Section 5: Project Description

1. Project Objectives:

We propose to test the hypothesis that Beaver Dam Analogues will achieve similar carbon sequestration and sensitive species habitat benefits as naturally occurring beaver dams. Our project objectives are to:

1. Restore 80 acres of Childs Meadow using cost-effective Beaver Dam Analogues and riparian fencing.
2. Increase carbon sequestration, as measured by soil organic carbon, across the meadow by 10% over 3 years post-restoration.

3. Increase groundwater levels and surface water extent in the restored section of the meadow by 10% over 3 years post-restoration.
4. Increase habitat by 60% based on stream miles in the restored portion of the meadow for two sensitive meadow species known to occur in the unimpacted portion of the meadow: Cascades frog (*Rana cascadae*) and Willow Flycatcher.
5. Determine carbon sequestration values in existing restored and unrestored mountain meadows across the Cascade Range and compare to values observed in the Childs Meadow study treatments.

2. Background and Conceptual Models:

In mountain watersheds, meadows and other wide floodplain and riparian areas represent only 25% of the river area, but store approximately 75% of the riverine organic carbon in floodplain sediment and coarse wood (Wohl et al. 2012). Due to extensive livestock grazing and widespread removal of beaver and willows, headwater meadows have transformed from multi-thread channels with seasonally active floodplains into single thread, incised channels that store less carbon and are lower in habitat quality for a diverse suite of meadow-dependent wildlife. In a study in the Rocky Mountains, Wohl (2013) estimated that in the past beaver meadows with active beaver stored ~23% of the carbon in the landscape. With the removal of beaver, and conversion of meadows from wet to dry grasslands, the carbon storage decreased by a factor of three and today represents only ~8% of the total storage in the landscape.

Beaver were thought to be non-native to the Sierra Nevada until 2013 when radiocarbon dating of two buried beaver dams, unearthed during a ‘pond and plug’ restoration, was dated to before the Gold Rush time, 1850±70 years for the first dam and 1820±30 years for the second dam (James and Lanman 2012). Additionally, recent research from the Rocky Mountains illustrates the role beaver have played over thousands of years in alluvial sediment storage and formation of meadow landscapes and the long-term carbon storage provided by beaver ponds, even after they are abandoned (Wohl 2013, Kramer et al. 2012, Polvi and Wohl 2012).

There are several mechanisms by which the activity of beaver or creating structures that mimic their behavior can increase the carbon storage, habitat value, water supply reliability and resilience of meadows. Beaver dams increase the vertical and lateral connectivity of rivers and create heterogeneous habitat for riparian birds and frogs. Beaver dams increase surface and groundwater storage, store sediment and organic material, and increase the frequency and magnitude of overbank flow. The dams attenuate moderate and small flood flows and increase late-season flows, sometimes converting intermittent streams into perennial ones (Naiman et al. 1988). By raising the water table around dams, beaver increase the productivity of riparian and aquatic vegetation that they rely on for forage, which in turn increases above-ground carbon storage. Finally, when beaver create wetland ponds they increase methane emissions, yet the combined contributions of beaver to both carbon storage and methane emissions requires additional research (Whitfield et al. 2014).

Management of grazing on meadows and balancing this with restoration and natural processes that facilitate the recovery of meadow function will also be important for the capacity of meadows to serve as carbon sinks and critical habitat. Cattle congregate and forage more intensively in the riparian areas where vegetation is most productive. Beaver populations where they have been reintroduced or survived naturally have failed to recover in riparian areas that are heavily grazed by cattle or ungulates like elk. This, combined with active and persistent removal of willows from meadow systems by landowners has limited beaver populations and other ecosystem processes (Baker et al. 2005, Beschta and Ripple 2011, Ripple and Beschta 2004). As a result of these broadscale changes to meadow function, their capacity to serve as natural sinks for greenhouse gases, to store and release water during the summer months, and to provide habitat for meadow-dependent wildlife have been severely compromised across the Sierra Nevada mountain range.

The Nature Conservancy plans to restore Childs Meadow, a 290 acre meadow near Lassen National Park, to increase carbon storage, improve water storage capacity, and increase populations of riparian birds and sensitive meadow-dependent species. Childs Meadow is an ideal location to conduct this restoration study for several reasons. It is typical of many Sierra meadows, having been grazed at levels common to other meadows, yet it has relatively recently been colonized by beavers in the lower section of the meadow, creating an area where the carbon and habitat value of seasonally grazed meadow and natural beaver ponds can be compared to restoration. Also, Childs Meadow is one of the few remaining strongholds for two severely imperiled meadow species, Cascades frog and willow flycatcher. In 2014, more than 40 individual Cascades frogs were found in one day near a recently constructed beaver pond that spans more than 100 feet across the meadow. All of the willow flycatcher and Cascades frog observations have been made in the downstream 1/3 of the meadow area where beaver have been building ponds and creating wetlands between 2006 and 2009.

The proposed project will use a modified Before-After-Control-Impact design to test the impacts of two restoration treatments in the middle portion of the meadow on carbon sequestration, hydrology, and sensitive species (Figure 1). The upper portion of the meadow will remain unrestored to provide a negative control, and the lower portion of the meadow with willow flycatcher, Cascades frogs, and beavers will serve as the positive control or desired condition. The treatments include (1) riparian cattle exclosure and placement of beaver analog structures in the stream channel, and (2) riparian cattle exclosure only. *We hypothesize that removing livestock grazing from the riparian area, planting willows, and building BDA structures in the restoration treatment area will promote sediment deposition, store more carbon, reduce flood peaks, increase streamflow at the end of the summer, and create more* *habitat for sensitive species than prior to treatment.* We expect this restoration area will score better in all response variables compared to the negative control section, and become more similar to the downstream section where beaver have raised the water table and increased wetland habitat. In the long-term, we also expect this restoration treatment to further mitigate the effects of climate change by creating refugia for mesic communities during dry periods in a climate characterized by less snow and more rain.

