Section 5: Project Description

1. PROJECT OBJECTIVES:

A. Introduction

Wetlands, including mountain meadows, are important components of the global carbon (C) and nitrogen (N) cycles. Wetland soils are characterized by high C contents which are maintained and increased by high primary productivity and litter inputs, in combination with low decomposition rates. High net primary productivity consumes atmospheric carbon dioxide (CO_2); however, the same conditions that lead to soil C accumulation can also promote the emission of methane (CH_4) and nitrous oxide (N_2O), potent greenhouse gases (GHG) with global warming potentials 34 and 298 times greater than CO_2 (Myhre et al. 2013). Wetlands account for 30-40% of total global CH_4 emissions and are also potential sources of N_2O (Myhre et al. 2013). Undisturbed wetlands are typically net GHG sinks, but the effects of drainage and grazing can result in net GHG loss to the atmosphere as well as a loss of ecosystem services and biodiversity (Norton et al. 2011, Viers et al. 2013).

Mountain meadows, though smaller in area extent than low-elevation wetlands, may be regionally important hotspots of GHG production and soil C sequestration on the landscape, comprising approximately 5 % of montane forested areas globally (Follett et al. 2000). Many California mountain meadows have been degraded through overgrazing and draining, likely becoming net sources of GHG to the atmosphere. Wetland degradation can also lower water quality, reduce wildlife habitat, and decrease biodiversity (Norton et al. 2011, Viers et al. 2013). Within the Tahoe Basin, historic sheep grazing resulted in widespread destruction of the diverse and abundant mountain meadow systems. By the mid-1900s, nearly the entire historic meadow complex extending inland from the Upper Truckee Marsh had been subjected to channelization, meadow draining and destructive land use practices. The urban development boom following the 1960 winter Olympics resulted in further modifications to these ecosystems. The Upper Truckee Marsh is the largest remaining wetland in the Sierra Nevada but it has been severely degraded (Roll et al., 2013). Its prolonged disturbance has resulted in poor ecosystem function in terms of water quality, habitat, and biodiversity (Murphy and Knopp, 2000; Swanson Hydrology and Geomorphology, 2004 and references therein), and is hypothesized to have caused significant GHG loss. **Thus, the restoration of mountain meadows in the Upper Truckee River Watershed offers the opportunity for GHG sequestration and co-benefits of improved water quality and habitat.**

Mountain meadow restoration projects, such as those in the Upper Truckee River Watershed, have been shown to reverse some of these negative water quality and biological impacts, but little research has quantified the net GHG benefits – if any – of restoration efforts over short and long time scales. **The primary goals of this project are to measure and monitor existing mountain meadow restoration projects to characterize C and N pools and fluxes in order to quantify the net GHG balance, while also quantifying potential co-benefits for water quality and habitat restoration.**

Montane areas are likely to be particularly sensitive to on-going global changes. Increases in atmospheric CO_2 concentrations, temperature, and atmospheric N deposition may stimulate plant growth which could result in higher soil C storage in montane meadows. However, these changes will also significantly impact the hydrology of montane meadows, leading to earlier spring melts and drier summer conditions. Drier, warmer soils may promote soil organic matter decomposition and decrease soil C storage. Anthropogenic increases in N deposition throughout the Western US are negatively impacting terrestrial and aquatic ecosystems (Fenn et al. 2003a, 2003b). The Sierra Nevada are downwind from major urban areas and are estimated to receive at least 3 kg N ha^{-1} (Fenn et al. 2003b), with deposition expected to increase (Fenn et al. 2003a). Nitrogen addition can change vegetation populations and increase N_2O emissions. Understanding the mechanistic drivers of GHG production and C and N cycling in mountain meadows is needed to better predict their responses to restoration and to future global change, but little research has specifically investigated these systems.

B. Project objectives

This project aims to quantify the ability of mountain meadow ecosystem restoration projects to offset greenhouse gas (GHG) emissions and improve ecosystem services at multiple spatial and temporal scales in order to inform investments of past and future restoration efforts. The project will leverage over $50 million that the local resource management agencies have invested in restoring mountain meadows within the watersheds draining to the Upper Truckee Marsh. The research will monitor and model 6 sites along a restoration chronosequence in the Upper Truckee River (UTR) and Trout Creek Watersheds. The three main objectives for this project are to:

1) ***Determine the long-term net GHG fluxes by measuring seasonal GHG fluxes (CO_2, CH_4, N_2O) and using a biogeochemical model (DAYCENT) to estimate fluxes under current and projected climatic conditions.*** The model will be used to extrapolate and quantify the net C and GHG fluxes to other comparable mountain meadow restoration sites throughout the Sierra Nevada.
2) Identify and quantify the effects of mountain meadow restoration on hydrologic variables for meadow function and select vegetation and biological indicators of habitat value.
3) Create a toolkit to define process, metrics and reporting formats for meadow restoration efforts in the Sierras on project and watershed scales. The toolkit will allow land managers to cost-effectively prioritize projects and predict and verify GHG costs and benefits as a function of restored meadow geomorphology, soil characteristics, climate and other key attributes of ecosystems services.

2. BACKGROUND AND CONCEPTUAL MODELS:

A. Background

Mountain meadow carbon cycling:

Mountain meadow C cycling is similar to other terrestrial ecosystems (Figure 1). Plant growth consumes CO_2 from the atmosphere and incorporates C into plant tissues above and below the soil surface. Mountain meadow productivity is sensitive to moisture availability, and wet meadows typically have higher biomass and biomass turnover than dry meadows (Fisk et al. 1998). Plant C is transferred into the soil organic matter pool when roots die and when surface litter is incorporated through mixing, translocation, or burial by flood deposits. Mountain meadow soil C is typically high; soils were 3-9 % C in the 0-12 cm depth in a sub-alpine meadow in Yosemite (Blankinship and Hart 2014), 3 % C (0-20 cm depth) in an alpine meadow in the eastern Sierra Nevada (Walker et al. 1992), and 1-4 % C in 83 mountain meadows in or adjacent to the Stanislaus National Forest (Norton et al. 2011). Soil organic matter accumulates to such high levels because it is more slowly decomposed by microbes under the saturated soil conditions common in mountain meadows due to oxygen limitation (Whalen 2005). Mountain meadows typically have high water contents throughout most of the year: up to 40% in one alpine meadow throughout the summer (Walker et al. 1992), and up to 69 % in another subalpine meadow in June and September (Blankinship and Hart 2014); high moisture content under warm temperatures can promote CH_4 production. However, if soils are characterized by an overlying aerobic zone, CH_4 may be oxidized before it is emitted from the soil (Smith et al. 2003, Whalen 2005, Blankinship and Hart 2014). Soil C can also be lost through leaching (dissolved organic C) and physical erosion. Sediment loads in highly functioning restored mountain meadows are low because soil is physically protected by vegetation.

Degradation of mountain meadows causes large net C losses from the ecosystem. Channel straightening creates drier soils that flood less frequently; the exposure of soil organic matter to aerobic conditions leads to accelerated decomposition. Plant productivity decreases, decreasing organic matter inputs and exposing soil to erosion. Channel incision destabilizes stream banks causing erosion. A broad survey of mountain meadow soil properties showed that, on average, channelized mountain meadows had half the soil C compared to functioning wet meadows in the Sierra Nevada (10 kg C m^{-2} vs. 20 kg C m^{-2}, respectively) (Norton et al. 2011). Aerobic degraded soils may oxidize more CH_4, but this likely does not offset such large soil C loss. As a result, degraded mountain meadows are hypothesized to be net sources of GHG.

Some evidence indicates that restoration projects can revert wetland function so the restored ecosystem is a net sink (Audet et al. 2013), but no work has specifically compared GHG emissions from restored and degraded mountain meadows. The net GHG impact of mountain meadow restoration is determined by the change in GHG fluxes and the change in soil C stocks. In order to determine the net GHG impacts, the main pools and major fluxes must be quantified before, during, and after restoration.

Global changes that will impact mountain meadow C cycling in the Western US include warmer temperatures, earlier snow melt, and more precipitation as rain than snow (Stewart et al. 2005, Barnett et al. 2005, Coats 2010, Myhre et al. 2013). Across many types of ecosystems, soil CO_2 emissions increase exponentially with increasing temperature (Smith et al. 2003). However, some warming experiments in the Rockies showed little effect of temperature (Harte et al. 1995). Projected climate changes are likely to produce drier soils in the Sierra Nevada. Although no research has been conducted in the Sierras, drought stress significantly decreased mountain meadow CO_2 uptake in the Rocky Mountain study (Saleska et al. 1999). The response of Sierra Nevada mountain meadow C cycling to climate change has not been quantified and is highly uncertain.

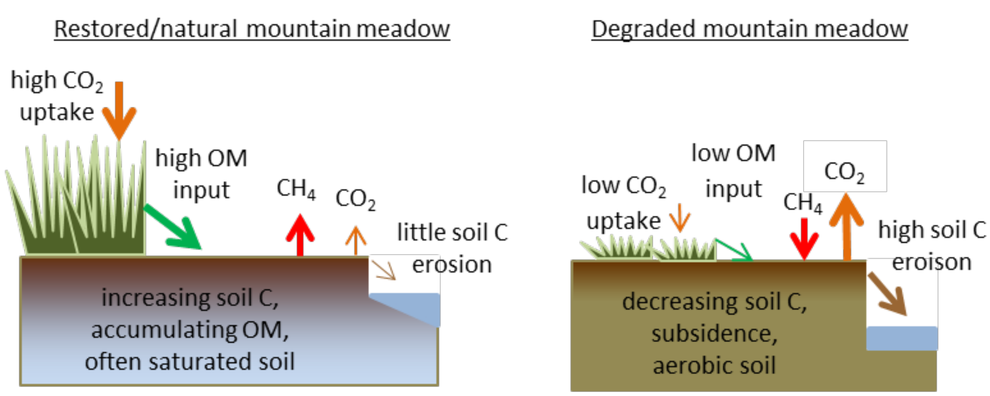

Figure 1. Comparison of hypothesized carbon cycles in natural/restored and degraded mountain meadows. Arrow size corresponds to relative flux rate.

