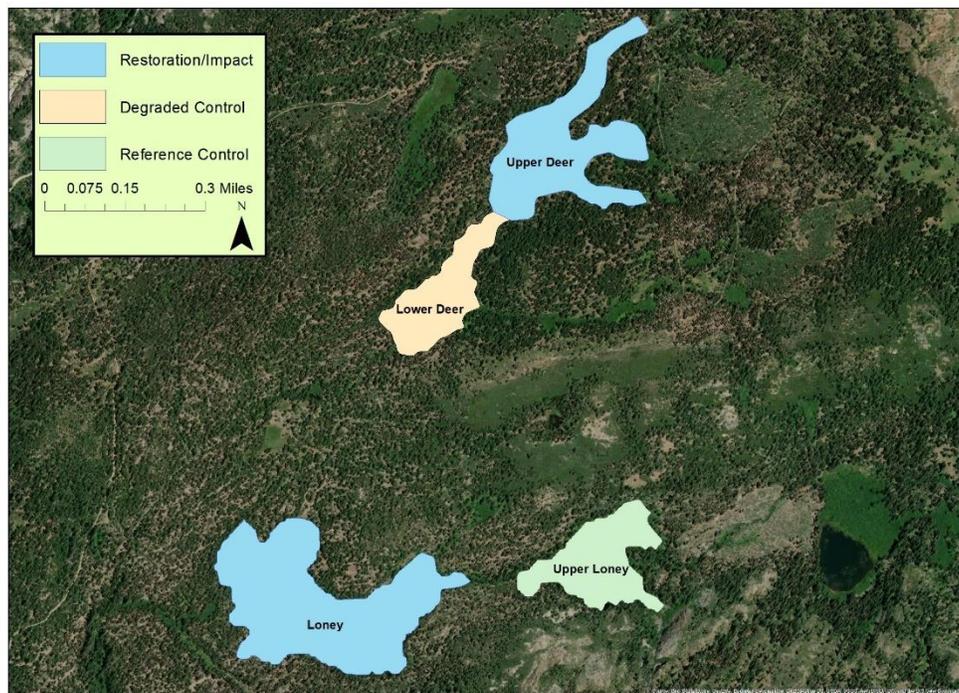
Map 1. Meadows in the headwaters of the Yuba River Watershed. Study meadows identified by green stars in the North Fork Yuba Basin and by red stars in the South Fork Yuba Basin.

## North Yuba Basin Study Meadows



Map 2. Study meadows in the North Fork Yuba Basin colored to show restoration and control meadows.

## South Yuba Basin Study Meadows



Map 3. Study meadows in the South Fork Yuba Basin colored to show restoration and control meadows.

## Loney Meadow

Texas Creek feeds the beautiful wet-meadow complex of Loney Meadow (47 acres). The meadow has a mean elevation of 5,890 feet and a gradient of approximately 3% percent. In the context of this study, Loney Meadow is the restoration or impact meadow and makes up one of three meadows in the Loney Meadow Complex, which also includes Deer Meadow (degraded control) and Upper Loney Meadow (reference control). Loney Meadow was under private ownership until 1989. It has had a long history of intensive grazing, and was once the site of a dairy operation. There is evidence of Gold Rush-era mining nearby, and the area was intensively logged during the late 19th and early 20th centuries. The intensity of grazing has steadily decreased since the 1960s, but historic activities have resulted in a partially incised stream channel, destabilized stream channels, ditching, an instream habitat that lacks complexity, compromised wetland vegetation communities, and encroachment by disturbance-tolerant plant species (see Figure 1 below).

Loney Meadow was identified in the National Fish and Wildlife Foundation's (NFWF) Sierra Nevada Meadow Restoration Business Plan as one of only three priority restoration sites in the entire 1,340 square mile Yuba River watershed. The NFWF Business Plan states that Loney Meadow is one of the few large meadows where complete restoration of hydrology and vegetation could be achieved at a reasonable cost. An additional benefit is that the site is easily accessible for restoration work and presents a unique educational opportunity for the general public. The greatest current threat to Loney Meadow is the continued incision of Texas Creek, which lowered the water table and disconnected the stream channels from its historic floodplain. Lesser threats are gully erosion at an abandoned roadbed and the encroachment of conifers.



*Figure 1. Loney Meadow, clockwise from top left: overall view of the meadow; interpretive trail through meadow; example of channel incision; relatively intact stream channel in one portion of the meadow.*

## Deer Meadow

Deer Meadow is a 46-acre, high gradient meadow located near Bowman Lake in the South Yuba River watershed. The meadow has a mean elevation of 6250 feet and a gradient of approximately 7 percent. The meadow has two distinct areas, a very degraded area referred to as Upper Deer Meadow and a less degraded area referred to as Lower Deer Meadow (Figure 2). Lower Deer Meadow is the degraded control meadow and makes up one of three meadows in the Loney Meadow Complex, which also includes Loney Meadow (restoration/impact) and Upper Loney Meadow (reference control). Upper Deer Meadow was restored as part of this project but, due to its much steeper slope, was not considered a reference site candidate for Loney Meadow.

Historic land use in the area included mining, logging, grazing and the associated roads and trails. The TNF acquired this meadow in 1989 in a degraded condition. Sustainable grazing has continued under the current management, and the network of non-motorized trails in the watershed has been improved in recent years. The upper end of the meadow has thick alder on three wet slopes that reach down to the degraded portion of the meadow. Topsoil has largely been lost in the upper end, resulting in poor vegetative cover, potential for increases in GHG emissions, decreased carbon sequestration, rills and gullies from rainstorm and snowmelt runoff. Both old roads and ditches divert and concentrate water resulting in gullies down through the middle and lower portion of the meadow. A stock pond in need of maintenance is located on the southwest side of the meadow and may provide habitat for sensitive amphibians.



*Figure 2. Upper (left) and Lower (right) Deer Meadow. Upper Deer was restored as part of this project and Lower Deer was the degraded control meadow as part of the carbon, greenhouse gas, vegetation, and groundwater experiment conducted at the Loney Meadow Complex and across the Sierra Nevada.*

## Upper Loney Meadow

Upper Loney Meadow is an 18.6-acre meadow located approximately 600 ft. upstream of Loney Meadow (Figure 3). It is relatively undisturbed, with minimal stream channel incision. Upper Loney Meadow is the reference control meadow and makes up one of three meadows in the Loney Meadow Complex, which also includes Loney Meadow (restoration/impact) and Lower Deer Meadow (degraded control). Its similarity to Loney Meadow regarding several attributes (slope, aspect, elevation, vegetation, geology, and hydrogeomorphic type) and its placement directly upstream presents a unique opportunity to compare the results of a meadow restoration with an “undisturbed” reference meadow.



*Figure 3. Upper Loney Meadow, overall view.*

#### Beartrap Meadow

Beartrap Meadow is approximately 30 acres in the headwaters of Chapman Creek, a tributary to the upper reaches of the North Yuba River. This relatively high gradient (5%) site is around 7,000 feet elevation (Figure 4). The meadow condition inventory conducted by American Rivers (2012) rated Beartrap Meadow as fair to good. The channel in the upper portion of the meadow has split into multiple channels and is down cut for over 700 feet in length. The instability is hydrologically connected to a channel originating at the outlet of the culvert, on the road that traverses the upland north of the meadow. There are several additional locations along the middle and lower portion of the meadow that also have culvert outlets directly connected to the meadow channel, causing localized instability, direct sediment input and increases in peak flows. The road drainage in this meadow has been identified as a threat to meadow condition for many years. Also, this northern hillslope has large areas of bare soils and concentrated surface flow paths that are supplying sediment and increased flows to the meadow. Lands within and adjacent to this meadow have been intensively managed for many decades. Past uses include heavy sheep grazing, mining and timber logging in the late 1800's and early 1900's. Recent management has continued grazing and forest treatments, along with recreational use, but at a more sustainable level.



*Figure 4. Beartrap Meadow. Photo shows head cut erosion in the stream channel and previous attempts to stabilize the degraded channel with large wood.*

#### Freeman Meadow

Freeman Meadow (45.7 acres) is a represent a degraded, “unrestored” reference meadow to compare with Beartrap meadow. Freeman Meadow (Figure 5) is in the North Yuba watershed and has incised stream segments in the upper meadow, which comprises the majority of the meadow area. This instability was caused by various factors including existing road alignment and drainage. This meadow also contains several cobble-filled gabion grade control structures, which range from stable to unstable. These structures were installed within the past 40 years to control erosion and need to be repaired or removed as many are no longer functioning as intended.



*Figure 5. Freeman Meadow.*

## Co-Benefit Monitoring

### Hydrologic Monitoring

Hydrologic monitoring included both groundwater and surface water monitoring to test specific hypothesis about the benefits of restoration actions to the meadow hydrology at each restoration and control meadow site (Table 1). Barologgers were installed at Loney Meadow and Beartrap Meadow to compensate for barometric pressure and data was applied to neighboring meadows.

*Table 1. Piezometer and Stream Gage installation and monitoring timeline. Manual measurements at stream gages (including water quality) and piezometers occurs every three weeks during the snow free months.*

<b>Meadow</b>	<b>Installation</b>	<b>No. of piezometers</b>	<b>No. of Stream Gage(s)</b>	<b>Monitoring Start</b>	<b>Monitoring End</b>
Loney	July 2015	10	2	August 2015	Duration of project
Upper Loney	July 2016	3	1	September 2016	Duration of project
Lower Deer	July 2016	4	0 (no perennial flow)	September 2016	Duration of project
Beartrap	September 2016	6	1	September 2016	Duration of project
Freeman	September 2016 and 2019	6	4	September 2016 and 2020	Duration of project

### Groundwater Monitoring

Groundwater monitoring was conducted at Loney, Lower Deer, Upper Loney, Beartrap, and Freeman meadows for the duration of the grant term. Groundwater data was collected by installing drive-point piezometers. Drive-point piezometers serve as an affordable method to monitor shallow groundwater in suitable conditions (Solinst 2019). Well points were coupled to 8 feet of galvanized steel pipe and installed underground using a post pounder. Fences were installed around each piezometer to deter cows and protect the equipment. Additionally, each piezometer was vented for atmospheric stabilization and a well cap and lock placed at the top of each pipe. Groundwater was monitored to test several hypotheses:

- We expect that groundwater levels will increase in areas that hydrologically benefited from restoration actions.
- We expect that vegetation will shift to include more wetland species in areas where groundwater levels have changed as a result of restoration actions.

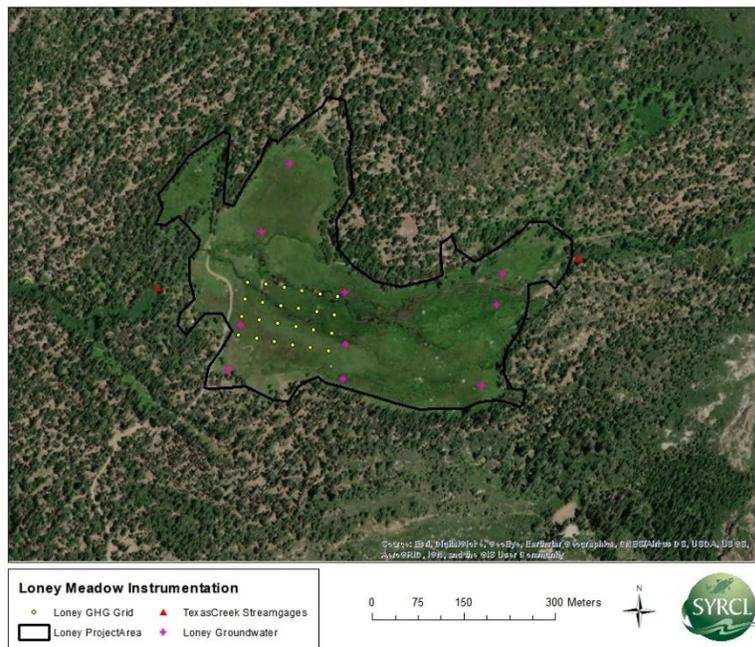
In order to determine the effect of restoration on groundwater levels, statistical analyses were performed on piezometer data during the summer recession period (June- Sept). A one -way analysis of variance (ANOVA) was used to determine significance between 3 or more groups (i.e. between water years), Welch’s t-test to test significant difference between 2 groups (or 2 means, i.e. pre vs. post years), and a Wilcoxon rank sign test (non-parametric) was used to test for the difference between two groups when assumptions of normality and homogeneity of variance assumptions were not met (i.e. small sample sizes)

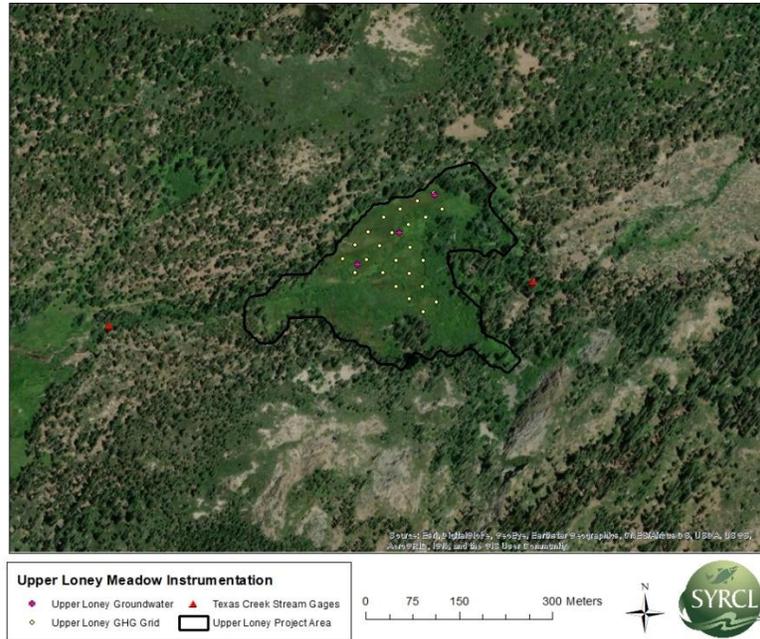
A Welch’s t-test was performed to test for statistically significant changes in belowground water levels for years grouped as pre-restoration 2016-2017 and post-restoration 2018-2019 and an ANOVA was used

to test for differences across all years. Percent change of pre/post groundwater levels was calculated using the following formula:  $(\text{post rest GW height} - \text{pre rest GW height}) / \text{pre rest GW height} * 100$ .

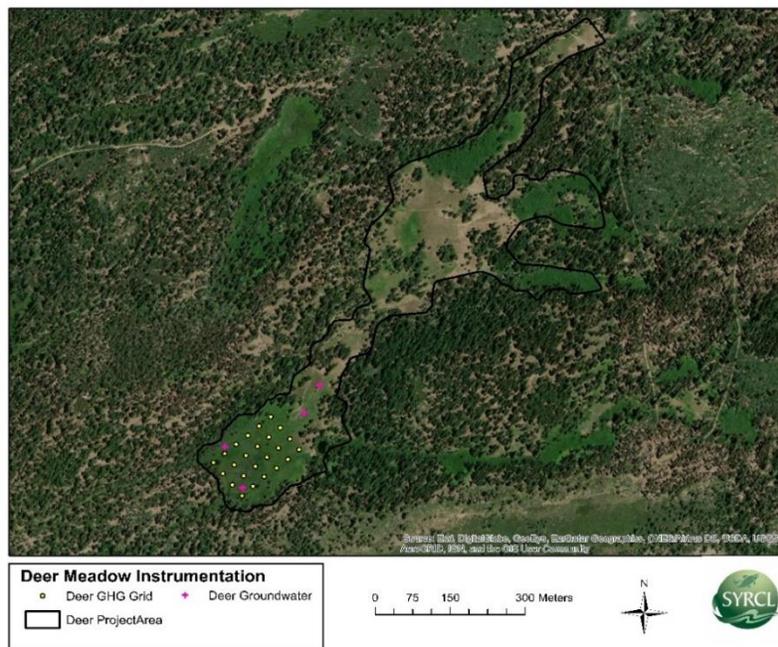
#### Loney Meadow (Restoration)

In July of 2015, ten piezometers were installed along three transects across Loney Meadow. A total of six Solinst levelloggers were deployed, two within each of the three transects (Map 4). Manual measurement of depth to water within the wells occurred between August and November of 2015. For the duration of the project (2016-2019), wells were manually measured every three weeks during the snow free months (approximately May through November). Levelloggers were downloaded annually, before the snow fell.





Map 5. Upper Loney Meadow Instrumentation.

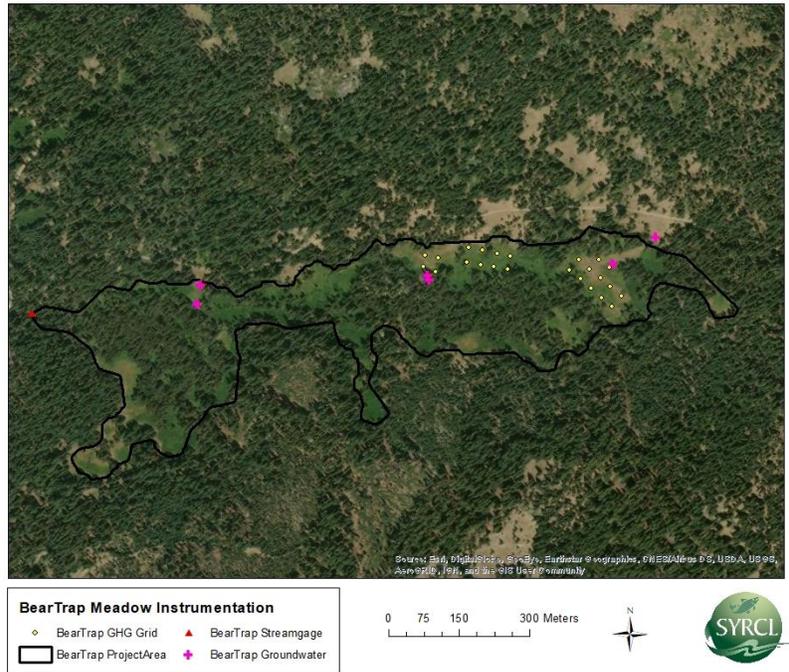


Map 6. Lower Deer Meadow Instrumentation. Upper Deer Meadow (North East end of meadow) was restored in 2018.

