Project Title: Decision support for meadow conservation and restoration in the Sierra Nevada Ecoregion: leveraging landscape-scale retrospective and near real-time data to enhance understanding of vulnerabilities and adaptation options under changing climate

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Project Duration: 2 years

Total Requested Funding: $187,530

Partners/Contributions/Leveraging: Key partners include: **Dave Weixelman**, Range Ecologist, **USDA Forest Service**, R5, dweixelman@fs.fed.us, 530-478-6843 – Dave is currently leading the effort to update the UC Davis meadow layer, which will be used as a foundation for this analysis. In addition, Dave will provide expertise in meadow hydrogeomorphology, assist with developing the decision framework, and assist with field work. The **Amador-Calaveras Consensus Group (ACCG; ACCG project representatives: Julia Stephens**, Project Coordinator, Central Sierra Environmental Resource Center, julias@cserc.org, 209-586-7440; **Reuben Childress**, Watershed Conservation Associate, Foothill Conservancy, reuben@foothillconservancy.org, 209-223-3508). The ACCG is a community-based organization that includes partners from **34 different organizations** as well as private land owners. The ACCG works to create fire-safe communities, healthy forests and watersheds, and sustainable local economies in the greater Amador and Calaveras counties. They will provide feedback on the usefulness of the decision framework and monitoring tool and will conduct ground-truthing field work to assess conditions in meadows identified in the framework. Toni Lyn Morelli (USGS/NECSC, tmorelli@usgs.gov, 413-545-2515) and Sean Maher (Missouri State Univ.) will provide guidance on use of their CALCC-funded connectivity and refugia datasets for the spatially-explicit meadow vulnerability analysis.

Geographic Scope: Sierra Nevada Ecoregion (see Figure 1)

Partner Contributions/Leveraging: Total = $37,000+

DRI will contribute **$10k** for development of the ClimEngine tool. The USFS will contribute **$5000** and the ACCG will contribute **a minimum of $9000** to provide feedback on tool and decision framework and conduct field site visits. CSP will contribute **$10k** in computing equipment, including staff computers, 2 data servers, analytical software, and associated backup devices. We will leverage analytical methods, data processing and analysis code, and results developed as part of an existing Southwest Climate Science Center (SWCSC) project – *Linking interannual variations in extreme winter precipitation to hydrologic and ecological responses in the Sierra Nevada* (PIs: Dettinger and Albano).

Project Description:

While meadows cover less than one percent of the Sierra Nevada, these ecosystems are of high ecological importance (Viers et al. 2013), given their role in carbon and nitrogen storage (Norton et al., 2011), mediation of surface water flows, groundwater recharge, and sediment filtration (Ratliff, 1982; Weixelman et al., 2011), and serving as refugia for numerous species (Kattelmann and Embury, 1996; Knopf and Samson, 1994). Sierra Nevada meadow ecosystems are highly vulnerable to changing hydrologic regimes and processes associated with climate change (Hauptfeld et al. 2014). These groundwater-dependent ecosystems rely on the persistence of a shallow water table and input from surface flow, springs, seeps, and precipitation (Lowry et al., 2011; Ratliff, 1985; Weixelman et al., 2011; Wood, 1975). Climate influences meadows directly through the timing and amount of precipitation and evapotranspiration, which modifies the position of the water table, and indirectly through encouragement or deterrence of episodic tree invasion (Bartolome et al., 1990; Fites-Kaufman et al., 2007). Due to the relatively shallow groundwater systems that support many meadows in the Sierra Nevada, decreases in spring snowpack and an earlier peak snowmelt may limit the availability of late-season water, resulting in a loss of meadow area and a shift to upland/xeric dominated ecosystems (Drexler et al. 2013). Meadows may also experience declines in groundwater recharge over longer time periods as warmer temperatures and longer growing seasons lead to increased evapotranspiration.

Understanding how – and where – to conserve and restore meadow ecosystems is a critical management question facing US Forest Service (USFS) and other land managers in the Sierra Nevada, given their importance to wildlife species and potential to mediate the effects of changing hydrologic regimes associated with climate change. Since 2014, California Trout has led partners in an effort to develop a Sierra Meadow Strategy and Prioritization (Sierra Meadows Research and Restoration Partnership). The USFS strategic framework for responding to climate change identifies the use of decision support tools and incorporation of science to facilitate management priorities and consideration of climate change in planning and activities (USDA 2008). In 2011, the USFS Region 5 identified ecological restoration as a core objective to respond to climate change, shifting hydrologic patterns, increasingly dense and unhealthy forests, and a growing human population (USDA 2011). Actions identified by Region 5 leadership specific to this proposal are to restore at least 50% of accessible, degraded meadows, to expand watershed improvement programs (inventory, prioritization and scheduling of restoration), and to work with partners (USDA 2011). The Amador-Calaveras Consensus Group received funding through the Collaborative Forest Landscape Restoration Program to complete 100 acres of meadow enhancement (www.fs.fed.us/restoration/CFLRP/index.shtml); the group is currently tackling how to prioritize meadow restoration on the landscape.

Numerous studies suggest that the response of individual meadows to changing hydrology associated with climate and/or management activities depends on the hydrogeomorphology of the meadow and the landscape setting (Loheide & Gorelick 2007; Lowry et al. 2011; Weixelman et al. 2011; Drexler et al. 2013, many others). Local geology can influence the relative timing and amount of groundwater and surface water inputs into montane wetlands (Onda et al 2001; Kitlasten 2015). The hydrologic response of the watershed in turn influences surface geomorphic features such as shallow landslides (Onda et al. 2004) and drainage characteristics (Horton 1945; Strahler 1957; Farvolden 1963). Furthermore, the permeability structure of hillslope materials (e.g. glacial till vs. talus) can affect the timing and amount of shallow groundwater discharged to downstream wetlands (Harman and Sivapalan, 2009). Permeable fractured volcanic and/or metamorphic rocks (typical of the Cascades) can transmit and store more water than impermeable crystalline intrusive rocks (typical of the Sierras), resulting in differential long-term responses to climate change (Drexler et al 2013). Localized fracture zones that exceed a percolation threshold (Berkowitz 2002) associated with intrusive contacts (e.g. Seagall and Pollard 1983) and/or geologic structures may explain some of the variation in responses that are not captured by these broad geologic descriptions. In addition, mid-elevation watersheds are predicted to be more vulnerable to changing climate compared to high-elevation watersheds that will likely still be snow dominated (Young et al. 2009; Null et al. 2010; Stewart 2012).

