WaterSMART: Quantifying Environmental Water Requirements for Groundwater Dependent Ecosystems for Resilient Water Management

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EXECUTIVE SUMMARY

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The proposed three-year project (Oct. 2020-Sept. 2023) will combine field observations, satellite remote sensing data, hydrologic modeling, statistical modeling, and state-and-transition simulation modeling to fill a gap in process-based connections between groundwater availability, ecosystem response, and associated decisions to improve water supply reliability, provide flexibility in water operations, and improve water management. The proposed project will generate estimates of groundwater requirements for groundwater dependent ecosystems (GDEs), including both the amount of groundwater used by vegetation and sensitivities of vegetation to changing groundwater availability across gradients of climate, soils, and different types of GDEs (e.g., mesic meadow vs. xeric shrubland) in watersheds contributing to Nevada and the Great Basin. Results will be translated into a publicly available, quantitative, predictive, and easy-to-use framework called the *Groundwater Requirements for GDEs framework.* The framework will be used to generate timely, transparent, and scientifically defensible estimates of groundwater requirements to sustain GDEs and the services they provide based on GDE type, climate, soils, and groundwater availability. We will demonstrate the framework's utility by using it to identify regions in the study area with greater GDE sensitivities to changing groundwater availability. Results will also be used to enhance existing state-and-transition models of a Great Basin landscape by informing quantification of new model parameters to simulate potential for long-term vegetation transitions associated with changing groundwater availability. By providing model-based estimates of GDE groundwater use, this project will provide more reliable information about water availability that can help managers balance and meet requirements related to conjunctive management, water rights administration, drought management, and sustaining the ecosystem services GDEs provide for watershed health and protection of endangered species. The proposed project is not located on a federal facility, but has relevance to the many federal facilities in the study area (e.g., Truckee River facilities, Colorado River facilities, Humboldt Project, and the Newlands Project in Nevada and other facilities in the region) as Reclamation and stakeholders consider the best practices for providing reliable water resources for multiple purposes, including human and ecosystem needs. This project addresses Department of Interior priorities by designing a tool to restore trust with local communities while striking a regulatory balance through the process of developing the framework with ongoing feedback from potential users and demonstrating its utility to quantify water requirements for GDEs.

TECHNICAL PROJECT DESCRIPTION AND MILESTONES

Our project consists of five key tasks. The timeline and milestones are identified in Table 1.

Project Rationale and Objectives

Groundwater comprises over 1/4 of all water withdrawals for human use in the US[1] and is increasingly being relied upon in areas experiencing reduced surface water availability due to drought, higher demands, climate change, or other factors[1–4]. In addition to providing water for humans, groundwater sustains groundwater dependent ecosystems (GDEs) that benefit human well-being by providing water storage and purification, preserving soils, storing carbon, reducing flood risk and providing recreational and economic benefits[5]. However, the amount of groundwater needed to sustain GDEs remains a key uncertainty in understanding water availability and for making sustainable water management decisions that balance societal, economic, and environmental needs[6,7].

While a number of methods for estimating plant groundwater use exist, including the use of tracers, water table fluctuations, water or energy balance, and remote sensing approaches[8], these each have limitations, with the former two requiring very site specific measurements, and the latter often too coarse in scale to apply to narrow riparian GDEs or GDEs that tend to be small in size. In addition, these empirical approaches do not provide the process understanding needed to anticipate how GDE vegetation might respond to changing groundwater availability based on differences in plant species traits, soil texture, geologic characteristics, availability of surface water, climate, and aspects of the groundwater regime[9,10] such as depth, timing, or rate of change that could affect connectivity of GDEs with groundwater. This information is necessary to predict how GDE water use and vegetation may respond to drought, groundwater pumping, or declining snowpack due to warming temperatures. To address these gaps and to generate information to complement existing approaches to estimating groundwater use, we will develop and test mechanistic models of GDE plant water use for watersheds contributing to the Great Basin and state of Nevada study area (Fig. 1). ***Our principal objectives are to:*** *1) generate estimates of groundwater use by GDE vegetation considering ecological and environmental attributes of the GDE, 2) assess sensitivities of vegetation productivity to changes in groundwater availability across the gradient of climatic and soils conditions that exist across the study area, 3) deliver these results in the form of a regionally applicable and easy-to-use framework, and 4) use these results to parameterize and enhance state-and-transition models that simulate long-term changes in vegetation communities associated with changes in groundwater availability.*

This project will integrate biophysical process modeling with statistical modeling to provide estimates of GDE vegetation groundwater use and productivity based on characteristics such as vegetation association (e.g., herbaceous mesic meadow, xeric phreatophytic shrubland, mesic riparian forest, etc.) and environmental settings defined by soil types, climate, and access to groundwater (e.g., depth to groundwater, rates of water table decline, etc.). The outcome of this work will be the *Groundwater Requirements for GDEs* framework (e.g., a 'lookup table' of predictive relationships or other easy-to-use tool) that provide timely, transparent, and scientifically defensible estimates of GDE water use and vegetation responses to variations in groundwater availability that stakeholders can use to weigh tradeoffs between maintaining the ecosystem services GDEs provide and other competing uses. In addition, the framework will be used with state-and-transition simulation modeling (an approach for organizing and communicating understanding of ecosystem changes[11]) to simulate the nature and rate of vegetation class transitions associated with changing groundwater availability. Such transitions have the potential to be significant to both groundwater use and ecological sustainability, given that GDE plant communities cover over seven million acres (~10%) of NV[12]. Potential consequences of declining groundwater levels include impacts to connected streams and surface water bodies, loss of ecological systems [2,13,14], reduced vegetation cover, invasion of exotic plants[15] and atmospheric dust production[16].