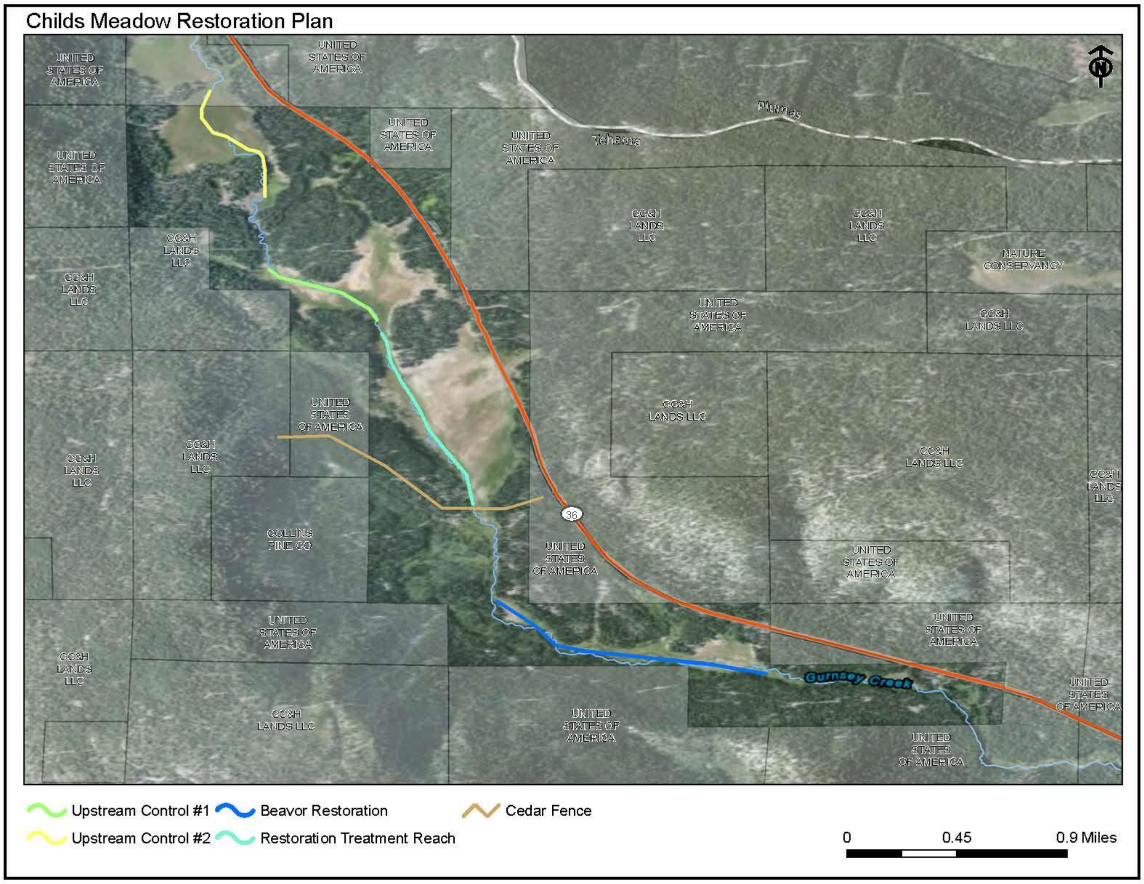

Figure 1. Overview of Childs Meadow in Tehama County, California. Colors show treatment and control reaches within the meadow.

This project is unique to California in that we are testing whether beaver dams and beaver dam analogs can be used as successful meadow restoration tools for reducing GHG emissions and increasing biodiversity. The ultimate goal for the beaver dam analogs is for beaver to move into the middle section of the meadow and maintain the dams over time. We believe that restoration efforts should exploit the interactions of biological and physical processes to accelerate the recovery of incised streams with disconnected floodplains.

The restoration treatment in Childs Meadow will be compared to restoration projects already completed in six meadows with Cascade frogs to provide a regional comparison of carbon storage and habitat co-benefits. More than half of meadows are considered degraded and there is increasing effort to restore meadows on public and private land in the Sierra Nevada and Cascade Range. However, there is a gap in understanding beaver dam building and carbon storage, and how to balance beaver and livestock. This study and restoration project can inform mountain meadow management and accounting for carbon storage with low-cost restoration approaches.

Conceptual Model for Childs Meadow. Our conceptual model centers on willows as a key resource for beaver pond construction. With enough tall willows present on the site, it is clear, both from the historical accounts of beaver use, and the current beaver damming of the lower meadow, that beaver will dam Gurnsey Creek and create perennial ponds in Childs Meadow. Beaver ponds will raise the water table in the surrounding meadow lawns, as well as creating expanded pond-margin habitat for willow. Improved willow habitat will result in greater growth and storage of carbon in live woody tissue. The ponds themselves will also trap both mineral and organic bedload and suspended load out of the creek. However, the perennially saturated pond environment is likely to produce anoxic conditions on the pond bottom, which may result in methane and/or nitrous oxide production. We expect that the beaver ponds will result in greater net storage of GHGs. In addition, cattle grazing will be excluded from two 9-acre restoration treatment areas (one with beaver dam analogs, one without), and the removal of grazing will have an estimated net storage of GHGs as well. Removal of grazing will result in greater plant cover and stature in meadow lawns, allowing for more photosynthetic uptake of CO_2, some of which will be stored in the long-term soil carbon pool. Cattle also graze willows, so removal of grazing will increase willow height and cover, allowing for more woody biomass carbon storage. In addition, removing grazing will remove the methane produced by cattle digesting the consumed plant material. The interactions of these components are illustrated in Figure 2.