Although the influence of these hydrogeomorphic controls on meadow responses to changing hydrology are well documented at local scales, the influence of these controls – and the degree to which existing spatial datasets sufficiently capture important variation in these controls – is not well-documented at landscape to regional scales for Sierra Nevada meadows. Identifying generalizable patterns in meadow response to changing hydrology using landscape-scale predictors would have great utility to managers by allowing them to better anticipate meadow trajectories and persistence in response to climate. Preliminary analyses completed by project PIs relating interannual variability in late-season meadow vegetation greenness and wetness to climate variables suggest significant heterogeneity in meadow responses to climate (Fig 1).

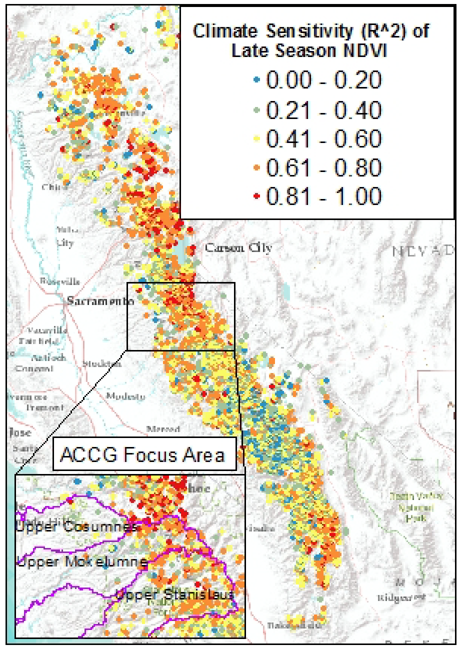

Figure 1. Results of preliminary regression analyses of Landsat-derived late season Normalized Difference Vegetation Index (NDVI – an indicator of vegetation productivity) in Sierra Nevada meadows (> 5 acres in size) in response to a suite of climate variables. Climate sensitivity of meadows (indicated by R^2 values) varies significantly across the project area. We propose to leverage findings from region-wide analyses of climate-vegetation-hydrogeomorphology relationships to help to inform meadow restoration priorities in the Amador Calaveras Consensus Group (ACCG) focus area and to increase understanding of meadow responses to contemporary changes in climate.

Landsat satellite imagery has proven to be an effective and efficient data source for monitoring meadows and riparian systems (Ager and Owens, 2004; Cohen and Goward, 2004); however, scaling and generation of automated vegetation index algorithms has proven to be difficult due to large Landsat data archive requirements, computational limitations, and the need for automatic Landsat archive updating. Accordingly, the Co-PIs have developed new cloud computing and web application tools using Google Earth Engine and Google App Engine that address these issues by avoiding costly data storage and computing times. We aim to leverage and customize Climate Engine $_{beta}$ (climateengine.org), developed by PI Huntington and others at DRI, to integrate meadow boundaries and attributes of interest into a custom Google Earth Engine cloud computing visualization tool. This tool will allow end-users to select single Landsat and climate pixels or meadow polygons and retrieve and display historical (1985-present) and near real-time vegetation and climate conditions with statistical summaries to better understand current meadow conditions relative to past conditions, and assess meadow sensitivity to climate fluctuations and trends or management activities (Figure 2 & 3). To date, the Climate Engine has proven extremely useful to land managers for assessing and analyzing impacts to meadow and riparian systems from water management, vegetation management, restoration, and fires (Liebert et al., 2015; Huntington, 2014; Huntington et al., 2014; Hegewisch et al., 2015)

To address the needs of the USFS and other stakeholders in the Sierra Nevada ecoregion, we propose to leverage a 26-year time series (1985-present) of climate and remotely sensed data in ~6000 meadows to analyze meadow vegetation responses (i.e., their sensitivity) to contemporary variation in climate. Our principal research goal is to characterize how these responses vary in accordance with hydrogeomorphic contexts (e.g., geology, elevation, topographic position, soils, stream network topology, etc.) at an ecoregional scale.

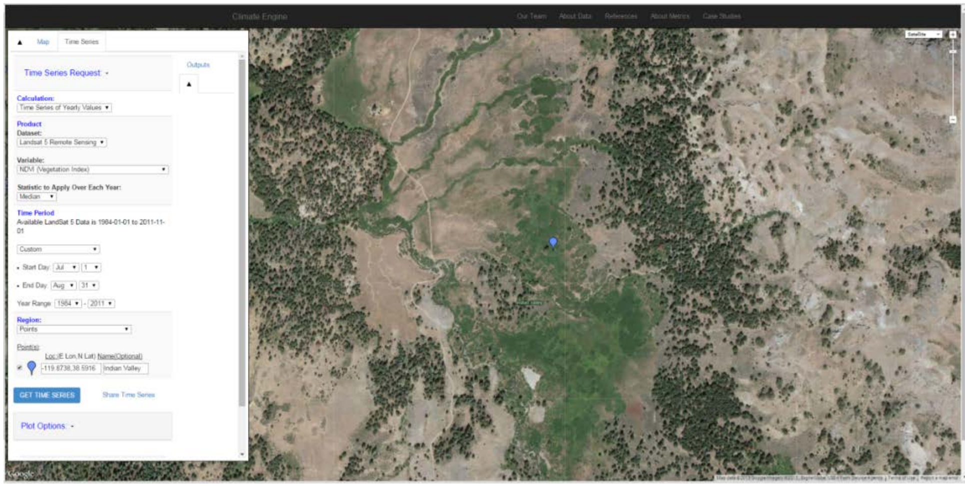

Figure 2. Print screen of Climate Engine showing the location of Indian Valley, a 500-acre meadow atop the Sierra Crest in Alpine County, CA, and headwaters to the Mokelumne River being restored to improve hydrologic connectivity and meadow ecosystem function.