Mountain meadow nitrogen cycling

Nitrogen cycling in terrestrial and aquatic ecosystems has been extensively studied, but it is also extremely complex. Nitrogen is found in solid, dissolved, and gaseous phases which are transformed through biotic and abiotic pathways. Nitrification, the oxidation of ammonia (NH_4^+) to nitrate (NO_3^-) by microbes, is generally an aerobic process (Conrad 1996, although see Yang et al. 2012). Denitrification is an anaerobic, microbially-driven process that produces N_2O and nitrogen gas (N_2). Field and modeling studies suggest that N_2O emissions are sensitive to soil C and N contents, oxygen availability, and soil moisture (Firestone et al. 1980).

Soils are generally net sources of N_2O. During denitrification in soils, N_2O is reduced to N_2, but the rate of N_2O production usually exceeds the rate of N_2O reduction. A review of reports of N_2O consumption suggested that soils with high water-filled pore space and low NO_3^- availability would be most likely to be at least temporary N_2O sinks (Chapuis-Lardy et al. 2007). These conditions may be met in many restored alpine meadows; N_2O consumption has been measured during the summer in one California subalpine meadow (Blankinship and Hart 2014).

Nitrous oxide fluxes in wetlands are typically low, but heterogeneous in space and time. Abrupt changes in soil conditions can result in rapid microbial responses and pulses of N_2O emission. For example, thawing of soils has been shown to produce some of the highest N_2O emissions from soils in cold regions (Christensen and Tiedje 1990, Filippa et al. 2009). Likewise, precipitation events can also trigger pulses of N_2O emissions (Filippa et al. 2009). Drying is also likely to stimulate N_2O production as N mineralization increases during organic matter decomposition. These dynamics make N_2O fluxes highly variable in space and time. However, they can be the dominant drivers of seasonal and annual N_2O emissions from ecosystems and, thus, are important to accurately characterize in mountain meadow soils.

In many ecosystems, N_2O emissions are increased by N additions (Chadwick et al. 2000, Avrahami and Bohannan 2009, van Groenigen et al. 2011, Li et al. 2012, Audet et al. 2014). Increasing N deposition has been observed and is predicted to increase in the Sierra Nevada (Fenn et al. 2003b), but the impact of this on the net GHG balance of mountain meadows is uncertain. Experimental fertilization of mountain meadows has shown varying results, with fertilization sometimes increasing N_2O emissions and sometimes decreasing them (Jiang et al. 2010, Li et al. 2012); fertilization also impacted the C cycle, but the results were also equivocal. The data currently available are insufficient to predict mountain meadow response to observed and predicted increases in N deposition. Characterization of mountain meadow N cycling and the mechanisms driving N_2O production is needed to better predict their response to future N deposition.

Mountain meadow ecosystem services

Extensive degradation of mountain meadows due to draining for grazing purposes has negatively impacted hydrologic function, water quality and ecosystem biodiversity and function, as well as released stored soil C. Restoration of mountain meadows as a result of modifications in geomorphic form equates to measureable increases in beneficial ecosystem services (Figure 2). Restoration actions that modify the geomorphic form of a mountain meadow system result in conditions that enhance and restore a collection of ecosystem attributes and supporting services. These include water quality, groundwater recharge, vegetation complexity, and biological diversity (Figure 2). Attributes at each functional level of a mountain meadow wetland can be quantified in a manner that collectively document project scale as well as cumulative watershed scale restoration benefits.

Upper Truckee River Watershed

Upper Truckee River (UTR) restoration efforts are reestablishing natural geomorphic form, providing significant downstream water quality and habitat benefits. Geomorphic improvements increase overbank flow, floodplain inundation, raise groundwater levels, and improve habitat quality for fish and wildlife (Millar, 1996; Loheide et al., 2009). The UTR watershed supports over 80% of the approximately 340 wildlife species found in the Lake Tahoe Basin (TRCD, 2003). Substantial downstream pollutant load reductions specific to the UTR watershed have been recently documented (2NDNATURE 2014). This is critical to improving the clarity of Lake Tahoe, because the UTR watershed contributes an estimated 25% of the total amount of fine sediment entering the Lake every year (Roll et al., 2013). Furthermore, the UTR region also supports a variety of recreation opportunities to residents and visitors, including snow and water sports, hiking, biking, climbing, birding, hunting, and fishing. These benefits can have tangible economic value (e.g. Guo et al., 2000).

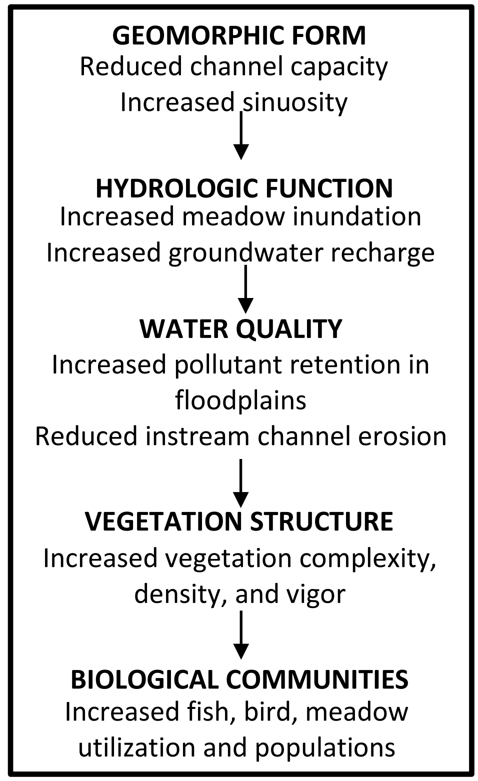

Figure 2. Conceptual model of the linkages between restoration actions that directly modify geomorphic form and restore meadow function. Specific example attributes that may be monitored, quantified and recommended for tracking over time for this effort (in addition to GHG reductions) are provided (modified from 2NDNATURE et al., 2010).

The local natural resource managers within the Tahoe Basin have made, and continue to make, exceptional progress towards restoring the function of a significant area of mountain meadows. Over the past two decades, the Lake Tahoe Basin has received over $2 billion of federal and state monies to enhance and restore the basin in an effort to protect the valued unique natural resource status of the area. To this end, mountain meadow and wetland restoration have been a prioritized strategy to reduce pollutant loads to the Lake, restore and protect natural ecosystem function, enhance the habitat quality and quantity of important biological species, and improve recreational benefits. These meadow restoration efforts have been led, and continue to be led, by the primary land owners: the California Tahoe Conservancy (CTC), USFS Lake Tahoe Basin Management Unit (LTBMU) and California State Parks (CSP). This coalition of supporting public entities is in an excellent position to guide restoration efforts into the future. As a recent Blue Ribbon expert panel review of the UTR Restoration Strategy summarized: “what is done here in UTR could/should become the hallmark for management in the entire basin, state, and nation. This document/Strategy should not be viewed simply as means to achieve specific projects in the lower 9 miles, but as a general model for watershed restoration throughout the basin” (UTR Workshop 3 May 2013).

B. Study Sites

The study sites are located along the UTR and Trout Creek (TC), both of which flow through the largest drainage to Lake Tahoe, the Upper Truckee Marsh. The UTR watershed contributes the greatest average annual volumes (40% of all stream discharge) and sediments loads (2400 tons per year) compared to any other drainage in the Basin. The watershed is a low gradient depositional environment and extends nearly 9 miles from the shores of South Lake Tahoe. It was historically comprised of tens of thousands of

Restoration Name	Acreage	Lead Agency	2014 Status	Total Cost *
Upper Truckee River Golf Course	280	CA State Parks	*To be completed 2018*	$ 15,000,000
Upper Truckee Sunset Reach 5	85	USFS	*To be completed 2016*	$ 7,100,000
Upper Truckee Marsh	500	CTC	*To be completed 2020*	$ 15,000,000
Lower West Side	16	CTC	Completed 2005	$ 13,000,000
Angora Sewerline	20	CA State Parks	Completed 2002	$ 600,000
Upper Trout Creek	40	City of SLT	Completed 2001	$ 2,000,000

