Section 5: Project Description

1. <u>Project Objectives:</u>

Research Objective: The overarching research objective of **The Lower Deer Creek Meadow Restoration Project** is to support development of methods for estimating net carbon (CO2-equivalent) sequestration under pre- and post-restoration conditions for mountain meadows. The framework and methods employed in this project will be aligned with those proposed by other meadow restoration projects that represent a wide range of meadow conditions throughout the Sierra Nevada under the Sierra Meadow Restoration Research Partnership (SMRRP), of which Sierra Streams Institute is a member. We have two research objectives:

1. Determine potential contribution of GHG emissions to the overall carbon budget for project meadow and other meadows of same hydrogeomorphic type, geographic area (climate,

growing season), and parent material represented by this project area by measuring changes in soil carbon and peak GHG emissions under un-restored and restored conditions.

2. Support development of parameters and proxy variables that will be used to build a model to estimate meadow carbon sequestration and GHG emissions by measuring soil carbon and GHG emissions along gradients expected to control GHG flux, such as depth and duration of saturation, soil texture and carbon content, plant community type, and length of growing season.

Restoration Objective: The project will restore hydrologic function to a degraded riparian meadow, in an effort to increase carbon sequestration capabilities (see Research Objective, above), as well as mitigate the expected impacts of climate change on the local riparian ecosystem. The proposed project is one element of a comprehensive, multi-year effort focused on lower Deer Creek, aimed at restoring critical habitat for a range of climate-sensitive riparian organisms including ESA-listed species of amphibians and anadromous fish and their associated ecosystems. In this proposal, we focus on re-vegetation and hydrologic restoration of a rare meadow in the otherwise steep canyon-bound lower watershed. We have two primary restoration objectives:

1. Restore hydrologic function to the target meadow via hydrologic re-routing of a deeply incised stream.

2. Restore ecological function and integrity to the target meadow via non-native vegetation removal, native vegetation planting, invasive wildlife exclusion, and rare or threatened wildlife enticement.

Primary objectives and proposed actions are listed in Table 1.

Table 1. Lower Deer Creek Meadow Restoration Project goals, deliverables, and expected outcomes.

Objective	Proposed Action	Expected Long-term Outcomes
Restoration of 9 acres of degraded meadow and 2600 linear feet of foothill stream	See below (both vegetative and hydrologic restoration)	Increased overall meadow function with net increase in vegetative, terrestrial, and aquatic biodiversity metrics; net increase in late-season flow and C storage of the surrounding landscape
Increase in native plant community coverage and decrease in non-native plant community coverage	Non-native plant removal coupled with planting of at least 1500 native plants, including native grasses, woody shrubs, and riparian trees.	Vegetative succession of native plant community, with adaptive management, leading to resilient ecological conditions, and increased soil organic carbon and plant biomass
Increase in late-season in-stream flows and overall water retention	Hydrologic restoration; re-connection of creek to floodplain via re-grading of incised creek bank	Net increase in downstream flows with decreased peak flow and increased base flow in late season.
Restore and expand habitat for native avian, terrestrial, and aquatic biotic communities	Enhancement of ecosystem services through hydrologic and vegetative restoration of the meadow and riparian corridor.	Improve water quality for native fish through decreased stream temperatures and improved meadow filtration, while enhancing riparian habitat.
Increased understanding of quasi-headwaters regions below terminal Rim Dams	Analysis of interactions among hydrologic processes, ecological communities, and C balance via ordination and other multivariate analysis techniques (see Project Description, below)	Construction and implementation of robust meadow assessment and restoration plans for increasingly common yet under-managed Rim Dam meadows, including the Rim Dam Restoration Toolkit
Increased SOC and LOC (Net increase in overall meadow C budget)	Increased soil moisture and decreased soil temperatures, coupled with increased above- and below-ground biomass production and shallow intermittent flooding (see conceptual model)	Net increase of approximately 1800 metric tons of C uptake over the life of the project, with continued increases in C budget following project completion and adaptive management
Predictive model of carbon flux dynamics of meadows under varied hydrologic conditions	Robust analysis of net GHG flux relative to all high-resolution meadow-wide parameters such as canopy cover, soil temperature, soil moisture, biomass production, vegetative community composition shift, and climatic variation using various multivariate techniques	Increased knowledge of GHG dynamics in meadows relative to restoration among researchers and managers; adoption of guidelines and principles in both the scientific community and the land management community to inform future restoration targets

2. ***Background and Conceptual Models:***

This proposal focuses on the restoration of the only meadow in the lower Deer Creek watershed, known as the Sheatsley Meadow (Figure 1). The triangular-shaped meadow straddles the confluence of Deer Creek and its tributary Squirrel Creek. Located one mile from the Yuba confluence, the meadow is of particular strategic importance because of its proximity to salmon and steelhead spawning grounds and juvenile rearing grounds, and its potential to increase base flow during the summer and fall low-flow season (Loheide and Gorelick 2007). The meadow is privately owned and has been placed in a conservation easement along with 114 surrounding acres. Sierra Streams has partnered with property owners The Sheatsley Trust since 2000, collecting monthly water quality data at three sites on the property. Proposed work will build on the extensive water quality and vegetation dataset already collected via this partnership.