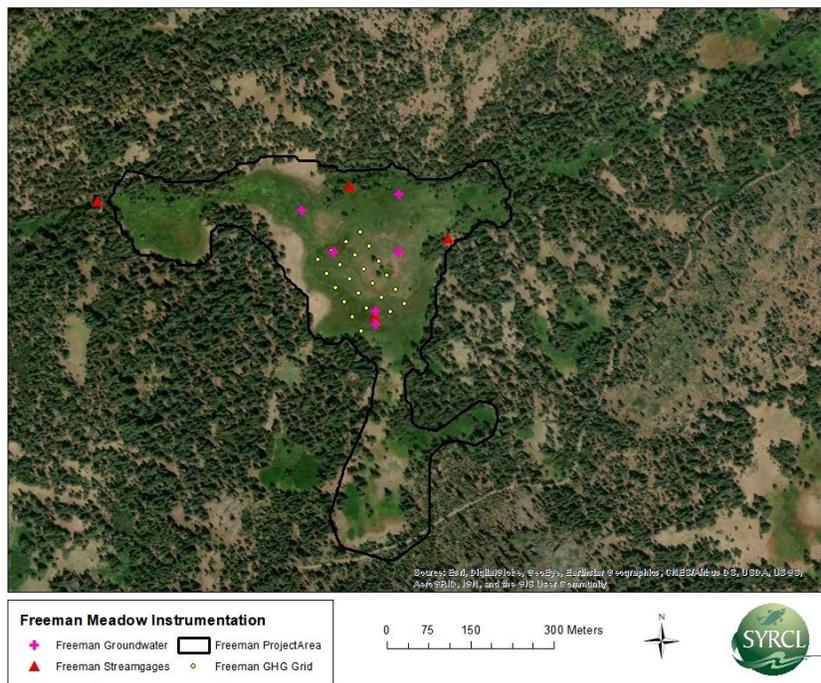
Beartrap (Restoration) and Freeman Meadow (Control)

Six piezometers were installed at Beartrap Meadow and three in Freeman Meadow in September 2016 (Maps 7 and 8). Two of the piezometers at Beartrap Meadow were instrumented with Levelloggers. Due to sedimentation issues, an additional three groundwater wells, all instrumented with Levelloggers, were

installed at Freeman in September 2019. Monitoring occurred every three weeks during the snow free months for the duration of the project.



Map 7. Beartrap Meadow Instrumentation.



Map 8. Freeman Meadow Instrumentation.

### *Surface Water Monitoring*

Surface water monitoring was conducted at three locations along Texas Creek (Maps 4 and 5) upstream of Upper Loney, downstream of Upper Loney/upstream of Loney, and downstream of Loney, and at the outlet of Beartrap (Map 7) to test specific hypotheses about how outflow changes due to the impacts of restoration actions within Loney and Beartrap meadows:

- We expect that restoration actions will shift the hydrologic regime, delaying the recession and increasing baseflows at outflow locations.

To isolate the effect of restoration efforts on streamflow patterns, we used a paired gage method in order to compare the amount of streamflow leaving the meadow (outflow) relative to the streamflow entering the meadow (inflow). This method removes the influence of climatic effects happening at both gages, such as heavy precipitation in the form of rain or snow. Stream flow gages were installed between 2015-2019 and manual discharge data collection occurred in the snow free months every three weeks to establish a strong rating curve. To assess changes in streamflow patterns during the study period, percent change of outflows vs inflows was calculated. Percent change represents the amount of streamflow leaving the meadow (outflow) as a function of the streamflow entering the meadow (inflow). For example: % change = (outflow - inflow) / (inflow)\*100.

Baseflow was calculated for each water year at each stream gage using the EcoHydRology package in R with streamflow data from 2016-2019 at the gages below Loney, above Loney, and above Upper Loney to estimate baseflow data leaving Loney and Upper Loney (Nathan and McMahon 1990). This calculation results in a number that represents the percentage of streamflow that is considered baseflow. To compare the annual difference in baseflow, we subtracted Year2 baseflow percentages from Year1 baseflow percentages at each of the three gages.

Each stream flow gaging station includes a staff plate for visual water level observations, a Solinst Levelogger (Solinst 2013) housed in a galvanized pipe for continuous absolute pressure measurements collected every 15 minutes, and a cross section for taking discharge measurements. Additionally, Loney and Beartrap meadow were both instrumented with a Solinst Barologger (Solinst 2012) in galvanized pipe for continuous (15-minute intervals) barometric pressure measurements.

The Solinst Leveloggers recorded absolute pressure (water column + atmospheric pressure) and the data were compensated using atmospheric pressure data to get accurate water level values (Solinst 2013). The Solinst Barologger recorded atmospheric pressure to allow for compensation of the Levelogger data (Solinst 2012). One Barologger is capable of compensating data from Leveloggers within a 20-mile radius and within an elevation change of 1,000 ft, thus the Beartrap Barologger provided adequate coverage for the Leveloggers at Beartrap and Freeman and the Loney Meadow Barologger for Loney, Lower Deer, and Upper Loney (Solinst 2012).

A stage-discharge relationship or rating curve was created for each gage to estimate the annual water flow. Discharge and stage data were collected every three weeks when meadows were accessible before and after the winter season typically between the months of May to October to create these relationships. A flowmeter and a top setting wading rod were used to collect discharge measurements while wading. Discharge measurements followed the protocols outlined in Rantz et al. (1982) for measurement of discharge by current meter methods. A cross section was established at the sample location across a portion of stream in uniform flow using a tape measure and rebar. The total width of the creek was recorded and used to divide the creek into 25-30 subsections. The depth, width, and velocity of the stream

was recorded at each section. Staff plate readings occurred before and after discharge measurements (Figure 6).

Discharge was calculated using the following equation:

$$Q = \sum (a * v)$$

where  $Q$  is total discharge,  $a$  is the cross-sectional area of an individual subsection, and  $v$  is the velocity of the flow in the subsection. Discharge measurements followed the midsection method for current meter measurement outlined in Figure 6 (Rantz et al. 1982). Velocity measurements were made using the six-tenths depth method, where an observation of velocity was made with the current meter at 0.6 the depth below the water surface, and representative of the mean velocity for the individual vertical or subsection. For depths greater than 2.5 ft when flows were not rapidly changing, the two-point method was used, in which velocity observations were made at 0.2 and 0.8 the depth below the water surface and averaged to get a representative velocity for that station. Standard USGS procedures of 25-30 subsection measurements, with closer spacing of subsections in areas of greater depth and velocity were utilized. Total discharge for the creek was then calculated as the summation of discharges for all the subsections.

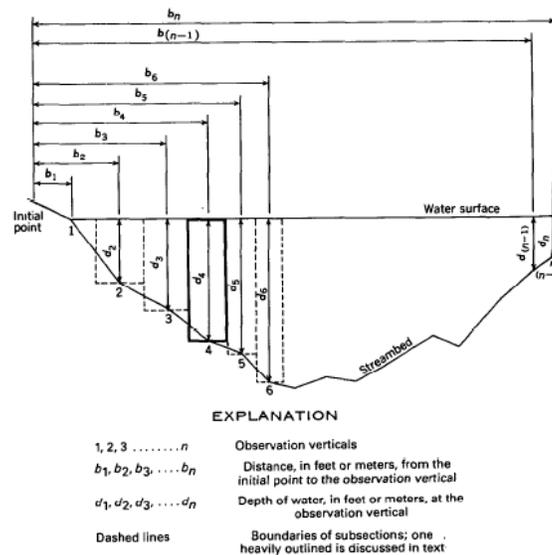


Figure 6. Sketch of the midsection method for taking discharge measurements (From Rantz et al. 1982).

### Rating Curves

Rating curves were established to estimate annual water flow by creating a relationship between stage and discharge (Rantz et al. 1982b). The rating curve was constructed in the statistical program “R” by plotting the data on an X-Y scatter plot, with Stage (ft) as the X variable, and Discharge (cfs) as the Y variable. After plotting the data, a polynomial trend line was plotted against the data, with an equation, and the  $R^2$  and p-values calculated. This equation was used to calculate discharge values using the generated stage data from the Levellogger vs. Staff Plate linear relationship. Collecting data on discharge and stage over time allows for a relationship to be developed between the two variables, so that discharge can be estimated from stage data within the range of measured discharges.

Loney, Upper Loney, and Lower Deer

In July of 2015, stream gages and staff plates were installed in Texas Creek at the entry and exit points of Loney Meadow (Map 4). Monitoring of stream flow at the gages occurred between the snow free months of the year in 2016 and for the duration of the project. A third stream gage was installed above Upper Loney Meadow (Map 5) on Texas Creek in August 2016 and was monitored at the same time as the other two stream gages on Texas Creek for the remainder of the grant period. Leveloggers were installed in all three stream gages. Deer Meadow was not instrumented because no perennial flow existed.

Beartrap and Freeman

A stream gage and staff plate at the base of Beartrap meadow was installed in September 2016 (Map 7). Sampling occurred with the same schedule, every three weeks during the snow free months for the duration of the project. Freeman meadow was identified as a priority for future restoration and four stream gages were installed in Freeman meadow in 2019 (Map 8). Sampling of stream gages installed in Freeman in 2019 will fall outside of the duration of this project and funding from the Wildlife Conservation Board was acquired to fund planning of this restoration project.

Water Quality

Water quality was measured during stream gage monitoring at Texas Creek (every three weeks during the snow free season). Measurements taken include water pH, conductivity, dissolved oxygen, turbidity and temperature. These measurements began in June of 2015 and continued during the snow free months for the duration of the project. In addition, stream temperature was measured with the leveloggers at 15-minute time steps for the duration of the project. Water quality was monitored to test the following hypothesis:

- We expect that the following water quality parameters will improve as a result of restoration at Loney Meadow:
  - We expect that water temperatures will decrease compared to pre-restoration conditions in the late season.
  - We expect that turbidity levels will decrease compared to pre-restoration conditions throughout the year.

In order to determine the effect of restoration on water quality levels, statistical analyses were performed on all water quality data. A one-way analysis of variance (ANOVA) was used to determine significance between 3 or more groups (i.e. between water years), Welch's t-test to test significant difference between 2 groups (or 2 means, i.e. pre vs. post years), and a Wilcoxon rank sign test (non-parametric) was used to test for the difference between two groups when assumptions of normality and homogeneity of variance assumptions were not met (i.e. small sample sizes).

Amphibian Surveys

In order to document baseline conditions and post restoration conditions, surveys were conducted to detect the presence of amphibian species of interest in Loney Meadow before and after stream bank restoration activities. For each survey (2015, 2016 and 2019), a series of repeat visual encounter surveys was conducted during the spring and summer breeding seasons. Surveys were conducted during a variety of timeframes (morning, mid-day and evening) over a period of 2 days to determine the presence and life stages of amphibian species occurring in the meadow. Similar effort surveys were conducted for two years following restoration activities to determine any potential changes in amphibian species presence and diversity.

Meadow and stream channel surveys were conducted in Loney Meadow (2015, 2016, 2019) following survey protocols detailed in Heyer et al. (1994). Both day and night surveys were conducted with four surveyors using combined methods such as visual observation, dip netting, and auditory surveys to maximize potential detection of herpetofauna. During each survey, surveyors walked across the meadow at equal intervals, zig-zagging along a transect corresponding to the longest meadow axis. All visible and accessible stream channels were also walked in pairs, with one surveyor on each bank and one or two surveyors in the channel. In both the meadow and stream channels, surveyors used dipnets and D-nets to sweep vegetation and aquatic habitat for individuals. Upon observation of species, locations were marked, and survey time was stopped during processing and identification. Survey effort was calculated for each survey by the total survey time multiplied by the number of surveyors. Prior to and following surveys, all equipment and field gear were decontaminated following protocols outlined in CCDAC (2007).

### Carbon and Greenhouse Gas Experiment

Methodologies for the following section were developed by the technical advisory committee as part of the Sierra Meadows Restoration Research Project (SMRRP). The experimental design included setting up a 24-point grid within each meadow at 30-meter intervals where all sampling took place (Maps 4-6). Variables that were sampled as part of this project included: above ground biomass, above ground carbon, species composition and cover, below ground carbon and nitrogen within roots, bulk density, soil temperature, surface temperature, and soil moisture. Sampling timing for each variable is discussed below. A one-way analysis of variance (ANOVA) was used to determine significance between 3 or more groups (i.e. between water years), Welch's t-test to test significant difference between 2 groups (or 2 means, i.e. pre vs. post years), and a Wilcoxon rank sign test (non-parametric) was used to test for the difference between two groups when assumptions of normality and homogeneity of variance assumptions were not met (i.e. small sample sizes)

#### *Above Ground Biomass Sampling*

Biomass and vegetation sampling occurred at each of the permanent markers within the grid at Loney, Upper Loney and Lower Deer Meadows (Maps 4, 5, 6). Biomass was sampled by clipping this year's vegetation within a 625 cm<sup>2</sup> square plot. This biomass was taken at the peak of the growing season (between July and August) and at senescence (late September through October). Vegetation (percent cover of all species within the plot at 2% cover or more) was sampled within the 625 cm<sup>2</sup> square plot as well as in a 1m<sup>2</sup> plot centered around the permanent marker. Biomass and vegetation sampling occurred pre (2016) and post (2019) restoration at all three meadows. Biomass was monitored to provide measurements of above-ground carbon stock, in order to measure whether there has been an increase in Loney Meadow's carbon stocks following restoration actions.

#### *Soil Sampling*

Soil samples were collected at every other plot within the 24-point grid using a bulk density sampler equipped with a slide hammer and 15-cm soil corer. Samples were collected between 1 and 2 m south of the GHG incubation plot, where above-ground biomass was clipped. Intact bulk density soil cores were collected from the following depths (Table 2) within the 24-point grid, pre (2016) and post (2019) restoration at all three meadows (Maps 4, 5, 6). Soil samples were collected to provide measurements of below-ground carbon stock, essential for an accurate carbon budget estimate in order to measure whether there has been an increase in Loney Meadow's carbon stocks following restoration actions.

Table 2. Summary of soil core collection depths and number of cores collected at each respective depth. 28 cores were collected at each of the three meadows.

Soil Core Collection Depths (cm)	Number of Cores Collected
0-15	12
15-30	6
30-45	4
45-60	4
60-100	2

It was not feasible to use the bulk density sampler to obtain all the soil cores needed below 60 cm where soils are very rocky. For these sites at these depths, soil samples, for which carbon content is expected to change very slowly over time, was collected during summer 2016 and 2019 using a hand auger, as determined by the Sullivan soils lab.

Bulk density samples were air dried, then sieved using a 2 mm sieve, during which the roots and rhizomes are separated out. The remaining soil sample is then dried in a 105°C oven for 48 hours, weighed, and then pulverized and homogenized prior to analysis for total carbon and total nitrogen in a LECO CHN analyzer. All soil processing and analysis were performed in the Sullivan lab at University of Nevada at Reno. Sieved rocks over 2mm are weighed and included in the total bulk density weight for each sample.

Fine and coarse roots separated from the soil as described above are weighed and reported separately for each 15 cm depth increment sampled. Roots are dried, ground and analyzed for total carbon and total nitrogen in a LECO CHN analyzer.

Changes in soil carbon (Cs) and root carbon (Cr) pools were measured by comparing measurements at two time points. Samples were collected and analyzed a year prior to restoration, and then again at the end of the second year after restoration. These two sampling times make it possible to estimate the change over time (e.g., kg of carbon per hectare per year) in soil and root carbon pools in the restored vs. unrestored meadow using the following equation:

$$\text{Change in soil carbon pool} = (\text{carbon at time 2} - \text{carbon at time 1}) / (\text{time 2} - \text{time 1})$$

#### *Greenhouse Gas Sampling*

A grid of 24 permanent markers were installed in Loney in August 2015 and Lower Deer, and Upper Loney in September 2015 (Maps 4, 5 and 6; Table 3). Greenhouse gas (GHG) sampling, including carbon dioxide, methane, and nitrous oxide, occurred every three weeks during the snow free season, and 1-2 times during the winter season for a year after installation of the grid for pre-restoration data (September 2015- September 2016) and again post-restoration (September 2018-September 2019). In addition, air temperature, soil temperature (6in depth), soil moisture (6in depth), and surface temperature are measured at each sampling location during each sampling campaign. GHG sampling that occurred at Lower Deer and Upper Loney meadows, acted as controls for Loney Meadow.

The grid of 24 permanent markers was installed in Beartrap and Freeman meadows (Maps 7 and 8) in September 2016. Funding for GHG sampling was not secured at Beartrap and Freeman meadow; therefore, pre and post restoration GHG monitoring did not occur. These meadows can be easily re-occupied to act as proxy meadows after the SMRRP model is completed.

Greenhouse gases were monitored in order to measure whether there has been a change in carbon flux rates at Loney Meadow following restoration actions. Biomass, Soils, and greenhouse gases were monitored pre and post restoration in Loney Meadow to test the following hypothesis:

- We expect that Loney Meadows carbon stocks will increase following restoration actions: 1) relative to any change in carbon flux rates and 2) relative to increases in carbon stocks in the undisturbed reference meadow (Upper Loney).