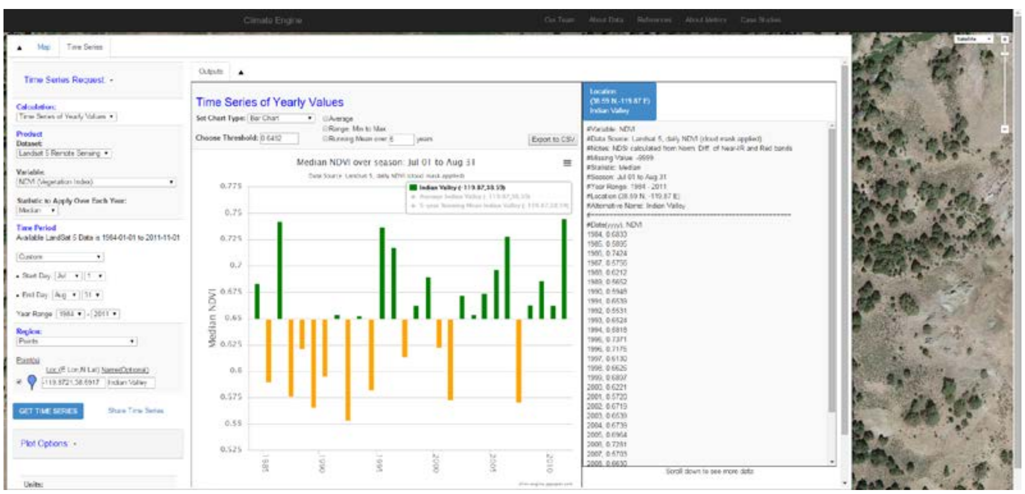

Figure 3. Print screen of Climate Engine showing yearly July – August median Normalized Different Vegetation Index (NDVI) derived from Landsat 5 for a sub area of Indian Valley shown in Figure 2.

We will use resultant information to develop a spatially-explicit vulnerability assessment of Sierra Nevada meadows based on our meadow *sensitivity* results, projections of climate variables that meadows are sensitive to (*exposure*) and indicators of *adaptive capacity* (e.g., geomorphic context, connectivity, intactness, etc.). Building from principles and characteristics of Climate-Smart Conservation (Stein et al. 2014), we will develop a decision framework (sensu Gillson et al. 2013) that provides guidance on where to focus restoration and conservation actions based on meadow vulnerability assessment results. This framework can then be incorporated into existing meadow prioritizations to allow practitioners to more rigorously consider climate impacts and adaptation options. As described above, we will also develop a customized web-based monitoring tool that utilizes Landsat satellite image and gridded climate data archives available in the Google Earth Engine cloud-computing environment, which will allow stakeholders to assess and monitor meadow condition and response to climate and management activities in near real-time. The information and tools generated from this project have the potential to significantly increase understanding of meadow responses to climate, associated changes in hydrology, and can be used to develop conservation and restoration priorities that are strongly aligned with climate-smart principles (Stein et al. 2014) across multiple jurisdictions in the region. We will pilot our decision framework and monitoring tool with the Amador-Calaveras Consensus Group (ACCG) to help guide their prioritization of 20 meadows for restoration in the upper Mokelumne, Stanislaus, Calavares, and Consumnes watersheds (Fig. 1).

Approach and scope of work:

Our proposed project will build on several existing efforts by the project PIs and partners, including existing datasets and analyses developed by our team as part of the Southwest Climate Science Center (SWCSC) project: *Linking interannual variations in extreme winter storms to ecological and hydrologic responses in the Sierra Nevada* (PIs Dettinger and Albano); the Climate and Integrated earth Monitoring Engine (CLIM Engine) being developed by Desert Research Institute (Huntington); and ongoing forest and watershed restoration efforts initiated by the Amador-Calavaras Consensus group on USFS lands.

As part of the SWCSC project mentioned above, we have generated a time series of Landsat-derived vegetation indices, including NDVI (Normalized Difference Vegetation Index – an indicator of vegetation productivity) and NDWI (Normalized Difference Wetness Index, an indicator of vegetation moisture content (Gao 1996)) and climate variables derived at 4-km resolution (Abatzoglou, 2013) for the 1985-2014 time period for a subset of 18,000 Sierra Nevada meadow polygons compiled by Fryjoff-Hung and Viers (2012), that are > 5 acres in size. We have conducted preliminary analyses to relate vegetation index responses to interannual variability in climate variables (See Fig. 1). The meadow polygons are currently in the process of being redigitized for improved accuracy (current efforts led by Dave Weixelman). The proposed project will unfold over the following timeline:

1. Generate an expanded suite of landscape variables hypothesized to influence meadow responses to climate to supplement existing variables (Fryjoff-Hung and Viers 2012). These include: 1) stream network statistics (Peterson and Ver Hoef 2014; Ver Hoef et al 2014), 2) geologic characteristics that indicate the potential importance of the groundwater system (e.g. fracture density (Bonnett 2001 and proximity to potential aquifers), and 3) watershed characteristics that influence the timing and amount of precipitation (e.g. basin hypsometry, contributing area, watershed aspect). *(Months 1-6)*
2. Leverage analytical methods and code developed as part of the SWCSC project to reevaluate climate sensitivity of all meadows based on the improved meadows dataset. Analyze the relative importance of the above mentioned landscape variables on meadow responses to climate variability using robust model selection and multi-model inferential techniques (Burnham and Anderson 2002). *(Months 6-12)*
3. Overlay climate sensitivity, climate projections (exposure), and adaptive capacity (e.g., geomorphic characteristics, connectivity) datasets to develop a spatially-explicit vulnerability assessment. Drawing on these results, we will develop a decision framework to prioritize the selection of meadows for restoration that is structured around key characteristics of Climate-Smart Conservation (Stein et al. 2014). *(Months 3-18)* The decision framework will be refined based on feedback from the ACCG and field testing (see step 5).
4. Develop a meadow and riparian monitoring tool that allows stakeholders to visualize near real-time vegetation conditions using climate and satellite image archives through Google Earth Engine cloud computing and visualization technology (See Figs 2-3). Customization of ClimateEngine.org will be tailored to meet the needs of management partners, where users will have the ability to control climate

variables and time scale they would like analyze, and visualize map and time series results in a Google Maps environment. The customization and implementation will consist of modifying existing Java Script and Python workflow, to allow users to interactively select, for example, riparian and meadow polygons of interest to produce spatially averaged drought indices, vegetation indices, and climate variables in time, create custom reports, and plot time series relative to long term averages, etc. The tool will be able to be applied to any area of interest at regional scales and have functionality to download all results. The tool will be refined based on feedback and iteration with the ACCG group. (Months 1-24)