** Total cost includes actual or estimated planning, design, construction and monitoring dollars.*

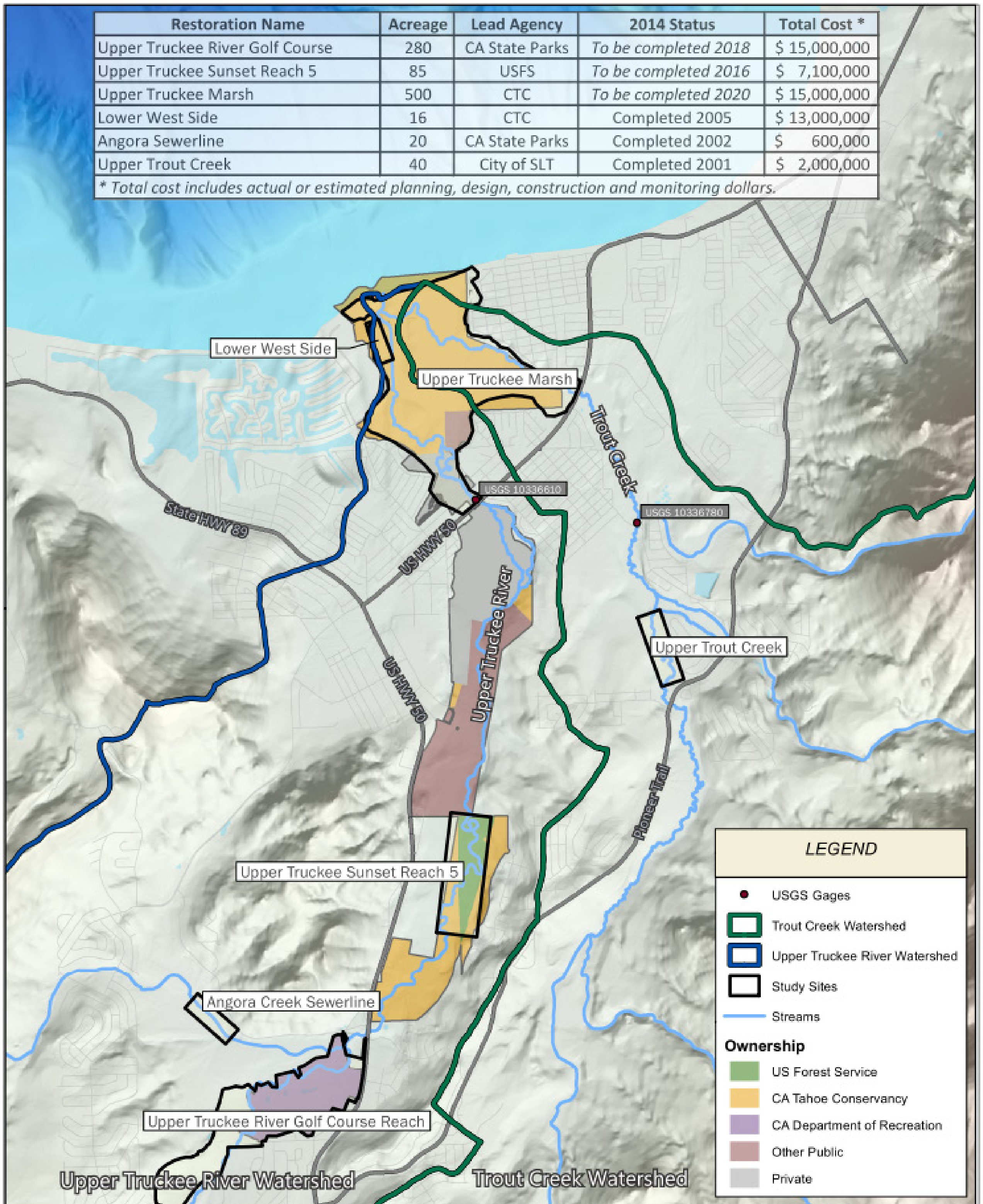

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Figure 3. Mountain meadow study sites

Table 1. Summary of study sites and comparison of current meadow conditions.

Restoration Name	Drainage Area (sq mi)	Acreage	Lead Agency	2014 Status	Current meadow inundation frequency*	Downstream water quality benefits (sediment)	Current vegetation community assemblage	Biological habitat value relative to potential
Upper Truckee River Golf Course	42.4	280	CA State Parks	*planned completion 2018*	never	contributes 26 MT/yr ^	60 % managed turf 40 % dry meadow	very low
Upper Truckee Sunset Reach 5	51.3	85	USFS	*planned completion 2016*	infrequency; isolated to very large runoff events	removes 1 MT/yr ^	60% dry meadow 20% upland 20% willow scrub	low
Upper Truckee Marsh	98	500	CTC	*planned completion 2020*	spatially variable but majority requires above average water years	none	20% upland 40% dry meadow 20% willow scrub 20% obligate sedge meadow	moderate
Lower West Side	20	16	CTC	Completed 2005	require average water year	some; but no estimates available	80% obligate sedge meadow 20% mesic meadow	high
Angora Sewerline	4.4	20	CA State Parks	Completed 2002	annually	removes 1 MT/yr ^	50% mesic meadow 50% wet meadow	very high
Upper Trout Creek	23.7	40	City of SLT	Completed 2001	annually	removes 11 MT/yr ^	85% wet meadow 15% willow scrub	very high

** Inundation includes both main channel overbank and surfacing of shallow groundwater during spring snow melt conditions.*

^ Sediment estimates in metric tons (MT) by 2NDNATURE 2014

acres of functional mountain meadows; however, nearly all of this mountain meadow habitat was degraded by the mid-1900s. Recent restoration efforts have started to bring portions of the watershed back to pre-industrial conditions. The range of mountain meadow condition that exists today will be leveraged in our experimental design.

Six study sites have been prioritized within the UTR watershed**.** The location, size, current status, property owner, and total or expected restoration costs are provided in Figure 3. Table 1 provides a summary of the study sites and their current meadow conditions. More detailed site descriptions including photographs of site conditions are in Appendix 1. Each of the six sites has been or are planned to be restored and one site, Sunset Reach 5, will transition from pre to post project during this study. These ecosystems likely functioned similarly to each other in the past, but today possess a diverse range of inundation frequency, soil characteristics, vegetation distributions, and associated biological utilization. Each of the meadow sites selected has been identified as high priority opportunities for restoration in the UTR Watershed (Tahoe Resource Conservation District, 2003 and Swanson Hydrology + Geomorphology. 2004).

The table in Figure 3 is organized from most degraded to most functional as of 2014. The Upper Truckee River Golf Course Restoration represents the most degraded of the existing mountain meadow sites. Field sampling of native meadow surfaces (not managed turf of the golf course) within this meadow complex will be representative of pre-restored conditions. Upper Trout Creek and Angora Sewerline meadows represent the functionally restored and desired mountain meadow habitat type. This range of meadow condition will facilitate the application and extrapolation of the GHG and co-benefit findings to allow reasonable estimates of the expected benefits on all previous and planned restoration projects.

C. Project Justification

Objective 1: Quantification of mountain meadow greenhouse gas emissions and carbon sequestration

Mountain meadows comprise ≤ 3 % of the Sierra Nevada, California (Keeler-Wolf et al. 2012; USGS, 2014) but may be important hotspots of GHG production or uptake and C sequestration within alpine and subalpine landscapes. For example, a small spring-fed wetland in the Sierra Nevada foothills had significantly higher CH_4 and N_2O emissions compared to surrounding oak savannah (Oates et al. 2008). However, CH_4 and N_2O uptake occurred in a subalpine meadow in Yosemite National Park in July and August, with strong soil water content effects (Blankinship and Hart 2014). Snow cover slowed but did not stop GHG production or consumption in alpine meadows (Sommerfeld et al. 1993, Liptzin et al. 2009, Riveros-Iregui and McGlynn 2009, Saito et al. 2009, Suh et al. 2009, Filippa et al. 2009, Hu et al. 2010).

Restoration of wetlands has not consistently produced net GHG benefits. The high global warming potential of CH_4 compared to CO_2 means that increases in CH_4 emissions may offset C sequestration. Research on a restored wetland in the Sacramento-San Joaquin Delta (Miller et al., 2011) and two restored wetlands in Denmark (Herbst et al., 2011; Audet et al., 2013) has shown potential for restored wetlands to remain GHG sources. No similar work has been done on mountain meadows.

Justification: We will measure CH_4, N_2O, and CO_2 simultaneously over two complete years, including snow-free and snow-covered periods, in conjunction with soil data and hydrologic monitoring. These data will offer an unprecedented opportunity to understand the mechanisms controlling GHG production By measuring along a restoration chronosequence, we can infer the progression of ecosystem development following restoration over 12 years. This field data will enable the first biogeochemical modeling of mountain meadows in California (using DAYCENT) which has been shown to accurately represent ecosystem C and N pools and fluxes in many ecosystems including alpine tundra (Chimner et al. 2002, Hartman et al. 2007), agricultural fields (Del Grosso et al. 2006, De Gryze et al. 2010), grasslands (Ryals et al. in press). We will use the model to predict changes in net GHG fluxes across a range of environmental conditions (spatial scaling) and under future climate scenarios (temporal scaling).

Objective 2: Quantification of mountain meadow co-benefits

Mountain meadow restoration projects result in a myriad of co-benefits. Useful assessment of these co-benefits for resource managers requires quantification of a key set of metrics. These metrics should characterize the primary improvements, can be conducted by resource (in addition to research) personnel, and are functional across a range of restoration types and regions. We will identify and quantify which ecosystem parameters provide the optimal set of characteristics that can be used by resource managers to track the effectiveness of restoration projects and prioritize future restoration initiatives. Evaluation of ecosystem co-benefits is grouped into 5 categories: Geomorphic Form, Hydrologic Function, Water Quality, Vegetation Structure, and Biological Communities.

Justification: Our work will provide the first systematic collection of restoration co-benefit data, and by leveraging pre-existing data, we will quantify the co-benefits of restoration over moderate timescales (<10 y) and determine protocols for best practices in site monitoring. The diversity of sites studied here will enable us to scale our results regionally and state-wide.