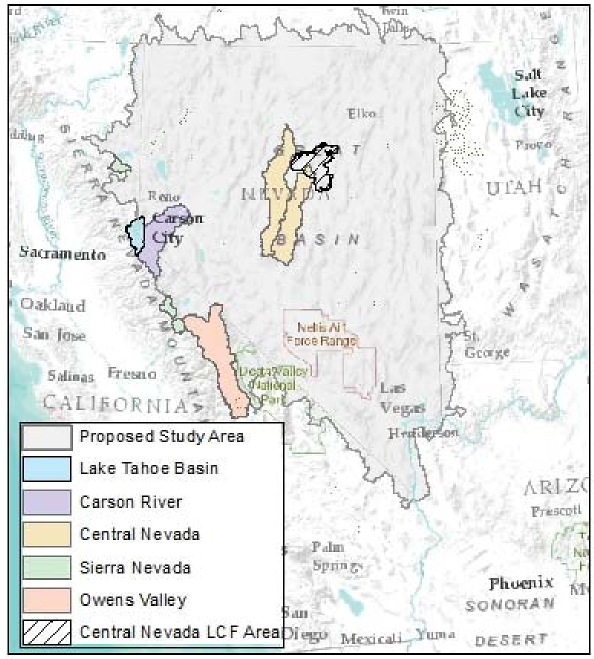

Figure 1. Project location, including the state of Nevada, the western Central Basin and Range (CBR) ecoregion, and HUC 10 watersheds contributing to the state and western CBR. Colored watersheds on map indicate regions with identified field data that are available for use in this project. Hatched area indicates location of Landscape Conservation Forecasting (LCF) modeling application. Results from the study are intended to apply to groundwater dependent ecosystems within the entire study area shown here.

This project leverages support and input from a large network of stakeholders, well-established biophysical[17], statistical[18], and state-and-transition[19] modeling approaches, remotely sensed data derived from the Landsat archive, and field-based observations from sites across a wide environmental gradient, including those from a unique 30+ year monitoring dataset of groundwater levels, soils, and vegetation composition and cover from the Owens Valley of California, to accomplish this work. While the geographic focus is on watersheds that contribute to the western Great Basin ecoregion and Nevada, in particular, the approach described here could be readily applicable or transferred to other arid regions of the west.

Approach, Key Tasks, and Milestones

Task 1: Develop conceptual framework and research design

GDE plant species vary considerably in their ability to tolerate changes in groundwater availability depending on physiological and morphological adaptations related to canopy characteristics, stomatal response, root structure and growth rates, life history strategies for reproduction, and adaptations for dealing with water stress[20,21]. These adaptations also influence how much groundwater is consumed by plants, as do environmental setting factors that determine available water from precipitation or surface water inputs and the amount of connectivity with the water table[10]. For example, differences in climate may cause the same species to have greater groundwater needs in a more arid climate, where shallow soil water resources are scarcer[20]. Furthermore, soil characteristics that influence soil water holding capacity, hydraulic conductivity, and the height of the capillary fringe may also influence a species' relative reliance on surface soils vs. deeper groundwater resources[22]. Taking this into consideration, we will develop a draft conceptual *Groundwater Requirements for GDEs* framework (Milestone 1a) and associated research design for assessing water use and vegetation responses to changes in groundwater availability for 3-5 selected GDE archetypes that vary in terms of their characteristic vegetation, surface expression of groundwater, and interactions with surface water and examine how requirements vary across the range of environmental settings in which they may occur. We anticipate that these archetypes will cover GDE types such as mesic meadow, streamside riparian, and groundwater dependent forest or shrublands, for example. For each of these we will define a set of parameters that describe the salient features of each GDE, including 1) plant species traits (i.e., riparian vegetation-flow response guilds[21]) representing different tolerances to drought or anoxic conditions, 2) attributes of the soil profile such as depths, layering, and textures, 3) attributes of the groundwater system, including ranges of timing of recharge, rate of seasonal water table decline, and depth to groundwater, and 4) surface water influences (Fig. 2).

We will develop a stakeholder advisory committee consisting of local, state, and federal agencies with responsibilities related to appropriation of groundwater rights or management of GDE species or ecosystems. Representatives from our **participating agencies** (i.e., Carson Water Subconservancy District, Nevada Department of Wildlife, Nevada Division of Natural Heritage, and Nevada Division of Water Resources) will be on this stakeholder advisory committee. This committee will serve as a core group of potential end users that will provide feedback throughout the duration of the project. We will present the draft framework to this committee and other interested parties (see attached letters of support) in a workshop setting that will be open to the public to solicit feedback on selection of focal GDE archetypes, the parameters used to characterize them, and the types of changes in groundwater availability to be simulated (Milestone 1b), and utility of the framework prior to finalizing the design (Milestone 1c).

Task 2: Model development, implementation, and validation

Once the conceptual Groundwater Requirements for GDEs framework is established, we will develop a biophysical model and associated suite of numerical simulations to estimate plant groundwater use (ETg) and biomass production (Prd) for each GDE type across a gradient of climate and soil textures that occur across the study area. Our core dataset for calibrating these simulations is a long-term (~1985-present) monitoring dataset from 169 GDE sites in the Owens Valley of California. At 28 of these sites, monthly observations of soil moisture are collected to depths of 2 (for herbaceous communities) to 4 m (for shrub communities) using a neutron probe. Groundwater levels are also recorded on a monthly basis and 100 m vegetation transects are measured in midsummer on an annual basis. These data are also collected at an additional 141 sites, albeit less frequently. This unique dataset provides an opportunity to understand long-term dynamics of GDE vegetation in relation to groundwater availability. In addition, the climate, soil and geomorphic settings, and variety of GDE types occurring in the Owens Valley are typical of the Great Basin, making it an ideal model system from which to gain process understanding that may be extrapolated to other parts of the study region. We will supplement this dataset, as needed, to capture additional archetypes that are not represented in the Owens Valley dataset with sites in the Sierra Nevada and Great Basin where similar multi-year groundwater level measurements, vegetation inventories, and soil moisture data exist, including those instrumented by Co-PI S. Loheide (Yosemite National Park and Plumas National Forest), collaborator J. Chambers with the U.S. Forest Service (15-18 wet meadow and riparian sites in central NV with > 10 years of data), the National Park Service (Yosemite, Sequoia Kings Canyon, and Devil's Postpile National Parks) and in the Carson River watershed (Fig. 1).