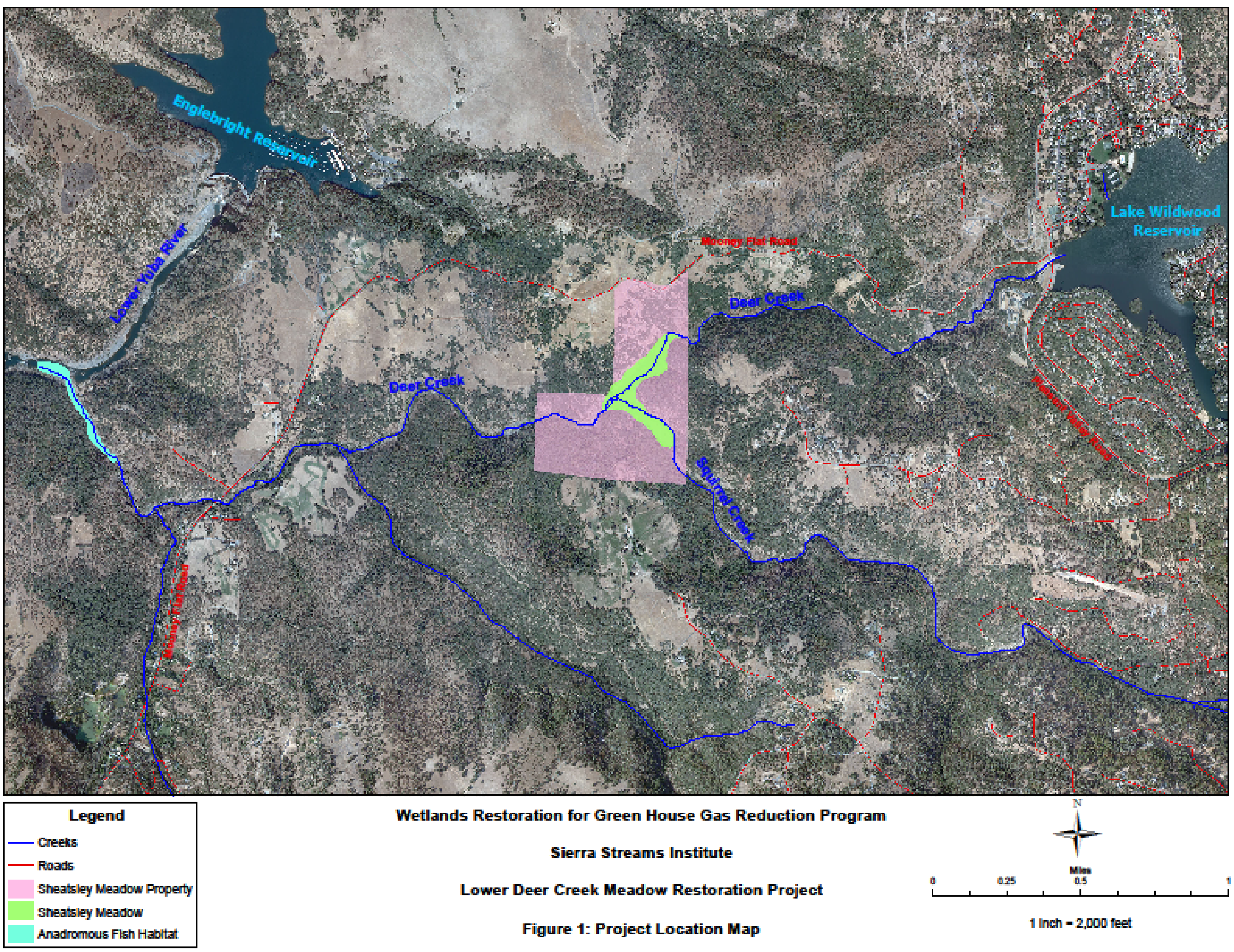

Figure 1. Proposed project location, Sheatsley Meadow, CA

The meadow's hydrological and geomorphological functions have been severely impaired by a series of impacts since the time of the Gold Rush, resulting in its transformation into seasonally parched upland-type habitat. Waste rock from gold mining operations settled in the creek margins, altering the hydro-geomorphology of the system and drastically reducing the frequency of floodplain inundation. Flooding is a major component of a natural disturbance regime in any healthy meadow, and maintenance of diverse riparian floral and faunal communities depends on maintenance of that disturbance regime (Bendix 1997). Addressing climate impacts of reduced in-stream flows and associated meadow flooding can also directly benefit native, rare, or threatened species present at the site, such as the willow flycatcher (*Empidonax traillii)* (Cain III et al. 2003) and the Foothill Yellow-legged Frog (*Rana boylii*).

Major grazing operations were in effect on the property throughout the 1900s, enabling the encroachment of invasive species such as Scotch broom (*Cytisus scoparius*) and yellow star thistle (*Centaurea solstitialis*) resulting in excessive uptake of water and a lowering of the water table that was already impacted by reduced flood frequency. Native species are highly vulnerable to the impacts of climate change, while successful invasive non-native species are less vulnerable and in some cases may even be helped by warmer dryer conditions (Moyle et al. 2013). By restoring native vegetative communities, we can mitigate the impacts of both lowered water table and increased fire susceptibility. This restored native vegetative community can also directly contribute to increased overall meadow function, which in turn can increase C uptake (Norton et al. 2011). Figure 2 is a conceptual model demonstrating restoration needs, targets, and expected outcomes.

While American beaver (*Castor canadensis)* are already present in Lower Deer Creek, suitable habitat is limited in this area due to a lack of preferred forage species (cottonwood – *Populus* spp., willow – *Salix* spp., and alder – *Alnus* spp.). *C. canadensis* uses these native riparian species for food and building material, with a particular preference for members of the Salicaceae family (willows, cottonwood, and aspen; Johnston and Naiman 1990,(Naiman et al. 1988). By felling trees for food and dam building, beavers change both the tree architecture and the environment. These changes positively influence habitat heterogeneity (Rosell et al. 2005) and biodiversity (Naiman et al. 1993, Hagglund & Sjoberg 1999), by creating wetland and instream habitat and maintaining healthy stream function, such as overbank flooding (Hammerson 1994, Naiman et al. 1994). Studies have shown that the presence of active beavers in a stream system can positively influence fish (Hagglund & Sjoberg 1998), amphibians (Stevens et al. 2006), arthropods (Martinsen et al. 1998, Bailey & Whitham 2006), and vegetation diversity (Mitchell 1999, Johnston & Naiman 1990). Beavers are expected to be particularly sensitive to climate change, as their habitat and behavior is entirely dependent on perennial streams and their associated riparian ecosystems. By enhancing and restoring the species assemblage and ecological function of the meadow and riparian corridor, this project will entice beaver populations to locate their impoundments in locations that will have the greatest ecological impact, thereby creating conditions that will have a cascading effect on the entire ecosystem (Ripple 2012) and build climate change resilience.

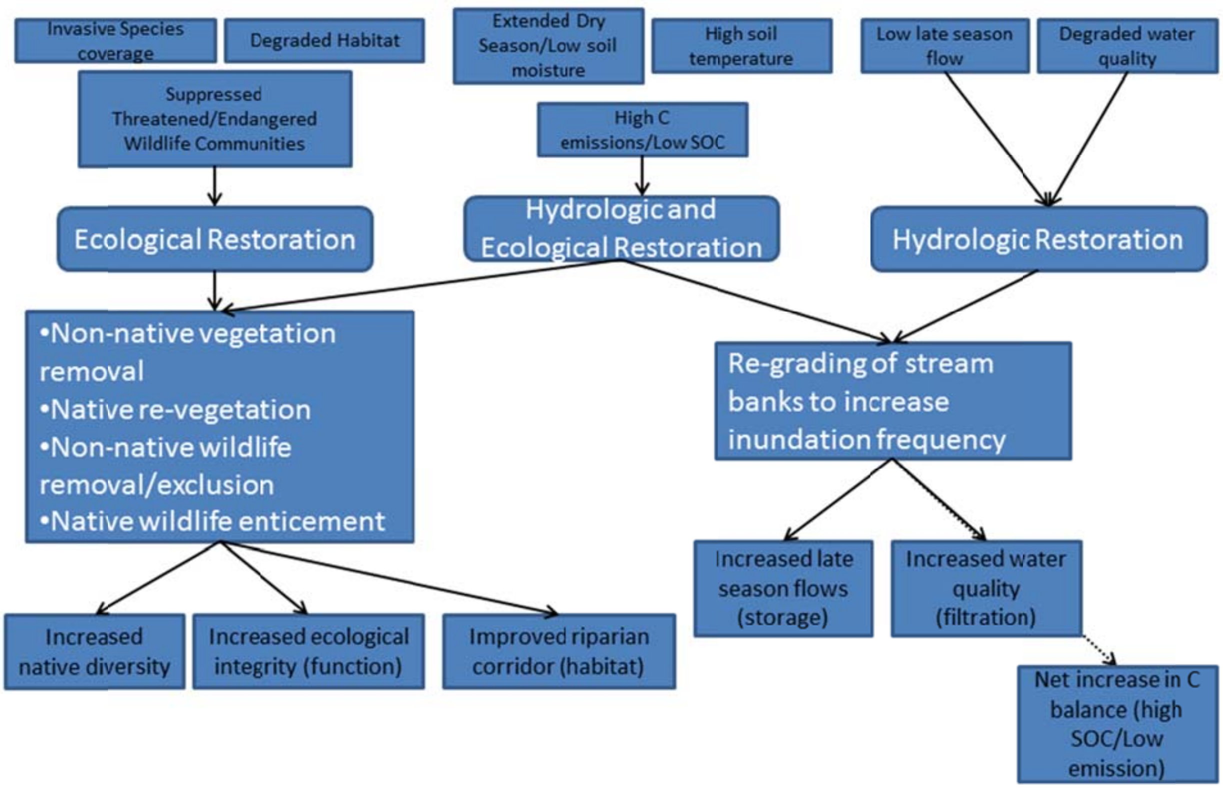

Figure 2. Conceptual model of restoration targets, goals, and expected outcomes.