5. We will visit a subset of meadows within the ACCG planning area that we identify within the decision framework as potential priorities for restoration. Meadows identified will be evaluated with the American Rivers Meadow Scorecard (American Rivers 2011) and/or California Rapid Assessment Method (CRAM) – wet meadow module and/or another methodology identified by the ACCG. Meadows that were visited in the field and meadows already evaluated by American Rivers (Hunt and Nylen 2012) will be compared to identify where field based restoration needs overlap with restoration focuses identified in the decision framework. Additional qualitative meadow attributes may be added to the scorecard to link field data to large-scale spatial datasets used in our analyses. The ACCG will provide final feedback on the decision framework based on this field implementation. *(Months 9-24)*

This project builds new interdisciplinary partnerships between the DRI, USFS, CSP, and the larger ACCG collaborative group. In addition, this information can inform the Sierra Meadows Research and Restoration Partnership work associated with the Sierra Nevada meadow strategy and prioritization. The products we are deriving could be readily used by numerous other partners within the region for multiple purposes and will promote understanding of ecosystem processes at regional to site-specific scales. Our regional analyses of meadow vegetation responses to climate will contribute to a broadened and empirically-based understanding of the role of hydrogeomorphic settings in mediating climate sensitivity of meadows in the Sierra Nevada. By incorporating this information into a decision framework that is structured around the key characteristics of the Climate-Smart approach, we will generate a product that is interpretable and useful not only to our partners, but to other stakeholders within the region trying to prioritize meadows management activities. For example, our proposed near real-time monitoring tool will allow stakeholders to rapidly evaluate site-specific responses of vegetation to restoration or other management activities, or to identify and prioritize areas for restoration activities (e.g., meadows with downward trends in vegetation vigor might be targeted for field efforts to identify causal factors and/or restoration activities). Moreover, our tool will allow stakeholders to track longer time scale vegetation conditions as they relate to climate and hydrologic drought effects in addition to tracking shorter time scale vegetative drought, restoration, and recovery.

The proposed project offers an opportunity to integrate several existing science and management efforts that have potential to both enhance understanding of ecosystem processes and provide practical information to guide specific management objectives identified by State and Federal, non-profit environmental, academic and private-sector partners. Specifically, CA LCC funding would provide the opportunity to leverage analyses conducted by the SWCSC and monitoring tools being developed by the DRI to address a discrete landscape-scale planning process being implemented by the USFS and the ACCG. Once this process is tested, this will provide a unique and complimentary addition to the Sierra Nevada Meadows Research and Restoration Partnership. This project will also build on the CALCC's Connectivity and Refugia project (PI Morelli et al.) and the wet meadow assessment (Hauptfeld et al. 2014) in the Sierra Nevada Ecosystem Vulnerability Assessment by adding a spatially-explicit component. The results generated from the proposed project will be transferrable across all jurisdictions and size of meadows within the Sierra Nevada, as they provide an opportunity to greatly enhance the existing knowledge related to how hydrogeomorphic setting mediates responses of meadows to climate and management at a landscape scale. Once developed, the CLIM Engine tool will be highly transferrable, as it could be easily updated to address a wide variety of management questions, vegetation types, and geographies.

CA LCC Priorities and Place-based Project Criteria addressed:

As described above, our proposed project addresses a **high-priority ecoregional need** involving understanding how and where to conserve and restore meadows in the Sierra Nevada. Our project builds on existing partnerships within the ACCG and establishes several new **partnerships** between DRI, USFS, USGS, CSP, and the larger ACCG collaborative group**.** We will generate and integrate new and existing **information** on meadow responses to climate change. Our framework and monitoring tool will provide **decision support** to managers to help to establish **climate-smart strategies** based on a spatially-explicit analysis of meadow vulnerabilities to climate change, and use this information to prioritize candidate meadows for restoration **actions** by the ACCG and to **monitor** meadow responses to these activities in near real time.

Capacity:

Our team is well-equipped to complete the proposed project. **Christine Albano** is a Lead Scientist with the nonprofit Conservation Science Partners, Inc. Her graduate research and professional experience includes studying how geomorphic context influences ecological responses to changes in hydrology in mountain streams, conducting landscape-level spatial analyses to identify conservation priorities under changing climate in the western US, and researching use of scientific information in natural resource management decision-making. As a program manager for a regional conservation non-profit for five years, Christine's primary role was to develop and implement collaborative research and ecological restoration projects to support public lands management decision-making, in partnership with state and federal agencies. Christine will coordinate the project, compile data, conduct statistical analyses, and co-lead the development of the vulnerability assessment and decision framework. **Shana Gross** is an ecologist for the Forest Service in the Central Sierra Province. She is involved in applied management work in Sierra meadows. She has been involved in updating Region 5 range monitoring scorecard for evaluating meadow health, she wrote a natural range of variability meadows document for planning efforts in the Sierra Nevada and Southern Cascades, she is currently working with National Parks in CA to establish reference plots to compare to FS range meadow plots, and participates in project planning activities in meadows. Shana will lead interpretation and translation of work to guide management priorities and activities in the Amador-Calaveras Consensus Group, and for the USFS more broadly. She will also be involved with development of the decision framework and monitoring tool. **Dr. Justin Huntington** is an Associate Professor of Hydrology at Desert Research Institute (DRI). He and his DRI research team (Mr. Charles Morton and Dr. Britta Daudert) are highly experienced in developing, testing, and applying Landsat, MODIS, and climate data products within the Google Earth Engine cloud computing framework and have close collaborative working relationships with Landsat Science Team partners, Google, U.S. federal agencies (BLM , USFS, FWS, LCCs), CA state agencies, and universities. Huntington's group is currently working with the Google Earth Engine team through a Google faculty research grant to develop various remote sensing and gridded climate drought products and riparian system visualization and monitoring tools. As part of this collaboration, Google has committed to provide free data storage and climate data support, which was recently featured in the White House Climate Data Initiative (http://www.whitehouse.gov/the-press-office/2014/03/19/fact-sheet-president-s-climate-data-initiative-empowering-america-s-comm). Huntington's expertise in ground-surface water interactions, meadow hydrology, and promoting of communication, coordination, and awareness among federal agencies regarding opportunities to utilize remote sensing and climate products in their management operations to improve efficiencies and outcomes of programs will help ensure a successful project and web-enabled tools that are useful.