We will base our numerical simulations on a one-dimensional biophysical model of root water uptake and groundwater flow under variably saturated conditions that was introduced by Lowry and Loheide (2010) and applied to a riparian meadow archetype inspired by meadows in Yosemite National Park and other parts of the Sierra Nevada. To calibrate and parameterize the model, we will select a subset of monitoring sites for each focal GDE archetype that span a range of environmental settings (Fig. 2; e.g., loamy sand, 6-8" precipitation). Soil properties and atmospheric water demand parameters will be determined based on the environmental setting type. Other model parameters related to vegetation attributes such as the growth rate and distribution of roots and soil attributes such as depth and layering will be derived from the literature and representative of GDE type. Groundwater influence will be driven by observed groundwater levels, and simulations will be run over the period of record for each site. The model will be implemented using COMSOL Multiphysics software, which provides a novel and highly customizable environment for solving partial differential equations[23]. We will evaluate model performance by comparing 1) the timing, rate of change, and depths of simulated vs observed soil water content, and 2) simulated Prd with annual ground observations of vegetation cover (where available) and satellite-based vegetation index (e.g., Normalized Difference Vegetation Index) indicators of vegetation productivity from the 35-year Landsat archive (Milestone 2a). To assess transferability of model results, we will reserve data from 3-5 field sites for model validation (Milestone 2b).

Once model performance and transferability is deemed satisfactory, we will incrementally alter groundwater attributes such as the start of growing season depth to groundwater (magnitude), rate of drawdown, and timing of growing season initiation for each GDE type and environmental setting to assess sensitivities of ETg and Prd to scenarios of changing groundwater availability that might be associated with water extraction, restoration, less snow vs. rain precipitation, or earlier snowmelt runoff due to warming temperatures. Outputs of this analysis will be estimates of ETg and Prd across ranges of start of season groundwater depth magnitudes, rates of seasonal drawdown, and timing of growing season start for each combination of GDE type, climate (i.e., annual precipitation amount), and set of soil attributes (Milestone 2c).

To maximize the utility of our results and extrapolate them to environmental settings that were not explicitly modeled, we will compile all model simulations (n = ~10,000) into a synthetic dataset that includes the mechanistic model parameters (e.g., attributes of climate, soil, plant species, groundwater) and simulated ETg and Prd and use these data to train a