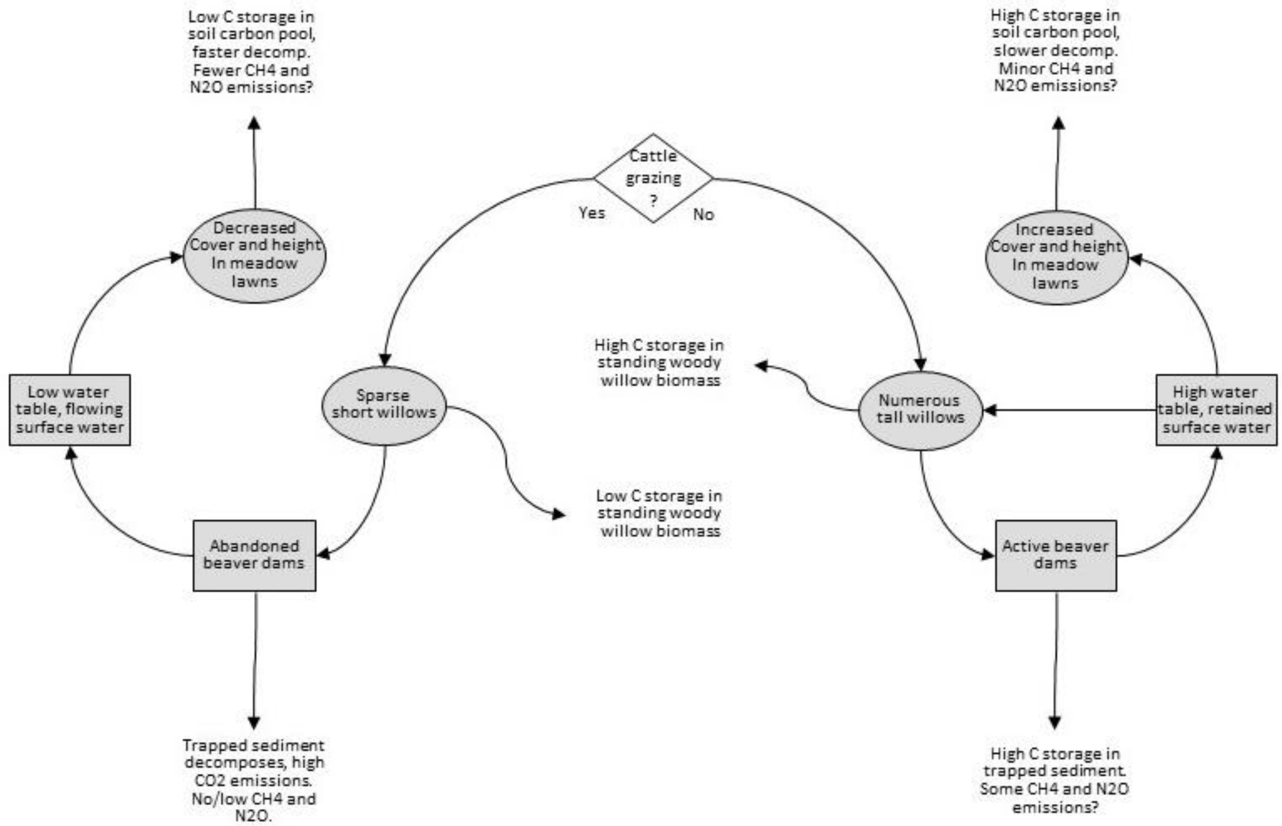

Figure 2. Conceptual model of the grazed and ungrazed, beaver dammed, and undammed effects on GHG emissions.

Scientific Concepts for Measurement and Modeling Carbon: Soil organic matter is produced by plant photosynthesis that fixes atmospheric CO_2 and uses this energy to grow above- and below-ground plant tissue. Above-ground plant tissue is influenced by herbivory, fire, solar heating, desiccation and wind transport or rapid decomposition after senescence. Most non-woody above-ground plant production has rapid turnover rates and contributes little to the soil carbon pool. Below-ground production of roots and rhizomes delivers atmospheric carbon directly into the soil where the cool, low oxygen soil environment results in slow decomposition and greater inputs to the long-term stable soil carbon pool. Sedge-dominated plant communities are essential in forming and maintaining the soil organic matter and carbon storing capacity of mountain meadows. In addition, willow communities can store significant amounts of carbon both above- and below-ground in woody tissue that decomposes slowly, thereby contributing directly to the long-term carbon pool. Willow-riparian/beaver pond communities and the low-growing herbaceous lawns of open meadows have very different vegetation structure and require significantly different methods for measuring their GHG fluxes. Gas flux from meadow lawns can be measured in permanently located small plots using a portable plastic chamber. Gas emissions and uptake from tall, broad willows cannot be practicably measured directly, but can be estimated based on above- and below-ground productivity.

Creating a Carbon Budget: To create an annualized model of carbon flux in the meadow lawns at Childs Meadow, we will measure and model the two primary CO_2 pathways into and out of the ecosystem: photosynthesis and respiration. The model for photosynthesis will be a function of incoming solar photosynthetically active radiation (PAR), air temperature, and plant phenology (the seasonal cycle of growth and senescence). The model for respiration will be a function of soil temperature, soil moisture, and plant phenology. The models will be calibrated using regular field measures of photosynthesis and respiration made using a clear plastic chamber and infrared gas analyzer (IRGA, PP Systems EGM-4) at meadow lawn sites. For this same time period, we will take continuous field measurements of solar radiation using a Campbell Scientific CR1000 data logger (Logan, UT) equipped with a REBS, Inc. Q*7.1 net radiometer (REBS Inc., Bellevue, WA). Soil temperature, water level, and air temperature will be measured hourly using field sensors equipped with data loggers (Onset Computer Corp, Bourne, MA). Plant phenology will be measured using a time-lapse camera pointed at the study plots. Daily images will be taken at midday, corrected for light levels, and then analyzed for the amount of green. Greenness will serve as the phenology factor in the carbon flux models (http://phenocam.sr.unh.edu/webcam/).