Deliverables/Timeline/Accessibility:

See Appendix A.

Measuring results:

Our study will be directly incorporated in management planning for meadow enhancement within the upper Mokelumne, Stanislaus, Calavares, and Consumnes watersheds, allowing immediate feedback on the utility of our decision framework and monitoring tool. This offers the opportunity to increase the utility of our products based on user feedback, ahead of making these products available to a broader audience of managers and stakeholders within the Sierra Nevada region. The proportion of meadows identified in our decision framework that are selected for place-based meadow enhancement projects will be one measure of project success. Project success will also be measured as the number of users accessing the CLIM Engine monitoring tool. We will also have the ability to track how the tool is applied, so that it's utility and applications can be refined over time based on patterns of use and feedback from end-users.

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U.S. Department of Agriculture, Forest Service [USDA FS]. 2013**.** Forest Service Handbook 1909.12 – Land Management Planning Handbook, Chapter 10. Section 12.11 – Terrestrial Ecosystems, Aquatic Ecosystems and Watersheds Overview. Forest Service Handbook National Headquarters, Washington, D.C. pp 14-15.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2008**.** Forest Service Strategic Framework for Responding to Climate Change. Version 1. 21 pg.

Ver Hoef J.M., Peterson E.E., Clifford D., and Shah R. (2014). SSN: An R package for spatial statistical modeling on stream networks. Journal of Statistical Software, 56(3).

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Weixelman, D. A., B. Hill, D. J. Cooper, E. L. Berlow, J. H. Viers, S. E. Purdy, A. G. Merrill, and S. G. Gross, 2011, Meadow Hydrogeomorphic Types for the Sierra Nevada and Suuthern Cascade Ranges in California - A Field Key, *in* U. S. D. o. Agriculuture, ed., Vallejo, CA, U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, p. 34.

Wood, S. H., 1975, Holocene stratigraphy and chronology of mountain meadows, Sierra Nevada, California., Dissertation, California Institute of Technology, Pasadena, California, USA.

Young, C., M. Escobar-Arias, M. Fernandes et al. (2009) Modeling the hydrology of climate change in California's Sierra Nevada for subwatershed scale adaptation, Journal of the American Water Resources Association, 45(6), 1409-1423.

Budget

California Landscape Conservation Cooperative 2015 Proposal Budgets

TOTAL	CA LCC Request	Partner(s) Contribution(s) (monetary)	Partner(s) Contribution(s) (non-monetary value/in-kind)	**Total**
Salaries	$ 118,612.95	$ -	$ 19,320.00	$ 137,932.95
Supplies	$ -	$ -	$ -	$ -
Overhead	$ 64,520.98	$ -	$ -	$ 64,520.98
Equipment	$ -	$ -	$ 10,000.00	$ 10,000.00
Other (specify)	$ 4,396.00	$ -	$ 7,708.00	$ 12,104.00
	$ -	$ -	$ -	$ -
Total	$ 187,529.93	$ -	$ 37,028.00	$ 224,557.93

Other:

Other (CA LCC Request) includes travel costs for two trips to Murphys, CA for Huntington, Daudert, and Albano to meet with the ACCG ($2396), and two field trips for Gross to work with ACCG on field validation and meadows scorecard ($2000). Other (partner contribution) includes field work costs for ACCG and Gross. See proposal cover page for breakdown of partner contributions.

Appendix A. Deliverables/Timeline/Accessibility

Deliverable Name	Deliverable Type (select from pull-down)	Expected Delivery Date	Description	How will access to this product be provided? (See examples)	Target Audience (be as specific as possible)
Quarterly Financial and Progress Reports	Administrative	Quarterly	These are the quarterly reports required of all projects.	Quarterly Financial and Progress Reports should be emailed to CA LCC	Financial: CA LCC; Progress: CA LCC and Partners
Spatially-explicit meadow vulnerability assessment	Datasets: Vector geodata	1 year from project start	Integration of meadow climate sensitivity analysis results, geomorphic attribute datasets, and climate change projections into spatially-explicit vulnerability assessment	CA Climate Commons, Databasin	Amador Calavaras Consensus Group, Federal, state, local and tribal managers and stakeholders in Sierra Nevada ecoregion
Preliminary decision framework for climate-smart selection of meadows for restoration in the Sierra Nevada	User Manual or Guidance Document	1 year from project start	Synthesis of meadow climate sensitivity and vulnerability assessment results into decision framework.	In-person, product will be pilot tested by stakeholders	Amador Calavaras Consensus Group
Revised decision framework for climate-smart selection of meadows for restoration in the Sierra Nevada	User Manual or Guidance Document	2 years from project start	Revised version of above, incorporating feedback from stakeholders and information from field validation efforts	In-person, materials posted on the Climate Commons	Amador Calavaras Consensus Group, Federal, state, local and tribal managers and stakeholders in Sierra Nevada ecoregion
Preliminary customized CLIM -Engine tool for meadow vegetation monitoring	Application or Tool	1 year from project start	CSP, DRI, USFS, USGS, and stakeholders will start the collaborative customization and testing within the Google Earth Engine framework for monitoring vegetation, drought, and and climate for areas of interest. Efforts will focus on software development, engagement with the USFS and stakeholders to allow for collaborative 'two-way' tool development and CLIM Engine enhancement based on stakeholder engagement and feedback.	In-person, product will be pilot tested by stakeholders	USFS, Amador Calavaras Consensus Group
Final CLIM-Engine tool for meadow vegetation monitoring	Application or Tool	2 years from project start	Scaling up the tested CLIM Engine customization activities in year one to regional scales. CSP and DRI will work with the USFS and stakeholders to identify site-specific challenges not encountered in the test cases and to develop strategies to address such issues. Initial data products will be developed for review by USFS and collaborators at selected test areas where accurate reference datasets exist.This will result in a dynamic, near real-time vegetation and climate monitoring interface in a friendly and familiar Google Earth environment that allows users to view and analyze different types of vegetation indices in conjunction with climate information in space and time through maps and time series tools.	In person, tool will be linked on the CA Climate Commons	Federal, state, local and tribal managers and stakeholders in Sierra Nevada ecoregion
Peer-reviewed journal article(s) focused on decision framework for selecting meadows for restoration in the Sierra Nevada	Publication	2 years from project start	Synthesis of meadow vulnerability assessment and decision framework and applications for prioritizing meadows for restoration.	Electronic copies will be sent to CA LCC via email, and provided to Climate Commons for posting.	Federal, state, local and tribal managers and stakeholders in Sierra Nevada ecoregion, Scientists and academics