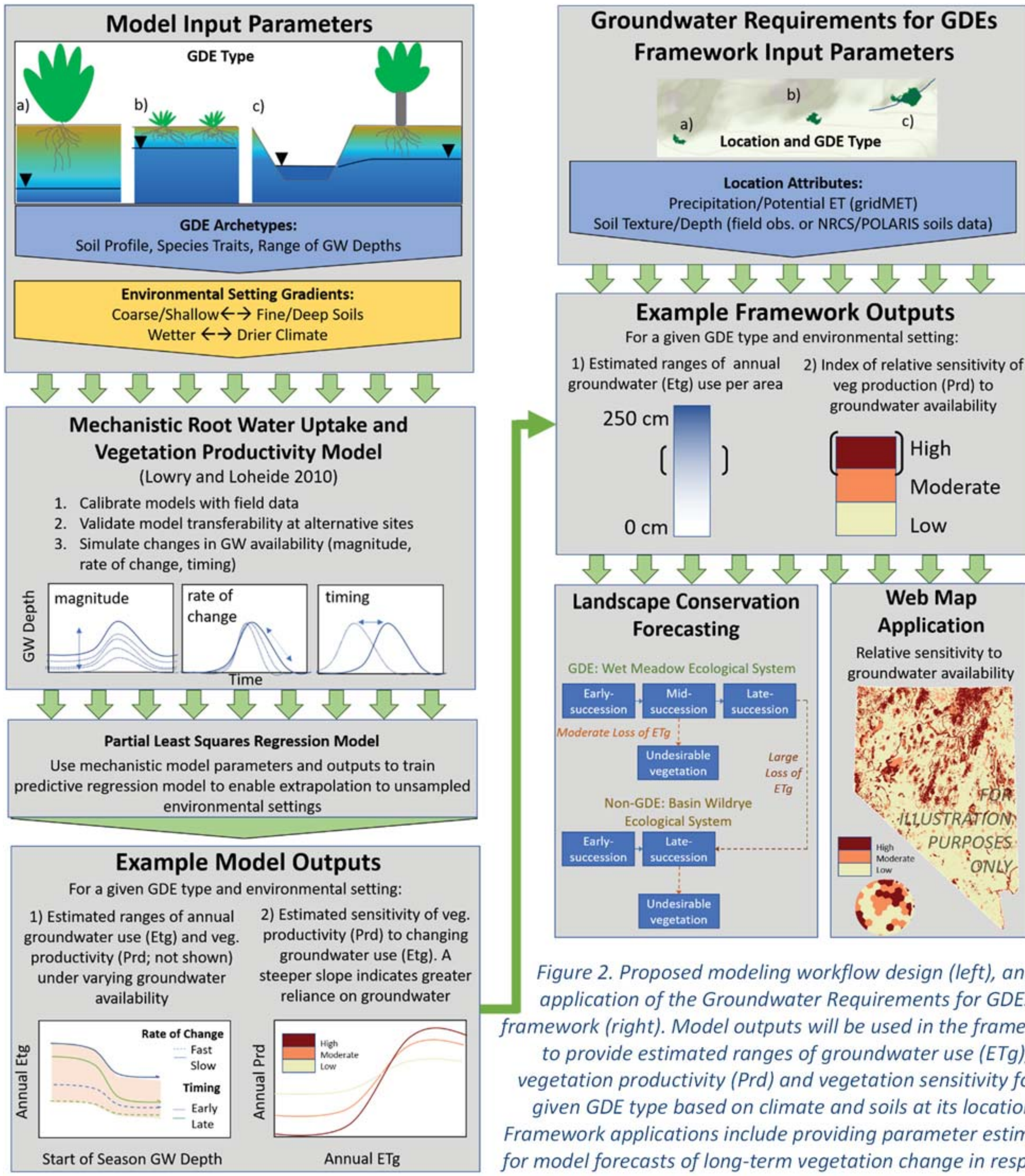

Figure 2. Proposed modeling workflow design (left), and application of the Groundwater Requirements for GDEs framework (right). Model outputs will be used in the framework to provide estimated ranges of groundwater use (ETg), vegetation productivity (Prd) and vegetation sensitivity for a given GDE type based on climate and soils at its location. Framework applications include providing parameter estimates for model forecasts of long-term vegetation change in response to changing groundwater availability and an interactive web map application of spatially explicit estimates of groundwater use and sensitivity.

predictive statistical model for each GDE type (Milestone 2d). We will develop this statistical model using partial least squares regression, which has an advantage over standard regression techniques because it can accommodate multicollinearities among a large number of predictor variables[18]. Outputs from the statistical model will form the basis of the *Groundwater*

Requirements for GDEs framework that will be a 'lookup table' or other easy-to-use tool to enable end users to access quantitative estimates of ETg and Prd based on information that is readily obtained from field observations or maps such as GDE type, climate, and soils attributes (Fig. 2). We will test the framework on another 3-5 field sites for which we have groundwater and vegetation data to validate that the range of quantitative estimates are appropriate. Once the framework is finalized, it will be distributed publicly through a site hosted by DRI, TNC, or an agency partner website as an interactive web application or Excel spreadsheet that generates statistical model predictions based on user inputs of GDE type, climate, soils and potentially other information that can readily be obtained from maps or field observations. Framework outputs will be model-predicted estimated ranges of plant groundwater use, vegetation productivity, and sensitivity of vegetation to changing groundwater conditions. Options for exploring effects of changing groundwater availability on output values will also be included.

We will hold two workshops with this task. When we have preliminary modeling results, we will prepare a first cut version of the Groundwater Requirements for GDEs framework and have a workshop to share results and get input from potential users of the framework on its utility, aspects that could be improved, and other factors to consider as we proceed with further modeling (Milestone 2e). When the framework is complete, we will have another workshop to publicize its availability and demonstrate its application (Milestone 3b; see below).

Task 3: Develop web map application

Recently, the Nevada Department of Wildlife (NDOW) and The Nature Conservancy (TNC) released a Nevada Indicators of Groundwater Dependent Ecosystems (iGDE) database and story map web map application. This effort compiled available data on phreatophytic communities, wetlands, springs, lakes and playas, rivers and streams and species into a spatial resource about where GDEs are across Nevada. Using data from the Nevada iGDE database and maps of climate and soil properties, we will apply the *Groundwater Requirements for GDEs* framework to develop an additional component of the Nevada iGDE database with environmental water requirements for GDEs (Milestone 3a). Because we will also have access to data outside of Nevada for other tasks on this project, we will use best available data on GDEs for those areas to include them in the mapping tool. As with the Nevada iGDE database, users will be able to view information about GDE water requirements by hydrographic areas (the groundwater administrative units in Nevada) or by 1-mi^2 hexagons. Climate data will come from gridded data such as gridMET[24]. Soils will be obtained from POLARIS[25], SSURGO or STATSGO.

The interactive web map application will be designed to visualize areas with different groundwater requirements relative to each other. For example, hydrographic areas with greater groundwater requirements per mi^2 or with higher sensitivities to changing groundwater availability will appear darker (Fig. 2). The map might also visualize how groundwater needs vary by season. Once a preliminary web map application is developed, we will present it, along with the framework, during Workshop 3 (Milestone 3b) and have a review period for stakeholders to review the tool and provide input on how it can be improved or be more useful.

We will incorporate the feedback to produce the final web map application and add it to the Nevada iGDE story map (Milestone 3c).

Task 4: Use Landscape Conservation Forecasting to model vegetation transitions in response to variation in the groundwater regime

An important aspect of this project is the linkage of the *Groundwater Requirements for GDEs* framework with state-and-transition simulation modeling[11] of GDEs and their vegetation classes (i.e., natural succession and human-impacted classes) to consider GDE sensitivity to changes in the groundwater regime (i.e., magnitude, rate of change and timing) and how management actions such as restoration, recharge activities like rapid infiltration basins, or groundwater use actions like groundwater pumping could affect GDEs (Milestone 4). TNC in Nevada developed the Landscape Conservation Forecasting™ (LCF) methodology, which uses remotely-sensed vegetation map layers, scenario-based state-and-transition simulation models, and metrics of success to explore these types of questions[19,26,27]. LCF is a process to forecast how simulated activities and environmental changes might impact departure from desired future conditions for a series of management actions implemented in mapped ecological systems[19,26]. LCF has been used to consider climate change impacts, fire management, range management, sage grouse habitat conservation, federally-listed Utah prairie dog habitat conservation, and other landscape dynamics. LCF is run with the freeware ST-Sim in the Syncrosim architecture that uses a semi-Markovian process and Monte-Carlo replication[28].