Soil C sequestration has been suggested as a possible mitigation technique for increasing atmospheric concentrations. Soil C represents the largest single pool on the planet, with global soil C concentrations estimated to be approximately twice that of atmospheric concentrations (Dixon et al. 1994). Most studies of C flux, to date, have focused on carbon sequestration in vegetation. Recent discussions have pointed to the need for increased focus on overall ecosystem productivity (NEP) versus net primary productivity (NPP) when examining potential carbon pool efficiency (Catovsky et al. 2002). For example, while much is known about carbon uptake in plant tissue itself, and many studies have focused on soil-based organic carbon (SOC), very little work has been conducted relating aboveground carbon uptake to in-ground carbon stores across various ecosystem types.

Wetlands represent < 5% of global land surface, but provide a disproportionate amount of beneficial ecosystem services, including flood attenuation, nutrient input and/or filtration, sediment capture, late-season flow management, and carbon storage (Altor and Mitsch 2008). Maximizing carbon storage, specifically, has been identified as a primary restoration target in created and managed wetlands (Whiting and Chanton 2001), and current and future wetland and meadow restoration projects should include a GHG flux monitoring component.

Increasing carbon storage in wetlands can only be achieved via increased understanding of wetland GHG flux processes relative to hydrological processes, as carbon influx and methane efflux are largely a function of hydrology (Altor and Mitsch 2008). For example, Davis et al. (2001) observed measurable uptake of phosphorous, nitrogen, and carbon by wetland substrates from the water column in a fully inundated deep-water wetland. Depth of water column and length of wetland inundation also significantly influence carbon uptake and methane emissions. Altor and Mitsch (2008) observed increased CO_2 uptake but also increased CH_4 efflux in continuously inundated wetlands, but Hirota et al. (2006) report decreased methane efflux in shallow wetlands compared to deep wetlands, demonstrating important interactions between inundation period and depth. Similar dependence on moisture is seen in seasonally dry meadows, with total soil organic carbon decreasing with decreased soil moisture (Norton et al. 2011). These findings, coupled with reports of decreased LOC in meadows with higher temperatures (Xu et al. 2012) demonstrate the need for long term field studies examining changes in GHG dynamics following hydrological restoration in order to better model potential carbon storage in restored meadow systems under a warming climate, particularly in climate-sensitive environments. Historically inundated meadows that now run dry can benefit from hydrologic restoration through re-inundation, which can be achieved via re-grading of highly incised channels to re-connect floodplain and stream.

In soils and sediments, nitrous oxide emissions typically occur as a result of two processes: nitrification and denitrificiation (Davidson et al. 1986). Nitrification is an aerobic, oxidative process that converts ammonium to nitrate. Nitrous oxide is produced by nitrification during the incomplete oxidation of ammonium to nitrate. On the other hand, denitrication is a reductive process, meaning it occurs in anaerobic environments by which nitrate is reduced to nitrous oxide and eventually to dinitrogen gas. In well drained soils, nitrification is an important source of nitrous oxide, but in wet, anaerobic sites, denitrification is the primary source of nitrous oxide (Davidson et al. 1986). However, even under optimal conditions for both processes, denitrification usually produces more nitrous oxide than nitrification, all else being equal (Wrage et al. 2001). Thus, restoration from a dry and well drained meadow to a moist and more productive meadow could cause a shift in nitrous oxide sources from nitrification to denitrification, and increase nitrous oxide emissions. Areas of a hydrologically restored meadow where soil saturation remains high and organic matter is biologically available could support denitrification and associated nitrous oxide emissions. Similarly, in anaerobic conditions, decomposition of organic matter by soil microbes produces methane (methanogenesis). Coupled increases in C uptake following inundation, however, would potentially offset any increase in nitrous oxide emissions, resulting in net increases in overall C budget (Figure 3). Therefore, any increase in soil C accumulation due to restoration must also carefully consider the production of methane and nitrous oxide to the environment.

General ecological restoration of meadow and wetland habitat can also have direct impacts on carbon dynamics. Hatanaka et al. (2011) reported patterns of increased biodiversity in regions with greater standing C stocks, and while it remains unknown if the relationship is causal in either direction (i.e. diversity increasing carbon, or higher carbon increasing diversity), the significance of the correlation demonstrates the potential for the use of communities with high diversity as indicators of increased carbon storage. Meadows identified as “non-functioning” or impaired have been shown to have decreased soil C and elevated N concentrations (Norton et al. 2011). Restoration of general meadow function can therefore address multiple conservation and adaptation goals, ranging from wildlife habitat and ecological connectivity to GHG mitigation.

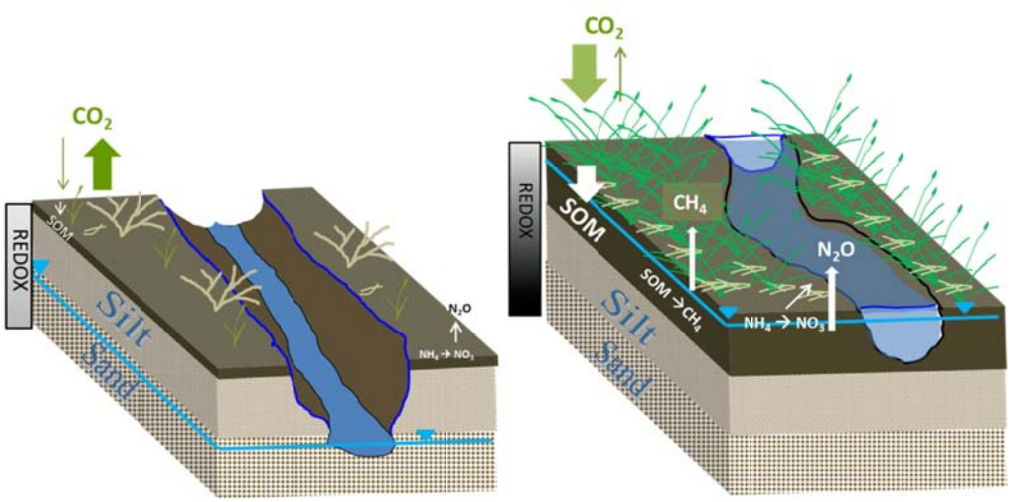

Figure 3. Conceptual model of meadow restoration effects on C sequestration and GHG dynamics (a) Hydrologically degraded meadow to the left with a groundwater table below the rooting zone during the growing season, supporting plant community with overall low productivity. Most of litter is rapidly decomposed, leaving little soil organic materal (SOM). Small amounts of litter is mineralized, supporting low rates of nitrification and no or small N2O emissions through by product of nitrification. (b) Restoration raises growing season water table to support much more productive plant community; saturated soils support very slow anaerobic decomposition, leading to rapid build up of soil organic material (SOM), and potentially supporting reductive processes of denitrificiation and methanogensis.

Riparian and meadow ecosystems are hotspots of biological diversity throughout the Sierra Nevada, a region which is home to approximately two-thirds of California's wildlife species. Riparian corridors provide critical habitat for more species than any other habitat type in the Sierra Nevada and are particularly important for birds and amphibians (Kauffman and Krueger 1984). The foothills location of the project site is especially critical for climate change adaptation, at the upper and lower elevation boundaries of many species. The wildlife corridors provided by healthy riparian ecosystems will be essential for enabling climate-induced migration of plant and wildlife species (Lenihan et al. 2003), as well as nutrient transport.

The large number of "Rim Dams" that border the Central Valley were originally constructed for flood mitigation and irrigation, but have long since been shown to have negative impacts downstream all the way to the Sacramento-San Joaquin Delta and beyond (Yoshiyama et al. 1997, Moyle et al. 2008). Functionally, many areas immediately below these Rim Dams are now similar to high elevation mountain meadows, acting as quasi-headwaters regions that directly influence downstream water quality and quantity. California, with its Mediterranean climate, fire-prone landscape, and expanding population, coupled with heavily impacted species of all types, is of peak concern when it comes to climate change vulnerability (Hayhoe et al. 2004).