Objective 3: Development of a management tool

An on-going challenge for resource managers is integrating effectiveness monitoring into restoration. This has resulted in irrelevant pre-restoration characterization, excessive sampling variability between pre- and post-project monitoring, limited sampling durations, as well as the lack of clear and focused experimental designs to account for the inherent natural climatic and hydrologic variability within the datasets obtained. The Blue Panel expert review of the UTR Restoration Strategy stated that, “there was inadequate reference to or utilization of existing methods of data management and sharing tools” (UTR Workshop 3 May 2013). This has limited the ability for the partners to clearly articulate priorities to stakeholders and the public. In turn, the ability to extrapolate the cumulative benefits of mountain meadow restoration on a regional and basin wide scale has also been stalled.

Justification: While a significant amount of restoration and improvements have been implemented to date, there remains a critical information gap regarding the development and evaluation of specific restoration objectives. 2NDNATURE led the development of an approach to quantify, report, and manage mountain meadow restoration actions with the Tahoe Basin practitioners (2NDNATURE et al. 2010). Building from the 2NDNATURE framework established in 2010 and from the 2013 review of the UTR Restoration Strategy, this project will identify field observations, quantitative measurements, and reporting formats to guide practitioners in prioritization efforts and evaluate post-project effectiveness.

***3. DETAILED PROJECT DESCRIPTION, INCLUDING ALL TASKS TO BE PERFORMED*:**

To achieve the objective of this project – to quantify the net GHG benefit of mountain meadow restoration and evaluate ecological and water quality co-benefits – we will perform the following tasks: 1) quantify the net GHG balance of 6 mountain meadows along a restoration gradient through field measurements (Task 1A) and model alternative and future conditions using the ecosystem biogeochemistry model DAYCENT (Task 1B); 2) quantify the co-benefits of mountain meadow restoration; 3) develop a management tool to guide evaluation of net GHG fluxes and co-benefits of restoration; 4) produce a final report and disseminate the results.

Task 1A: Quantify the impact of restoration on GHG fluxes – UC Berkeley

The restoration of alpine meadows is hypothesized to decrease net GHG fluxes but these have not been systematically measured or quantified previously, with few exceptions (Norton et al. 2011). The Upper Truckee River watershed offers a unique opportunity to evaluate mid-term GHG benefits of restoration by substituting space for time: we will measure GHG fluxes at a series of mountain meadows representing a range of 'time-since-restoration' as well as pre-restoration (i.e., degraded) conditions. This approach is common in ecology and has been used to evaluate restoration activities in the Sacramento-San Joaquin River Delta (Hatala et al. 2012). This approach allows us to evaluate the impacts of restoration over a longer timespan than would be possible by studying only one restoration site over the duration of the grant period.

GHG fluxes will be measured using two approaches, one which will monitor both inter- and intra-annual variability (static chambers) and the other which will capture short term variations associated with major changes to soil conditions such as thawing and flooding (automatic chambers). We will deploy static flux chambers every 2-4 weeks at each site that will provide a spatially extensive time series of GHG fluxes across a range of climatic and soil conditions. Static flux chambers have been used to monitor GHG fluxes in many ecosystems, including wetlands (Teh et al. 2011, Burgin and Groffman 2012, Audet et al. 2013, 2014) and alpine tundra (Torn and Harte 1996). During each GHG flux measurement using a static chamber, soil moisture and temperature will be measured at the chamber location. We will also install soil moisture, oxygen, and temperature sensors at 3 depths in 3 locations in each site. These will be connected to a solar-powered data logger to collect nearly continuous measurements. This will enable the correlation of soil conditions and climate with GHG fluxes at a fine temporal scale. At one site we will also deploy automatic chambers connected to a trace gas analyzer to collect quasi-continuous gas flux measurements during periods when GHG fluxes are expected to fluctuate, such as thawing, drying, or warming periods (Mosier et al. 1993). These will also provide a comparison for the static flux data, enabling us to scale the less frequent static chamber measurements to estimate more robust mean annualized GHG flux rates.

Personnel and feasibility: GHG measurements, soil sampling, and soil analysis will be carried out by Dr. Justine Owen, a researcher in the lab of Professor Whendee Silver at UC Berkeley. Dr. Owen has led similar research projects to quantify the net greenhouse gas impact of grassland management in California (Owen et al., submitted; Owen and Silver, in preparation). She will be assisted by a to-be-hired laboratory technician and undergraduate assistants. Dr. Owen will be assisted in field work and sample analysis by a to-be-hired laboratory technician and Heather Dang, the lab manager in Dr. Silver's lab. The Silver lab owns and operates an automatic chamber system and cavity ring down spectroscopic laser for GHG analyses in a remote tropical forest. They have a working relationship with the companies that build the system, and will have access to their technicians for assistance in the design and deployment of the sampling system. Gas sampling campaigns of similar scale have been successfully completed in Dr. Silver's lab.

Task 1B: Biogeochemical modeling of mountain meadows – UC Berkeley

Ideally, the net GHG and ecosystem benefits achieved by mountain meadow restoration will be widespread, long-lasting and self-sustaining, but most field monitoring programs of restored meadows provide limited predictive ability over large spatial and temporal scales. Biogeochemical models offer a means to predict ecosystem C and N budgets across a range of environmental conditions and in a future affected by global changes in temperature, precipitation characteristics, and N pollution, changes that may significantly alter ecosystem function. Models require careful parameterization and calibration with high quality field data. DAYCENT has been used to effectively model C dynamics in various wetland ecosystems (Chimner et al. 2002, Cheng et al. 2013; Malone et al., in review), which provides a strong basis for using DAYCENT in mountain meadow ecosystems. We will use the data collected in Tasks 1A and 2 to parameterize and calibrate DAYCENT for each study site. Daily climate data are required to run DAYCENT; daily temperature, precipitation, and snowpack data for the Upper Truckee River Watershed are available beginning in 1955 from the Western Regional Climate Center.

Using the model, will we quantify the net GHG balance of the study sites historically based on past management data and project decades or centuries into the future. In the futurecasts we can explore the effects of increasing temperature, changing precipitation characteristics, and increasing N deposition, and quantify the net GHG balance of the sites under a range of future scenarios. We will also test the model across a range of environmental conditions typical of mountain meadows throughout the state.

Personnel and feasibility: Dr. Justine Owen of UC Berkeley will collaborate with Dr. William Parton of Colorado State University to parameterize DAYCENT. Dr. Owen has used DAYCENT to model intensively managed pastures in California and calculate historic and future net GHG balances (Owen et al., submitted). She created new parameters to model different types of manure amendments. Dr. Parton is the original developer of DAYCENT (Parton et al. 1998) and its parent model CENTURY (Parton 1996) and will contribute his vast expertise to assist in parameterizing DAYCENT for mountain meadows.

Task 2: Quantify the co-benefits of restoration – 2NDNATURE

Geomorphic Form: Restoration efforts typically involve modifying the channel to increase sinuosity and decrease bank height, in order to promote floodplain inundation on a 1.5-2 year recurrence interval and restore the natural balance in lower grade alluvial channels (Leopold et al., 1964; Williams 1978; Dunne and Leopold 1978). We will characterize channel geometry with measurements including channel slope, sinuosity, and entrenchment ratio (Rosgen 1996; CWMW 2009). Channel geometries are not expected to vary significantly during the course of this study. Field measurements will be collected during the first site visit and repeated only if significant changes, such as major flood events, have occurred.

Hydrologic Function: Hydrologic connectivity operates in longitudinal, lateral, and vertical dimensions and over time (Schumm 1977; Ward 1989). We will quantify the spatiotemporal degree of floodplain inundation by installing staff plates and stage recorders at each site. Stage recorders provide continuous measurements of channel flow depth. This will be integrated with USGS streamflow measurements and LiDAR datasets to model and quantify the hydrologic attributes of each meadow. The frequency of overbank flow and the duration of floodplain inundation will be will be quantified. We hypothesize that an increase in the frequency in the duration of floodplain inundation is related to sediment accumulation on the floodplain and linked with overall net carbon benefits. We will also use the characterization of topographic complexity of the floodplain surface to evaluate the meadow's ability to hold and store water in topographic depressions, thereby increasing groundwater recharge and pollutant retention. Groundwater recharge will be estimated by comparing expected stream flow estimates and actual measurements at stream stage recorders.

Water Quality: Successful restoration of self-sustaining fluvial processes is expected to reduce pollutant inputs from bank and bed erosion and increase pollutant retention on the floodplain. We will estimate downstream sediment load reductions as well as nutrient deposition on the floodplain. Reducing downstream sediments loads limits undesirable runoff to Lake Tahoe and promotes sediment deposition in the floodplain, stimulating vegetation growth and increasing soil C and N content.

Previous research has been conducted to evaluate stream sediment load reductions as a result of restoration efforts in the Tahoe region (2NDNATURE, 2013, SLRTv1). The research resulted in the public release of a tool, the Stream Load Reduction Tool (SLRT), which predicts site specific stream sediment loads based on user input. Recently applied to 7 restoration efforts in the UTR watershed (2NDNATURE, 2014), SLRT will provide a consistent and standardized methodology to estimate the average annual sediment loads at each site which will be compared to previous estimates. The methodology will incorporate existing floodplain and terrain modeling as well as hydrologic, geomorphic, physical and vegetation attributes of each study site.

The most significant water quality pollutant affecting the clarity of Lake Tahoe is fine sediment. We will install a total of 9 passive samplers across three transects at each study site to collect sediment during overbank flow in order to characterize the lateral (distance from stream), longitudinal (distance downstream), and vertical (water depth) sediment retention capabilities of the meadow. The samples will be analyzed for total sediment and nutrient concentrations. Any amount of fine sediment that is retained on the floodplain instead of carried downstream is a net benefit in preserving the clarity of Lake Tahoe. Nutrient concentrations will be measured to determine a linkage between floodplain deposition and habitat benefits.