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Education

Master of Science in Ecology, Colorado State University, Fort Collins, CO 2006
Bachelor of Science in Biology, Westminster College, Salt Lake City, UT 2002

Professional Appointments

Conservation Science Partners, Truckee, CA.
Lead Scientist Dec. 2014 – present
Associate Scientist Apr. 2012 - Dec. 2014
John Muir Institute of the Environment, University of California-Davis, Incline Village, NV.
Assistant Specialist Jan. 2012 – Dec. 2015
Grand Canyon Trust, Flagstaff, AZ
Program Manager Apr. 2007 – Mar. 2012
U.S. Geological Survey, Utah Water Science Center, Moab, UT
Biologist July 2006–June 2007
Colorado State University, Stream Ecology Lab, Fort Collins, CO
Graduate Research and Teaching Assistant Sept. 2003–July 2006
U.S. Geological Survey, Utah Water Science Center, Salt Lake City, UT
Hydrologic Technician Feb. 2002–Aug. 2003
Student Aide – Biological Sciences Jan. 2000- Feb. 2002

Selected Relevant Publications

Dickson, B.G., **C.M. Albano**, B.H. McRae, D.M. Theobald, J. J. Anderson, L.J. Zachmann, T.D. Sisk, M.P. Dombeck. In Review. Informing strategic efforts to expand and connect protected areas of the western US using a model of ecological flow. Proceedings of the Natl. Academy of Sciences.

Theobald, D.M., D. Harrison-Atlas, W.B. Monahan, **C.M. Albano**. 2015. Ecologically-relevant maps of landforms and physiographic diversity for climate adaptation planning. PLoS ONE 10(12): e0143619.

Albano, C.M., M.D. Dettinger, M.I. McCarthy, T.L. Welborn, D.A. Cox. 2015. Application of an extreme winter storm disaster scenario to identify vulnerabilities, mitigation options, and science needs in the Sierra Nevada Mountains, USA. Natural Hazards 80(2) p 879-900.

Lawler, J., D. Ackerly, **C.M. Albano**, M. Anderson, S. Dobrowski, J. Gill, N. Heller, B. Pressey E. Sanderson, S. Weiss. 2015. The theory behind, and the challenges of, conserving nature's stage in a time of rapid change. Conservation Biology. 29: 618–629.

Anderson, M., P. Comer, P. Beier, J. Lawler, C. Schloss, S. Buttrick, **C.M. Albano**, D. Faith. 2015. Case studies of conservation plans that incorporate geodiversity. Conservation Biology. 29: 680–691.

Albano, C.M. 2015. Identification of geophysically diverse locations that may facilitate species' persistence and adaptation to climate change. Landscape Ecology. DOI: 10.1007/s10980-015-0167-7

Albano, C.M., M.D. Dettinger, M.I. McCarthy, K.D. Schaller, T.L. Welborn, D.A. Cox. 2014. ARkStorm@Tahoe: Stakeholder Perspectives on Vulnerabilities and Preparedness for an Extreme Storm Event in the Greater Lake Tahoe, Reno and Carson City Region. University of Nevada Cooperative Extension Special Publication-14-16.

Mac Nally, R.., **C.M. Albano**, E. Fleishman. 2014. A scrutiny of evidence for pressure-induced shifts in estuarine and nearshore ecosystems. Austral Ecology. 39(8) p898-906. DOI: 10.1111/aec.12162

Dickson, B.G., L. Zachmann, **C.M. Albano**. 2014. Identifying new conservation priority areas on roadless BLM lands in the western United States. Biological Conservation. DOI:10.1016/j.biocon.2014.08.001

Bernstein, E.J., **C.M. Albano**, T.D. Sisk, T.M. Crews, and S.S. Rosenstock. 2014. Seeding cool-season grasses on a degraded rangeland on the Colorado Plateau. Restoration Ecology. doi: 10.1111/rec.12023

Albano, C.M., C. Angelo, R. Strauch, and L. Thurman. 2013. Potential Effects of Climate Warming on Visitor Use in Three Alaskan National Parks. Park Science. 30(1) p. 36-43.

Baker, D. W., B.P. Bledsoe, **C.M. Albano** and N.L. Poff. 2011. Downstream effects of diversion dams on sediment and hydraulic conditions of Rocky Mountain streams. River Research and Applications. 27(3) p. 388-401.

Sisk, T.D. and 13 Co-authors. 2010. Integrating restoration and conservation objectives at the landscape scale: The Kane and Two Mile Ranch Project. Pp. 45-66 in The Colorado Plateau IV. University of Arizona Press, Tucson, AZ.

Brasher, A.M.D., **C.M. Albano**, R.N. Close, Q.H. Cannon, M.P. Miller. 2010. Aquatic macroinvertebrate communities and habitat characteristics in the northern and southern Colorado Plateau networks: pilot protocol implementation. Natural Resources Technical Report NPS/NCPN/NRTR-2010/320, 107p.

Albano, C.M. and E. M. Giddings. 2007. Characterization of habitat and biological communities at fixed sites in the Great Salt Lake Basins, Utah, Idaho, and Wyoming, Water Years 1999-2001. USGS SRIR 06-5300.

Waddell, K., R. Baskin, E.M. Giddings, S.J. Gerner, J.R. Cederberg, S.A. Thiros, and **C.M. Albano**. 2004. Water quality in the Great Salt Lake Basins, Utah, Idaho, and Wyoming. U.S. Geological Survey Circular 04-1236.