The National Fish and Wildlife Foundation's Sierra Nevada Meadows Business Plan identifies meadow restoration as a critical adaptation to California's warming climate. Sierra meadows have the potential to expand water storage capacity to mitigate for the reduction of runoff from snowpack and related increase in precipitation in the form of winter rain, overwhelming the capacity of reservoir storage and causing downstream flooding. The proposed project represents an important step in addressing such vulnerability in the dam-disturbed Sierra Nevada foothills, and will follow the conceptual model shown in Figure 2.

Here we propose ecological and hydrologic restoration of a Sierra Nevada foothill meadow below a terminal Rim Dam to increase carbon sequestration and decrease carbon emissions, increase climate change resilience in the region, and improve riparian and in-stream habitat and ecological integrity. We also propose development of a modified meadow health index for use in identifying restoration targets below Rim Dams. Lastly, we propose using hydrologic and ecological restoration of the meadow site as an experimental opportunity to examine relationships among hydrologic regime, ecological meadow integrity, and carbon flux in heavily disturbed, altered, or dry meadow systems.

We will develop and apply the science to measure GHG (carbon, methane, and nitrous oxide) gains from restoration on the Sheatsley Meadow. The same protocol will be applied to partner meadow-restoration projects in 2015 across the Sierras, and to 3 type-matched degraded control meadows to clearly demonstrate effects of restoration on net sequestration. Other meadows will be added in subsequent years to include a full range of meadow types. Peer reviewed findings will be shared at an annual conference, developing a protocol to measure GHG dynamics and quantify the impact of restoration strategies on GHG capture in Sierra meadows.

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

Sierra Nevada Meadow Restoration and Research Partnership

The Sierra Meadow Restoration Research Partnership (SMRRP), of which Sierra Streams Institute is a member, will provide a robust and coordinated regional response to the historic opportunity that AB 32 presents. The Partnership, comprising of eight NGO's, three Academic Institutions, a number of Forests and Resource Agencies, Consulting Scientists and Volunteers - represents a potential research sample of 22 Sierra meadows in 2015. SMRRP will work together to advance our understanding of GHG dynamics in Sierra Nevada meadows and address the meadow restoration needs prioritized in the CA State Water Action Plan.*

The Partnership will leverage proposed data from a wide range of SMRRP-member meadow types, locations, conditions, and predictive variables for a robust assessment of variability on GHG emissions in the Sierra Nevada. The Partnership will provide SMRRP-members with peer reviewed and standardized field sampling protocols, lab methodologies, and data analysis procedures for GHG measurements, allowing for a comparative analysis of meadows across the Sierra Nevada.

Over four years, CalTrout will facilitate the quarterly meeting of a technical advisory committee (TAC) comprised of Consulting Scientists and SMRRP partners to coordinate projects, develop methodologies, integrate and analyze data, train regional practitioners in sampling procedures, and develop a predictive model to be submitted for approval by CAR, ACR and VCS.

*SMRRP partners include: American Rivers, California Trout, Feather River Coordinated Resource Management, Sierra Foothill Conservancy, Spatial Informatics Group, South Yuba River Citizens League, Stillwater Sciences, Truckee River Watershed Council., University of Nevada at Reno, University of California at Merced, University of California at Davis, Tahoe National Forest, Sequoia National Forest, Sierra Streams Institute and others.

Research Approach

The Sierra Meadow Restoration Research Partnership works from the premise that re-establishing hydrological connectivity between the stream and surrounding meadow will increase plant biomass above and below ground, increase soil organic matter, and thereby improve soil capacity to sequester GHGs from the atmosphere. The partnership leverages the considerable experience and expertise of Academic and Consulting Scientists, Practitioners and Resource Agencies to (1) establish the scientific foundation for what drives variation in GHG emissions and net carbon sequestration across a range of Sierra meadow types, (2) standardize field sampling, lab methodologies, and data analysis procedures for GHG measurements, (3) develop a predictive model for net carbon sequestration in Sierra meadows and an associated quantification protocol. The partnership also leverages a wide range of meadow types, locations, and conditions that will provide a 'gold mine' of information on the range of variability and associated controls on GHG emissions in the Sierras. Information on GHG emissions and their proximate controls will be collected at these sites and used to develop a predictive model for meadow carbon sequestration that is robust for the entire Sierra region. Finally and very importantly, through the process of implementing this project, the partnership will build regional and local capacity to monitor (and predict, using quantitative models) carbon sequestration and GHG emissions in meadows across the Sierras.

The proposed research will address the basic question: How does restoration of mountain meadows alter carbon sequestration in these ecosystems? We will address this broad question by collecting two sets of data at complimentary temporal and spatial scales. The first data set will be applied to what we refer to as the 'state factor meadows', and will address the question of how state factors (Jenny 1994), including climate (elevation and latitude), parent material, topography (slope and aspect), vegetation zone, and time since disturbance, affect carbon sequestration and GHG emissions. Effects of these state factors will be addressed by measuring GHG emissions and associated field characteristics at coarse temporal yet fine spatial scales in Sierra Meadow Restoration Research Partnership meadows representative of the range meadows across the Sierra Nevada. The second data set will be collected in focus meadows in order to (a) build robust annual GHG emission budgets that will inform annual estimates for other sites, and (b) to characterize key fine-scale hydrologic, geomorphic, vegetative, and biogeochemical parameters that relate to soil GHG fluxes. Information gained from this two-pronged approach will be used in order to create an empirically based model that can accurately predict the effect of restoration on soil GHG fluxes and carbon sequestration in meadows throughout the Sierra Nevada. Data from the proposed project will be made available to the entire SMRRP team to support development of the predictive model for meadow carbon sequestration.

Data from the state factor and focus meadows will be combined to establish quantitative relationships between readily measured proxy variables and carbon sequestration and between proxy variables and GHG emissions in Sierra meadows. These relationships will be used to build a model that estimates carbon sequestration and GHG emissions from un-restored and restored meadows in different parts of the Sierra Nevada. This draft model will be validated using emissions and sequestration data collected at a subset (at least one meadow complex) of the state factor meadows that will not be used develop model parameters, but rather set aside for this purpose. The quantitative model will be part of the carbon credit protocol for developed for meadow restoration through the SMRRP and under the leadership of CalTrout.

Table 2. Location and state factors associated with meadows to be sampled through the SRRMP. Hydrogeomorphic types are taken from Weixelman et al. (2011). RLG = riparian low gradient, RMG = riparian mid gradient, RHG = riparian high gradient, D = dry, DS = discharge slope

Meadow Name	Proposed Study Type	Elevation (ft)	Mean Annual Precip (cm/yr)	Mean Annual Temp (oC)	Parent Material	Vegetation Zone	Hydro - geomorphic type
Bean Creek	State factor	3100	84	14.1			RLG
Bear Trap	PROXY - Restoration	7078	178	4.4	granodiorite	Conifer	RMG
Clarks Meadow	Focus	5400					
Deer Meadow	Focus	6345	178	4.4	Mixed volcanics-granitics	Sierra Mixed Conifer	RHG
Foster Mdw Lower	State factor	6850					RLG
Foster Mdw Upper	State factor	7100					RMG
Freeman	PROXY - Reference	6834			andesite	Conifer	RLG
Greenville	Focus	5050					RLG
Loney	Focus	5968	178	4.4	Mixed volcanics-granitics	Sierra Mixed Conifer	RMG
Mattley Meadow lower	State factor	7050					RHG
Mattley Meadow upper	State factor	7100					RMG
Middle Martis Valley	State factor	5850	80.3	6.22	Andesite, alluvium	White fir zone	RMG
Osa Meadow	Focus	8500					RMG
Red Clover-McReynolds	Focus	5600					
Truckee Wetlands	State factor	5850	80.3	6.22	Glacial outwash, volcanic source	White fir zone	DS
Upper Goodrich	Focus	5200					RLG
Upper Loney	Focus	6031	178	4.4	Mixed volcanics-granitics	Sierra Mixed Conifer	RLG
Upper Truckee River Meadow	State factor	6240	44.2	5.72	Granite	Subalpine	RLG
Sheatsley Meadow	Focus	810	114.3	14.7	granite, basalts	Valley-Foothill Riparian	D