Vegetation Structure and the Biological Communities: Improved meadow function produces improvements to local habitat quality. A restored meadow includes vegetation that provides shading and root structures that promote bank and channel stability (Simon et al., 2006). A well-developed stream bank vegetation canopy will reduce maximum daily temperatures, provide allochthonous organic material to the stream ecosystem, serve as a source of woody debris to the stream, assist with overhanging bank development, and provide food supply as well as predation protection to aquatic wildlife (USFWS 1992; Entrekin, 2008). Increases in terrestrial and aquatic species diversity as well as growth within individual populations are both indicators of overall meadow health.

Vegetation structure will be evaluated along three transects that extend from the channel to the edge of the meadow on both sides of the stream. Multiple observations will be made along each transect. At each location, vegetation type, vegetation vigor, and rooting depth will be recorded based on observations within a standardized radius. Additionally, the relative density of shrub vegetation species, particularly willow, will be measured as the number of established individuals along the transect. At the steam/meadow interface, streambank vegetation will be quantified by measuring the proportion of relative cover over a standardized bank length based on the vegetation type.

Terrestrial and aquatic habitat quality encompasses a wide range of physical, chemical, and biological conditions. Some species in the UTR Watershed, such as bats and birds, are more susceptible to perturbations of the riparian ecosystem and can serve as proxies for meadow habitat quality (2NDNATURE, 2010). Bats feed on terrestrial insects and benthic macroinvertebrates typically in the dusk hours; bat presence is expected to be higher in riparian ecosystems with more abundant insect populations (Reid, 2006). Bat abundance will be measured as the total number of individuals observed from 1 hour pre-dusk to 1-hour post-dusk. Desired avian species in the meadow, such as willow flycatchers, are also highly sensitive to meadow health. This species requires standing water on the floodplain in close proximity to mature shrubs to reduce predation during the breeding season (Greene et al. 2003). The abundance of willow flycatchers and other songbird species will also be evaluated.

Personnel and feasibility: 2NDNATURE will oversee and conduct all monitoring and quantification of the ecosystem co-benefits. 2NDNATURE has been extensively involved in assisting the Tahoe land managers with quantifying and reporting the co-benefits of mountain meadow restoration efforts. 2NDNATURE team members were employees of Swanson Hydrology + Geomorphology in the early 2000's and contributed to all aspects of the data collection, site surveys, data analysis and reporting of the two guiding Watershed Plans for the UTR. 2NDNATURE has also conducted multiple-year floodplain studies on the Upper Truckee River (2008-2010) and Trout Creek (2010-2012), characterizing the ecosystem benefits described herein and is currently monitoring the Upper Truckee marsh. In 2012, 2NDNATURE authored an adaptive management plan for the North Creek Restoration Project (2NDNATURE et al., 2012). Most recently 2NDNATURE applied their customized Stream Load Reduction Tool (SLRT) to 7 planned or completed meadow restoration projects within the UTR Watershed to quantify the average annual expected fine sediment load reduction achieved by each restoration project (2NDNATURE 2014). 2NDNATURE developed the SLRT and has worked with numerous public agencies (e.g. CTC, USFS, State Parks, LTBMU, and EPA) to improve and validate SLRT estimates (2NDNATURE, 2013; 2014).

Task 3: Management tool development – 2NDNATURE

A priority of this research effort is to make the results accessible to managers. Combining the direct benefits of GHG reductions with the co-benefits in water quality and habitat in a user-friendly tool will be valuable to resource managers and fill a critical gap in evaluating effectiveness and prioritizing projects. We will evaluate the data collected in Tasks 1 and Task 2, identify key and diagnostic metrics and develop a toolkit to evaluate the benefits of mountain meadow restoration efforts throughout the Sierras. Completion of Task 3 requires the following: a) collaboration of the entire research and support team, b) identification of the key metrics using standardized formats, and c) final categorization of the net GHG and associated co-benefits of mountain meadow restoration efforts.

We will coordinate workshops to screen potential metrics and select the most adequate parameters to quantify benefits. In addition to clearly documenting the projected net GHG benefits, at least one parameter from each of the five primary categories will be included - Geomorphic Form, Hydrologic Function, Water Quality, Vegetation Structure, and Biological Communities. A priority of this research is that the results can be expanded spatially and temporally for application to other projects within the UTR Watershed, the Lake Tahoe Basin, and the Sierra Nevada.

Personnel and feasibility: 2NDNATURE, in partnership UC Berkeley, will lead coordination of the tool development with the local stakeholders. For the last ten years, 2NDNATURE has worked with area stakeholders (e.g. USFS, CTC, State Parks, local city and country agencies) to identify cost effective measures and develop tools that assist in the prioritization of adaptive management projects (e.g. RoadRAM, BMP RAM, and Rural RoadRAM, www.2ndnaturellc.com). 2N led the development of the Riparian Ecosystem Restoration Effectiveness Framework (2NDNATURE, 2010). From guiding pre-construction objective development to reporting of post-construction priority metrics, this framework provides an adaptive management process for resource managers. Dr. Silver, as lead scientist of the Marin Carbon Project, worked with the implementation team and the Environmental Defense Fund to develop a nationally-recognized C sequestration reporting protocol for compost amendment to rangelands (American Carbon Registry 2014). This has led to project implementation throughout Marin County, demonstrating the potential for the application of management practices derived from hypothesis-driven research.

Task 4: Dissemination of results and scientific merit – UC Berkeley and 2NDNATURE

A **final report** will be co-written by UC Berkeley and 2NDNATURE personnel and delivered to CDFW at the conclusion of the project. The report will comprehensively describe the original purpose, approach, results, and conclusions of the work outlined in this proposal.

The data, interpretation, and management tool generated by this project will be disseminated in several ways. The final report will be made publically available by posting it on UC Berkeley's eScholarship site (a permanent open-access site) and in the California state data repository at http://data.ca.gov/, as well as the websites of 2NDNATURE and CTC. 2NDNATURE will organize **workshops** with land managers in the Upper Truckee River Watershed for input during the model development and education following its completion. **Information sheets** generated by UC Berkeley and 2NDNATURE personnel summarizing the quantitative results and documenting the management tool will be freely available at the workshops and online.

This project will generate **several scientific manuscripts** of broad scientific interest for publication in peer-reviewed journals. These include:

- a paper that compares field measured ecosystem characteristics along the restoration chronosequence and quantifies net ecosystem benefits (GHG balance and co-benefits) in the short term (< 10 y),
- a paper that describes the novel calibration and application of DAYCENT to restored mountain meadows and estimates mountain meadow net GHG balance under future climate scenarios in the long term (10-100 y), and
- a paper that compares the results of DAYCENT to those of the management tool developed by this project.

These papers will be written by Drs. Owen and Silver with input from 2NDNATURE personnel. Due to the time required for manuscript preparation, review, and publication, these papers may not be published by the time the project funding is complete. They will be published in open-access journals or we will pay for the open-access option so that they are freely available on the journal websites and can be posted to the same data repositories and websites described above for the final report.

4. Timeline:

Sites have already been selected and permissions granted, thus fieldwork can begin as soon as funding is granted.

	2015			2016				2017				2018	
Task	**su***	**f**	**w**	**s**	**su**	**f**	**w**	**s**	**su**	**f**	**w**	**s**	**su**
Task 1A: Quantify the impact of restoration on GHG fluxes													
static chamber sampling	■	■	■	■	■	■	■	■	■				
gas analysis		■	■	■	■	■	■	■	■				
order automatic chamber	■	■	■										
deploy automatic chamber				■	■			■	■				
soil sampling	■				■								
soil processing		■	■			■	■						
data analysis and interpretation		■	■	■	■	■	■	■	■	■	■		
Task 1B: Biogeochemical modeling of mountain meadows													
model parameterization				■	■	■	■	■	■				
model calibration and calculation of net GHG balances						■	■	■	■	■	■		
calculation of net GHG benefit of restoration						■	■	■	■	■	■		
Task 2A: Geomorphology, hydrology and water quality													
geomorphic form measurements	■												
hydrological monitoring equipment installation	■												
hydrological monitoring	■	■	■	■	■	■	■	■	■				
passive sediment sampler deployment and collection			■	■			■	■					
Task 2B: Vegetation and biological co-benefits													
vegetation and biological surveys	■	■	■	■	■	■	■	■	■				
Task 3: Tool development													
tool development					■	■	■	■	■	■	■		
workshops for land manager input and education						■				■		■	
tool test												■	
Task 4: Final report													
preparation of final report								■	■	■	■	■	
delivery of final report													■

* su = summer, f = fall, w = winter, s = spring

5. Deliverables:

Final Report The final report will document all measurements (GHG, soil, hydrology, geomorphology, vegetation, and biology) and synthesize the results into a comprehensive, quantitative analysis of:

- the current GHG balance and ecosystem functioning of each site
- the benefits of restoration either already achieved at the restored sites or expected at the degraded sites
- the potential for continued GHG sequestration under future climate scenarios
- the key ecosystem metrics necessary for the evaluation of restoration outcomes
- the regional potential for GHG sequestration through mountain meadow restoration

The report will also describe the development of the management tool and its applicability.

Documentation of tool and protocols We will provide a separate report documenting the technical aspects of the management tool and protocols for its implementation.

Information sheets As part of our outreach efforts, we will produce information sheets describing the management tool and its application aimed at land managers and land-owning agencies.

Workshop results We will produce reports describing the workshops; these will summarize the information presented by project personnel, feedback from attendees, and subsequent actions.