We will use equations modified from Riutta et al. (2007) to model gross primary production (GPP) and ecosystem respiration (ER). GPP will be modeled for the main plant communities studied as a function of PAR and a seasonality/phenology term based on a four-week running average (21 days before, 7 days after) of daily mean air temperature (RAV) [Equation 1]. A rectangular hyperbola function will be used to model ecosystem photosynthetic response to incoming PAR, and a Gaussian function will be used for the seasonality term, allowing modeled GPP to follow seasonal dynamics associated with plant phenology.

$$\boldsymbol{GPP_i = \frac{A_{max} * \alpha * PAR_i}{A_{max} + \alpha * PAR_i} * e^{\left[-0.5\left(\frac{RAV_i - RAV_{optGPP}}{RAV_{devGPP}}\right)^2\right]}} \qquad (1)$$

In Equation 1, A_{max} (g CO_2-C m^{-2} hr^{-1}) represents the asymptotic maximum potential rate of GPP, and α (g CO_2-C µmol PAR^{-1}) represents the light use efficiency, or initial slope of the light response function. The parameter RAV_{optGPP} (C°) represents the optimum value of RAV for GPP and RAV_{devGPP} (C°) represents the standard deviation of the Gaussian function, which controls the spread of the distribution.

Ecosystem respiration will be modeled as a function of air temperature (AT), water table position (WTP), and a seasonality term [Equation 2]. A modified van't Hoff equation will be used to model ER as increasing exponentially with air temperature. The response of ER to water table position will be modeled as a negative exponential equation, and a Gaussian function similar to that of the GPP model will be used to account for seasonal variation in ER.

$$\boldsymbol{ER_i = R_{10} * Q_{10}^{\left(\frac{AT_i - 10}{10}\right)} * e^{-b*WTP_i} * e^{\left[-0.5\left(\frac{RAV_i - RAV_{optER}}{RAV_{devER}}\right)^2\right]}} \qquad (2)$$

In Equation 2, R_{10} (g CO_2-C m^{-2} hr^{-1}) represents ER at 10°C when other model factors are not limiting, Q_{10} represents the rate of increase in ER per 10°C increase in air temperature, b (g m^{-2} cm^{-1}) represents the initial slope of the rate of increase in ER per decrease in water table position below the peat surface. RAV_{optER} (C°) and RAV_{devER} (C°) represent the optimum RAV value for ER and the standard deviation of the Gaussian function controlling seasonality in ER, respectively.

The effect of hydrologic restoration on carbon fluxes in mountain meadows has previously been demonstrated using these same approaches (Chimner & Cooper 2003a,b; Schimelpfenig *et al.* 2013, Millar in prep). These efforts were for sites that were hydrologically modified by ditches and other dewatering processes and natural intact meadows in the Rocky Mountains. Soil organic matter plays a key role in retaining soil water (Hudson 1994; Saxton & Rawls 2006, Ankenbauer and Loheide 2014). A change in plant community composition that causes a shift to an annual net-loss of soil carbon will result in a concurrent loss in soil water holding capacity. This sets up a feedback of degradation with the loss of soil water limiting vegetation growth and ground cover, exposing soil organic matter to the atmosphere resulting in greater decomposition.

In mountain meadows where the water table drops below the ground surface for a significant portion of the year, like Childs Meadows, methane production is likely to be very near zero because redox potentials never drop to levels (lower than -250 mV) necessary for methanogenesis (Cooper *et al.* 1998; Dwire, Kauffman & Baham 2006). In a study at Delaney Meadow, Yosemite National Park, 68 of 72 plot measurements showed a small average net uptake of methane (Blankinship & Hart 2014). Similarly, the flux of nitrous oxide is expected to be negligible in Childs Meadows due to a small load of nitrogen in high elevation Sierra watersheds (Williams *et al.* 2014). Research at Delaney Meadow (Blankinship & Hart 2014) found a small net uptake of nitrous oxide across all plots. However, they note that they may have missed a significant nitrous oxide pulse emission during snowmelt (Christensen & Tiedje 1990). Therefore, our sample protocol will began as soon as soil is exposed by melting snow. However, the presence of cattle on the site could significantly alter nitrogen dynamics, therefore measurements of nitrous oxide will be important. Additional details on the carbon sampling methods are provided in section 3 below.

We expect that the effect of protecting the meadow lawn from herbivory will result in a net CO_2 storage increase similar to the difference already observed between grazed and ungrazed wetland plots in other studies (Hirota *et al.* 2005, Wolf unpublished data). Averaging the findings of the two studies produces an estimated reduction of emissions of approximately 0.80 g CO_2-C g m^{-2} d^{-1}(Table 1). Based on limited existing studies, we expect to see very low fluxes of methane and nitrous oxide from the meadow lawns during the summer growing season, although significant unknown fluxes may occur very early during saturated snowmelt conditions.

Table 1. Estimated carbon dioxide benefit of the grazing-exclosure restoration.

Hirota (2005) grazed-ungrazed difference	0.96	g CO_2-C m^{-2} d^{-1}
Wolf (unpublished) grazed-ungrazed difference	0.64	g CO_2-C m^{-2} d^{-1}
Average of two grazing studies	0.80	g CO_2-C m^{-2} d^{-1}
Estimated annual (60 day growing season) benefit of grazing exclosure	48.0	g CO_2-C m^{-2} yr^{-1}
Multiplied by the 75200 m2 restoration area	628	g CO_2-C yr^{-1}

Estimates of carbon storage in beaver ponds are fairly rudimentary and are generally made across landscape scales (Wohl et al. 2012 Nature Communications, Figure 3). Their effect can be significant however: active beaver ponds store 23% of total carbon storage on a landscape scale and relict dams store ~8% (Wohl 2013, AGU). Pond-scale measurements indicate sedimentation rates of about 5 cm per year, with an organic carbon content of about 20% by volume, equaling 1 cm of organic matter per year (Butler & Malanson 1995). Assuming 50% carbon content and a bulk density of 0.224 g/cm^3, this indicates a carbon accumulation rate of 0.112 g/cm^2 of pond area per year. The total proposed restoration beaver analog pond area is 498 m^2. This yields an estimated 557,760 g C yr^{-1} accumulated in the restoration ponds. The total area of beaver ponds in the lower end of the meadow is 4,641 m^2, which is 5,197,920 g C yr^{-1}.