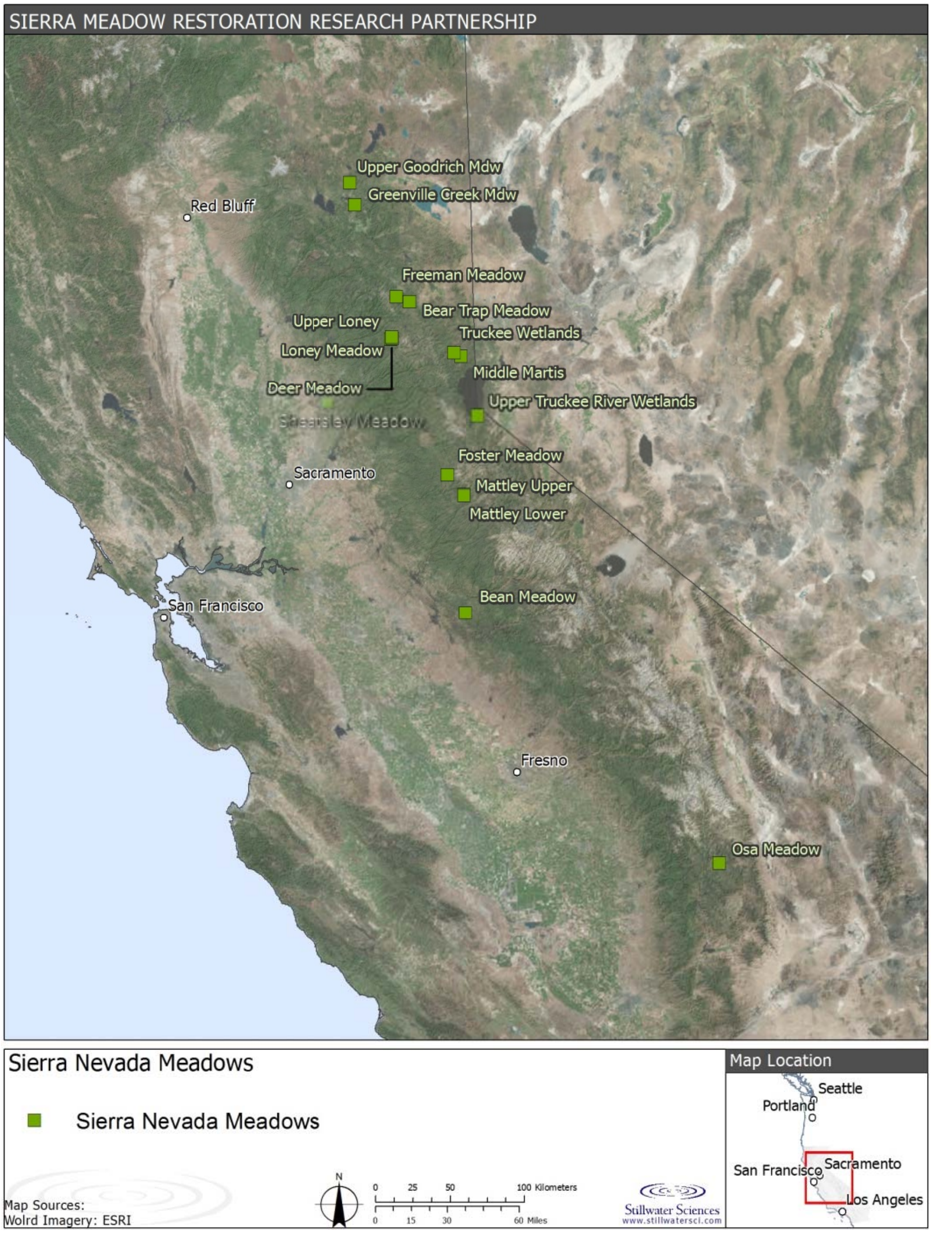

Figure 4. Meadows in proposed as part of the SMRRP represent a wide range of geographies in the Sierra Nevada. The target meadow in this proposal is "Sheatsley Meadow", in the upper left portion of the map.

Through this project, we will collect GHG emissions according to the 'focus meadow' methodology, as outlined below.

Task 1. Measure net carbon and GHG in Focus Meadows

All GHG emissions data will be collected by SSI Ecologists Jeff Lauder, Ori Chafe, and River Scientist Justin Wood, with assistance from trained field volunteers. Data on GHG emissions will be collected at high spatial and temporal resolution using a 'focus meadow' protocol. GHG emissions and other field data from this more intensive study design will be used to (1) develop a robust annual budget of net carbon sequestration and net GHG flux under pre and post-restoration conditions; and (2) initial predictive relationships between GHG emissions and more easily measured proxy variables, such as soil carbon content, groundwater level, and plant community type. These modeled relationships will be validated and refined using emissions and site characteristic data from the state factor meadows as described under the Research Approach for the Sierra Meadow Restoration Research Partnership.

Task 1.1 Identify reference meadows and establish transects

Control meadows, with the same hydrogeomorphic class and in close proximity to the target restoration meadow, will be selected in the spring of 2015 for each restoration meadow. Paired control sites will be selected as meadows that have experienced hydrologic alteration and degradation similar to the target restoration meadow. The target meadow for this proposal is spatially paired with a control meadow directly across Deer Creek, which will not receive hydrologic restoration but serve as an appropriate paired control. Pairing of control degraded meadows with treatment (meadows to be restored) will also provide controls on interannaul variability that could confound effects of restoration. Four to five transects will be established across the meadow perpendicular to the dominant slope and to the degree possible, aligned with existing ground water well transects and positioned to capture the vegetation types covering the greatest surface area of the meadow.

Task 1.2 Develop annual GHG budget

GHG fluxes will be measured using static chamber methodology (Hutchinson and Mosier 1981) used by others to measure GHG emissions in mountain meadows in the Sierra Nevada and Intermountain West, including by SMRRP participants Sullivan (UNR), Hart (UC Merced), and Senock (CSU Chico) in various ecosystem types (Sullivan et al. 2008, Blankinship and Hart 2014, Senock unpublished data). Boardwalks will be erected each year along these transects in wet areas to avoid trampling meadow soils and to minimize methane ebullition (bubbling) into the chambers during incubation measurements (Megonigal et al. 2004, Teh et al. 2011). Use of chambers vs. the eddy covariance method (Hutchinson and Mosier 1981; Baldocchi et al. 1988) will enable us to measure both nitrous oxide and methane emissions, and to link emission differences to sub-meadow scale varation in site conditions. Chambers will be constructed of polyvinyl chloride (PVC) tubing and be approximately 30 cm in diameter to reduce the inherent spatial variability associated with soil gas fluxes (Sullivan et al., 2010). In the field, the vented static chambers will rest on PVC collars that are permanently installed 2-3 cm deep in the soil to reduce soil disturbance and plant root mortality associated with repeated chamber-based flux sampling. Collars will be installed at least one month prior to the first measurement to allow stabilization of the surrounding soil and vegetation. Collars will be beveled on the soil-facing edge to minimize soil disturbance during installation. Soil fluxes of carbon dioxide, methane, and nitrous oxide production will be measured as part of a complete soil GHG flux estimate. Ancillary data on ground water level, soil temperature, and water filled pore space will also be collected with the gas samples.