LCF is a raster-based spatial approach that uses remote sensing to classify each pixel as an ecological system with an associated state-and-transition model. We propose to do a proof-of-concept modeling exercise by using a previously mapped central Nevada landscape (Fig. 1) that contains many different types of GDEs and for which LCF is currently used to estimate mining mitigation banking debits and credits for sage-grouse habitat conservation[29]. The state-and-transition model includes probabilities of how vegetation classes in that system would transition to other vegetation classes under natural succession or under disturbance or major forcing factors (e.g., wildfire, drought, climate change, etc.) or management (e.g., prescribed fire, forest thinning, riparian restoration, etc.). The existing central Nevada models[29] will be revised to incorporate dependencies between ecological processes and changes in the groundwater regime. We will use the *Groundwater Requirements for GDEs* framework to develop parameter values (or transition probabilities) for natural succession, disturbance, or management that will both allow vegetation class and GDE system changes. We will include disturbance scenarios of lower groundwater tables, flooding, and drought, and management scenarios of riparian or meadow restoration and managed recharge. The output of this task will be a demonstration of how the framework can be partnered with state-and-transition models to forecast vegetation transitions in response to variations in groundwater regime.

Task 5: Project reporting and publication development

We anticipate generating at least two peer-reviewed publications based on the results from this study. The first will focus on the biophysical and statistical modeling aspects of the project and application of results to the Groundwater Requirements for GDEs framework

(Milestone 5a). The second will focus on the application of modeling results to examine long term responses of GDEs to changing groundwater availability based on the LCF simulation results (Milestone 5b). We will also complete a final performance report (Milestone 5c) and a webinar (Milestone 5d).

PROJECT LOCATION

See Fig. 1

Table 1. Project timeline, key tasks, and milestones.

Project Timeline, Tasks, and Milestones	Year 1				Year 2				Year 3			
1. Conceptual Framework/Research Design	■											
a. Draft Framework	■											
b. Stakeholder Advisory Meeting and Workshop 1	■											
c. Final Framework		■										
2. Model Development and Validation		■	■	■								
a. Mechanistic Model Development, Calibration, and Validation		■	■	■								
b. Model Transferability Assessment				■								
c. Estimates of groundwater use and vegetation productivity across ranges of groundwater depth, rate of change, recharge timing					■		■					
d. Application of Statistical Predictive Model					■	■	■					
e. Stakeholder Advisory Meeting and Workshop 2						■						
3. Develop Web Map Application							■	■	■			
a. Develop Application							■	■	■			
b. Stakeholder Advisory Meeting and Workshop 3									■			
c. Finalize web map application									■	■		
4. Model GDE Vegetation Transitions							■	■	■	■	■	
5. Reporting and publications							■	■	■			
a. Modeling results and framework application manuscript							■	■	■			
b. Responses of GDEs to changing groundwater availability manuscript										■	■	■
c. Final Performance Report												■
d. Webinar												■

DATA MANAGEMENT

Data management practices will follow the National and Regional Climate Adaptation Science Centers Data management plan guidance. Following categorizations in this guidance, data from this project will include: 1) Data inputs – Existing Collections, 2) Models, 3) Web Tools, and 4) Data products. Inputs, models, tools, and products will be documented according to this guidance. Model simulations will be generated on a computer cluster or on local desktop computers and model code and outputs will be backed up on a daily basis on DRI's servers. The statistical model will be available with documentation in a GitHub repository so that end-users can make quantitative predictions using their own input. The web map application will be developed as an ArcGIS StoryMap and available from the Nevada Division of Natural Heritage. Metadata for all spatial data will be formatted according to Federal Geographic Data Standard (FGDC) and the ISO standards and will be compatible with GIS platforms.

EVALUATION CRITERIA

A. Project Benefits:

1. Management issues addressed, and severity of issues:

This project will address the need to understand and quantify water needs for GDEs, which is a key uncertainty in water supply availability and reliability and an important component when considering sustainable water supplies for people and nature. With increased stress on groundwater supplies, having better information for water and resource managers on how much water can be used while maintaining important ecosystem functions that also benefit people is a critical need. With this information, better decisions can be made when addressing competing demands for water, water scarcity with drought, water conflicts and other water management issues.

As the driest state in the US, Nevada maintains a strong reliance on groundwater resources for irrigation, mining, and municipal uses, in particular[1]. Appropriation of groundwater rights is based on the concept of perennial yield, which has been defined in some rulings by the Nevada State Engineer as "the maximum amount of groundwater that can be salvaged each year over the long term without depleting the groundwater reservoir[30]." The perennial yield is often equated with the recharge to a groundwater basin, but because recharge is so difficult to measure, most estimates are based on "discharge" of groundwater by springs and by plants through evapotranspiration[30]. Thus, theoretically, full appropriation of the perennial yield would result in no water remaining for groundwater dependent seeps, wetlands, and meadows, as well as roughly three million acres of groundwater-dependent shrublands and forest. The implications of this are significant, as GDEs support almost half of the more than 350 endemic species in Nevada[12] and most federally protected species in Nevada depend on GDEs for one or more life stages. In addition, the state is currently working on how to manage surface water and groundwater together (i.e., conjunctive management), which is especially important for sustaining stream and baseflows.

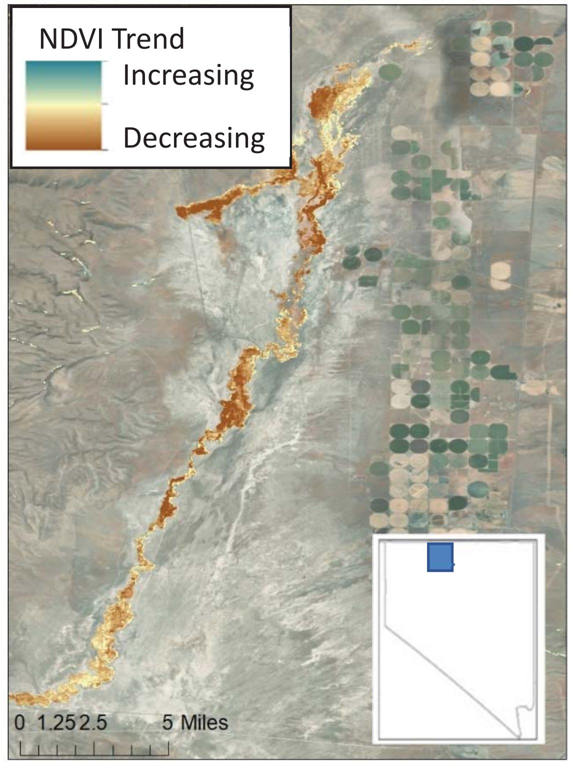

Figure 3. Statistically significant linear trends (p< 0.05) in Landsat-derived Normalized Difference Vegetation Index (NDVI; a measure of vegetation vigor) in riparian vegetation along the Quinn River in northern Nevada, 1984-2018. Declining trends are evident along riparian corridors and valley bottoms, where groundwater levels have also significantly declined over the past several decades. Trends were calculated after accounting for interannual variability in precipitation and evapotranspiration and are thus not likely to be climate-driven (Albano, McGwire, Huntington, et al.,unpublished data).