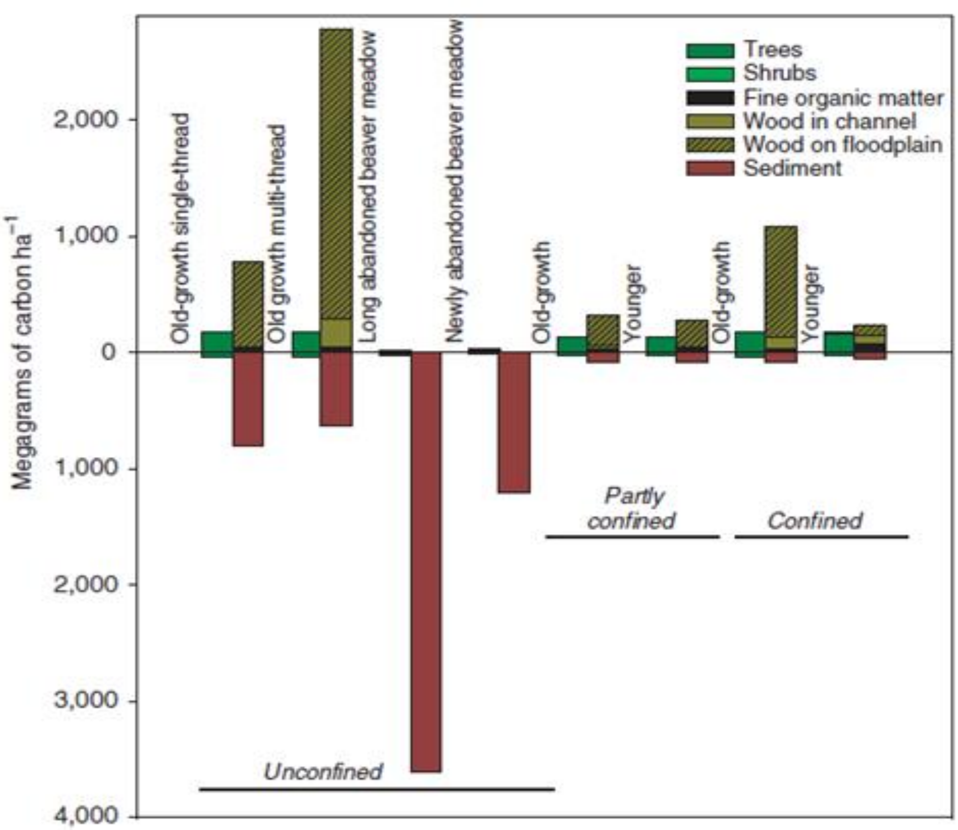

Figure 3. Carbon pools (Mg per ha) of different ecosystem components within each of the eight valley types. Components of above-ground biomass are shown above the x axis; below-ground carbon components are shown below the x axis. Quantities of carbon in tree regeneration and herbaceaous vegetation are too small to be visible in this figure. Reproduced from Wohl et al. 2012.

We made a very rough estimate of the methane emissions reductions that will occur as a result of preventing grazing in the two ~9 ac restoration treatment areas. The ~18-acre (7.3 ha) restoration treatment is occurring within the 208.2 ha Childs Meadow, representing 3.5% of the total area of the meadow. The cattle herd size in the entire meadow is 84 cow-calf pairs, which graze the meadow for 5 months, resulting in 420 animal-unit months (AUM) of grazing. Because a restoration that removed grazing from the entire meadow would remove all 420 AUMs, we scaled the effect based on the proportion of the meadow where grazing is excluded, resulting in a removal of 14.7 AUM (3.5 % of 420 AUM). Assuming 30 days in a month, and a conservative average methane emission rate of 200 g CH_4 per day per animal-unit, this yields 6000 g CH_4 per AUM, or 88,200 g CH_4 eliminated per year by excluding cattle from the restoration area. Methane is $12/16^{th}$ carbon by mass, therefore the grazing treatment eliminates an estimated 66,150 g CH_4-C emissions per year.

3. Detailed project description, including all tasks to be performed:

Carbon, hydrogeomorphic conditions, and habitat value will be quantified and compared across Childs Meadow treatments. The restoration plan will include two restoration treatments in the central section of Childs Meadow, with the upper and lower sections of Childs Meadow left untreated as controls. This study design allows a comparison of the benefits of low-cost restoration strategies to business as usual grazing (upper meadow) and the impacts of grazing exclusion combined with natural beaver activity (lower meadow). The central meadow channel (restoration treatment reach) will be fenced to exclude cattle and planted with willows, with ½ of the reach also modified with beaver dam analogues. We limited the number of BDA structures to six to qualify as a demonstration project under CEQA categorical exclusion. The tasks to be performed for meadow restoration include:

1. *Complete Fencing on Lower Meadow (2 channel miles):* We will complete fencing of the lower meadow to exclude cattle grazing (Figure 1) using a combination of split rail cedar (TNC property) and barbed wire fencing (US Forest Service property), in collaboration with the US Forest Service. Beaver moved into this section of Gurnsey Creek after 2006 and have built two lodges, a multi-dam complex consisting of 15 dams ranging from 6-113 feet wide and creating ponds up to 0.37 acres in size (Figure 4). We expect

the removal of livestock grazing in this portion of the meadow will lead to increased carbon storage in willow and other riparian vegetation, as well as carbon stored in existing and any newly constructed beaver ponds.