We will measure in situ fluxes every two weeks during the growing (frost-free) season, and bi-monthly in the non-growing season in each plant community/hydrogeomorphic zone on each transect. We will also measure GHG fluxes from seasonally and perennially inundated sediments, including the created ponds and saturated zones in restored sites, using floating chambers.

Task 1.3 Soil carbon and biomass production

Soil carbon and biomass samples are collected along transects established across the meadow, as described above. Four one-foot square plots will be chosen along each transect, with each plot representing a soil/vegetation type. Sample plot locations will be randomly selected and interspersed. In an effort to make between-meadow comparisons, attempts to duplicate soil/vegetation types among similar meadows will be made.

Samples within the one-foot square plot will be removed in the following pre-determined, definable layers: 1. All above-surface biomass material within the square is clipped to ground level. Soil surface is defined as the top of the O horizon. Material is removed, bagged and labeled by plot number for the entire square foot area. Documentation of meadow use, i.e. grazed or un-grazed is made, and percentage of utilization is estimated. 2. Due to the target meadow being hydrologically classified as dry, the O horizon of the entire square foot will be taken. After restoration, wet meadow substrate will be sampled with a 4" soil auger. O horizon material consists of duff, litter and residual live plant material, down to a bare, mineral soil surface. O horizon material will be removed, bagged and labeled. 3. Three foot soil cores will be extracted from the center of each soil sample location, and approximately 20% of extracted soil will be subsampled for analysis 4. During augering, a representative bulk density sample (Blake, G.R., and K.H. Hartge, 1986) will be collected for each foot of depth. Bulk density samples are collected at 9", 18" and 27". Soil cores will be collected using an Oakfield 3-ft. Model B 36" Soil Sampler. Bulk density samples will be collected with a 0200 soil core sampler manufactured by Soilmoisture Equipment Corp. All samples will be stored in plastic bags, and labeled with meadow, plot number, depth, and date.

Biomass will be quantified in-house at the Sierra Streams Institute lab. All above ground biomass material recovered from the one foot square will be oven dried. Soil samples, separated for each foot of depth, will also be dried. Soil texture analysis will consist of sieving through standard ATSM sieve analysis sieves, with all material passing through the #10 sieve retained for soil C measurements. Large roots will be removed and added to the biomass measurements as below ground biomass.

Approximately one teaspoon of each well mixed and sieved soil sample (per foot of depth) will be submitted to the LSU Agricultural Soils lab to measure total soil C, SOC, total N, pH, nitrate, total phosphorus, and potassium. The bulk density data will then be used to scale all soil carbon measurements per m^2.

Soil temperature at all sample locations will be measured using soil flux plates and thermocouple probes to establish soil temperature gradients. This is to account for shifts in GHG flux along those gradients (Figure 5; Senock unpublished data).

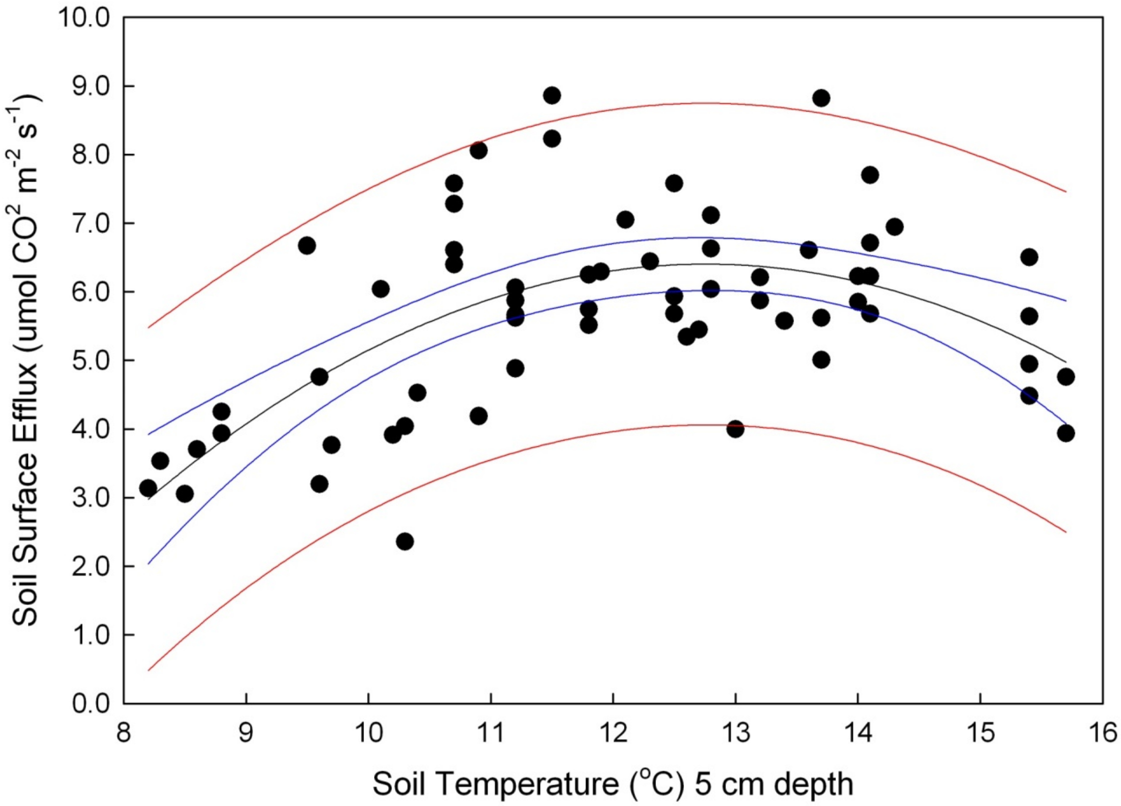

Figure 5. Relationship between soil temperature and soil surface C efflux from pilot study in low-elevation dry grassland (Senock, unpublished data).

Task 1.4 Identification of GHG flux covariates and project monitoring

Identification of site-specific variation and potential GHG flux model covariates will be carried out via intensive monitoring of various meadow parameters, with the help of Sierra Streams Institute citizen-scientists. Trained volunteer teams that regularly conduct various stream and wildlife surveys will assist in multiple monitoring phases:

<u>*Sampling design:*</u> This study follows a simple before-after/control-impact (BACI) design for most parameters, with parameters for which reasonable controls cannot be established or identified being measured before and after treatment (BA). All measurements conducted in this study will take place at permanent sample plots randomly interspersed in either restored or non-restored locations prior to restoration activities (i.e. stratified random design). All restoration success assessments will be conducted by SSI Staff Ecologists Ori Chafe and Jeff

Lauder, and SSI River Scientist Justin Wood, along with assistance from volunteers, students and interns from the local community, California State University, Chico and Sierra College, in order to categorize overall meadow function relative to hydrologic regime, biotic integrity, and carbon stocks.

Meadow Ecological Function Monitoring: Ecological monitoring will be conducted by SSI Ecologists Jeff Lauder and Ori Chafe. Water quality lab sample processing and analysis will be performed by Kaitlyn Hacker, SSI Chemist. To measure and monitor meadow vegetation diversity and community structure before, during, and after inundation, transects will be established at 20m intervals across the meadow, and $1m^2$ plots will be randomly distributed along transects (Figure 2). All plant cover within plots will be identified to species and percent cover will be estimated. Size and stature of woody species will be recorded. Soil moisture, class, and texture will be measured or described for each plot location. Aquatic community response will be assessed via continued collection of benthic macroinvertebrate (BMI), algae, and water chemistry samples above and below project work before, during, and after project implementation. Fish community health will be assessed above, within, and below restoration target sites before, during, and after project implementation via electro-fishing (e-fishing). Riparian habitat immediately adjacent to the target meadow will be assessed by conducting standardized physical habitat (PHab) transects above and below project work before, during, and after project implementation.