Table 3. Greenhouse gas sampling schedule for meadows. Sampling occurs for a year at pre and post restoration at a frequency of every three weeks.

Meadow	Grid Installation	Pre-restoration GHG sampling begin	Pre-restoration GHG sampling end	Post-restoration sampling start	Post-restoration sampling end	Vegetation/ Biomass Sampling
Loney (Restoration)	Aug 2015	Sept2015	Sept 2016	Sept 2018	Sept 2019	July/Aug 2016 and July/Aug 2019
Upper Loney (Control)	Sept2015	Sept2015	Sept 2016	Sept 2018	Sept 2019	July/Aug 2016 and July/Aug 2019
Lower Deer (Degraded control)	Sept 2015	Sept2015	Sept2016	Sept 2019	Sept 2020	July/Aug 2016 and July/Aug 2019
Beartrap (Restoration)	Sept 2016	n/a	n/a	TBD	n/a	n/a
Freeman (degraded control)	Sept 2016	n/a	n/a	TBD	n/a	n/a

### Vegetation Sampling

Vegetation (percent cover of all species within the plot at 2% cover or more) was sampled at each GHG sampling location (n=24 per meadow) within a 625 cm<sup>2</sup> square plot as well as in a 1m<sup>2</sup> plot centered around the permanent marker at peak vegetative growth (~July). GHG grid vegetation sampling occurred pre (2016) and post (2019) restoration at Loney, Lower Deer, and Upper Loney meadows.

Vegetation was monitored to test the following hypothesis:

- We expect the vegetation community to shift towards more obligate or facultative wetland species or wetland communities following restoration actions in Loney Meadow.

Data analysis of vegetation data included categorizing species using the wetland plant list indicator ratings<sup>1</sup> (Lichvar et al. 2012) and conducting an ANOVA to determine if there was an increase in wetland species between the pre- and post-restoration time steps (2016 and 2019) at each meadow. FAC= Facultative, FACU = Upland Facultative, FACW= Wetland Facultative, N/A= No Existing Wetland Status, OBL= Obligate Wetland Species.

To look for patterns of plant community change between meadows and across the two timesteps (2016 and 2019), square root transformed species cover for each year of the study were analyzed using NMDS ordination with the “metaMDS” routine in the Vegan Package in R (Oksanen 2011). metaMDS” calculates the amount of community overlap, using Sorensen Bray-Curtis (beta-diversity) ordination distance, between each blocking factor (e.g., year or meadow). Stress, which measures the fit of the observed dissimilarities to applied ordination distances, was recorded for each NMDS run. This metric is considered acceptable at 0.20 and below (Oksanen 2011). To test for the significance of community

<sup>1</sup> <https://plants.usda.gov/core/wetlandSearch>

change between each year and meadow the “Adonis” routine was utilized, which is a multivariate analysis of variance (MANOVA) for distance metrics such as beta-diversity (Oksanen 2011).

## Restoration Monitoring

### Photo Point Monitoring

We used a photo point monitoring technique to evaluate the success of our restoration project (Hall 2001). Several sites of interest were chosen in order to qualitatively assess the ecological impact of our restoration actions at Loney, Deer and Beartrap Meadows. Photos were taken pre and post restoration at predetermined GPS points that captured restoration actions of interest. Photo points are labeled as the GPS point, followed by the bearing at which the photo was taken.

### Channel Morphology

Channel cross-sections were established at nine separate locations as a result of a desktop LiDAR and aerial imagery exercise and field visits. Elevations were pulled from a 2014 Tahoe National Forest LiDAR dataset to establish the extent of channel incision at these locations and to be used as baseline for future comparisons. Another LiDAR capture was completed in fall of 2018 by the USGS but the data has not yet been made available. Once available, SYRCL will compare pre/post channel conditions and can submit that data to CDFW.

### As-Built Monitoring

All installed structures at Loney, Upper Deer, and Beartrap were GPS'd post-restoration and monitored annually through the grant term by visual inspection by SYRCL and TNF staff.

## Results

### Hydrology

#### Groundwater Monitoring

##### *Loney Meadow (Restoration)*

Of the ten piezometers that were installed along three transects across Loney Meadow (Map 4), four of the piezometers showed a significant increase ( $p < 0.05$ ) in groundwater levels following restoration implementation (Figures 7 and 8). These four piezometers (A02, A03, B02 and B03) are centrally located and close to the braided stream channel network of Texas Creek that was reconnected through restoration actions. Four other piezometers (A01, B01, C01, and C04) located at the edge of Loney Meadow, showed no significant change ( $p > 0.05$ ) in groundwater levels following restoration implementation. Piezometers C02 and C03 showed a significant decrease ( $p < 0.05$ ) in groundwater levels following restoration implementation. Overall, a comparison of pre and post restoration averages during the summer recession months (June to Sept) shows that the average groundwater level at Loney Meadow increased by 8% following restoration implementation (Table 4).

Table 4. Comparison of average groundwater heights sampled between June 1<sup>st</sup>-Sept 30<sup>th</sup> in pre-restoration years (2016-2017) and post restoration years (2018-2019). Groundwater height defined as height of groundwater from bottom of piezometer. Percent change defined as: % change = (post rest GW height – pre rest GW height)/ pre rest GW height \* 100).

<b>Loney Meadow –Restoration Meadow</b>				
Summer Recession (June 1st-Sept 30th): Pre-restoration (WY 2016 and 2017) vs. Post-restoration (WY 2018 and 2019)				
<b>Well</b>	<b>Pre-restoration Average Groundwater height (ft)</b>	<b>Post-Rest Average Groundwater height (ft)</b>	<b>Total Change (ft)</b>	<b>% Change</b>
A01	3.14	3.40	0.26	8%
A02	4.22	5.46	1.24	29%
A03	2.67	4.74	2.07	77%
B01	3.89	3.11	-0.77	-20%
B02	3.08	4.09	1.01	33%
B03	4.60	6.25	1.65	36%
C01	1.27	0.41	-0.86	-68%
C02	3.09	1.48	-1.61	-52%
C03	5.58	5.49	-0.09	-2%
C04	1.96	1.74	-0.22	-11%
<b>Average</b>	<b>3.35</b>	<b>3.62</b>	<b>0.27</b>	<b>8%</b>

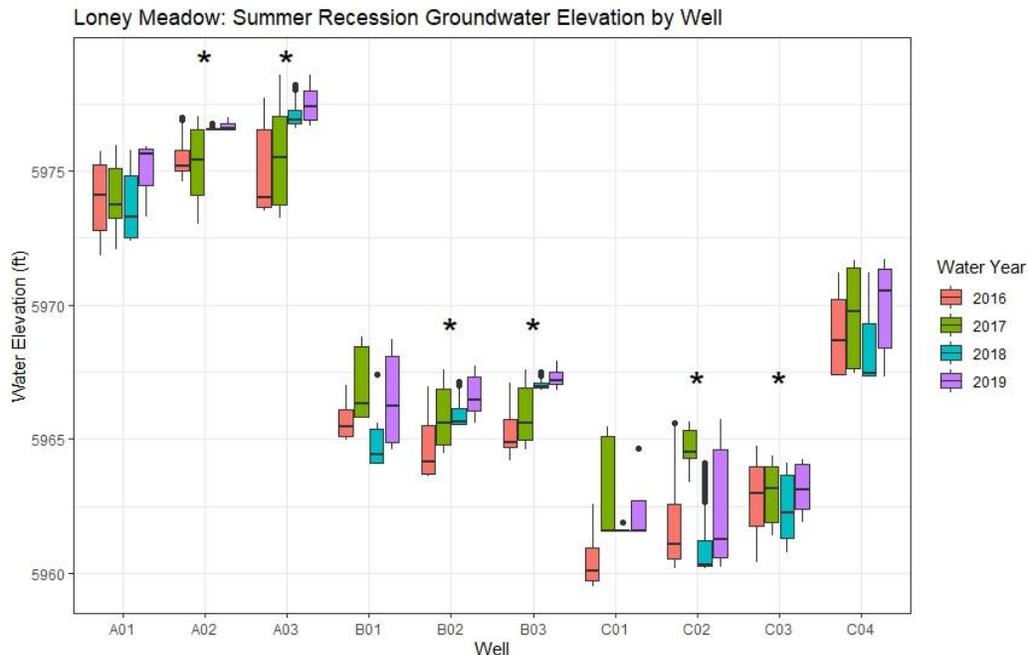


Figure 7. Groundwater wells in Loney Meadow, showing change in groundwater levels during the summer recession period in all years (2016-2019). Groundwater levels have been adjusted to reflect respective elevations at each well site. Summer recession period is defined as June-Sept. Asterisks denoted as \* represent significant differences ( $p < 0.05$  ANOVA).

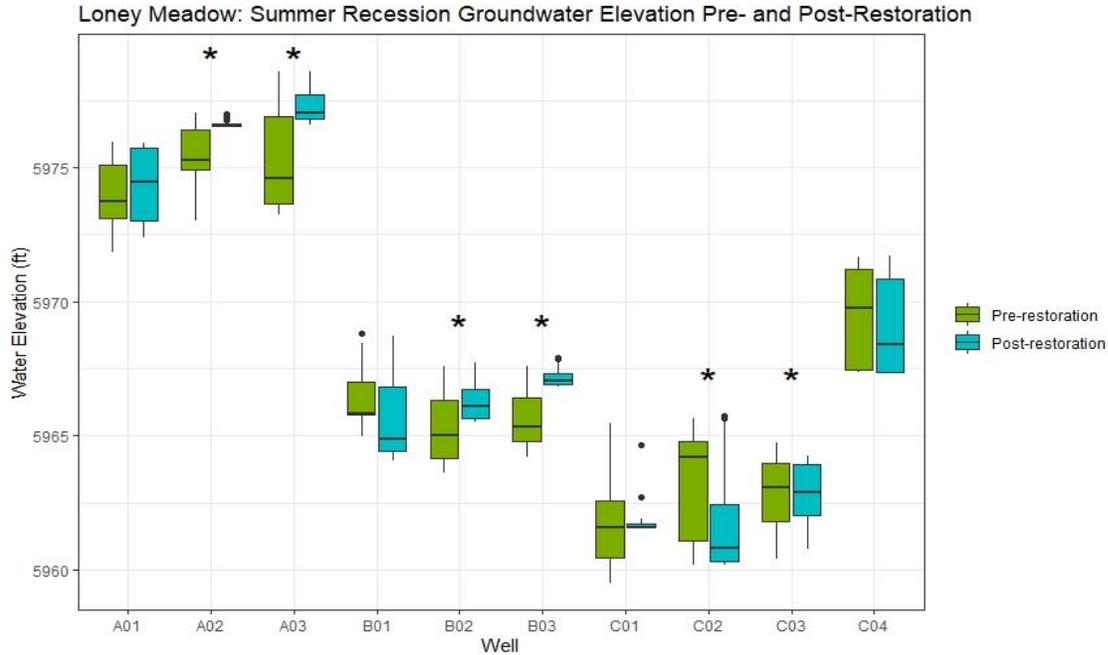


Figure 8. Groundwater wells in Loney Meadow, showing a change in groundwater levels pre (2016-2017) and post (2018-2019) restoration during the summer recession period. Groundwater levels have been adjusted to reflect respective elevations at each well site. Summer recession period is defined as June-Sept. Asterisks (\*) denote significant differences ( $p < 0.05$ ).

*Upper Loney and Lower Deer (Controls)*

Two of the three piezometers (UL01 and UL03) at Upper Loney Meadow (Map 5) showed a significant decrease ( $p < 0.05$ ) in groundwater levels from pre restoration to post restoration years (Figures 9 and 10). Piezometer UL02 showed no significant change from pre restoration to post restoration years ( $p > 0.05$ ). A comparison of averages from pre and post restoration years during the summer recession months (June to Sept) shows that the average groundwater level at Upper Loney Meadow decreased between 0% and 4% (Table 5). Two of the four piezometers at Lower Deer Meadow (Map 6) showed a significant decrease ( $p < 0.05$ ) in groundwater levels from pre restoration to post restoration years (Figures 11 and 12). Piezometers D02 and D04 showed no significant change from pre restoration to post restoration years ( $p > 0.05$ ). A comparison of averages from pre and post restoration years during the summer recession months (June to Sept) shows that the average groundwater level at Lower Deer Meadow decreased between 9% and -12% (Table 6).

Table 5. Comparison of average groundwater heights sampled between June 1st-Sept 30th in pre-restoration years (2017) and post restoration years (2018-2019). Groundwater height defined as height of groundwater from bottom of piezometer. Percent change defined as: % change = (post rest GW height – pre rest GW height) / pre rest GW height \* 100

Upper Loney Meadow - Reference Control				
Summer Recession (June 1st-Sept 30th): Pre-restoration (WY 2017) vs. Post restoration (WY 2018 and 2019)				
Well	Pre-Restoration Average Groundwater Height (ft)	Post-Restoration Average Groundwater height (ft)	Total Change (ft)	% Change
UL01	8.12	7.81	-0.31	-4%
UL02	5.84	5.61	-0.22	-4%

UL03	6.92	6.57	-0.35	-5%
<b>Average</b>	<b>6.96</b>	<b>6.67</b>	<b>-0.29</b>	<b>-4%</b>

Table 6. Comparison of average groundwater heights sampled between June 1st-Sept 30th in pre-restoration years (2017) and post restoration years (2018-2019). Groundwater height defined as height of groundwater from bottom of piezometer. Percent change defined as: % change = (post rest GW height – pre rest GW height)/ pre rest GW height \* 100

<b>Lower Deer Meadow - Degraded Control</b>				
Summer Recession (June 1st-Sept 30th): Pre-restoration (WY 2017) vs. Post restoration (WY 2018 and 2019)				
Well	Pre-restoration Average Groundwater Height (ft)	Post-restoration Average Groundwater Height (ft)	Total Change (ft)	% Change
D01	7.48	6.78	-0.69	-9%
D02	8.98	8.34	-0.65	-7%
D03	2.75	2.14	-0.60	-22%
D04	2.46	1.87	-0.59	-24%
<b>Average</b>	<b>5.42</b>	<b>4.78</b>	<b>-0.63</b>	<b>-12%</b>

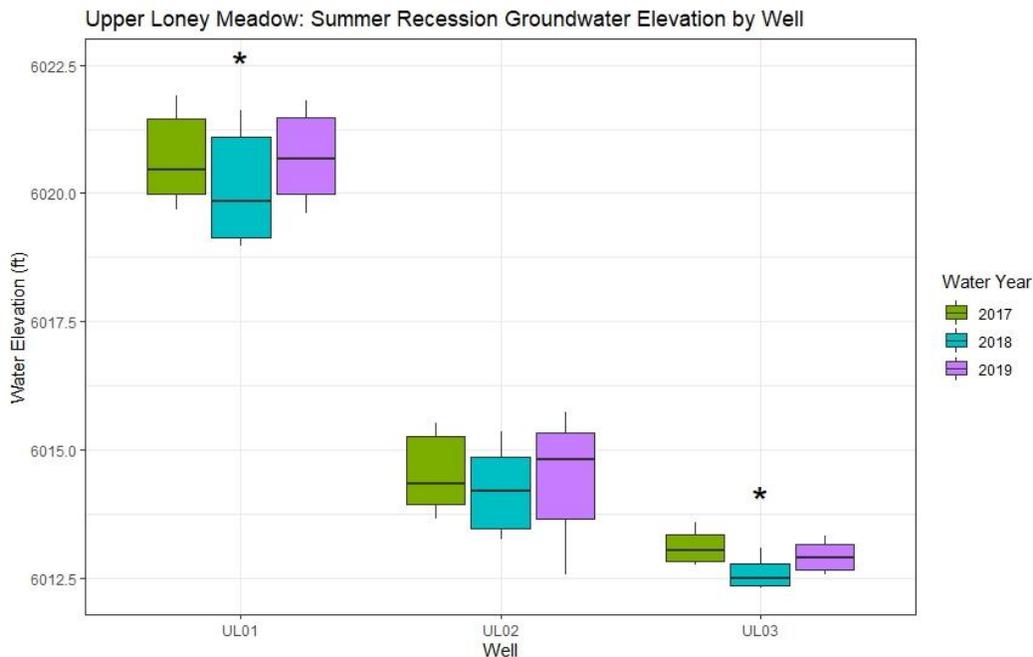


Figure 9. Groundwater wells in Upper Loney Meadow, showing a change in groundwater levels for the three sample years (2017, 2018, 2019) during the summer recession period. Groundwater levels have been adjusted to reflect respective elevations at each well site. Summer recession period is defined as June-Sept. Asterisks (\*) denote significant differences ( $p < 0.05$  ANOVA).