Groundwater rights are overappropriated in 95 of the 256 administrative groundwater basins in Nevada; 19 and 27 of these 95 basins are overappropriated by more than 200 and 300%, respectively[31]. The effects of declining water levels on groundwater dependent vegetation are evident in basins where extensive groundwater pumping has occurred (Fig. 3) and conflicts have arisen as groundwater depletions have affected senior surface water rights by reducing river baseflows[31].

2-3. Approach to addressing water management issues and expected benefits:

This project will facilitate timely, transparent, and scientifically defensible estimates of GDE vegetation responses to variations in groundwater availability that stakeholders can use to weigh tradeoffs between the ecosystem services GDEs provide and competing uses and make decisions about water allocations accordingly. This project will contribute toward meeting water management objectives of:

Meeting ESA species requirements: In the state of Nevada, 20 of 30 federally protected species are reliant on aquatic or riparian environments for most or all of their life cycles and nearly all of these environments are groundwater dependent. This project will quantify the amount of water needed to sustain GDE vegetation biomass production, which is a key ecological attribute that relates to nutrient cycling, ecosystem water and energy balance, and habitat structure for multiple species, including those that are protected or under consideration for protection by the ESA. For example, results from this study could help to understand how much water is needed to sustain wet meadows relied upon by sage-grouse[32], and during what time of year, so that pumping could occur without adverse impacts to this species.

Maintaining watershed health: In Nevada, over three million acres of non-riparian vegetation are estimated to be sustained by shallow groundwater[12]. With groundwater level declines, these plant communities may shift toward drought-adapted species, which can have cascading impacts on watershed health by altering microclimatic conditions and habitat structure for other species[33]. The loss of connection to groundwater will cause springs and seeps to cease flowing, which could lead to the disappearance of endemic springsnails and fish, with impacts to water availability and food resources for wildlife[34]. Wetlands, which usually have areas of standing water, may respond to reductions of water with loss of species less tolerant of drying conditions[33]. Over time, woody species that grow in adjacent uplands may replace wetland trees and shrubs. Reduction of wetland and wet meadow areas can limit forbs or insect communities that use those areas that are important for species such as sage-grouse[32,35]. For riparian areas, persistent water table declines can result in a decline of woody riparian species that might be replaced by upland vegetation[33]. Transitions for xeric phreatophytic ecosystems when water tables decline are more uncertain. It is hypothesized that species that can switch to shallow soil moisture from precipitation and tolerate some water stress may replace deeper rooted phreatophytes[20,33]. If the phreatophytic community undergoing transition is not surrounded by exotic annual species like cheat grass, it could transition to a big sagebrush community. However, if exotic species are nearby, the phreatophytic community is likely to transition to a weedy and fire-prone system that will have limited wildlife value because of very little shrub habitat[34]. Loss of vegetation cover due to declining water levels has also been associated with increased atmospheric dust production[16]. The linkage of the *Groundwater Requirements for GDEs Framework* to LCF state-and-transition models will enable us to examine how watershed health and species composition could change with reduction in water available through groundwater. This assessment can be done for temporary or seasonal loss of groundwater access, as well as for longer-term (i.e., multiple years or more) loss to help identify regions that might be more resilient to water loss versus others that could transition to undesirable landscapes with water loss.

Water rights administration and conjunctive management: The Nevada Division of Water Resources (NDWR) administers surface water and groundwater rights in Nevada. This project can be informative to NDWR in relation to considerations of 1) perennial yield (described above) and the public interest, 2) conjunctive management, and 3) whether interbasin transfers are environmentally sound. In terms of perennial yield and the public interest, The Nevada State Engineer can consider water needs for ecosystems under NRS §533.370(2) when s/he evaluates if an application "threatens to prove detrimental to the public interest," so having information about water needs to sustain GDEs can be helpful for that evaluation. In 2017, the Nevada Legislature passed a law that codified the priority of the state to conjunctively manage the appropriation, use and administration of water (NRS §533.024(1)(e)). Thus, the state is developing approaches to manage surface water and groundwater together (i.e., conjunctive management), which is especially important for sustaining stream and baseflows. For interbasin transfers, Nevada water law states that the State Engineer must consider whether the proposed interbasin transfer is environmentally sound in the basin from which water is to be exported (NRS §533.370(3)). The project will provide quantified estimates of groundwater needed to sustain GDEs, which can help the Nevada State Engineer in assessing environmental soundness of proposed interbasin transfers.

Drought management, water marketing, and water supply reliability: To manage and prepare for drought adequately, it is important to have robust estimates of water availability and water needs. GDE species in arid regions are adapted to wet and dry climate cycles, but extreme drought can put ecosystems over thresholds of sustainability[36]. Understanding water requirements for GDEs under different conditions of water availability will enable better management of water resources to improve resilience of these systems to drought while allowing water use to sustain human needs. Two approaches for addressing water supply reliability and drought management that are gaining attention are water marketing and managed aquifer recharge (MAR), both of which are being studied in the Carson River watershed in California and Nevada. The US Geological Survey has developed groundwater models to look at water management scenarios in the Middle and Upper Carson River watersheds, and the Carson Water Subconservancy District is currently studying water marketing alternatives for the Carson River watershed. The close interaction of groundwater and surface water in the Carson River watershed along with irrigation provide opportunities to use conjunctive management through water marketing or MAR to manage the variability in groundwater storage, improving the reliability of water supply during times of surface water storage. Understanding the effect of altering groundwater variability on GDEs is an important need in considering these management options to increase water supply reliability in the Carson River watershed and elsewhere that this project could address.