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Education

Master of Science: Environmental and Forest Biology
State University of New York, College of Environmental Science and Forestry, Syracuse, NY 2009

Bachelor of Science: Ecology
The Evergreen State College, Olympia, Washington 2000

Professional Experience

Associate Central Sierra Province Ecologist GS-0408-11, Pacific Southwest Region, USDA Forest Service, (10/2014-Present)
Forest Ecologist GS-0408-11, Lake Tahoe Basin Management Unit (LTBMU), USDA Forest Service, South Lake Tahoe, CA (07/2011-10/2014)
Adjunct Faculty, Lake Tahoe Community College, South Lake Tahoe, CA (2012-2013)
Botanist GS-0408-09 Lake Tahoe Basin Management Unit (LTBMU), USDA Forest Service, South Lake Tahoe, CA (11/2004-07/2011)
Biological Science Technician (Plants) GS-0404-07, Lake Tahoe Basin Management Unit (LTBMU), USDA Forest Service, South Lake Tahoe, CA (05/2003-11/2004)
Graduate Research Assistant, State College of New York, Environmental School of Science and Forestry, Syracuse, NY (2006-2008)
Biological Science Technician (Plants), Plumas National Forest, USFS, Quincy, CA (2002)
Lichen Physiology Intern, Albrecht von Haller Institute of Plant Sciences, Goettingen, Germany (2002)
Biological Surveyor, Boateng & Associates, INC, Mercer Island, WA (2001)
Biological Surveyor, Rhizosphere, LLC, Salem, OR (2000)

Publications

Weixelman, D.A., and S. Gross. (*in review*). Plant functional types in relation to disturbance and hydrologic gradients in mountain meadows, Sierra Nevada and Southern Cascade ranges, CA. *Journal of Vegetation Science*.

Gross, S. and M. Coppoletta. 2013. Historic Range of Variability for meadows in the Sierra Nevada and South Cascades. Unpublished report. USDA Forest Service, Pacific Southwest Region, Vallejo, CA.

Weixelman, D.A., B. Hill, D.J. Cooper, E.L. Berlow, J.H. Viers, S.E. Purdy, A.G. Merrill, S.E. Gross. 2011. Meadow Hydrogeomorphic Types for the Sierra Nevada and Southern Cascade Ranges in California. R5-TP-034 USDA, Forest Service.

Gross, Shana. 2009. Evaluation of Moss as a Potential Restoration Tool along Roadsides in the Sierra Nevada Mountains, CA. M.S. Thesis, State University of New York College of Environmental Science and Forestry.

Hauck, M., and S. Gross. 2003. Potassium uptake in the epiphytic lichen Hypogymnia physodes at concentrations and pH as found in stem flow. *Flora* 198(2): 127-131.

Hauck, M., A. Paul, S. Gross, and M. Raubuch. 2003. Manganese toxicity in epiphytic lichens: chlorophyll degradation and interaction with iron and phosphorus. *Environmental and Experimental Botany* 49(2): 181-191.

Curriculum Vitae – Justin L. Huntington

Professional Preparation

University of Nevada, Reno	Hydrologic Sciences	Ph.D., 2011
University of Nevada, Reno	Hydrologic Sciences	M.S., 2003
University of Nevada, Reno	Environmental Science	B.S., 2000

Professional Appointments

2014 – pres.	Associate Research Professor, Desert Research Institute (DRI), Hydroclimatologist, Western Regional Climate Center
2012 – pres.	Adjunct Associate Research Professor, University of Nevada, Reno
2012 – 2014.	Assistant Research Professor, DRI
2010 – 2012	Assistant Research Hydroclimatologist, DRI
2006 – 2010	Hydrologist, Nevada Division of Water Resources, Nevada State Engineer's Office
2004 – 2006	Research Assistant, DRI, Reno, Nevada
2002 – 2004	Research Assistant, Geophysics, Boise State University, Boise, Idaho

Honors and Awards

- Selected to serve on Governor Sandoval's Nevada Drought Forum (2015)
- Regents' Rising Researcher Award - Nevada System of Higher Education (2014)
- Advisor of the Year Award - Desert Research Institute (2013)
- Wagner Medal of Excellence for Scholars in Early Stages of Career Development - Desert Research Institute (2012)

Relevant Publications (* graduate student author)

Huntington, J., McGwire, K., Morton, C., Snyder, K., Peterson, S., Erickson, T., Niswonger, R., Carroll, R., *Smith, G., and R. Allen, (in revision). Rapid Processing of the Landsat Archive for Assessing the Role of Climate and Resource Management on Groundwater Dependent Ecosystem Changes in Arid Environments. *Remote Sensing of Environment – Landsat 8 Special Issue.*

Hobbins, M., Wood, A., McEvoy, D., **Huntington**, J., and C.G. Morton. (in press). Evaporative Demand Drought Index: Part I - Theory and Formulation. *Journal of Hydrometeorology*.

McEvoy, D., **Huntington**, J., Hobbins, M., Wood, A., and C.G. Morton. (in press). Evaporative Demand Drought Index: Part II - Application and Assessment. *Journal of Hydrometeorology*.

Hobbins, M.T. and J.L. **Huntington.** (in press). *Evapotranspiration and Evaporative Demand*, Chapter 44, Handbook of Applied Hydrology, edited by V. P. Singh, McGraw-Hill Education, New York.

*McEvoy, D.J., **Huntington**, J.L., Mejia, J.F., and M.T. Hobbins. (2016). Improved Seasonal Drought Forecasts using Reference Evapotranspiration Anomalies. *Geophysical Research Letters*, 377–385, doi:10.1002/2015GL067009.

Huntington, J.L., Gangopadhyay, S., Spears, M., Allen, R. King, D., Morton, C., Harrison, A., *McEvoy, D., and A. Joros. (2015). West-Wide Climate Risk Assessments: Irrigation Demand and Reservoir Evaporation Projections. *U.S. Bureau of Reclamation, Technical memorandum No. 68-68210-2014-01, 196 p., 841 app.,* http://www.usbr.gov/WaterSMART/wcra/

*McEvoy, D.J., Mejia, J.F., and J.L. **Huntington**. (2014). Use of an Observation Network in the Great Basin to Evaluate Gridded Climate Data. *Journal of Hydrometeorology, 15, 19131931. doi:10.1175/JHM-D-14-0015.*

Roy, D. P., Wulder, M. A., Loveland, T. R., Woodcock, C. E., Allen, R. G., Anderson, M. C., Helder, D., Irons, J. R., Johnson, D. M., Kennedy, R., Scambos, T., Schaaf, C. B., Schott, …, **Huntington**, J.,… and Zhu Z. (2014). Landsat-8: Science and product vision for terrestrial global change research. *Remote Sensing of Environment, 145: 154-172.*

*Jaksa, W., Shridhar, V., and J.L. **Huntington**. (2013). Evaluation of the Complementary Relationship using Noah Land Surface Model and North American Regional Reanalysis (NARR) Data to Estimate Evapotranspiration in Semiarid Ecosystems. *Journal of Hydrometeorolog. doi: 10.1175/JHM-D-11-067.1.*

Huntington, J.L. and R.G. Niswonger. (2012). Role of surface-water and groundwater interactions on projected summertime streamflow in snow dominated regions: An integrated modeling approach, *Water Resources Research, 48, W11524, doi:10.1029/2012WR012319*.