Data availability Data collected by the project will be **publically available electronically and in hardcopy**. The final report will be posted on UC Berkeley's eScholarship site (a permanent open-access site) and in the California state data repository at http://data.ca.gov/, as well as the websites of 2NDNATURE and CTC. Scientific manuscripts generated by the project will be published in open-access journals or we will pay for the open-access option so that they are freely available on the journal websites. We will also post them to the same data repositories and websites as for the final report. Following the publication of the scientific manuscripts, we will make the complete datasets and maps available.

6. Expected quantitative results (project summary):

Methods and the data necessary to predict the net GHG benefits of mountain meadow restoration projects are not currently available. We estimated the carbon sequestration potential of the sites included in this study using the soil C contents measured by Norton et al. (2011) in 86 mountain meadows, acknowledging that this does not account for CH_4 and N_2O fluxes. Degraded meadows had ~10 kg C m^{-2} less than functioning meadows. We used this number and the total acreage of degraded and restored mountain meadows considered in this project to estimate the potential C gain through restoration of the degraded meadows and the realized C gain in the already restored sites (Table 2).

Carbon offsets from other wetlands are now eligible to be traded in two voluntary markets in the United States. The first standard deals specifically with the restoration of degraded deltaic wetlands of the Mississippi Delta and was created by the American Carbon Registry. The second standard is a national standard for wetlands restoration and conservation created by Verified Carbon Standard as part of their Agriculture, Forestry and Other Land Use standards. If a protocol for C sequestration was created for mountain meadow restoration projects, offsets could be made available for the California compliance market if the ARB deems them eligible. **We calculated the value of this C in a carbon market (Table 2).** This would create a source of revenue for land managers in the Sierra to put toward additional restoration efforts and maintenance of restored mountain meadows.

Table 2 Estimated carbon sequestration and potential revenue for carbon offsets in a voluntary carbon market if a mountain meadow offset protocol is established.

Sites	Project Area	Sequestered Carbon[1]	Potential Revenue in Carbon Market[2]
	Acres	Tonnes	$
Restored Acres	76	3,076	$46,134
Degraded Acres	865	35,005	$525,075

[1] Based on a sequestration rate of 10 kg C m^{-2} (Norton et al. 2011). For degraded lands, we estimate the potential if land is restored.

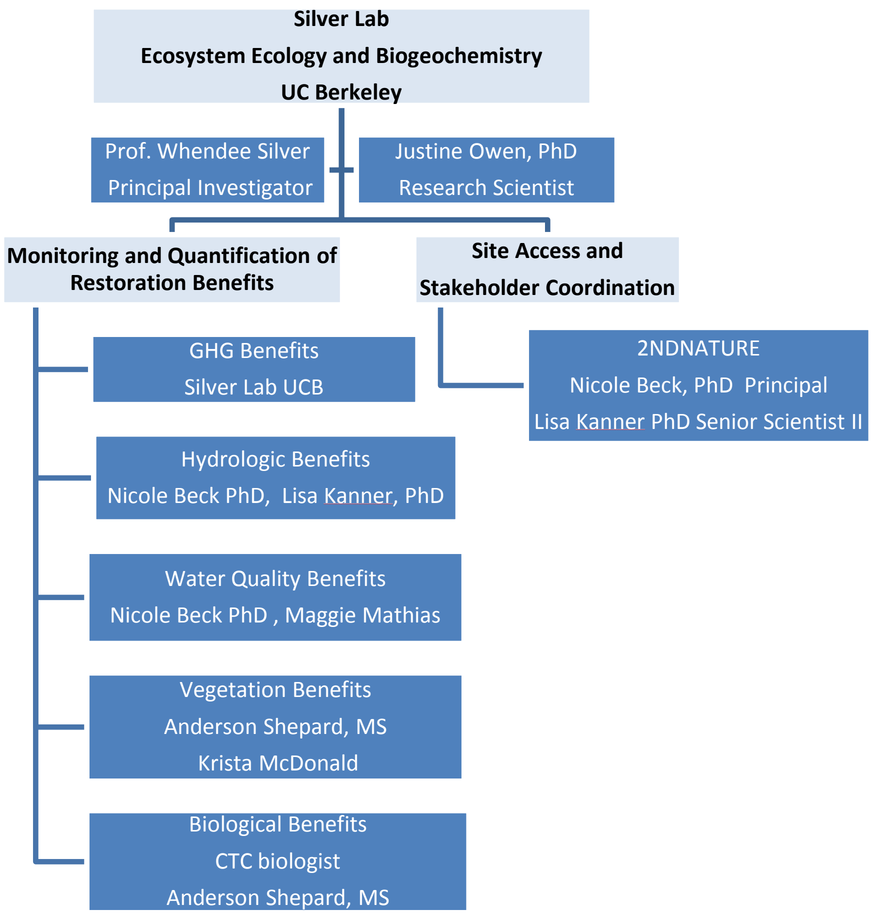
[2] Based on $15 per tonne of carbon.

Plan for maintenance of GHG gains in perpetuity

Landowners (USFS, CTC, State Parks) are invested in maintaining the meadows for co-benefits and will continue to monitor the sites. They will act if monitoring indicates decreasing meadow function and soil C retention. See attached letters of support.

7. Protocols:

Organization chart



Task 1A. GHG and associated measurements for calculating ecosystem net GHG balances

GHG measurements with static chambers

Twelve static chambers arranged in a grid oriented perpendicular to the stream channel will be used to measure trace gas fluxes at each site. Each chamber consists of a 30-cm diameter PVC ring base which is inserted ~10 cm into the soil. To avoid any effects of soil disturbance, the rings will be installed at least 30 minutes prior to sampling to allow time for the soil environment to stabilize. A vented chamber top will be placed each ring and gas samples will be collected at 0, 5, 15, 25, and 40 minutes using a flushed syringe. At each static chamber location, soil temperature and moisture will be measured in the underlying 20 cm using temperature and moisture probes. The gas samples will be stored in pre-evacuated gas vials until analysis using a Shimadzu GC-14A gas chromatograph (Shimadzu Scientific Inc., Columbia, Maryland, USA), equipped with a Porapak-Q column, flame ionization detector (FID), thermal conductivity detector (TCD), and electron capture detector (ECD) in Whendee Silver's lab at UC Berkeley. Fluxes will be calculated using an iterative exponential curve-fitting approach (Matthias et al. 1978).

GHG measurement with automatic chambers and laser gas analyzer

The automatic chamber system requires line power so it will be deployed at a site with available power. Nine automatic chambers will be deployed in a grid to capture GHG flux variations parallel and perpendicular to the stream. They will be connected to a portable PICARRO G2508 CRDS analyzer which simultaneously measures CO_2, CH_4, N_2O, NH_3, and H_2O with parts-per-billion sensitivity and at a measurement rate of less than 8 seconds. The analyzer uses a Telecom, Near-Infrared (NIR) laser with an effective measurement path length of up to 20 km. A small pump cycles a stream of air continuously from each chamber to a manifold which switches between inputs to measure gas concentrations in each chamber. Included software automatically calculates trace gas fluxes using standard curve-fitting algorithms.

Soil sampling, monitoring, and analysis

Soil samples will be collected at 5 locations along 40 m transects (i.e., 10 m apart) volumetrically using metal soil corers. Soils will be sampled at depth intervals of 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm, 30-50 cm, and 50-100 cm (if possible). At 3 locations in each field site we will install Apogee soil oxygen sensors and Campbell Scientific temperature and moisture probes at depths of 5 cm, 30 cm, and 1 m. These will be connected to Campbell Scientific data loggers and a solar power system. The data loggers will measure soil temperature, moisture, and oxygen content every 5 minutes and record the data as 30 minute means. Soils will be processed and stored in Whendee Silver's lab at UC Berkeley for analysis. A fresh sub-sample will be mixed with 2M potassium chloride (KCl) solution, filtered, and analyzed for inorganic N (NO_3^- and NH_4^+) on a Lachat autoanalyzer (Milwaukee, WI). A sub-sample will be air dried then oven dried at 105°C to determine bulk density and water content. Soil pH will be measured on a fresh sub-sample mixed in a 1:1 slurry with deionized water. An air-dry sub-sample will be sieved, have visible roots removed by hand-picking, and ground to a fine powder with a ball grinder (SPEX Sample Prep Mixer Mill 8000D, Metuchen, NJ), then analyzed for C and N concentration on a Carlo Erba Elantech elemental analyzer (Lakewood, NJ) using atropine as a standard.

Task 1B. Model calibration and evaluation

DAYCENT requires site specific inputs including soil characteristics (pH, texture, bulk density, C content, field capacity, wilting point, and saturated hydraulic conductivity over specific depth intervals), daily climate data (minimum and maximum temperature, precipitation, solar radiation, relative humidity, and windspeed), and vegetation type and growth characteristics. The soil data will be directly measured or calculated from direct measurements. Daily climate data will be downloaded from the Western Regional Climate Center's online database. Vegetation data will be derived from field measurements and literature values. We will validate the model by comparing the model outputs with measured values of soil water content, plant growth, soil organic C, and N flows. If these are not consistent, we will adjust model parameters within reasonable constraints until the outputs are within 10 % of measured values. We will test how sensitive the model is to specific variables through iterative runs. Once the model has been satisfactorily parameterized for each site, we will run simulations of future scenarios to quantify net GHG benefits of restoration over decadal to century scales. We will use the model outputs to calculate the average net GHG benefit by area for all the study sites as well as a range. We will also generate a generic mountain meadow parameterization which we will also use to calculate the net GHG benefit by area. Using these numbers and estimates of alpine meadow extent and state (degraded, restored, natural), we will calculate a state-wide estimate of the current net GHG benefit of natural and restored mountain meadows and the potential net GHG benefit of restoring degraded mountain meadows. The range in types of mountain meadows studied here will allow us to estimate the range and uncertainty of this calculation.