4. Complementary efforts:

Remote sensing and water balance approaches are currently being used to empirically derive estimates of groundwater use by vegetation at the basin scale[37]. Much of this work in Nevada is led by Dr. Justin Huntington at Desert Research Institute. The work proposed here would be completed in close coordination with these efforts and will be highly complementary, given that Dr. Albano works closely with Dr. Huntington as part of his team. Remote sensing approaches can provide reasonable estimates of vegetation groundwater use at the basin scale[37] but do not provide the necessary process understanding to predict how vegetation will respond to changing groundwater availability, do not capture small GDEs, nor do they discriminate among plant species or environments that result in different groundwater use efficiencies. Results from this project could provide information to help stratify statistical models that use remote sensing data to account for differences among vegetation communities or soil types. This may ultimately help to refine the remote sensing approach to gain more precise estimates of groundwater use over large scales. Results can also be used to develop refined groundwater model parameters to simulate GDE water use (see South Tahoe PUD support letter).

TNC is examining strategies for protecting and restoring GDEs. To do this, we need to know how much water is needed for GDE resilience and sustainability. TNC recently mapped GDEs in Nevada with the best available data and is in the process of looking at stressors and threats to GDEs. TNC is also in the process of studying xeric shrubland phreatophyte systems to develop state-and-transition models of those ecological systems. That information along with GDE flow needs determined from the proposed project will enable TNC to prioritize strategies and locations to engage in to ensure water for people and nature for future generations.

B. Need for Project and Applicability of Project Results:

1. Expressed Need:

The Western Governor's Drought Forum (2015) identified a need to enhance understanding of the relationships between snowpack, rainfall, groundwater recharge, soil moisture and temperature to improve predictions of water availability. Groundwater management and increased flexibility of water transfers for environmental purposes were also noted in the report, and this project will provide a science-based tool that could be used to address these needs. The Nevada Water Plan identifies the need for 'an ongoing, structured assessment process to determine where additional water supplies for wildlife and environmental needs are not being met as evidenced by deterioration in essential resource conditions' (pg. 6-9). It also stresses that 'Nevada has many threatened and endangered species and unique ecosystems, and has lost much of its wetland environments. Protection of water quality and recreation opportunities depend in large part on water availability. Because the water needs for these beneficial uses of water have not been adequately quantified and few water rights have been obtained to support them in the past, a thorough evaluation of the potential environmental impacts must precede any large scale water transfer' (Pg 7-9). A current ongoing water rights discussion in Nevada is occurring on the Lower White River Flow

System, where a two-year pump test ordered by the State Engineer (Order 1169) revealed connectivity between groundwater pumping in certain hydrographic areas with spring-fed surface water in other hydrographic areas that could conflict with senior decreed water rights or adversely affect the endangered Moapa dace (Order 1303). There are also concerns in watersheds that are interested in conjunctively managing water without violating decreed water rights (e.g., Humboldt River, Carson River), and in proposed interbasin transfers of water that in Nevada must be environmentally sound in the basin of origin. While the proposed work does not directly address these situations, results from our study would enable a more efficient process for evaluating water needs, benefits, and potential environmental impacts of competing groundwater needs.

Our project will benefit from the broad participation and support from eleven federal, state, and local agencies with responsibilities for water rights allocations (NV Division of Water Resources), water or energy delivery (South Tahoe Public Utilities District, Placer County, Truckee Meadows Water Authority, Carson Water Subconservancy District, NV Energy), and species and habitat management, monitoring, and protection (Inyo County Water, U.S. Fish and Wildlife Service, U.S. Forest Service, NV Dept. of Wildlife, NV Division of Natural Heritage). These entities have identified their interest in, and the potential utility of, project results and have offered to participate in one or more of the following ways: contribution of data and associated guidance on its use, attend and provide feedback at stakeholder meetings throughout the project, assist with identification of additional sites with relevant data, and to assist with outreach and dissemination of products (see eleven attached support letters).

2. *Applied tools and information developed, use and applicability to decision-making, transferability of results, and beneficiary involvement:*

This project will develop a simple and easy-to-use framework that can be used to generate scientifically defensible first-approximation estimates of groundwater requirements of GDE vegetation across a broad geographic extent based on the type of GDE and its environmental setting, including both the amount of groundwater vegetation consumes (ETg) and the sensitivity of vegetation productivity (Prd) to changes in groundwater availability. This framework will provide information that can help inform discussions about water allocations, conservation opportunities, and tradeoffs between the ecosystem services GDEs provide and water for human needs to enable decision-making with science-based information. The actual amount of water allocated among competing uses, including GDEs, will have to be determined based on the acceptable levels of risk that stakeholders are comfortable with, which will be best determined through collaborative planning. Collaborative planning is not a component of the proposed work, but we expect the results from this study to be helpful for stakeholders who need to consider tradeoffs and acceptable levels of risk. The framework and modeling approach developed in the proposed work could be readily transferred to other regions where quantifying GDE groundwater use could facilitate water allocation discussions. It could also be used to address groundwater needs of other GDE types, other species, or to address other aspects of the groundwater regime that species are hypothesized to be sensitive to.

The framework and research design will be developed with a core stakeholder advisory group consisting of representatives from local, state, and federal agencies who stand to benefit from the information that is generated from the project and who have responsibilities related to managing land or water resources, appropriation of groundwater rights or management of GDE species or ecosystems. The stakeholder advisory group will be involved throughout the duration of the project and will be convened at least three times throughout the project for workshops to ensure their involvement in study design, to convey research results, and to incorporate their feedback so that outputs are translated into a useable form. These workshops will also be open to all interested parties to maximize feedback and participation.