*McEvoy, D.J., **Huntington**, J.L., Abatzoglou, J., and L. Edwards. (2012). An Evaluation of Multi-scalar Drought Indices in Nevada and Eastern California. *Earth Interactions, 16, 1-18.*

Mejia, J., **Huntington**, J.L., *Hatchett, B., D. Koracin, and R.G. Niswonger. (2012). Linking Global Climate Models to an Integrated Hydrologic Model Using an Individual Station Downscaling Approach. *Journal of Contemporary Water Research and Education. 147:1, 17-27.*

***Huntington**, J.L., J. Szilagyi, S. Tyler, and G. Pohll. (2011). Evaluating the Complementary Relationship for Estimating Evapotranspiration from Arid Shrublands. *Water Resources Research. 47, W05533, doi:10.1029/2010WR009874.*

Relevant Oral Presentations

Huntington, J.L. Abatzoglou, J.T., Hegewisch, K.C., Daudert, B., Morton, C. *VanSant, D.. (2015). Drought Monitoring through Cloud Computing and Visualization of Remote Sensing and Meteorological Datasets. *Consortium of Universities for the Advancement of Hydrologic Science, Inc (CUASHI) Webinar Series on The Western US Drought on the Ground and from Space: Combining in situ and remotely sensed data to understand and mitigate drought, October 16.*

Huntington, J.L., Morton, C., McGwire, K., McEvoy, D., Niswonger, R., and S. Peterson. (2015). Groundwater Appropriation, Groundwater Dependent Ecosystems, and 3M Plans in the Great Basin. Great Basin Consortium, Boise, Idaho, February 17-19.

Relevant Synergetic Activities and Projects

- Member of the USGS and NASA Landsat Science Team (2012-2017)
- **PI,** Drought Monitoring and Fallow Field Tracking Through Cloud Computing of Landsat, MODIS, and Gridded Climate Archives, USGS
- **PI,** Mapping Riparian Vegetation and Water Use Changes in Nevada using the Landsat Archive, BLM
- **PI**, Developing Automated Remotely Sensed ET Maps in the Central Valley, NASA

CURRICULUM VITAE

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Professional Preparation

M.S.	2011	Geography, University of Nevada, Reno
B.S.	2004	Mechanical Engineering, University of Nevada, Reno

Professional Appointments

2011- Present	Assistant GIS/Remote Sensing Scientist; Desert Research Institute, Division of Earth and Ecosystem Sciences (DEES), Reno, Nevada.
2009 - 2011	Graduate Research Assistant; Desert Research Institute, DEES, Reno, Nevada.
2008 - 2009	Hourly Technical, Desert Research Institute, DEES, Reno, Nevada.
2007 - 2009	GIS Specialist, Center for Regional Studies, University of Nevada, Reno
2004 - 2007	Mechanical Engineer, Naval Air Warfare Center Weapons Division, China Lake, California.

Research Interests

Geographic Information Systems (GIS), Remote Sensing, Modeling and Simulation, Evapotranspiration.

Publications

Carroll, R., G. Pohll, **C. Morton**, J. Huntington, 2015. Calibrating a Basin-Scale Groundwater Model to Remotely Sensed Estimates of Groundwater Evapotranspiration. *Journal of the American Water Resources Association*.

Leibert, R., J. Huntington, **C. Morton**, S. Sueki, A. Acharya, 2015. Reduced evapotranspiration from leaf beetle induced tamarisk defoliation in the Lower Virgin River using satellite based energy balance. *Ecohydrology.*

Morton, C., J. Huntington, G. Pohll, R. Allen, K. McGwire, S. Bassett, 2013. Assessing Calibration Uncertainty and Automation for Estimating Evapotranspiration from Agricultural Areas Using METRIC. *Journal of the American Water Resources Association* 49(3):549-562. DOI: 10.1111/jawr.12054

Beamer, J., J. Huntington, **C. Morton** , G. Pohll, 2013. Estimating Annual Groundwater Evapotranspiration from Phreatophytes in the Great Basin using Landsat and Flux Tower Measurements. *Journal of the American Water Resources Association* 49(3):518-533. DOI: 10.1111/jawr.12058

Presentations

Google Earth Engine Applications. Google Earth Engine Research and Higher Education Technical Workshop, San Francisco, CA, 2014.

Toward Rapid and Accurate Remote Sensing of Evapotranspiration from Irrigated Lands using Landsat. Nevada Water Resources Association 2013 Annual Conference, Reno, NV.

Improving the Efficiency of Operational ET Estimates using METRIC. Western States ET Workshop, Boise, ID, 2012.

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Employment

04/2007 – Present Assistant Research Scientist, *Desert Research Institute, Reno,NV*

Software application developer for the Western Regional Climate Center in support of the Southwest Climate Science Center

04/2007 – 04/2012 Scientific Analyst, *LIGO Laboratory, Caltech, Pasadena, CA*

Software application and extensions developer for the Open Science Grid (OSG) in support of Laser Interferometer Gravitational-Wave Observatory (LIGO) and its pursuit of scientific grid computing

Education

Ph.D. Mathematics, 03/2007, *UC Riverside, Riverside, CA*

M.S. Mathematics, 05/2003, *UC Riverside, Riverside, CA*

B.S. Mathematics and Mathematical Physics, 06/2001, *NUI Maynooth, Maynooth, Ireland*

Additional experiences

Summer Project: Epidemic Modeling, 2005, *UC Riverside, Riverside, CA*

Dr. Bai-Lian Li, Advisor