Upper Loney Meadow: Summer Recession Groundwater Elevation Pre- and Post-Restoration

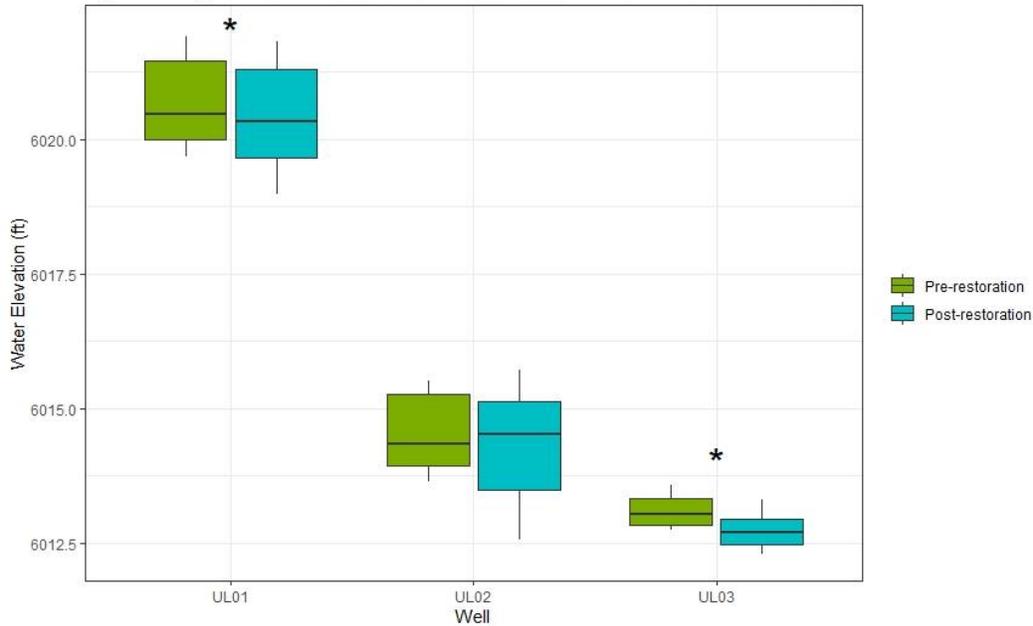


Figure 10. Groundwater wells in Upper Loney Meadow, showing a change in groundwater levels pre (2017) and post (2018-2019) restoration during the summer recession period. Groundwater levels have been adjusted to reflect respective elevations at each well site. Summer recession period is defined as June-Sept. Asterisks (\*) denote significant differences ( $p < 0.05$  Welch's t-test).

Deer Meadow: Summer Recession Groundwater Elevation by Well

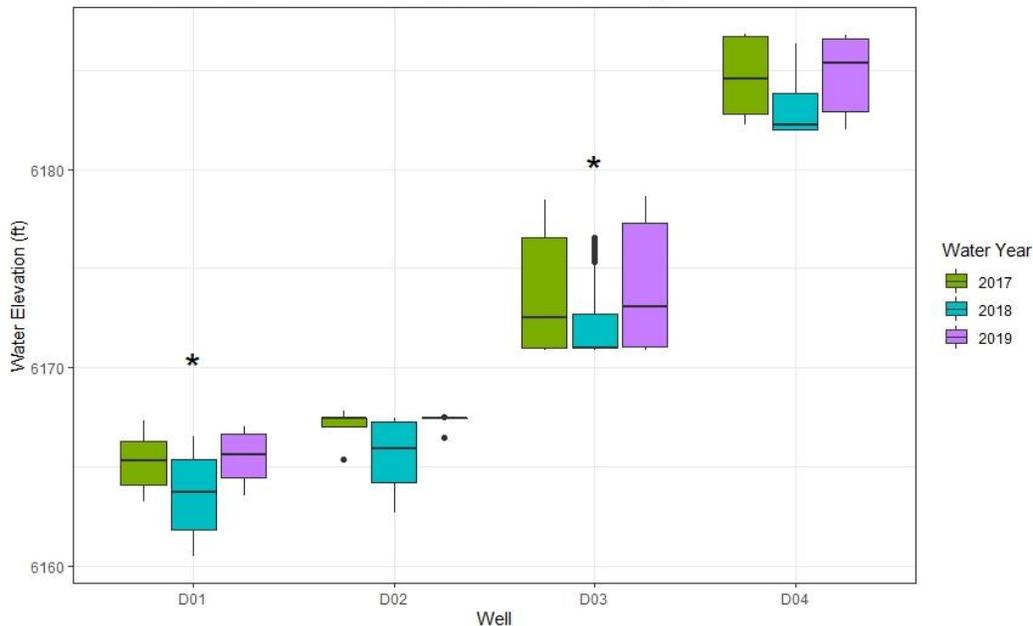


Figure 11. Groundwater wells in Lower Deer Meadow, showing a change in groundwater levels for the three sample years (2017, 2018, 2019) during the summer recession period. Groundwater levels have been adjusted to reflect respective elevations at each well site. Summer recession period is defined as June-Sept. Asterisks (\*) denote significant differences ( $p < 0.05$  ANOVA).

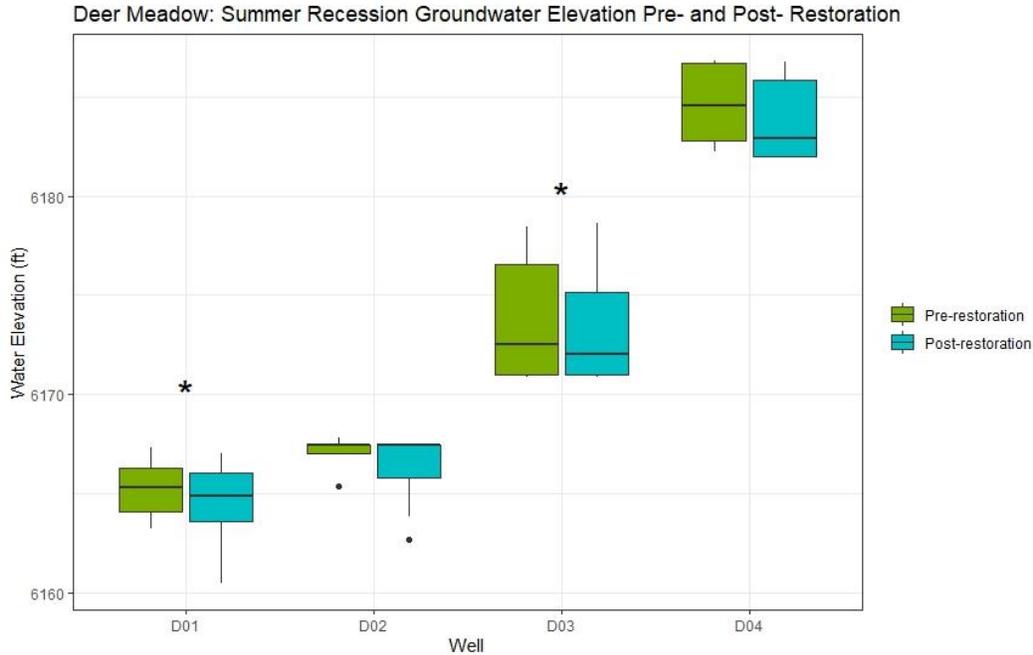


Figure 12. Groundwater wells in Lower Deer Meadow, showing a change in groundwater levels pre (2017) and post (2018-2019) restoration during the summer recession period. Groundwater levels have been adjusted to reflect respective elevations at each well site. Summer recession period is defined as June-Sept. Asterisks (\*) denote significant differences ( $p < 0.05$  Welch's t-test).

*Beartrap (Restoration) and Freeman Meadow (Control)*

Beartrap and Freeman Meadows, located in the North Fork basin of the Yuba River Watershed, will serve as test cases for the predictive model developed by Sierra Meadows Restoration Research Partnership (SMRRP) and CalTrout. Due their indirect role in our current assessment of the effects of restoration implementation on hydrology, plant community change, and carbon cycling in the Loney Meadow Complex, the results of groundwater change in these meadows are included in Appendix I.

Supporting depth to groundwater graphs (by well for each meadow) are contained in Appendix II. Rating curves for groundwater wells instrumented with Levelloggers plotted against manual measurements are contained in Appendix III.

Surface Water Monitoring

Prior to restoration, peak flows at Loney Meadow occurred in January, during which outflows exceed inflows by roughly 500%. Following restoration that same peak flow signature occurs later in the year, between Mid-February to March and is higher during March, with outflows exceeding inflows by about 850% (Figure 13). Notably, we are seeing a delay in peak flow following restoration in Loney Meadow shown by a distinct “crossover” in the pre-restoration vs. post-restoration percent change streamflow data (Figure 13). During the summer recession period (June-Sept) following restoration at Loney Meadow, outflows relative to inflows are 0% or less (Figure 13).

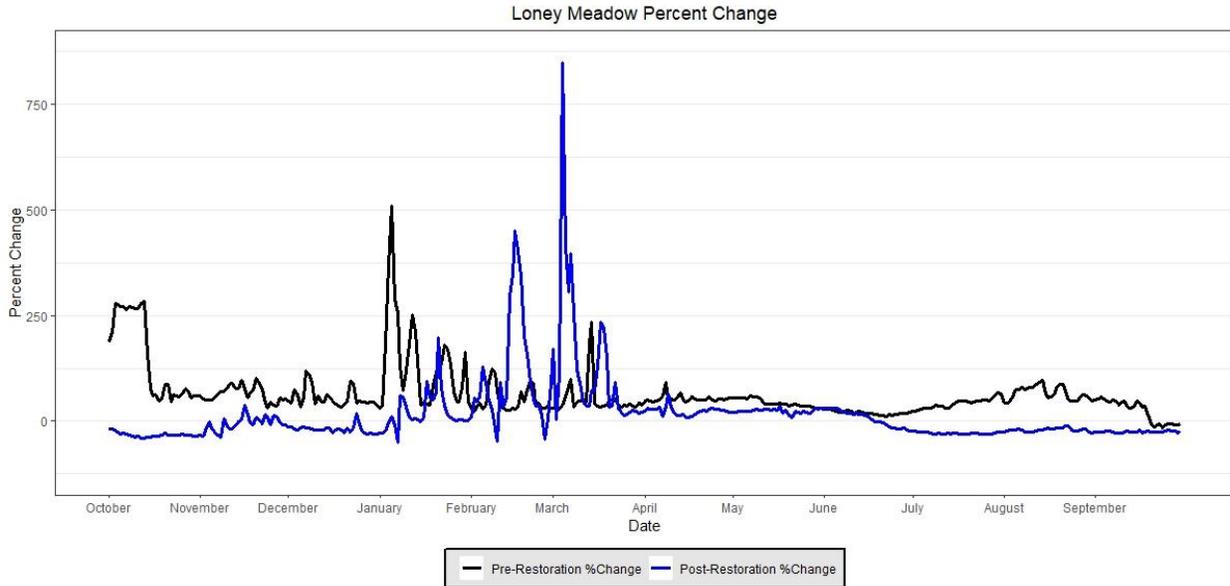


Figure 13. Streamflow percent change exiting Loney Meadow pre and post restoration. Percent change represents the amount of streamflow leaving the meadow (outflow) as a function of the streamflow entering the meadow (inflow). For example: % change = (outflow - inflow) / (inflow)\*100. Streamflow data is average daily flow collected every 15 minutes. Pre restoration years (2016 and 2017) are displayed in black. Post restoration years (2018 and 2019) are displayed in blue.

At Upper Loney, peak flows indicate that there was no change in seasonality of peak flows within the study period (Figure 14). This is shown by the lack of a distinct “crossover” in the plotted data of pre (2017) vs. post (2018 and 2019) restoration years (Figure 14). In 2017, Upper Loney is retaining much of its inflow water. In 2018 and 2019, outflows at Upper Loney exceed inflows for almost the entire year. Compared to 2017, late winter and spring pulses (Jan-March) are much higher in 2018 and 2019 (125% to 250%, range of peak % change post restoration).

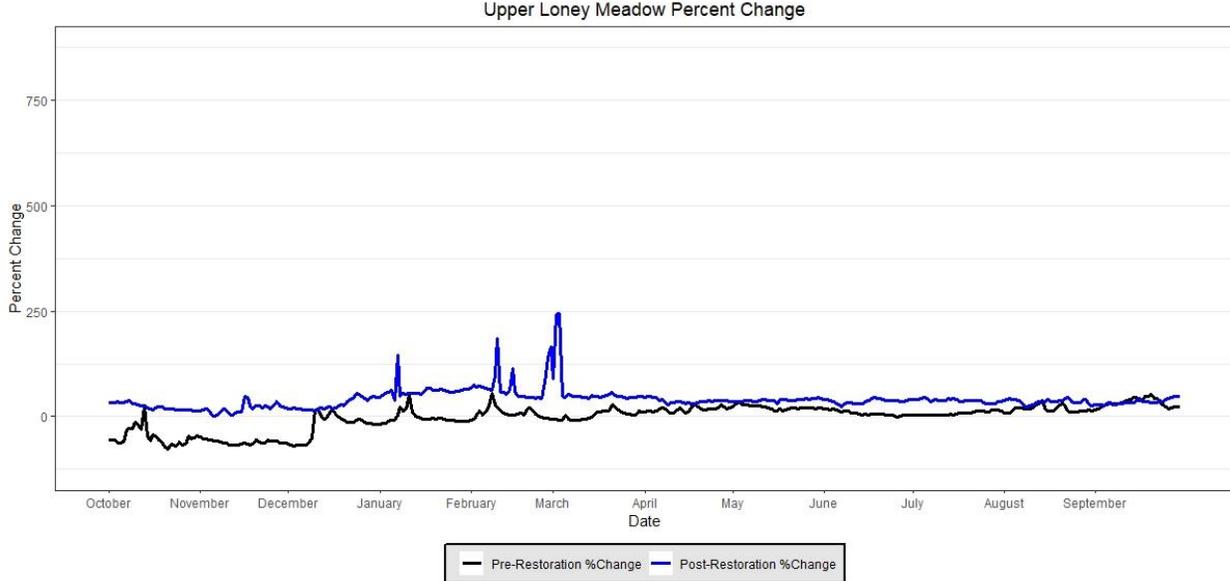


Figure 14. Streamflow percent change exiting Upper Loney Meadow pre and post restoration. Percent change Yuba Headwaters Meadow Restoration Monitoring Report  
South Yuba River Citizens League  
ERP ##P1496009

represents the amount of streamflow leaving the meadow (outflow) as a function of the streamflow entering the meadow (inflow). For example: % change = (outflow - inflow) / (inflow)\*100. Streamflow data is average daily flow collected every 15 minutes. Pre restoration year (2017) is displayed in black. Post restoration years (2018 and 2019) are displayed in blue.

On an annual basis, total streamflow leaving Loney Meadow as a percentage of inflow from Upper Loney Meadow was variable but only appeared to decrease substantially in the 2018 water year, directly following restoration, but not in the subsequent year (Table 7). This was not the case for total annual streamflow below Upper Loney Meadow in 2018, where streamflow leaving Upper Loney meadow was variable from year to year. The percentage of flow that is considered to be baseflow decreased in 2018, right after restoration, at all three gages (Figure 15). The difference in baseflow year over year (Year 2 – Year 1) was more pronounced in 2018 at the gages above Loney Meadow and less pronounced below Loney (Figure 16). Year over year change in Loney decreased between 2016 and 2017 while it increased in the gage above Loney.

Annual streamflow hydrographs for all gages are contained in Appendix IV. Streamflow rating curves are contained in Appendix V.

Table 7. Total Streamflow in Acre-feet (AF) at Above Upper Loney, Below Upper Loney, and Below Loney stream gages between the 2016 and 2019 water years.

Water Year	Above Upper Loney (AF)	Below Upper Loney (AF)	Below Loney (AF)	Total Difference (AF) and % Change Below Upper Loney	Total Difference (AF) and % Change Below Loney
2016	n/a	4,084	7,490	n/a	3,406 (83%)
2017	10,148	10,178	15,510	30 (0%)	5,332 (52%)
2018	3,966	5,113	5,447	1,167 (29%)	314 (6%)
2019	5,116	7,579	11,534	2,463 (48%)	3,955 (52%)

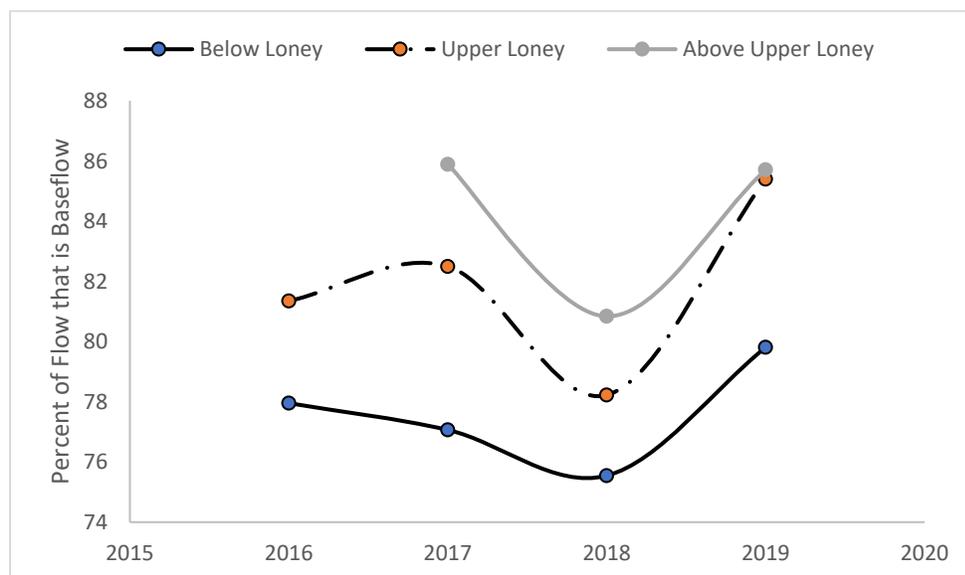


Figure 15. Percent of streamflow exhibiting as baseflow measured at the below Loney, Upper Loney (above Loney), and Above Upper Loney stream gages.