Hydrology Monitoring: Hydrologic monitoring will be conducted by SSI River Scientist Justin Wood, with assistance from trained field volunteers. Hydrologic function will be quantified via combination of soil moisture metrics and in-stream flow measurement. To measure groundwater levels before, during, and after restoration and relative to in-stream flow, transects of piezometers will be setup from stream-edge to meadow center. Automatic Camera traps will be used to monitor flooding and meadow inundation before/after. Pictures/video will be taken at 15-minute intervals to document rapidly changing conditions at the site. Permanent reference points will be established to monitor changes in flooding area and depth. Topographic surveys before and after restoration will be used to quantitatively establish terraforming targets, as well as gauge overall change in meadow topography relative to flood regime. All above measurements will be combined with flow data and stream morphology surveys to model flows through site before and after restoration. In-stream flow will be measured with a combination of field-deployed pressure transducers and hand-held flow monitoring systems, depending on accessibility.

Task 1.5 Data analysis and reporting

GHG emissions will be summarized annually and reported to the TAC and SRRMP team, along with measurements of biomass production, groundwater levels, soil carbon and water content, and soil temperatures for each GHG sampling date. Emissions will be summarized by vegetation /hydrogeomorphic type and for the meadow as a whole, and by season (sample date) and if feasible, estimated to the full year. Statistical comparisons of the pre vs. post restoration GHG emissions and net carbon sequestration will be made using the refrence site data as controls for inter-annual variation in climate. Findings will be prepared in annual reports (submitted by end of calendar year) and distributed to the SRRMP team and TAC members. It is anticipated that one or several peer reviewed publications on mechanisms that control GHG emissions and carbon sequestration in meadows also will be produced through this task. Internal data analysis and preparation will be conducted by Jeff Lauder.

Task 2. Project Implementation

All project implementation activities will be performed by SSI staff and subcontractors. Staff to take part in project implementation will include SSI Ecologists Jeff Lauder and Ori Chafe, River Scientist Justin Wood, and Geologist Kyle Leach. Permit-related surveys, reports, and applications will be conducted and prepared by all aforementioned SSI staff members, with an expected permit completion timeline of June 2015 – October 2016, with hydrologic re-routing implementation taking place in Fall of 2017.

Task 2.1 Hydrologic Restoration (Terraforming)

Hydrologic restoration will focus on restoring hydrologic function to the meadow and floodplain habitats at Deer/Squirrel Creek confluence, including reconnecting the meadow/floodplain system. We will use topographic data (topo surveys) combined with aerial imagery and other historic data to evaluate changes to the site over time, and identify areas that could be targeted for restoration (e.g. berm, high points, old foundations, remnant channels). The site will be regraded to contours that enable flooding of meadow at flood flows (flows would be run through hydraulics model to finalize design criteria). Contracted civil and geological engineers would assist in hydraulics modeling and final site grading design.

Task 2.2 Ecological Restoration:

Vegetative restoration at the project site will focus on establishment of native species and removal of nonnative vegetation. The site is currently dominated by nonnative annual vegetation (in the meadow) and invasive Himalayan blackberry (throughout the riparian corridor). By establishing native perennial vegetation throughout the meadow and riparian corridor, carbon will be sequestered in woody plant biomass and within enhanced SOC reserves. The restoration plant palette will be selected by SSI Restoration Ecologist, Ori Chafe. The plant palette will emphasize establishment of native perennial bunchgrasses and riparian trees (predominantly *Salix* and *Alnus* spp.), which are known for their rapid growth and extensive below-ground biomass. Revegetation will include broadcast seeding of native bunchgrass and forbs species, propagation of riparian tree species via cuttings, and transplanting of established native vegetation. Removal of invasive yellow star thistle (*Centaurea solstitialis*), scotch broom (*Cytisus scoparius*), and Himalayan blackberry (*Rubus armeniacus*) and revegetation will augment hydrologic restoration of the meadow to enhance carbon sequestration within the meadow and riparian corridor.

Task 3. Final Data Analysis

We will conduct data analysis in two ways: using ecological community matrices to assess restoration success and ecological trajectory, and assessing changes in meadow C flux both independently and relative to shifts in overall meadow function. All data analysis will be conducted using R (R Development Core Team 2011) and PC-ORD (Mccune and Mefford 2011). Initial data screening and preparation will consist of three steps:

- *Identification of plots with similar vegetative communities*. Heirarchical cluster analysis will be performed to identify groups of plots with similar vegetative communities. These groups will serve as the primary categorical groupings in analysis of restoration success. Plot group will also serve as a covariate in final models of C flux relative to meadow condition.

- *Identification of sites with similar C flux.* Sites that can be grouped for overall Sierra-wide comparison based on hydrologic type, vegetative community, and GHG flux patterns will be identified by two-way cluster analysis using vegetative community and hydrologic type as clustering categories. This analysis will identify similar sites to which GHG flux in our target meadow can be compared before producing final predictive models.
- *Identification of sites with similar BMI communities.* Comparison of IBI scores, heirarchical cluster analysis, and NMS ordination of BMI communities from other sites monitored by SSI will be used to identify other sites upstream and downstream of the project location that have similar baseline BMI communities. Shifts in identified groups of BMI communities will be assessed in order to reject a null hypothesis of BMI community change due to seasonal or random variation.

Analyses will be conducted according to the three primary project objectives listed below:

Objective 1: Increased C uptake and storage

C flux measurements will be first compared to previously published measurements in similar landscapes to assess C uptake and storage differences. Treatment effects on C flux will be compared using repeated-measures ANOVA, with plots grouped by treatment, previously identified vegetative community type, and location (control versus treatment meadow). Following objectives 2 and 3 (below), a multivariate predictive model will be constructed relating GHG emissions and uptake, inundation depth/regime, and vegetative community. The expected model will have two axes: non-native versus native vegetation, and inundation type (deep/often versus shallow/limited). GHG emissions will then be overlaid as vectors relative to these two primary restoration objectives (Figure 2). PHab, BMI community composition, and water chemistry will be included in construction of the model and relative contribution of each to GHG emission/uptake ratios will be considered.

Objective 2: Co-benefit - Restoration of meadow hydrology

Changes in meadow hydrologic function will be assessed using repeated-measures ANOVA, with plots grouped by both treatment (inundated versus control) and previously identified vegetative community type. Spatial analysis (ArcGIS) of piezometer/soil moisture data before, during, and after restoration will be performed to help inform how groundwater moves through the site and influences instream flows. Analysis of discharge data, camera trap data with reference depths and locations, and in-depth hydraulics models before versus after restoration will quantify input into in-stream flows during summer and fall, as well as overall site changes through time.

Objective 3: Co-benefit - Restoration of ecological function

Measures of diversity will be calculated for all vegetation data by plot, by treatment, and by plot x treatment. BMI sampling data will be categorized only as “before” or “after” restoration due to BMI communities not being sampled directly in restoration plots. Vegetative and BMI communities will be compared using Non-metric Multidimensional Scaling (NMS) ordination, coupled with Multi-Response Permutation Procedures (MRPP). NMS ordination will be used to compare two community samples (e.g. vegetation samples in treatment versus control plots) based on differences in overall plot composition (Sorenson distance) and allows visual assessment of plot similarity based on plot location in output graphics. MRPP provides quantitative estimates of differences between sample plots, again based on overall plot composition. Output includes estimates of within-group similarity (i.e. similarity among plots within a treatment) and between-group differences.