Task 2. Ecosystem Services
Geomorphic Form
Geomorphic field surveys will be conducted at the first site visit in Summer 2015 and will include visual observations and measurements that can be obtained with a stadia rod, tape, and a GPS device. For Upper Truckee Sunset Reach 5, which will undergo construction in 2015, pre-restoration and post-restoration geometry will be measured.

- A series of ***cross sections*** well-distributed along the reach will be measured at each site. GPS locations of all cross section endpoint monuments and thalweg locations will be taken.
- The ***slope*** (unitless) will be measured from the thalweg elevation at the upper and lower cross-section/channel length, per gradient calculations outlined in Roper et al. (2002).
- The ***entrenchment ratio*** (unitless) will be estimated using the cross-section measurements that include stage and channel geometry (Leopold et al., 1964; Rosgen, 1996; California Wetlands Monitoring Group, 2009).
- Average ***bank height*** (ft) will be measured at each cross section.

Hydrologic Function
The primary components of floodplain inundation monitoring include the installation of state recorders surveyed and tied to topographic elevations, development of stage-discharge curves, and installation of staff plates to QA/QC stage data. The state recorders will be set to 15-min intervals and provide a continuous time series of stream state over the duration of monitoring. Stage recorders and passive samplers will be installed in Summer 2015. 2NDATURE will request the CTC to periodically QA/QC site instruments.

- ***Inundation frequency*** (# of days/yr) will be calculated by (# of days out of bank)/(# of days where bankfull is exceed). The continuous stage time series will be used to constrain for annual hydrologic variations. A rating curve will be developed to compare event duration out of bank with peak stage/discharge.
- ***Groundwater recharge*** (acre-feet per season) will be determined by comparing expected vs. actual stream flow measurements or using stream base flow estimates and recession-curve displacement following USGS protocol http://water.usgs.gov/ogw/gwrp/methods/compare/.

Water Quality
Water quality monitoring will involve the installation of passive samplers to collect water samples during the rising limb of inundation events. The passive sampler housing will be installed in Summer 2015. 2NDNATURE will request the CTC to periodically maintain site instruments.

- ***Floodplain sediment retention estimates*** (kg/acre/yr) will be determined using passive samplers placed along surveyed cross-sections in floodplain. Passive samplers are a low-cost method to collect water samples associated with specific floodplain water surface elevations. Bottles can be installed weeks prior to the expected floodplain inundation events and collect a water sample on the rising limb of the hydrograph (standardizing sample collection across all sites) without the need for field personnel to be on-site during the overflow event. Passive samplers are self-sealing to preserve the sample until field personnel can safely retrieve the sample for laboratory analysis (Thurston, 1999). Passive samplers will installed at elevations specific to each sites that likely to receive overbank flow at least 2 times per year. Elevation and locations of the passive samplers will be tied to the stage recorders. Passive samplers are specifically engineered to fill during the rising limb of an overbank event and will seal when sampler volume capacity is reached (Figure 4). Turbidity of the water samples will be measured and used as a surrogate for estimates of fine sediment particles (FSP) concentrations (see conversion equations used in 2NDNATURE and DRI, 2014). To inform SLRT estimates, sediment retention results will extrapolated based on 3-D terrain model and hydrologic records to estimate annual loads by water year type. Floodplain sampling protocols were developed by 2NDNATURE and have been adopted by the USFS http://www.fs.fed.us/psw/partnerships/tahoescience/stream_sediment.shtml.
- ***Floodplain nutrient retention estimates*** (kg/acre/year) will also be determined using nutrients in water samples collected in passive samplers. Water samples collected in passive samplers will be retrieved to meet standardized laboratory holding times for nutrients.

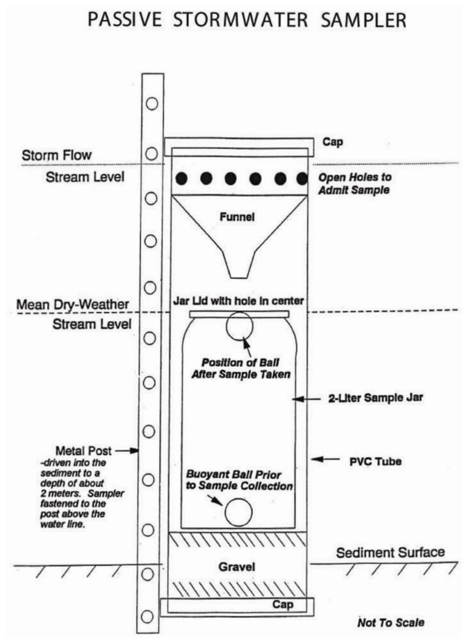


Figure 4. Cross section of passive samplers used to estimate sediment retention on the floodplain.

Vegetation Structure

Vegetation surveys will be conducted by 2NDNATURE personnel in Summer 2015, 2016, and 2017. Surveyors will walk along transects that extend from the channel to the edge of the meadow on both sides of the stream (2NDNATURE et al., 2012). The number of observations along the transects will be standardized across sites based on absolute distance between observations or the total number of observations as a percent of total transect length.

- ***Vegetation type*** (relative % of each species type) vegetation type may include grass, forbs, sedge, juncus, willow shrub, conifer, or none.
- ***Shrub density*** (average # of shrubs/100 yd^2 of floodplain or average # of shrubs/100 yd of stream bank) will be measured on the floodplain and the streambank. Shrubs must exceed 2 ft in height to be counted in the survey.
- ***Plant vigor*** (ft) will be measured by determining the average wet plant height. Using a 1 ft^2 area, complete 20-30 observations in randomly distributed locations that represent overall floodplain surface that is expected to have increased wet plant vigor as a result of restoration. Measure plant height using stadia rod placed vertically from the base of the plant. GPS location of observations and repeat observations in same locations over course of monitoring. Perform multiple times of the year if resources allow.

- ***Rooting Depth*** (ft) will be quantified at each location at locations were plant vigor are estimated. Holes will be dug or augured until roots are now longer available (0-3 ft). Rooting depth will be measured as the distance from the meadow surface to the depth at which there are approximately 100 roots <2 mm per square decimeter (i.e. where the main roots become smaller root hairs). A description of the root density at the top 0.1 to 1 ft of the hole as: "Dense" (roots visible over > 75% of circumference of hole), "Moderate" (roots visible over 25-75% of hole circumference), or "Bare" (roots visible over <25% of hole circumference).

Biological Communities
Biological surveys will be conducted by a trained professional from 2NDNATURE or the CTC. These evaluations will be conducted once a year at the same time of the year, which will be determined by the project biologist.

- ***Bat abundance*** (# of individuals per survey evening) observations will be conducted to look for bat roosting sites while following protocols outlined by the American Society of Mammalogists (1992). Dusk surveys will also be conducted using point count surveys. Season and location of evening observations will be standardized by the biologist following guidelines provided by Barclay and Bell (1988). Surveys will provide qualitative estimates of bat presence and abundance over monitoring duration.
- ***Songbird species richness*** (# of species) will be assessed to determine the species composition of birds. Point surveys will be conducted following well accepted protocols adapted from the US Forest Service (Ralph et al. 1993). A minimum number of 2 survey points are located with each project area. Species are recorded either by visual or acoustic confirmation. Observations begin at 0700 hours. Survey dates and locations of survey points are standardized by the biologist to instruct bird enthusiasts on proper field survey and data collection protocols. The number of species during each survey will be tracked over the monitoring durations.
- ***Trout abundance*** (# of species) will be determined through snorkel surveys by a trained fish biologist as adapted from the US Forest Service's protocols (Thurow 1994). Time of day, season and locations observations will be standardized to provide qualitative estimates of trout presence and relative density.

Task 3. Toolkit development
Developing the toolkit will require refinement of the metrics, description and reference to specific protocol, identification of sampling temporal and spatial frequency, and descriptions of some of the general considerations involved in monitoring effectiveness of the project. The cost of the restoration (construction + effectiveness monitoring and analysis) will be considered relative to the cost of equivalent carbon stored as a result of the project. Thus, the toolkit will include:

- A table detailing the anticipated cost of sequestered carbon as a result of the project.
- A table summarizing the objectives, metrics, protocols and expected years of sampling. All metrics will be standardized in space (per acre) and in time (per year).
- A narrative stating the anticipated construction budget per acre and the anticipated maintenance costs per acre per year.