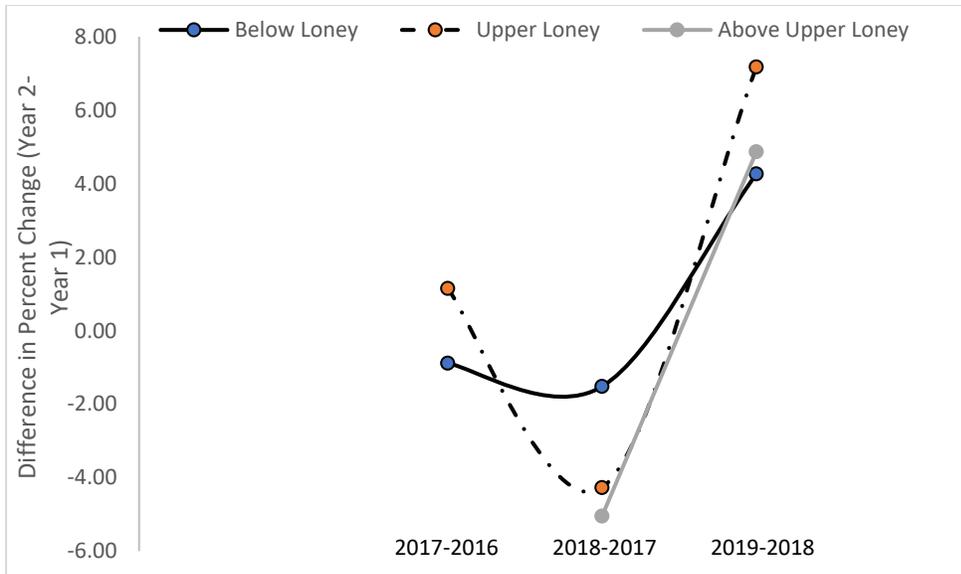


Figure 16. Annual difference of baseflow (calculated as percent of streamflow).

#### Water Quality Monitoring

##### *Temperature, Dissolved Oxygen, Turbidity and Conductivity.*

The only water quality parameter that showed a significant change—both between water years ( $p < 0.05$  ANOVA) and following restoration ( $p < 0.05$  Welch's *t*-test)—is temperature. Notably, there was a significant increase in temperature following restoration at both the Upper Loney and Lower Loney gages; however, variability in summer temperatures increased more at the Lower Loney gage than at the Upper Loney gage following restoration implementation (Figures 17 and 18). The Above Upper Loney gage showed a very slight significant decrease in temperature when comparing pre and post restoration years. This is likely due to the lack of 2016 data in the pre restoration dataset at the Above Upper Loney gage. The increase in variability between Upper Loney and Lower Loney gages following restoration can be attributed to an increase in diel temperature fluctuations (Appendix VI).

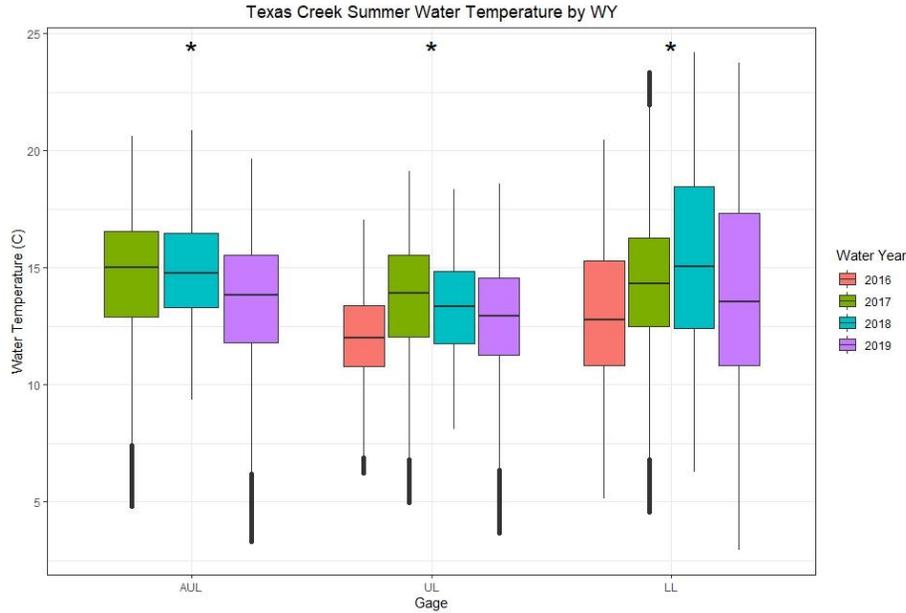


Figure 17. Summer water temperatures by water year at three gages moving upstream to downstream: Above Upper Loney (AUL), Upper Loney (UL), Lower Loney (LL). Data was collected during summer defined as June-Sept. Asterisk (\*) denote significant difference between water years ( $p < 0.05$  ANOVA).

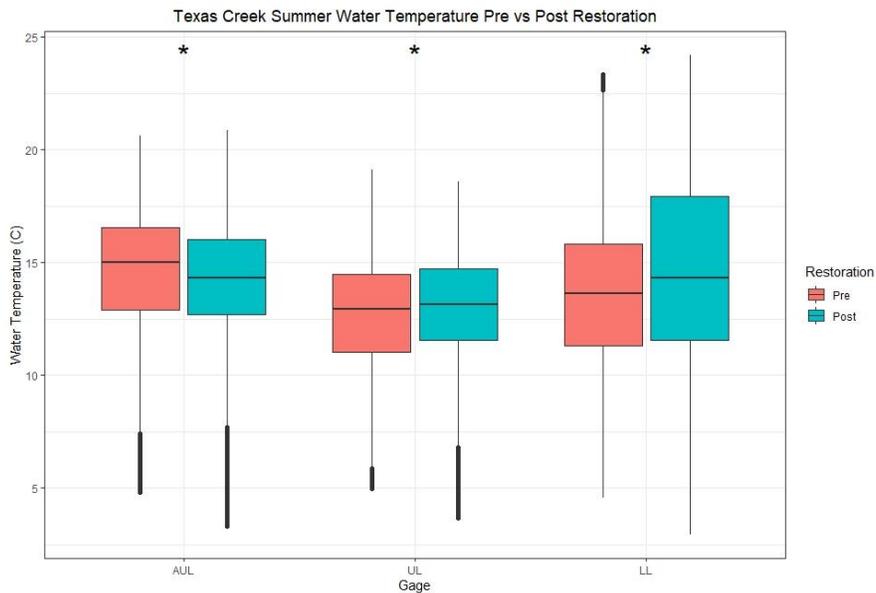


Figure 18. Summer water temperatures pre and post restoration at three gages moving upstream to downstream: Above Upper Loney (AUL), Upper Loney (UL), Lower Loney (LL). Data was collected during summer defined as June-Sept. Note that pre-restoration did not include 2016 at the AUL gage. Asterisk (\*) denote significant difference between pre and post restoration ( $p < 0.05$  Welch's t-test)

Despite the lack of statistically significant changes in dissolved oxygen (Figures 19-20), turbidity (Figures 21-22) or conductivity (Figures 23-24) at any of the gages from pre restoration to post restoration years ( $p > 0.05$  Wilcoxon Signed Rank test), we can still see a more profound increase in variability (for all parameters) at the Lower Loney gage than the two upstream gages, following restoration. Comparing changes in trends for turbidity levels between gages, there appears to be an increase in turbidity at the

Lower Loney gage relative to the other two gages, following restoration. An additional boxplot for pH is contained in Appendix VI.

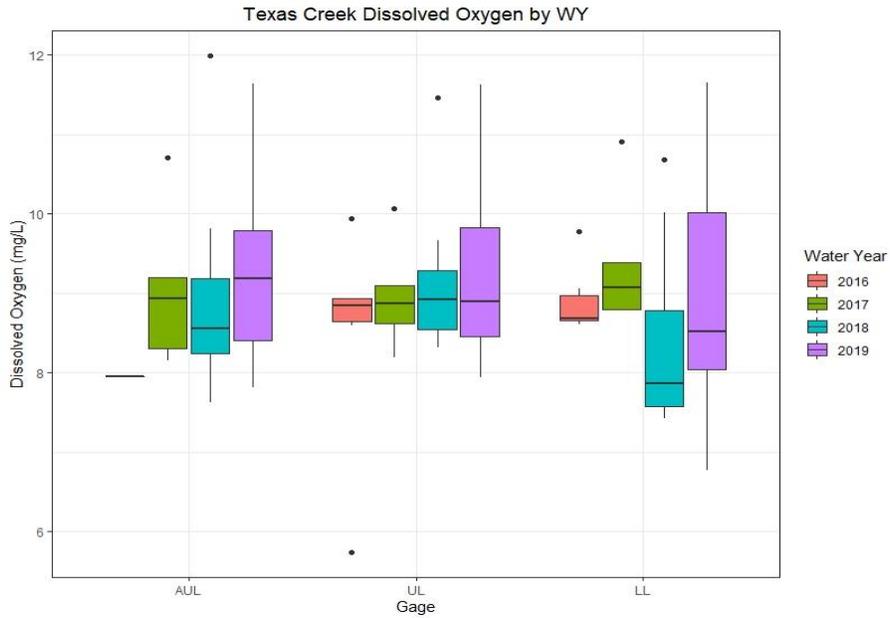


Figure 19. Summer dissolved oxygen levels by water year at three gages moving upstream to downstream: Above Upper Loney (AUL), Upper Loney (UL), Lower Loney (LL). Data was collected during summer defined as June-Sept.

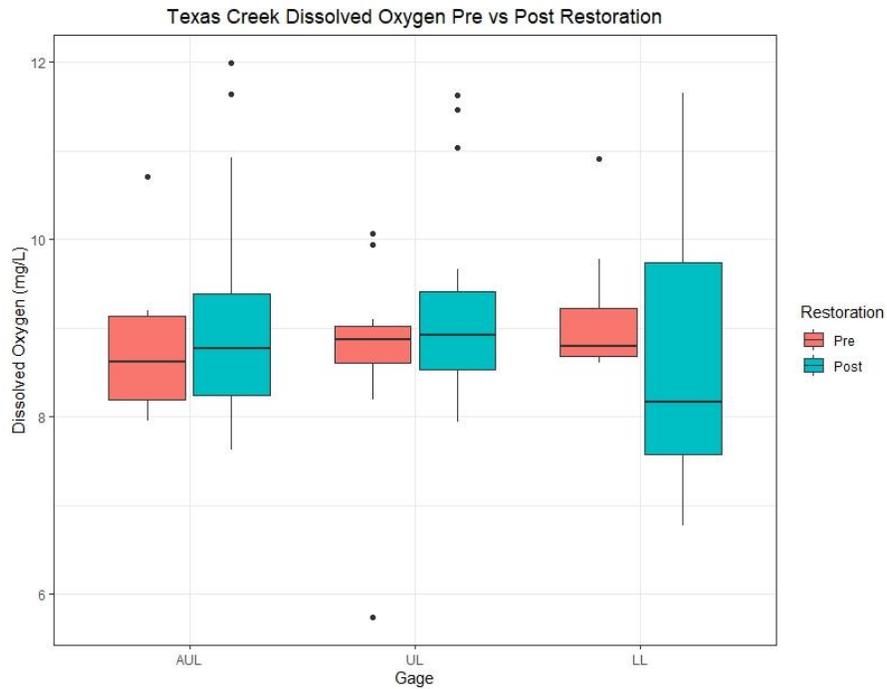


Figure 20. Summer dissolved oxygen levels pre and post restoration at three gages moving upstream to downstream: Above Upper Loney (AUL), Upper Loney (UL), Lower Loney (LL). Data was collected during summer defined as June-Sept. Note that pre-restoration did not include 2016 at the AUL gage.

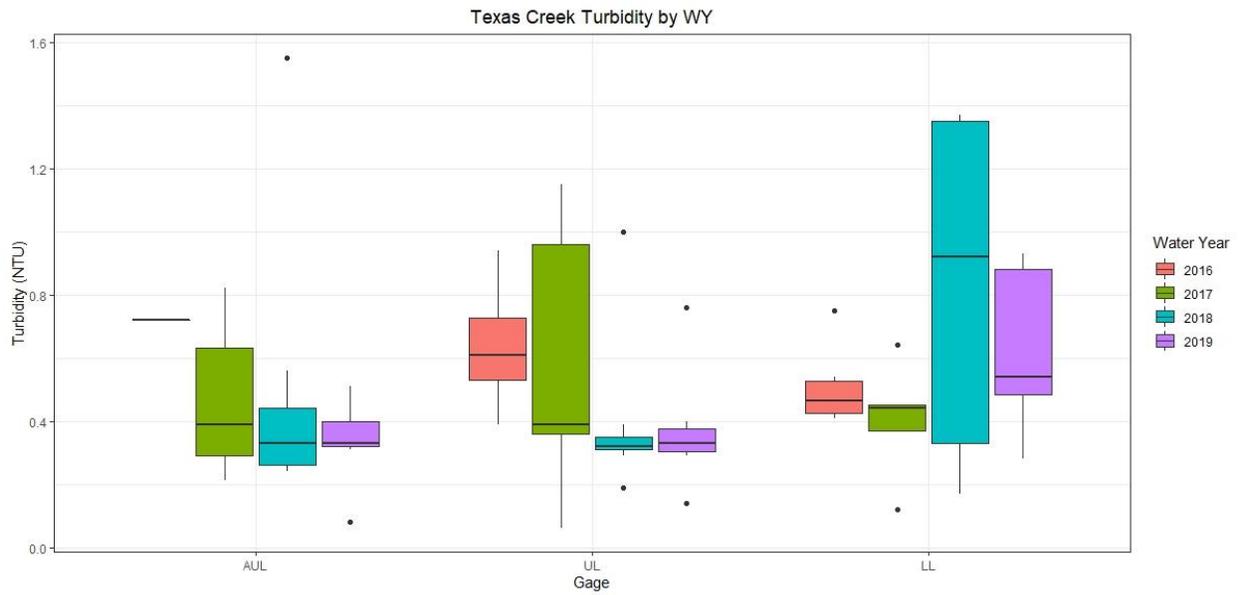


Figure 21. Summer turbidity levels by water year at three gages moving upstream to downstream: Above Upper Loney (AUL), Upper Loney (UL), Lower Loney (LL). Data was collected during summer defined as June-Sept.

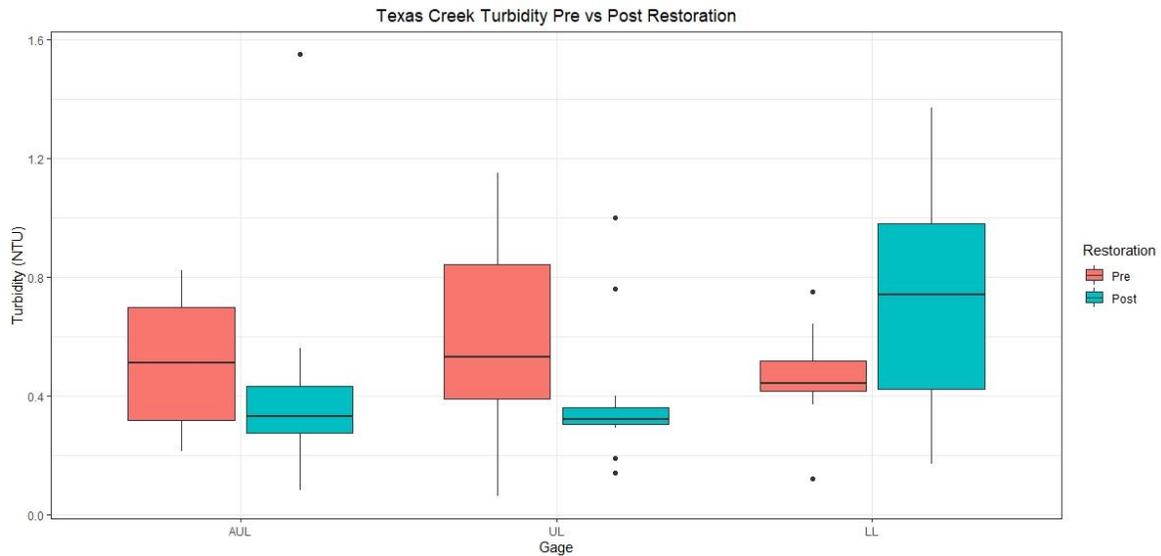


Figure 22. Summer turbidity levels pre and post restoration at three gages moving upstream to downstream: Above Upper Loney (AUL), Upper Loney (UL), Lower Loney (LL). Data was collected during summer defined as June-Sept. Note that pre-restoration did not include 2016 at the AUL gage.

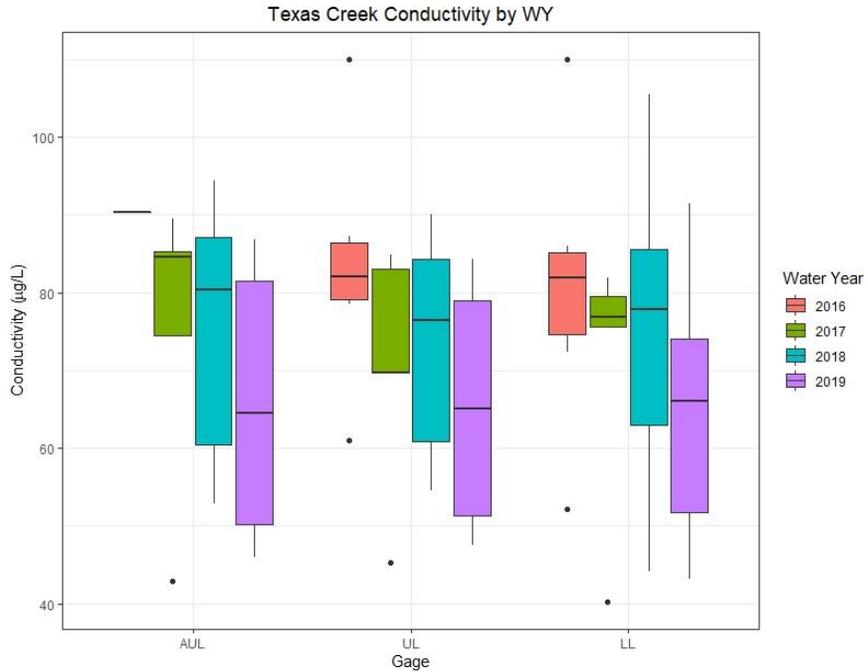


Figure 23: Summer conductivity levels by water year at three gages moving upstream to downstream: Above Upper Loney (AUL), Upper Loney (UL), Lower Loney (LL). Data was collected during summer defined as June-Sept.