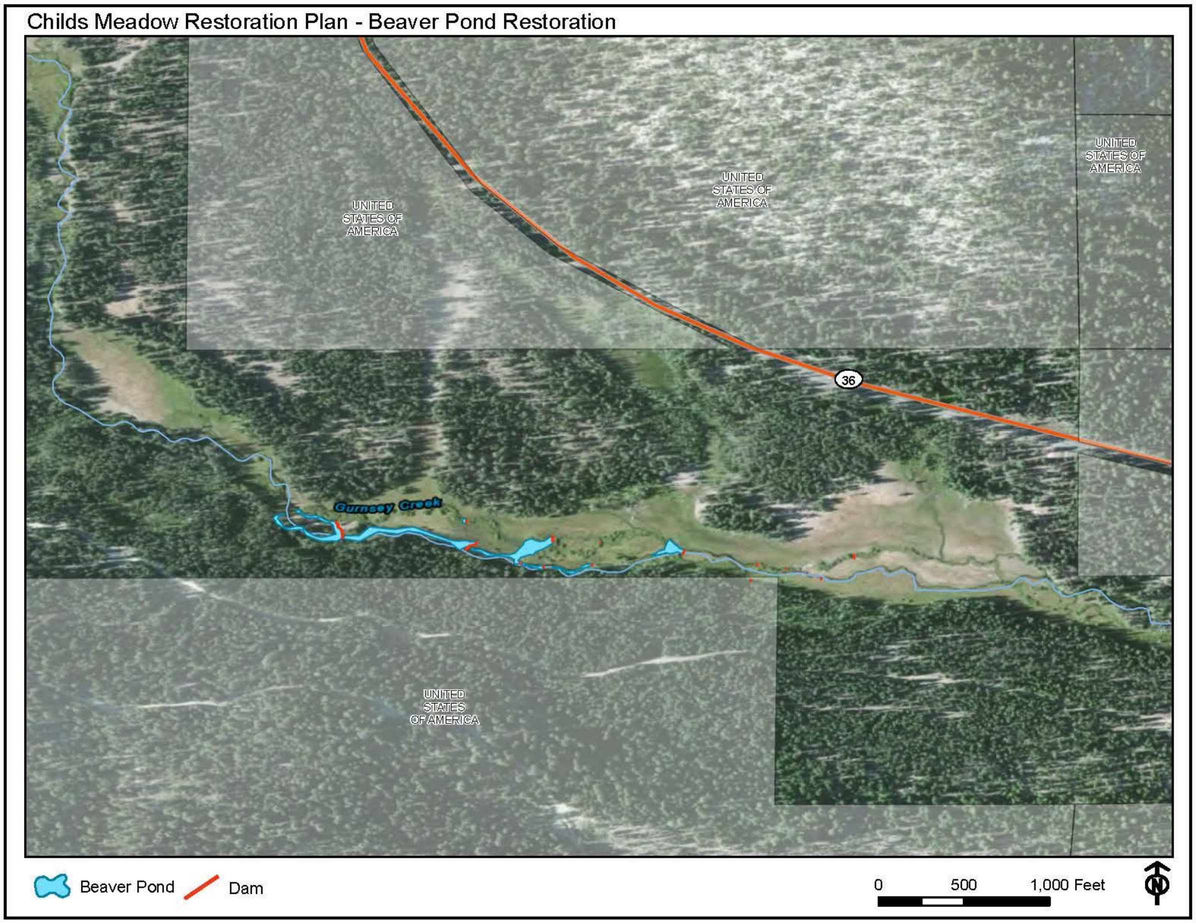

Figure 4. Lower portion of Childs Meadow where beaver dam currently exist.

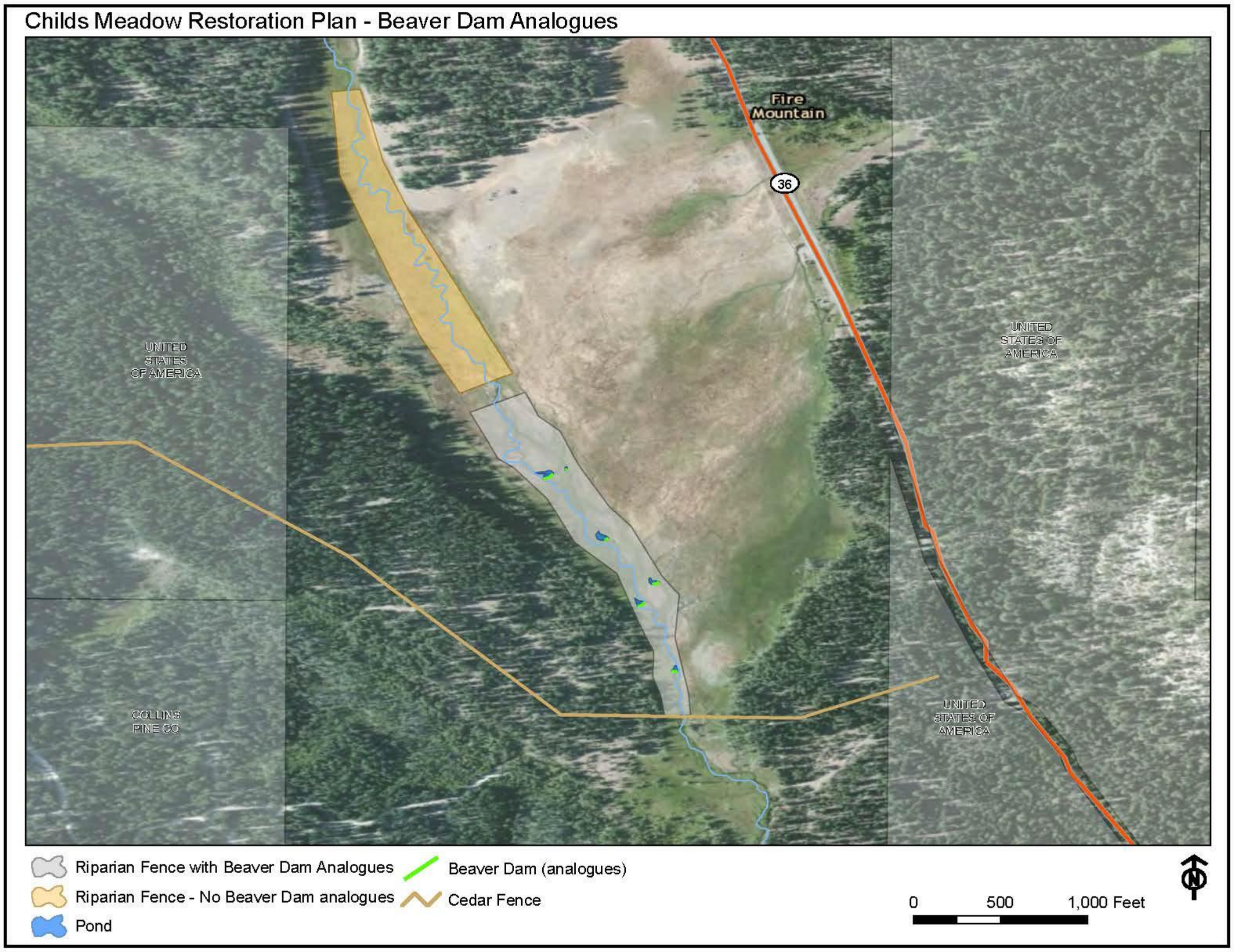

Figure 5. Middle portion of Childs Meadow showing restoration treatments with and without beaver dam analogues.