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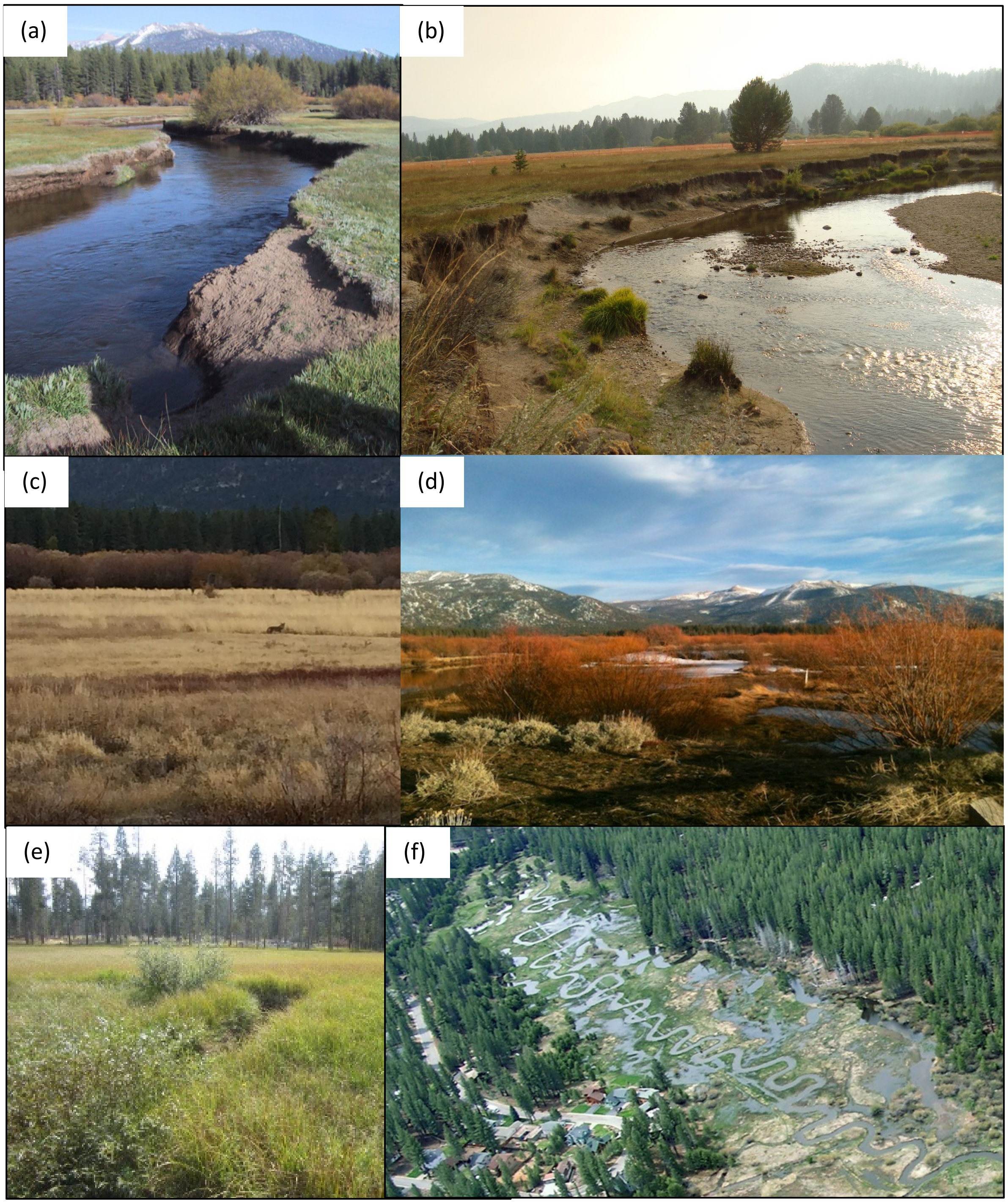
Appendix 1 – Study Site Descriptions

Figure A1. (a) Degraded dry meadow within Upper Truckee Golf Course Reach at snow melt peak, June 2011. (b) Degraded meadow in (pre-restoration) Sunset Reach 5; July 2013. (c) Dry meadow expanse in the Upper Truckee Marsh; July 2014. (d) Lower West Side site. (e) Restored meadow of Angora Sewerline; July 2013. (f) Restored meadow of Upper Trout Creek; June 2006.



1. Upper Truckee River Golf Course (Figure A1a): Restoration on the UTR Golf Course is in the preliminary design phase. The current reach has a significant amount of bank erosion and channel incision (Figure A1a). The adjacent meadow is characterized by over 50% bare soil and upland plant species with extremely poor vigor. The planned project will decrease channel capacity, channel slope, and substantially reduce bank heights. The restored meadow conditions are expected to be a mix of natural meadow and golf course turf. This restoration is currently facing public resistance. This could overcome with a demonstration of clear and quantifiable expected benefits to mitigate climate change and enhance ecosystem services. 2NDNATURE 2014 estimated the proposed restoration would reduce the average annual fine sediment particle loads in the UTR Watershed by 15 MT/km/yr.

2. Upper Truckee Sunset Reach 5 (Figure A1b): Restoration efforts on UTR Sunset Reach 5 are currently in progress and led by the LTBMU. Construction is planned to be completed in 2015. Current, pre-restoration conditions are characterized by very infrequent meadow inundation, excessive channel capacity, incision and bank erosion. This site provides the opportunity to monitor the immediate transition of a mountain meadow post-restoration. The restoration is intended to increase the frequency and duration of out bank events thereby restoring meadow function. 2NDNATURE 2014 estimated the proposed restoration would reduce the average annual fine sediment particle loads in the UTR Watershed by 13 MT/km/yr.

3. Upper Truckee Marsh (Figure A1c): The Upper Truckee Marsh is nearly 1 sq mile in size and significant potential opportunity for mountain meadow restoration. A preferred alternative for restoration efforts on the Upper Truckee Marsh have recently been approved by the CTC. Full design and environmental review is expected to be initiated in 2015 with a desired restoration completion by 2020. As the design and planning continue, quantification of the expected GHG and ecosystem benefits will be invaluable. 2NDNATURE is currently contracted with the CTC to apply SLRT to the Upper Truckee Marsh and conduct a detailed hydrologic and water quality assessment of the area. This contracted effort also includes a monitoring plan for the CTC to verify hydrologic and water quality effectiveness of the restoration.

4. **Lower West Side (Figure A1d):** This restoration was part of a larger project at the mouth of the Upper Truckee River and titled, “Cove East Restoration Project.” The project was primarily led by CTC and completed in 2005 for a total planning, design and implementation cost of $13 million. The restoration included surface lowering and contouring to increase floodplain inundation and improve meadow function. Meadow vegetation distribution is predominantly mesic meadow species with dense cover and moderate vigor. Full inundation of the restored meadow occurs during average water years, but the site has been relatively dry during the recent consecutive years of drought. A variety of pre-project topography, water quality and vegetation surveys are available. 2NDNATURE’s current hydrologic water quality monitoring effort on the Upper Truckee Marsh includes sites within this restored meadow.

5. Angora Sewerline (Figure A1e): A linear sewer line was constructed within Angora Meadow in the 1960’s. During sequential elevated flow conditions, the main channel of Angora Creek was fully overtaken by the linear sewer line. This resulted in lowing of the meadow water table and vegetation die off as well as a straightened and incised channel. Restoration efforts involved full reconstruction of the channel geomorphology, including reduction of channel capacity and channel slope while increasing channel length. Safeguards to prevent recapture were included in the restoration and completed in 2002. The successful increase in the channel grade has restored the elevations of the adjacent shallow groundwater table and resulted in a well vegetated mesic meadow with biologic diversity.

6. Upper Trout Creek (Figure A1f): The City of South Lake was the lead agency in the completion of $2 million effort to restore the upper reach of Trout Creek bounded by Pioneer Trail and the confluence of Cold Creek. As with all of these mountain meadows, the pre-restored condition was an extensive dry meadow complex due to the drainage and irrigation channel creation by Basque sheep headers in the 1880's. Restoration consisted of over 3,000 linear feet of new channel in the middle of the historic meadow. Extensive geomorphic, water quality, vegetation and biological data exists for this restoration for both pre- and post-restoration condition. This effort was extremely successful, receiving the Best in the Basin restoration award from the Tahoe Regional Planning Agency (TRPA). It is the model for a high quality meadow restoration. Over 80% of the 40 acres of restored meadow are characterized by dense, vigorous wet meadow species (2NDNATURE, 2013). 2NDNATURE conducted a detailed evaluation to quantify the effectiveness of the Upper Trout Creek Restoration (Table A1). In addition to document geomorphologic benefits, 2NDNATURE measured reach scale water quality improvements during 2010 and 2011 spring snow melt events. An estimated total of 4.9 MT and 9.7 MT of fine sediment were removed from Trout Creek, during the spring season for the respective years. SLRT estimates for the Upper Trout Creek restoration reduces the average annual fine sediment particle loads by 11 MT/yr (2NDNATURE, 2014).

Table A1. Quantified series of geomorphic form and channel/floodplain interaction benefits for the Upper Trout Creek Restoration (from 2NDNATURE 2013).

Ecosystem category	Attribute class	Attribute	Pre-restore	Post (2011)	% change
Geomorphic Form	Channel Stability	Channel slope	0.0016	0.0013	-19%
		Total stream length (m)	1530	1829	+20%
		Stream sinuosity	1.54	1.85	+20%
		Average top width (m)	7.9	4.0	-49%
		Outside bend length (m)	530	1001	+89%
		Outside bend bank height (m)	1.34	1.1	-18%
		Bank angle of outside bends (deg)	37	53	+43%
		Straight length (m)	1000	828	-17%
		Straight sections bank height (m)	1.0	0.76	-24%
		Bank angle of straight sections (deg)	34	39	+15%
	Channel/ Floodplain Relationship	Channel capacity (cfs)	200	88	-56%
		Water depth at channel capacity (m)	1.10	0.93	-15%
		Reoccurrence interval discharge at TCPT needed to exceed channel capacity (yrs)	5.0	1.9	-62%
		Duration of overbank flow (days) *(average annual using USGS data)*	1.2	17.8	+1,383%
		Volume of overbank flow (ac-ft) *(average annual using USGS data)*	96	1,380	+1,337%
		Average depth to groundwater (m)	1.09	0.65	-40%