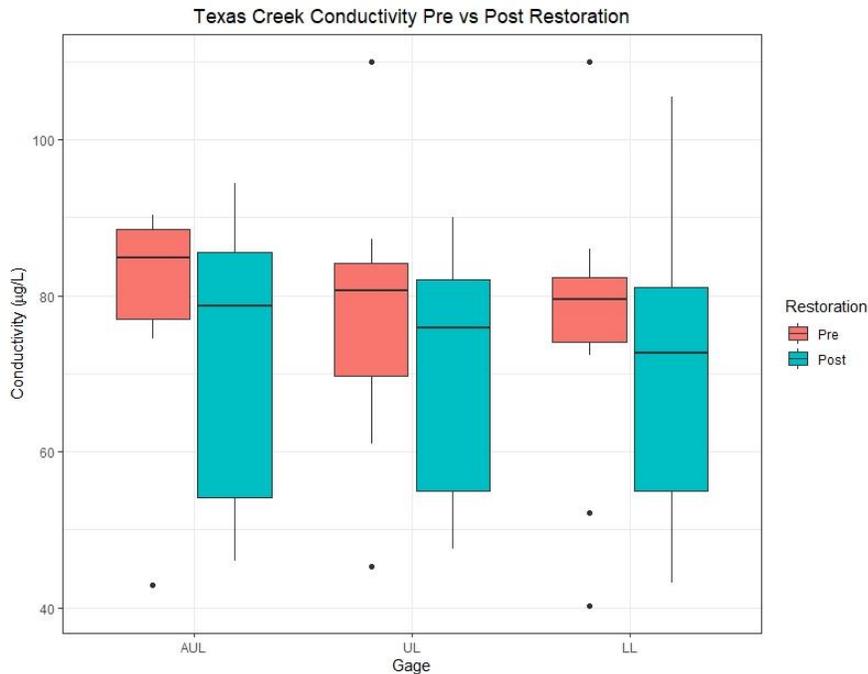


Figure 24. Summer conductivity levels pre and post restoration at three gages moving upstream to downstream: Above Upper Loney (AUL), Upper Loney (UL), Lower Loney (LL). Data was collected during summer defined as June-Sept. Note that pre-restoration did not include 2016 at the AUL gage.

## Amphibian Surveys

See pre- and post-restoration amphibian reports for detailed information on survey areas and which species were observed (Appendix VII). No changes in species composition or frequency were identified post-restoration compared to pre-restoration.

## Carbon and Green House Gas Experiment

### *Greenhouse Gas flux*

Peak CO<sub>2</sub> fluxes occur in late June and July in all meadows, before and after restoration (Figures 25A and 25B). These peak fluxes correspond with high air temperatures. Post restoration, we see another peak in August and September that is more pronounced in Deer and Loney Meadows than in Upper Loney Meadow. Peak CH<sub>4</sub> fluxes were much higher in Upper Loney Meadow than in Deer and Loney Meadows prior to restoration (Figure 26A). Following restoration CH<sub>4</sub> flux rates of Loney Meadow are much closer to those of Upper Loney Meadow, and peak in June and July (Figure 26B). Overall, both Deer Meadow and Loney Meadow appear to have higher seasonal fluxes of CH<sub>4</sub> in post restoration years, during the warm summer months of June and July. Rates of N<sub>2</sub>O flux are generally negative in all three meadows, both before and after restoration. Following restoration in Loney Meadow, N<sub>2</sub>O flux rates become more negative in late summer (Figures 27A and Figure 27B). Overall, greenhouse gas flux is dominated by CO<sub>2</sub> flux in the Loney Meadow Complex; N<sub>2</sub>O and CH<sub>4</sub> fluxes are minor components. Using a boxplot to display pre restoration CO<sub>2</sub> flux to post restoration CO<sub>2</sub> flux within each meadow (Figure 26), and after performing statistical analyses, we found no statistical difference between pre and post restoration CO<sub>2</sub> flux in any of the meadows ( $p > 0.05$  *Wilcoxon Signed Rank test*).

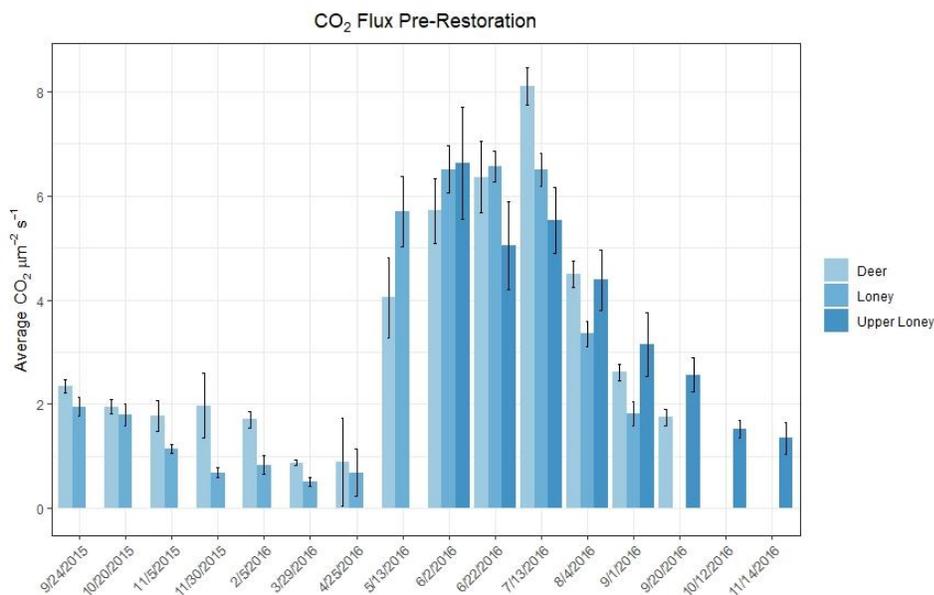


Figure 25A. Pre restoration seasonal CO<sub>2</sub> flux sampled Sept 2015- Nov 2016. Bars represent standard error.

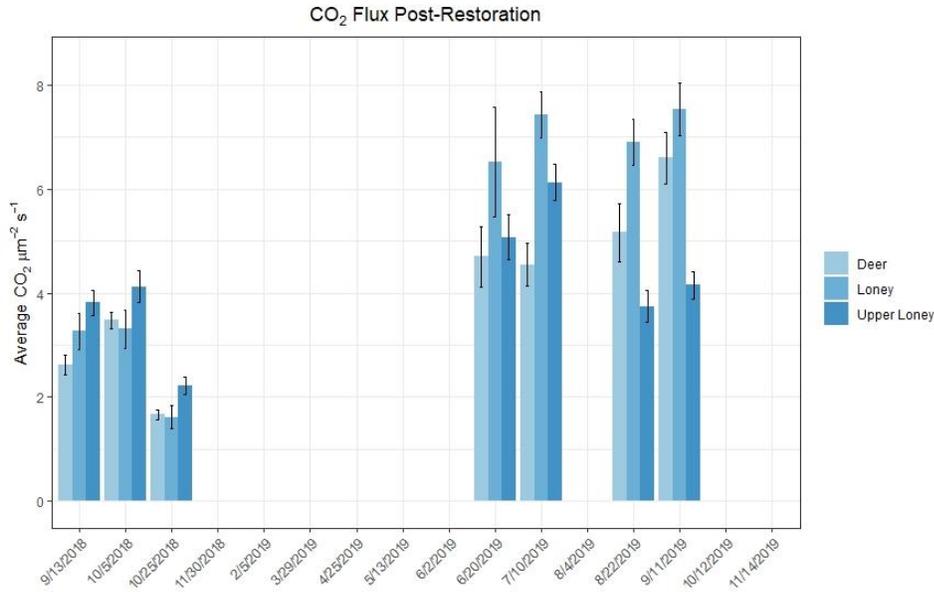


Figure 25B. Post restoration seasonal CO<sub>2</sub> flux sampled Sept 2018- Sept 2019. Bars represent standard error.

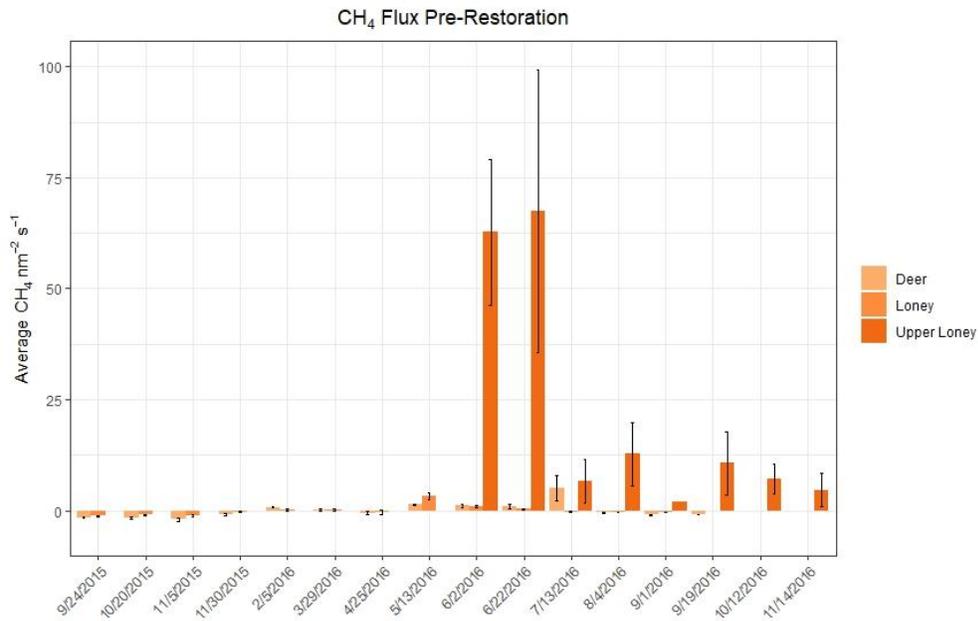


Figure 26A. Pre restoration seasonal CH<sub>4</sub> flux sampled Sept 2015- Nov 2016. Bars represent standard error.

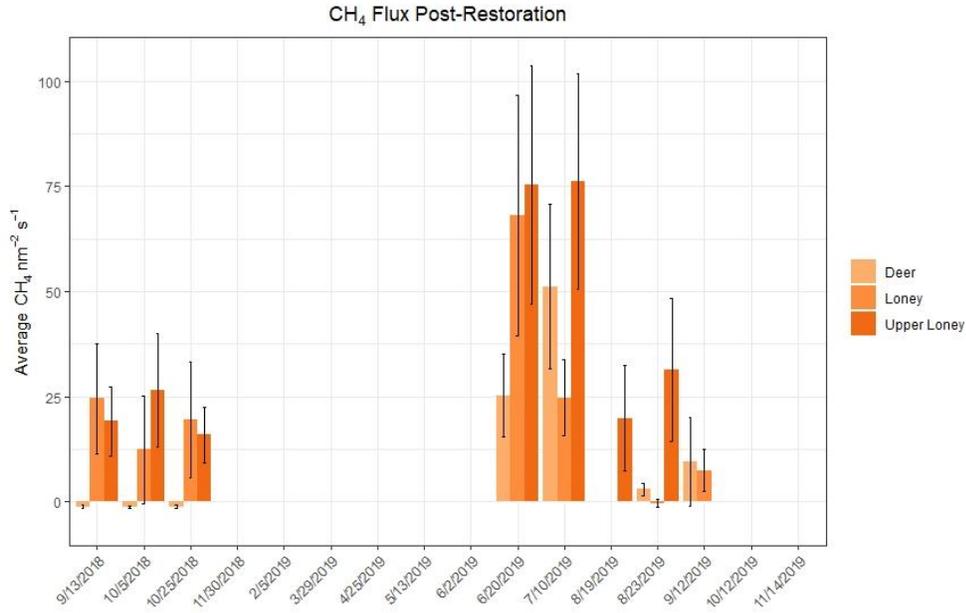


Figure 26B. Post restoration seasonal CH<sub>4</sub> flux sampled Sept 2018- Sept 2019. Bars represent standard error.

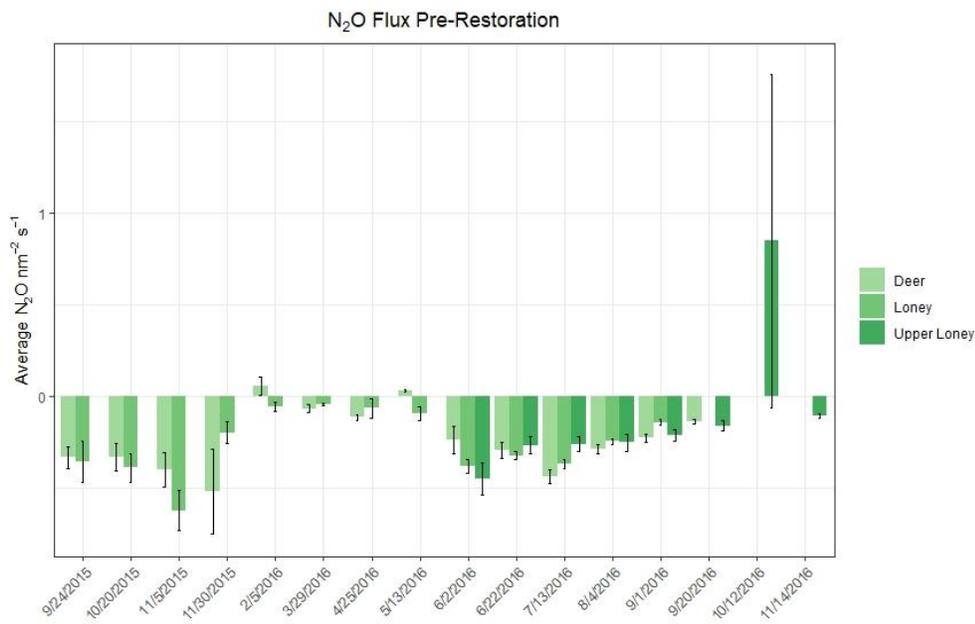


Figure 27A. Pre restoration seasonal N<sub>2</sub>O flux sampled Sept 2015- Nov 2016. Bars represent standard error.

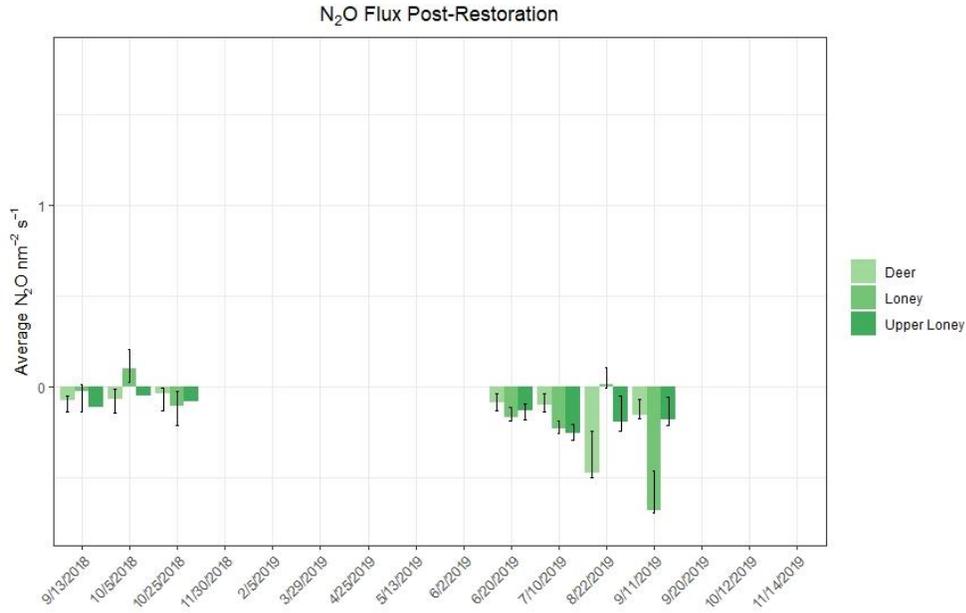


Figure 27B. Post restoration seasonal N<sub>2</sub>O flux sampled Sept 2018- Sept 2019. Bars represent standard error.