2. *Install fencing in the Central Meadow (0.8 channel miles):* The central section of the meadow is currently heavily grazed, and the riparian area in particular is heavily impacted by grazing, with an average utilization of herbaceous plants of 83% compared to 31% outside of the riparian corridor in 2014 (paired plot comparison). Average willow use was recorded as 82% for the 12 willow shrubs found in the central portion of the meadow. This level of grazing utilization and willow browsing by cattle exceeds the standards on National Forest meadows and is a concern as it limits potential for new willow recruitment that reduces above-ground carbon storage and habitat value of the meadow. TNC will construct 0.84 miles of riparian fencing (4 wire, smooth wire on bottom) to exclude cattle grazing along the edges of the braided channel in the middle section of the meadow, enclosing 9.3 acres of meadow area (Figure 5). We expect fencing this section to limit grazing will significantly increase above and below ground carbon storage, willow recruitment, and improve habitat conditions for wildlife.

3. *Complete Willow Planting in the Central Meadow (0.8 channel miles):* TNC will also complete restoration planting of willows along the entire middle section of Childs Meadow, using willow cuttings from on site, downstream of the beaver restoration reach. We will set up a volunteer willow planting day and plant the willows in patterns that mimic the willow distribution along the beaver ponds in the downstream end. We will use willow cuttings and willow bundles sunk into the streambank, focusing on planting in erosion areas caused by cattle crossings (Figure 5).

4. *Install Beaver Dam Analogue Structures in the Central Meadow (0.4 channel miles):* TNC will construct and install 6 beaver dam analogue (BDA) structures in the central reach of Childs Meadow to recreate the impacts of natural beaver activity. BDAs were first conceptualized by Michael Pollock, National Oceanic and Atmospheric Administration, and tested for coho salmon habitat improvement on Bridge Creek in Washington, where they were found to be successful at improving habitat and survivorship for salmon (Pollock et al. 2012, Pollock et al. 2014). The BDA structures will be constructed to approximate the width, spacing, and ponded surface areas of natural beaver dams documented in the lower meadow. The BDA structures will be designed based on successful applications of this technique on Bridge Creek in Washington and on the Smith River in California and consist of post lines with willow weaves that span the entire channel cross-section. We expect BDAs will promote bed aggradation by storing sediment and carbon, reconnecting the floodplain, and increasing instream and riparian habitat heterogeneity and habitat quality (Figure 2). The willow weave structures, built much like a beaver dam, are a low-cost alternative to the current method of meadow restoration, ‘pond and plug’ and channel realignment/reconstruction, which can cost up to $2.5 million per mile of meadow stream and do not incorporate the role of biotic processes such as beaver dam building and large wood. We will limit the number of BDA structure to 6 to qualify as a demonstration project under CEQA categorical exclusion.

5. *Monitoring and Quantification of Benefits*: We will conduct pre-sampling of all 3 meadow sections in spring/summer 2015 prior to the restoration treatments and continue monitoring during and 3 years after treatment. Variables to be measured include:

a) <u>Above and below-ground carbon:</u> For all of treatment sections, we will collect soil samples to compare carbon storage in grassland soils, beaver dam analogues, and beaver dams. For the ponds, constructed and created by beaver, we will survey the volume of sediment trapped behind the dams and collect sediment samples to determine total organic carbon. We will assume a bulk density of 1.8 g/cm^3 following the methods of Wohl (2013).

We will measure carbon dioxide flux in-situ in real time using an infrared gas analyzer and portable plastic chamber. Methane and nitrous oxide will be sampled from the chamber headspace using syringes, stored in glass exetainers under dark, refrigerated conditions, and transported to a lab for analysis on a gas chromatograph within one week of sampling. The methods for CO_2 and CH_4 will follow Chimner and Cooper (2002) and N_2O methods will follow Blankinship and Hart (2014). Sampling will begin as soon as soil is exposed by spring melt of the snow pack and will continue until the threat of snow in the fall. In-situ carbon dioxide flux will be measured twice per month and methane and nitrous oxide samples will be taken 4 times during the summer: 1) at the very first exposure of soil, 2) during vigorous spring growth of meadow plants, 3) at peak summer standing biomass, and 4) in late summer when plants are senescing.

A primary area of uncertainty for gas flux in Childs Meadows is for processes occurring at the meadow surface below the winter snowpack. If conditions permit, we will attempt winter subnivean sampling. We will also sample below the snowpack where it remains during the earliest spring sampling period. We will take below-snow gas samples by pushing a rod with attached gas-sample hose down through the snowpack to the meadow surface following the methods of Hubbard *et al.* (2005). Carbon dioxide concentration will be measured in-situ using the PP Systems EGM-4. The process of CO_2 sampling will pump air through the hose, purging the line, and all data and samples will be taken following the purge after CO_2 readings have stabilized. Immediately following CO_2 sampling, syringe samples will be extracted from the hose for CH_4 and N_2O analysis in the lab, as above.