Wildlife response to restoration will be assessed relative to sampling method. Small mammal community shifts will be assessed relative to both overall treatment (inundation) and local vegetative community shifts. Changes in capture rate will be examined relative to proximity to non-native vegetation and restoration activities, and overall shifts in modeled population densities will be examined pre- and post-inundation. Fish communities (presence and abundance by species) will be compared above, within, and below restoration worksites before, during, and after implementation using NMS and MRPP, as well as comparisons of capture rates over time.

Overall meadow function will be assessed by combining all measured meadow function metrics into a weighted multi-metric index (MMI) of meadow health (IMI, Index of Meadow Integrity). Multi-metric indices have become increasingly used to distill biotic function of target ecosystems into readily interpretable indices that ease selection of restoration goals, and our IMI will be modeled after the BMI-based Deer Creek IBI, previously created by SSI. IMI construction will synthesize complex statistical monitoring data into a simple numeric health score from 1-10 with an accompanying qualitative descriptor, from very healthy (10) to very unhealthy (1). The tool would complement the scorecard developed by American Rivers, which uses physical and hydrological rather than biological parameters. IMI scores will be compared before versus after meadow restoration to assess overall restoration success.

Materials

Monitoring and assessment activities will primarily require standard office and field equipment and supplies. Restoration activities will require the use of terraforming equipment such as a backhoe and hand tools. Restoration assessment sampling techniques will use: PVC frames (vegetation sampling); D-frame kicknets and jars of ethanol (aquatic sampling); and handheld YSI water quality probes, flowmate flow meter, Total Station surveying station, and lab equipment for water quality assays (water quality and flow).

4. *Timeline:*

This schedule assumes a June 1, 2015 start date and a September 30, 2019 end date.

Task	Timeline
1. Project Administration	Throughout lifetime of project

2. Measure net carbon and GHG in Focus Meadows	June 2015 – September 2019
2.1 Identify reference meadows and establish transects	June 2015 – December 2015
2.2 Develop annual GHG budget	June 2015 – December 2016
2.3 Soil Carbon and biomass production measurements	June 2015 – December 2016
2.4 Identification of GHG flux covariates and project monitoring plan	June 2015 – December 2016
2.5 Data analysis and reporting (SMRRP)	June 2015 – December 2016
3. Project Implementation and Monitoring	June 2015 – September 2019
3.1 Permitting and compliance	June 2015 – September 2017
3.2 Hydrologic and Ecological Monitoring plan formation and review	June 2015 – September 2017
3.3 Meadow geomorphology survey through consultation with Holdrege & Kull (Geotechnical survey and hydraulic modeling)	June 2016 – August 2017
3.4 Site preparation (erosion control, mitigation, permit compliance, etc.)	August 2017 – October 2017
3.5 Terraforming implementation	October 2017
3.6 Hydrologic and Ecological monitoring	June 2015 – September 2019
4. Final Data Analysis and Reporting	November 2017 – September 2019
4.1 Data preparation and screening (see text)	November 2017
4.2 Model construction and validation with SMRRP partners	September 2018 – September 2019
4.3 Rim Dam Meadow restoration handbook construction and publication	September 2018 – September 2019
4.4 GIS dataset completion and publication	September 2019
4.5 Peer-reviewed articles (see Deliverables)	September 2018 – September 2019
4.6 Progress reports and final report to CA	As necessary through life of project; Final

5. ***Deliverables:***

All proposed deliverables are listed in Table 2 below.

Table 3. Deliverables of proposed project by type, title, and expected delivery.

Deliverable Type	Title	Expected Delivery
Publicly available dataset	GIS dataset of mapped carbon measurements (SOC, LOC, Respiration), soil moisture, and inundation frequency/depth	January 2016 (pre-implementation C); September 2019 (post-implementation C)
Publicly available dataset	GIS dataset of mapped vegetative community change over time	September 2019
Publicly available dataset	GIS dataset of groundwater flow, depth to water table	January 2016 (pre-implementation C); September 2019 (post-implementation C)
Public dissemination/training	At least two presentations of: Use of IMI tool in setting restoration targets for Sierra Nevada Meadows	January 2018
Non-refereed Publication	Rim Dam Meadow Restoration Toolkit and Handbook	January 2018
Non-refereed Publication(s)	Annual Progress Reports and Final Project Report	As requested; September 2019
Pilot quantitative method(s)	Meadow GHG flux conceptual and predictive models; Meadow groundwater flow models	September 2019
Referreed Publication(s)	Two proposed publications in applicable journals (i.e. *Ecological Applications, Restoration Ecology, Biogeochemistry)*	September 2019

6. ***Expected quantitative results (project summary):***

This project is expected to increase C sequestration capacity of the target meadow by 1800 tons over the project lifetime. This budget was calculated with assistance from USDA Forest Service employees using modifications of the methods outlined in Powers et al. (2013). Allometric equations by tree species observed at the target meadow were used to calculate overall biomass in current stands as well as estimated increase due to planting of woody species. Biomass of living stands is assumed to be 50% C. Similarly, overall reduction in non-native species coupled with increased coverage of native bunch grasses was estimated on a per m^2 basis, and converted to standing C based on an assumption of 50% dry biomass being C in grasses and forbs.

Co-benefits: Overall meadow function, as determined through the SSI-constructed IMI is expected to show an average increase of 15-20% over the life of the project. This can be interpreted as moving overall collective meadow function from “highly degraded” (0-40% of IMI score range) to “average function” (40-60% of IMI score range). Adaptive management and continued monitoring is expected to find IMI scores increasing into the “fully functioning” (>60% of IMI score) range in the years following project implementation.

Total increase in late season flows of between 1-5 cfs (5 to 25 acre-feet) are expected following project completion.This number is based on results from restoration projects of a similar scale, and estimates of the amount of water the meadow could potentially hold based on the area of the meadow and estimated depth to bedrock. Essentially I did an estimate of 5 acres saturated to a depth of 1-10 ft to get the numbers. At 10 ft depth and 5 acres of meadow, if all space was filled with water, it would be 50 acre-feet (10 cfs). So I just took a fraction of that number, starting below half (assuming more than half of the pore space will be particles) to get the 1-5 cfs number. Completely a bullshit approach but I couldn't find any research that points to other good ways for estimating, especially using the data that is available to us.

Putting this flow into context, Deer Creek often experiences late season flows in the 1-5 cfs range, with up to 1 cfs of the flow constituting effluent discharge from the Lake Wildwood WWTP. This increase in late season flows will provide additional (cool*) water at the time period when Chinook salmon enter Deer Creek to spawn (Sept-Oct) and improve water quality by decreasing the concentration of wastewater effluent and reducing water temperatures, which are often near the critical threshold of 15C for salmon (could tie in to climate change, already near this threshold, need to buffer temps as air temp increases into the future).

7. ***Protocols:***

GHG measurement protocols will be developed in conjunction with SMRRP TAC committee suggestions and validation. GHG flux measurement protocols will be developed in conjunction with technical equipment manufacturer specifications. All ecological assessments will follow standardized protocols. Avian wildlife surveys will be conducted via the Point Reyes Bird Observatory Point Count Methodology (Ballard et al. 2003). Mammal surveys will be conducted following modifications of the USDA Forest Service Multiple

Species Inventory and Monitoring (MSIM) protocols (Manley et al. 2006), employing both live trapping and camera trapping techniques. BMI collection and in-stream water chemistry measurements will be made in accordance with CA DFW Surface Water Ambient Monitoring (SWAMP) protocols (Ode 2007). Vegetation surveys will be conducted following the California Native Plant Society's Vegetation Rapid Assessment Protocol (CNPS 2004).

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