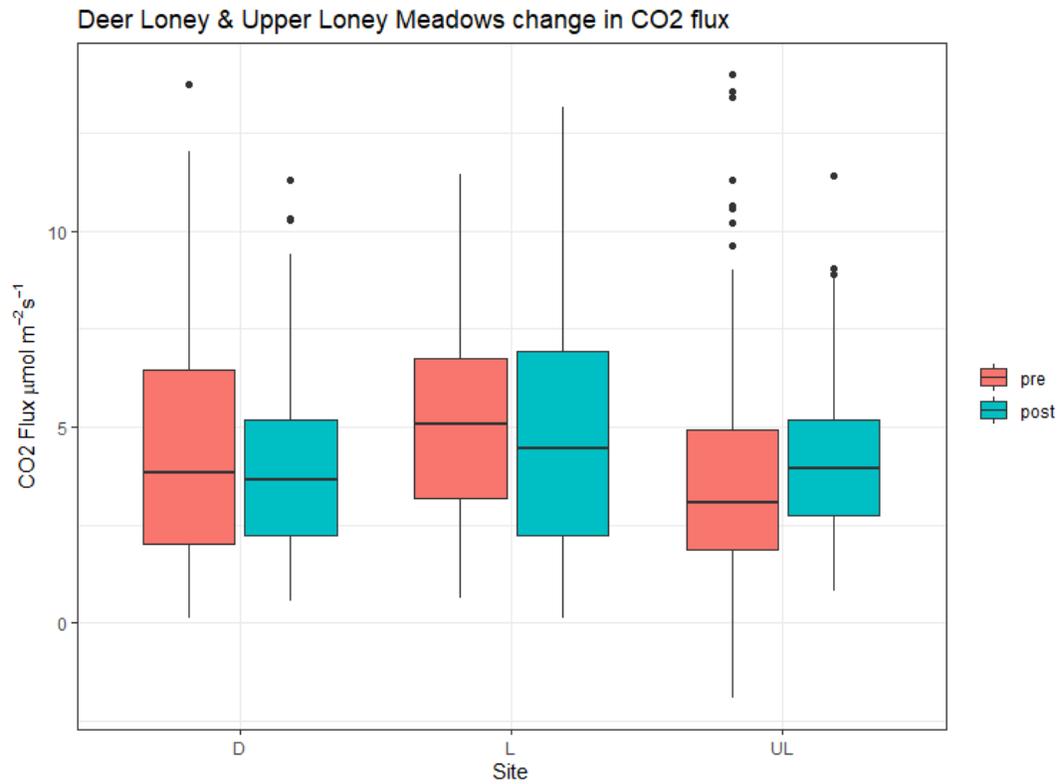


Figure 28. Pre versus post restoration CO<sub>2</sub> flux at Lower Deer (D), Loney (L) and Upper Loney (UL) meadows.

*Above ground C: Plant Biomass*

There are no significant changes in plant biomass C following restoration actions at Loney Meadow ( $p > 0.05$  Welch's *t*-test). When comparing pre-restoration biomass C to post restoration biomass C (Figure 29) within each of our two control meadows (Deer and Upper Loney) we see a significant decrease in plant biomass C ( $p < 0.05$  Welch's *t*-test).

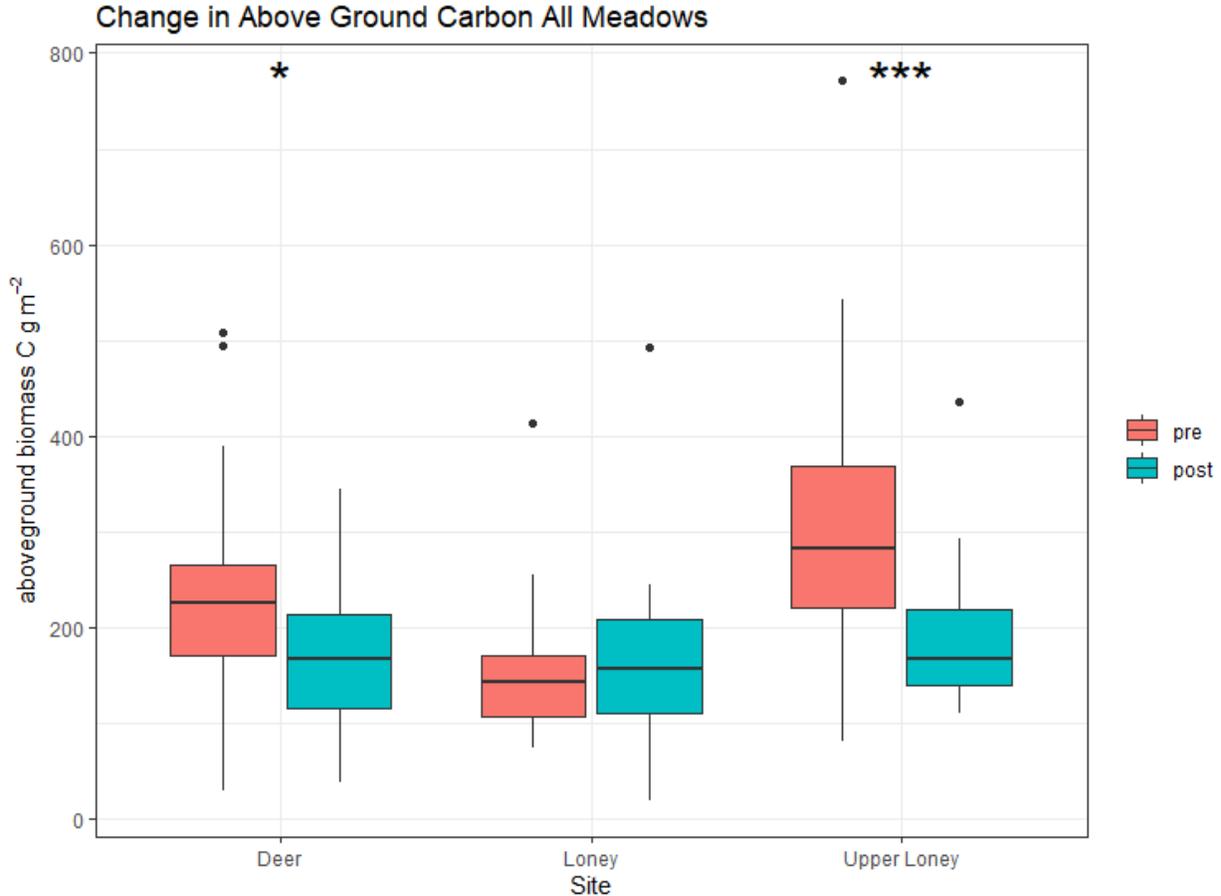


Figure 29. Pre versus post restoration change in aboveground biomass C at Lower Deer (Deer), Loney and Upper Loney meadows.

*Belowground C stocks: Total belowground C, Root C and Soil C*

Significant changes in belowground carbon stocks were only found from 0-15cm, and no significant changes occurred in deeper layers (15-30cm, 30-45 cm, 45-60cm, 60-75cm). Specifically, belowground C (0-15cm) increased significantly ( $p < 0.05$  Wilcoxon Signed Rank test) following restoration at Loney and Deer Meadows (Figure 30). In Upper Loney, we saw no significant change in below ground C following restoration ( $p > 0.05$  Wilcoxon Signed Rank test). For soil carbon stocks, Loney is the only meadow that showed a significant difference ( $p < 0.05$  Wilcoxon Signed Rank test); with an increase following restoration from 0-15cm (Figure 31). Both our control meadows, Upper Loney and Deer, showed no significant change in (0-15cm) soil carbon between pre and post restoration years. Change in root carbon from 0-15cm (Figure 32) is especially interesting within each of the three meadows; significant differences were found in each meadow (pre vs. post restoration:  $p < 0.05$  Wilcoxon Signed Rank test). Specifically, in a comparison of pre and post restoration years, in both of our control meadows (Upper

Loney and Deer) we saw a significant increase in root carbon stocks (Figure 32). Conversely, we saw a significant decrease in root carbon stocks in Loney Meadow following restoration.

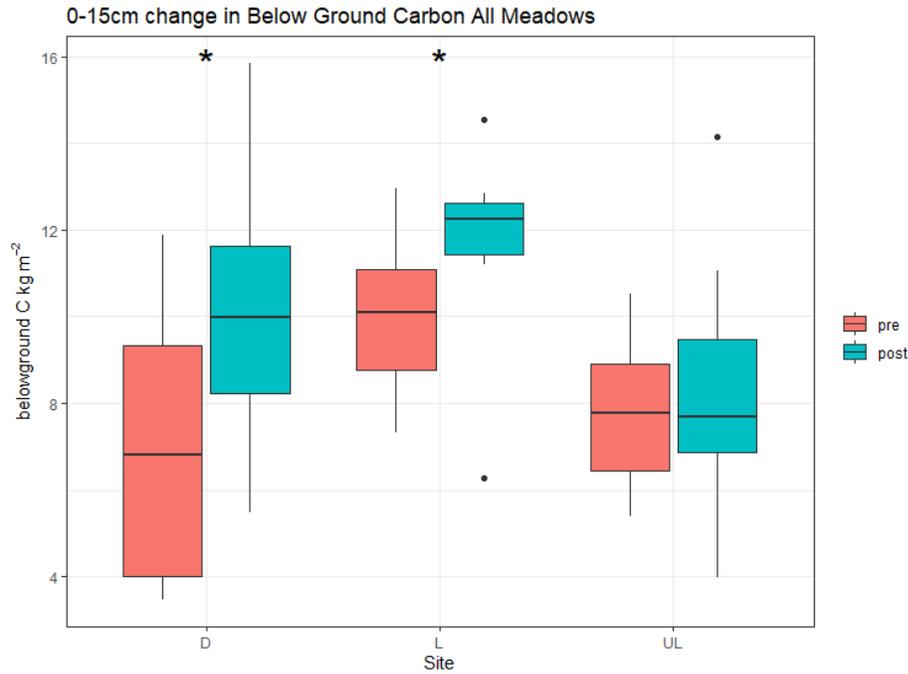


Figure 30. Pre versus post restoration change in belowground C at Lower Deer (D), Loney (L) and Upper Loney (UL) meadows. Belowground C = Soil C + Root C. Asterisks denote significant difference ( $p < 0.05$  Wilcoxon Signed Rank test).

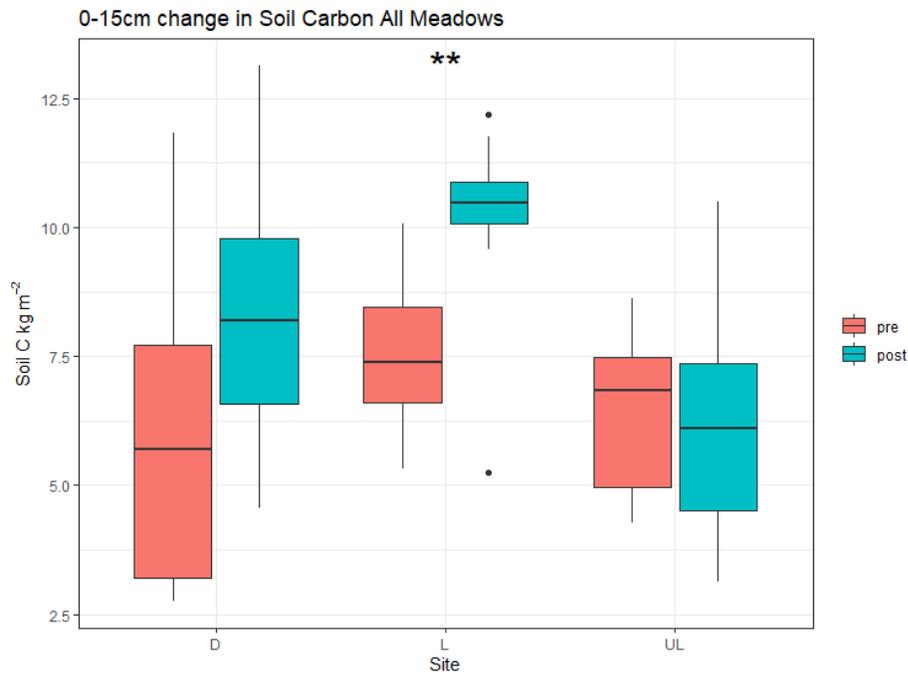


Figure 31. Pre versus post restoration change in soil C at Lower Deer (D), Loney (L) and Upper Loney (UL) meadows. Asterisks denote significant difference ( $p < 0.05$  Wilcoxon Signed Rank test).

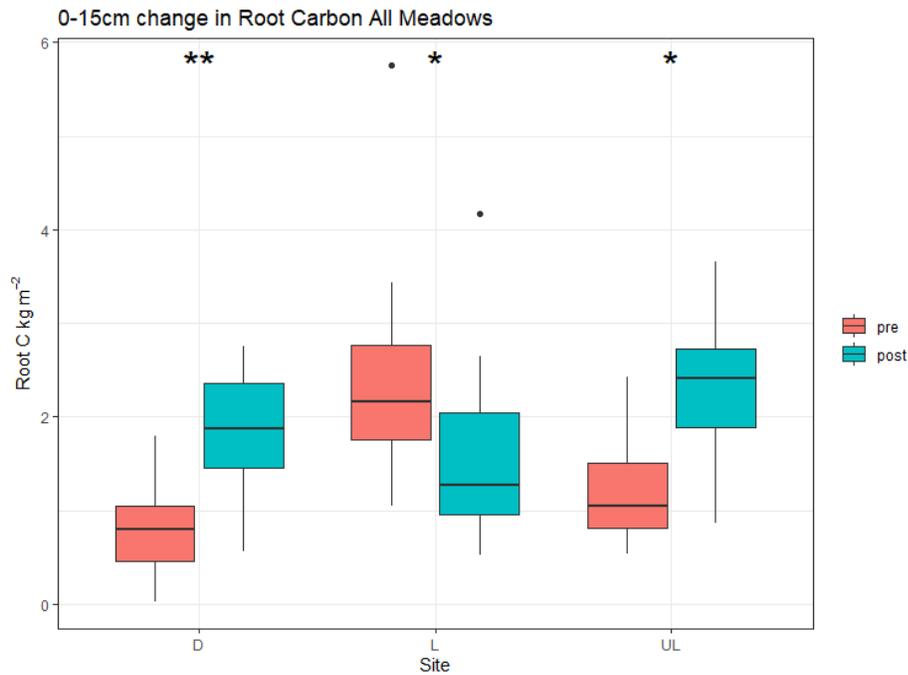


Figure 32. Pre versus post restoration change in root C at Lower Deer (D), Loney (L) and Upper Loney (UL) meadows. Asterisks denote significant difference ( $p < 0.05$  Wilcoxon Signed Rank test).

### Vegetation Sampling

In Loney Meadow, facultative wetland status plant cover decreased post restoration while facultative upland and facultative wetland increased in cover (Figure 33;  $p < 0.05$ ). There were no significant changes in plant cover by wetland status type in the two control meadows, however Deer Meadow did lose cover in the wetter facultative wetland class type and Upper Loney meadow gained cover in the drier facultative type. Upper Loney Meadow is generally dominated by obligate and wetland facultative species while Lower Deer and Loney are more mixed in their species wetland indicator type composition (Figure 33).

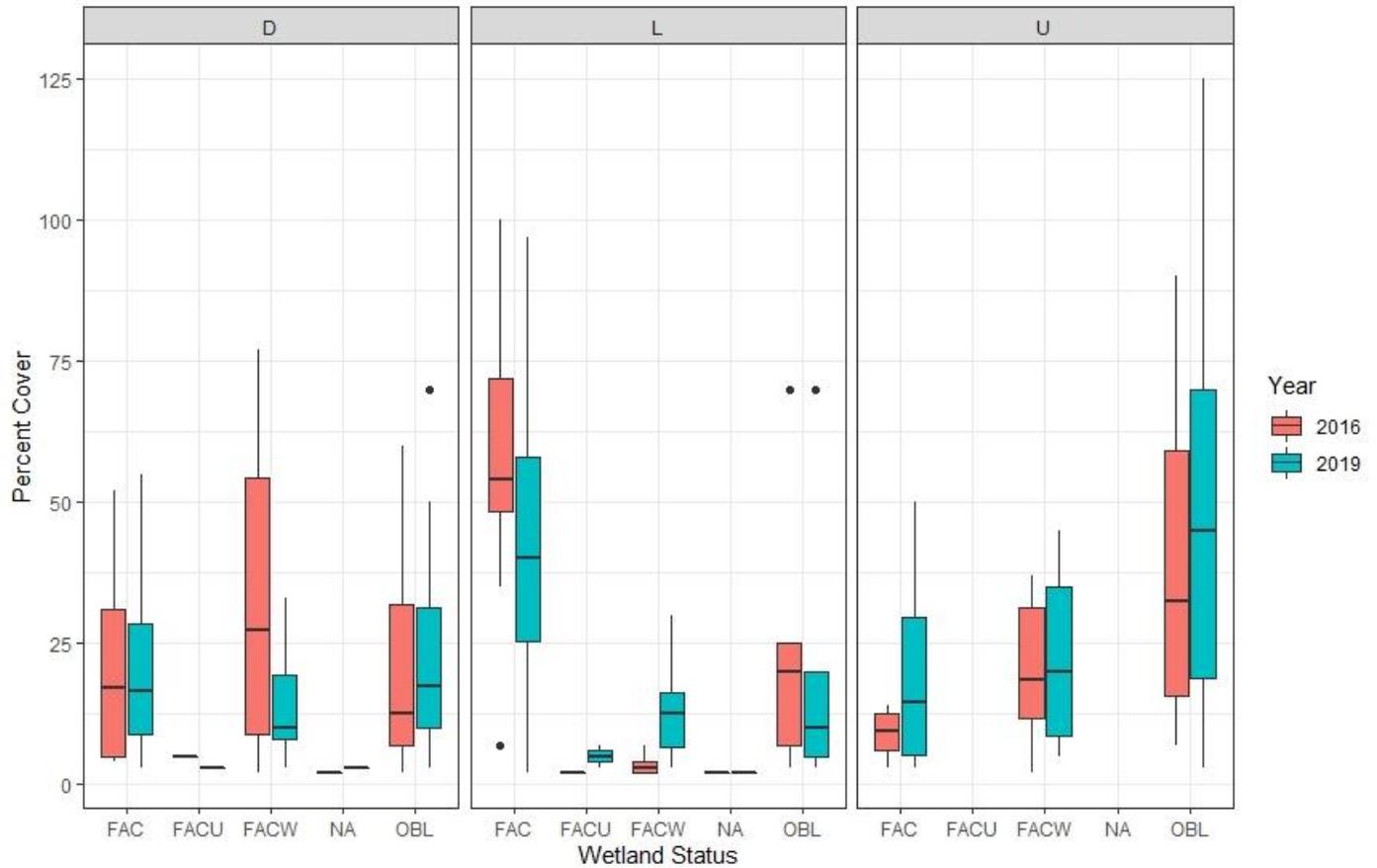


Figure 33. Percent cover of species by wetland indicator status type within each meadow. “D” is Lower Deer Meadow, “L” is Loney Meadow, and “U” is “Upper Loney Meadow. FAC= Facultative, FACU = Upland Facultative, FACW= Wetland Facultative, N/A= No Existing Wetland Status, OBL= Obligate Wetland Species.