b) Hydrogeomorphic conditions, including groundwater levels, stream flows, ponded water extent, water and air temperatures, channel morphology, and vegetative community structure. We will install a minimum of eight piezometers, 2 in each treatment section of the meadow to monitor changes in groundwater levels through time. We will install stage gages in the channels in each section, and use time lapse photography to monitor surface water extent in each meadow section throughout the spring and summer season. Water and air temperatures will be monitored in each treatment area using 15-minute loggers, and geomorphic conditions will be evaluated monthly in stream channels and pond locations following standard USFS protocols. Vegetative community structure will be evaluated seasonally using airborne lidar and photogrammetry. Results will be assessed in a GIS framework to allow for spatial comparisons through time.

c) Abundance and distribution of Cascades frogs: In all treatment and control sections, we will conduct population-level surveys for Cascades frogs following standard survey methodologies. In 2015, we will conduct at least three pre-restoration surveys and will follow with at least three post-treatment surveys every year for a minimum of three years. For Cascades frogs, all breeding locations and frog locations will be mapped and post-metamorphic frogs will be measured and marked with either a Passive Integrated Transponder (PIT tag) or Visual Implant Elastomer (VIE). In this way, we will be able to assess survival, movement and recruitment in the treatment and control sections (e.g., Pope 2008). All frogs will be swabbed for the amphibian disease, chytridiomycosis, to determine whether restored habitats improve or worsen conditions for this deadly fungal pathogen.

d) Avian monitoring: TNC will subcontract to and collaborate with Point Blue Conservation Science to conduct avian monitoring and quantify the short-term response of the avian community and willow flycatchers to the restoration treatments. We will compare these to avian diversity and abundance in the lower and upper meadow, as well as historic survey data from Childs Meadow. We will use existing historic data from Childs Meadow and the region to better quantify bird response to the proposed meadow restoration as a result of beaver, habitat impacts of BDAs, and riparian fencing, as well as link meadow bird density and health to measured meadow carbon sequestration benefits. Point Blue will establish five meadow bird demographic monitoring study plots along Childs Meadow. Each plot will be approximately 10 hectares. Plots will cover the range of restoration treatments including: grazing exclusion with recently active beavers, riparian fencing with artificial BDAs and planted willows, riparian fencing with no BDAs and planted willows, and no change in management. Within these study plots, Point Blue will locate and monitor nests and determine territory densities for five meadow focal bird species known to breed in Childs Meadow: Yellow Warbler, Song Sparrow, MacGillivray's Warbler, Wilson's Warbler, and Willow Flycatcher. Point Blue will monitor these plots from May 15 – July 31 for 2 years. In July, they will conduct vegetation assessments of every nest located that year as well as a sample of random locations. Response variables will include the density of these breeding birds and their nesting success. Nests will be checked at least once every four days and followed until their fate is determined. Each breeding male of the five focal species occurring on every plot will be followed at least 8 times to map a minimum convex polygon of their territory. Point Blue will produce a report summarizing results for the year. Pending funding we will continue monitoring these study plots for 2 additional years, culminating in a final report synthesizing all results.

6. *Place results from Childs Meadow in regional context*. In order to provide place the results from the Childs Meadow restoration activities in a regional context, we will compare the carbon sequestration values in at least five other existing restored and

unrestored mountain meadows across the Cascade Range to values observed in the Childs Meadow study treatments. We will select the comparison meadows in conjunction with a newly funded mountain meadow research project that focuses on delineating habitat suitability characteristics for Cascades Frogs (match funding provided by National Fish and Wildlife Foundation through USFS Pacific Southwest Research Station). Using the same methodology as in Childs Meadow and Wohl (2013), we will collect soil samples in each comparison meadow once seasonally in two years to account for potential yearly fluctuations in soil carbon content. Project coordination and management of all data collected both within Childs Meadow and in comparison Cascade Range meadows will be completed in consultation with a registered Project Management Professional at UC Davis.

4. Timeline:

The total project includes one year of pre-restoration and implementing restoration activities (June 1, 2015 – June 1, 2016) with the bulk of the activities to take place during the summer of 2015, three years of post-implementation monitoring (June 1, 2016-June 1, 2019), and six months following to complete final analyses, write final reports and publishable papers (June 1, 2019-November 30, 2019).

5. Deliverables:

We will proivde annual reports on the progress of each restoration and monitoring phase, to be delivered Dec 31 of each project year (starting in 2015). Reports will include an Executive Summary, Introduction, Task Reports, Conclusions and Recommendations as appropriate. By the end of the project, we expect to submit at least one manuscript to an appropriate peer-reviewed scientific journal, and to have presented project results at no less than two scientific conferences. We also expect to present project reports to the California Meadows Working Group (funded by National Fish and Wildlife Foundation), CDFW and other interested parties.

6. Expected quantitative results (project summary):

With installation of beaver dam analogues in the restoration treatment section, we expect an average storage of 1150-1400 Mg C/Ha in active beaver dams, 300-400 Mg C/ha in relict beaver dams, and 40-100 Mg C/ha in dry grassland soils, similar to values observed by Wohl (2013) in Rocky Mountain National Park in Colorado. She extrapolated these values as representing 8% of the total carbon storage in the headwaters with relict beaver dams, and

23% with active beaver dams, concluding that the loss of beaver populations in the headwaters drives conversion from wet beaver meadows to dry grasslands, with associated loss of carbon storage (Wohl 2013). We hypothesize the beaver meadow at Childs will store a similar amount of carbon per hectare (1150-1400 Mg C/ha), the beaver dam analogues will store moderately less carbon because there are no active beaver (300-400 Mg C/ha), and the restoration treatment without beaver dam analogues will store significantly less and will be comparable to the upstream dry grassland reach with no restoration treatment (40-100 Mg C/ha).

7. Protocols:

To estimate carbon storage both above and below ground in all observed meadows across the Cascade Range, we will follow protocols established by Wohl (2013) for beaver-occupied meadows in Colorado. Hydrogeomorphic conditions will be evaluated following protocols developed by the US Forest Service for meadow typing (Weixelman et al 2011) and stream surveys (Harrelson et al 1994). Sensitive species surveys will be conducted following visual encounter survey protocols developed by (Heyer et al 1994).

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