Using Sorensen’s Bray-Curtis dissimilarity, a measure of beta-diversity, we identified that the plant community within Loney Meadow shifted between pre- (2016) and post-restoration (2019) timesteps (Figure 34;  $p < 0.05$ ). Upper Loney and Lower Deer did not shift in species composition enough to be considered dissimilar from one another between the two timesteps ( $p > 0.05$ ). The species composition in Loney Meadow shifted along the x-axis and towards Upper Loney Meadow (Figure 34).

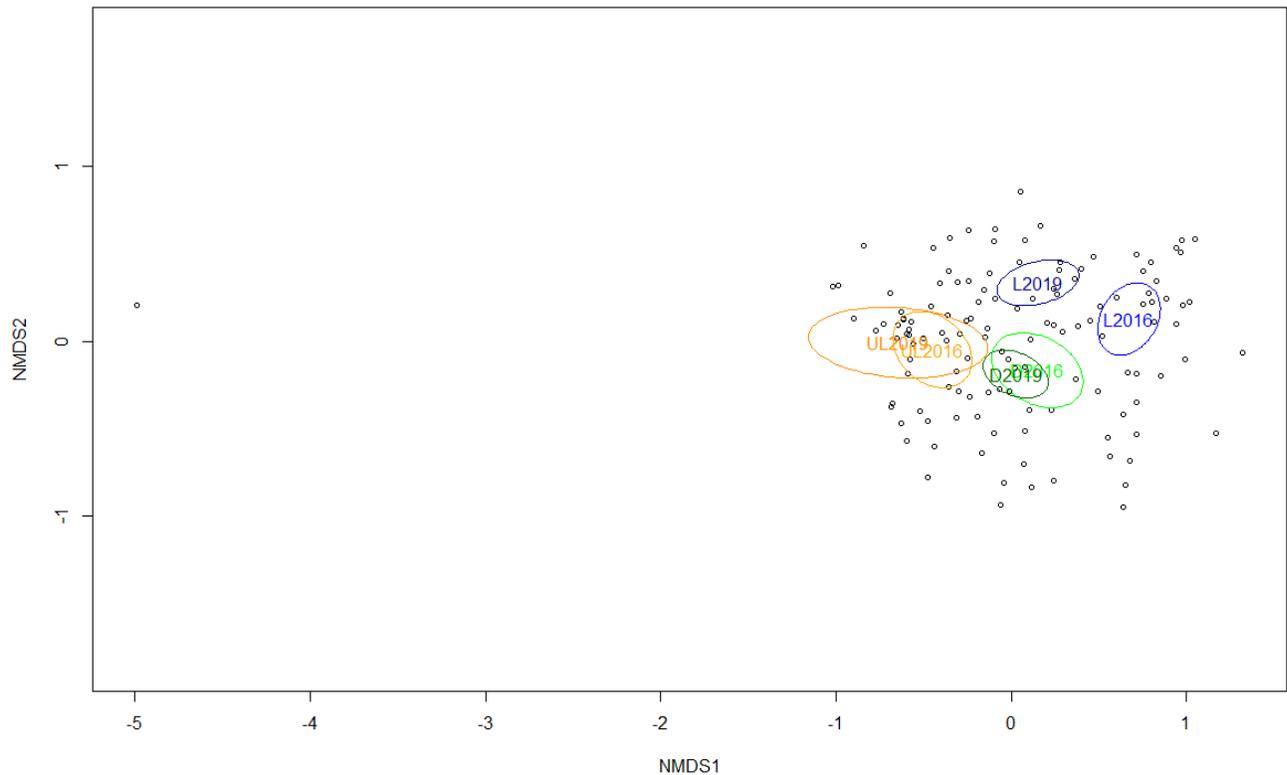


Figure 34. NMDS ordination of Sorensen Bray-Curtis distance for Loney, Upper Loney, and Lower Deer Meadow in 2016 and 2019. Ellipsoids indicate the 95% confidence intervals for each meadow/year combination. L=Loney (blue), D=Lower Deer (green), UL=Upper Loney (orange).

## Restoration Monitoring

### Photo-point Monitoring

Photo-points were collected before restoration in 2017, right after restoration in 2017, in 2018, and again in 2019. Photos are attached as Appendix VIII.

### Channel Morphology

Pre-restoration channel morphology was characterized by digital elevation model (DEM) that was created from the 2014 LiDAR dataset and was used to better identify channels that were in need of fill, channels that were historic and underutilized by the pre-restoration site conditions, and channels that were unnatural (“man-made”) (Figure 35; Appendix IX). The elevation data was also used to calculate an estimated amount of fill that would be needed to implement the restoration project. Post-restoration LiDAR data was collected in the fall of 2018 by the USGS, but has not yet been made available.

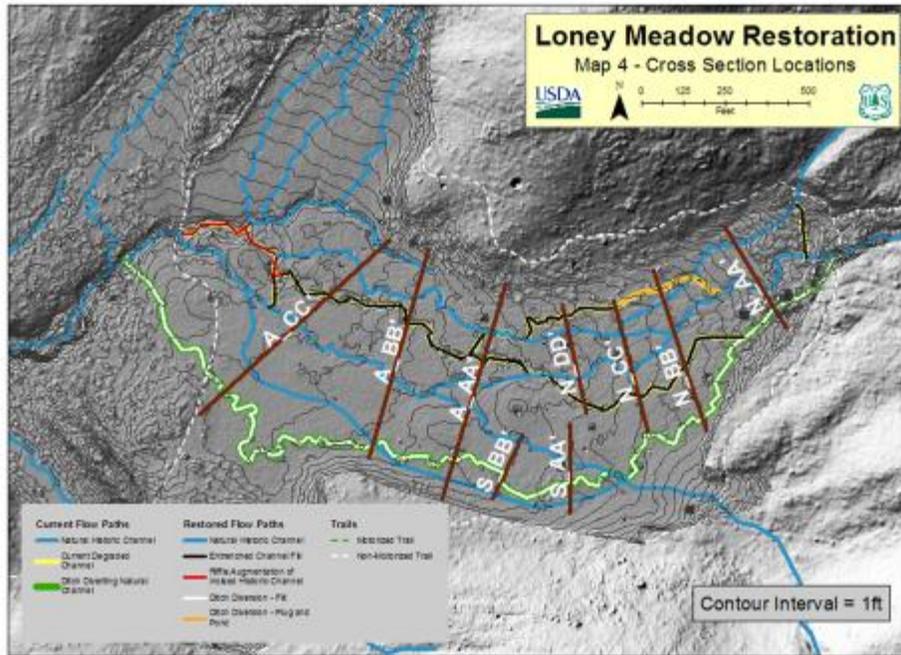


Figure 35. Loney Meadow cross-section locations utilized for the monitoring of long-term channel morphology and to identify fill locations and volume. Elevations were pulled from 2014 LiDAR datasets to determine channel depths across the meadow.

### As-Built Monitoring

As built monitoring occurred in summer 2018 and summer 2019. In 2018 we identified that there were a few channel segments where willow waddles could be used to further spread out flows with a goal of decreasing velocities. In 2018 we also identified the need to exclude cattle and utilized matching funds from NFWF and the Nevada and Placer County RAC to purchase and install cattle exclusion fencing around areas within the restored channel.

### Discussion

The main objective of this project was to determine the effects of restoration implementation on hydrologic and ecosystem function at Loney Meadow. We leaned on the assumption that re-establishing hydrological connectivity between the stream channel, remnant channels, and the meadow floodplain would increase groundwater levels and surface inundation resulting in a shift towards wetter plant communities and an increase in net carbon sequestration. We implemented a BACI experimental design, utilizing two nearby reference meadows as controls to validate our findings at Loney Meadow. The experimental design also provided us with more explanatory power to: 1) evaluate the restoration response within the context of annual changes in the hydrologic regime and 2) determine how and whether the restoration project impacted conditions specifically at Loney or if they were observed at other meadows in the same geographic vicinity. This experimental design allows us state with a fair amount of certainty that the restoration of Loney Meadow did result in wetter habitat conditions. The results of our hydrologic, vegetation, and carbon monitoring efforts quantify and support this finding.

Our results support that groundwater levels increased in the areas impacted by the restoration of Loney Meadow. The data shows a significant increase in groundwater levels following restoration in four groundwater wells in Loney Meadow (A02, A03, B02, B04). These four wells are located closest to the braided stream network that was reconnected via restoration implementation. Across all of the wells at Loney Meadow, we saw an overall 8% increase in total groundwater height following restoration at Loney Meadow. This positive result is bolstered by the fact that our two control meadows showed decreases in groundwater levels (Upper Loney -4%, Deer -12%) during that same time period.

However, the groundwater data collected in this study may have been impacted by a few factors. First, it is important to note that this project began at the end of a long drought (2011-2016) which may mean that initial year of data collected in Loney Meadow may be indicative of a period of lower than average groundwater levels compared to a period of time when more “average” hydrologic conditions would have been present. Secondly, our control meadows were only instrumented starting in the 2017 water year (October 2016-September 2017), while Loney Meadow was instrumented starting in the 2016 water year. Finally, it is also important to consider that while we think that there is little hydrologic connectivity between Upper and Lower Deer, the restoration action completed in Upper Deer in 2018 may have influenced the hydrology in Lower Deer. Additionally, Deer Meadow is a higher gradient meadow than Loney or Upper Loney and streamflow is seasonal rather than perennial.

The data supports that restoration actions shifted the hydrologic regime and delayed the recession at the outflow of Texas Creek in Loney Meadow compared to both pre-restoration and upstream conditions at Upper Loney Meadow. There is a distinct “crossover” in stream flow in plotted percent change of inflows to outflows after the restoration occurred which represents a shift in peak flows and shows a subtle delay in recession, by approximately one week. The same analysis at Upper Loney Meadow further support of this finding, showing that percent change of inflows to outflows showed no distinct crossover in post-restoration years. The data also show that while initially total outflows from Loney Meadow decreased, after one year, outflows as a percentage of total inflows returned to conditions similar to what was occurring before the restoration project. This initial loss of outflows is due to the groundwater basin recharging, resulting in less water leaving the system.

Our data shows that in the year following restoration, baseflows dropped less in Loney Meadow than at the two upstream gages, indicating that the restoration may have had a benefit to baseflow in this lower water year. However, additional data is required to better understand the baseflow dynamics in Loney and the upstream gages as it is also possible that in 2018, immediately following restoration, a larger portion of the streamflow was replenishing the groundwater table. Monitoring will continue in the Loney Meadow complex to better understand the longer-term benefits of this project.

We expected that water quality parameters would improve as a result of restoration at Loney Meadow. Specifically, we expected that water temperatures would decrease during the summer recession period following restoration. Conversely, our data show that water temperatures leaving Loney Meadow increased following restoration. Our expectation that water temperature would decrease was based on the assumption that baseflows would increase, providing more cold groundwater inputs into surface water flows. It is possible that once the groundwater basin is fully recharged, we may see trends towards cooler temperatures. Additionally, there is more water sitting on the surface of Loney Meadow as we rerouted the surface water from one main channel into a braided network of smaller channels that flow across the meadow surface. Consequently, that increased surface area to volume ratio is likely resulting in localized increases in stream temperatures. This is confirmed by our documentation of change in range of diel temperature flux following restoration (Appendix VI). The average diel temperature range during the

summer recession period following restoration is 11.3 °C to 17.5 °C. Prior to restoration we documented a range of 10.8 °C to 16.9 °C during the summer recession period. This increase in temperature is still within the optimal temperature range for amphibian species, including the listed species *Rana muscosa* – foothill yellow legged frog (Bradford 1984). Additionally, we only monitored water temperature at the outflow of Loney Meadow and it is likely that the post-restoration presence of persistent deep pools of water may offer cold water refugia to aquatic species that will benefit them over longer time scales as precipitation and climate shifts towards rain and warmer temperatures.

We expected that turbidity levels would decrease during the summer recession period following restoration. Our data showed an increase in variation and a slight increase in turbidity that was more pronounced in 2018, directly following restoration. This is likely due to the settling of the sediment plugs that were placed during the restoration. Our expectation that turbidity would decrease was again directly related to our assumption that there would be an increase in contributions of groundwater (baseflows). Long term, this still may be the case and Loney Meadow may still be “settling” post restoration disturbance. Turbidity levels (max of 1.4 NTU) following restoration are still within normal range for an aquatic environment with high clarity (turbidity < 5 NTU: Swanson et al. 1965) at Loney Meadow.

The wetter conditions at Loney Meadow post-restoration are thought to have shifted plant species dominance towards more wetland species. Additionally, post-restoration the plant community at Loney shifted in vegetation composition that is more similar to the vegetation composition at Upper Loney Meadow, our reference undisturbed control. Vegetation communities at Upper Loney and Deer did not change substantially in either the composition of wetland types or community similarity. This shift is likely due to the wetter conditions exhibited at Loney Meadow which are apparent in the increase in surface inundation and higher groundwater conditions in the vicinity of the vegetation plots.

We expected that Loney Meadows carbon stocks would increase following restoration actions: 1) relative to any change in carbon flux rates and 2) relative to increases in carbon stocks in the undisturbed reference meadow (Upper Loney). Our results support this as shown in the significant increase in belowground carbon stocks, following restoration, from 0-15cm at Loney Meadow. Our results show no significant change in belowground carbon stocks at Upper Loney Meadow (control). Therefore, relative to our undisturbed control meadow (Upper Loney), Loney Meadow’s increase in belowground carbon suggests that restoration actions contributed to increased carbon storage. Belowground carbon is the indicator for carbon storage as it represents net change in carbon; an increase in belowground carbon storage represents an increase in inputs relative to outputs (CO<sub>2</sub> flux). At Loney Meadow we found an increase of 14,622.3 kg/ha of belowground carbon from 0-30cm between the two timesteps. At Upper Loney we found an increase of only 6748.7 kg/ha of belowground carbon from 0-30cm over 3 years. Loney Meadow had 2.16 times more carbon sequestration than Upper Loney Meadow from 2016 to 2019. Lower Deer Meadow had an increase of 33,743.0 kg/ha of belowground C from 0-30cm over 3 years. This is quite substantial and illuminates a potential relationship between total nitrogen in aboveground biomass (or other environmental variables) and carbon sequestration rates. Early analysis of % total nitrogen (%TN) in peak aboveground biomass samples show that Lower Deer Meadow has elevated %TN when compared to Loney and Upper Loney Meadows. This analysis is very early and is certainly not indicative of such a relationship; however, future research on the relationship between carbon sequestration rates and environmental variables such as temperature, soil moisture, air temperature, aspect, TN, TN/TC ratios and plant species richness will be especially important in the understanding of drivers of carbon sequestration.

We found interesting trends within each meadow when looking at changes in each of the two components of belowground carbon, soil carbon and root carbon, separately. Soil carbon increased significantly following restoration in Loney Meadow, but not in the two control meadows (Upper Loney and Lower Deer). Root carbon increased significantly in Upper Loney and Deer meadows, but decreased significantly in Loney Meadow from 2016 to 2019. It's possible that due to reduced groundwater levels at Upper Loney and Deer meadows the plant communities at these meadows partitioned their carbon and energy transfer into roots rather than aboveground growth (Fuzhong et al. 2008). Our data support this with a significant reduction in aboveground C from 2016 to 2019 in Upper Loney and Deer Meadows. Following suit, increased groundwater levels at Loney Meadow could be responsible for the partitioning of carbon and energy transfer towards aboveground biomass rather than belowground roots; supported by our results showing significant reduction in root C and stable aboveground C at Loney from 2016 to 2019.

Greenhouse gas flux is dominated by CO<sub>2</sub> and change of CO<sub>2</sub> is within interannual variation in all meadows. Our finding of an increase in CH<sub>4</sub> following restoration at Loney Meadow with levels peaking in the wet and warm month of June and becoming more similar to those of (the wet undisturbed) Upper Loney Meadow is in alignment with the understanding that CH<sub>4</sub> flux increases in warm, wet environments (Blankinship and Hart 2014). Despite increases in CH<sub>4</sub>, the cumulative product of CH<sub>4</sub> flux (as CO<sub>2</sub> equivalent for GHG potential) and annual CO<sub>2</sub> flux, are outweighed by an increase in belowground carbon storage at Loney Meadow.

The Yuba Headwater Meadow Restoration Project focused on quantifying the response of Loney Meadow to restoration actions completed in 2017 in comparison to pre-restoration conditions and the response of two control meadows. We have demonstrated that we have shifted the hydrologic regime at Loney Meadow, including delaying peak flows, moderating baseflows, and increasing groundwater levels, that Loney Meadow may now be sequestering more carbon, be dominated by wetter vegetation, contain similar water quality, and more aquatic habitat. We feel that in order to understand how sustainable these benefits are, additional monitoring will be required to understand the long-term impacts and benefits of this restoration project.

## Acknowledgments

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## Appendices

Appendix I: Hydrology report—Beartrap and Freeman Meadow

Appendix II: Supporting Groundwater Data—Annual GW Measurements by well

Appendix III: Supporting Groundwater Data—Rating Curves

Appendix IV: Supporting Streamflow Data—Annual Hydrographs

Appendix V: Supporting Streamflow Data—Rating Curves

Appendix VI: Supporting Water Quality Data and Diel Temperature Graphs

Appendix VII: ` Amphibian Reports

Appendix VIII: Photo-point Data

Appendix IX: Channel Morphology: Cross-Sections