C. Project Implementation:

1-2: Objectives, methodology and approach, and work plan:

See Technical Project Description and Milestones.

3. Availability and quality of existing data and models:

This project draws from several data sources, including a unique 30-year dataset with monthly observations of groundwater levels, soil moisture, and annual measures of vegetation cover from the Owens Valley of California. This dataset is used as part of annual monitoring and reporting and is thus well-maintained and of high quality. Most data from additional field sites outside the Owens Valley are managed by university and agency researchers and have been used in peer-reviewed publications and thus are expected to be of high quality. We have allocated time in the budget for cleanup and preparation of data from collaborator J. Chambers' field sites. Satellite remote sensing data will be filtered, processed, and downloaded in the Google Earth Engine environment using well-established protocols for atmospheric correction[38] and cloud masking[39]. The biophysical model developed by Lowry and Loheide[17] in COMSOL multi-physics software is available and will be used for this study. Applications such as ShinyR and ArcGIS StoryMaps will enable widespread distribution and delivery of results in an interactive format. Modeling of vegetation transitions will occur with existing state-and-transition models developed by TNC in central Nevada for the proof-of-concept modeling exercise.

4. Qualifications of Team.

Our project team has expertise in ecohydrology of groundwater dependent ecosystems (Loheide, Saito, Albano), biophysical and hydrologic modeling (Loheide, Saito), multivariate statistical analysis of extensive climate and remote sensing datasets (Albano, Byer, Badik), development of web applications (Byer, Saito), state-and-transition modeling (Provencher, Badik), and have worked extensively with stakeholders to develop and implement applied research projects (Albano, Saito, Loheide, Provencher). We will be capable of immediately starting the project upon receipt of funding. Qualifications to complete the project are demonstrated below and their specific roles in the project are described in the budget narrative. Additional information on qualifications is available in attached CVs.

Dr. Christine Albano is a Postdoctoral Researcher at Desert Research Institute and is currently leading a collection of projects focused on using satellite remote sensing and climate data to assess status and trends in groundwater dependent ecosystems across the state of

Nevada. She received her BS in Biology from Westminster College, MS in Ecology from Colorado State University, and PhD in Hydrology from University of Nevada, Reno. Albano's research has explored the role of geomorphic setting as a mediator of 1) climate sensitivities of groundwater dependent vegetation in the Sierra Nevada and Great Basin and 2) effects of hydrologic alterations on aquatic ecosystems. She has experience with statistical analysis of hydrologic and ecological data as well as management and processing of large spatiotemporal climate and remote sensing datasets. As a non-profit program manager and lead scientist for several years, Albano has developed and implemented several collaborative research projects in partnership with state and federal agencies to support natural resource management decision-making.

Dr. Steven Loheide is a Professor of Civil and Environmental Engineering, Geological Engineering, and Freshwater and Marine Sciences at the University of Wisconsin – Madison. He received his BS in Environmental Chemistry and Geology from the University of Northern Iowa (1999), his MS in Geology from Indiana University (2001), and his PhD in Hydrogeology from Stanford University (2006). Loheide's research focuses on the interactions between ecological and hydrological processes in natural and built systems with special attention to the role of groundwater. His approaches use a combination of field data, remote sensing, and numerical modeling to understand the feedbacks between vegetation patterning, vegetative water use, soil moisture availability, groundwater regimes, and stream-aquifer interactions. This work is focused on improving the scientific basis for stream, floodplain, meadow, and wetland restoration efforts; quantifying the provisioning of hydrologic ecosystem services under current and future scenarios; and evaluating interactions among groundwater and urban, agricultural, and natural environments. Since 2001, he has conducted research in meadows of the Sierra Nevada including quantifying groundwater use, evaluating restoration scenarios through field based studies and numerical modeling, and developing the concept of groundwater subsidy. Loheide has been PI, Co-PI, or Senior Personnel on awards totaling ~$24 million since 2007 from agencies including NSF, DOE, EPA, NOAA, and NPS.

Dr. Laurel Saito has been the Nevada Water Program Director for The Nature Conservancy (TNC) since 2016. She is working to define and protect environmental flows in Nevada by using scientific approaches and engaging with Nevada water legislation and policy. Most recently she has led projects to develop the Nevada iGDE database and story map, and has participated in the 2017 and 2019 Nevada Legislative Sessions to engage in proposed legislation on water for the environment. She is currently Vice-President of the Nevada Water Resources Association. Saito previously was an Associate Professor at the University of Nevada Reno, where her research focused on interdisciplinary approaches to water resources management. Saito received her M.S. and Ph.D. in Civil Engineering from Colorado State University, and a B.S. in Civil Engineering from the University of California at Davis. She is a registered Professional Engineer in Nevada, Colorado, and California.

Dr. Louis Provencher is the Director of Conservancy Ecology for TNC and has worked for TNC for over 25 years. He pioneered Landscape Conservation Forecasting™(LCF) that was used in Hamlin Valley and the Black Mountains for the BLM Cedar City Field Office after years of leading vegetation modeling for the Great Basin region of the national interagency LANDFIRE project. He has led projects using LCF with the BLM and the US Forest Service in California, Nevada and Utah, Great Basin National Park, Nevada State Wildlife Action Plan with the Nevada Department of Wildlife, on mixed private and public lands with Newmont Mining Corp. and Barrick Gold USA, and on private land. He created the ST-Sim simulation database for the central Nevada landscape that will be used for this project. Provencher earned his B.S. and M.S. in Biology at the Université due Québec à Montréal and his Ph.D. in Ecology at the University of Tennessee.

Dr. Kevin Badik has been the Rangeland Ecologist for TNC since 2015. He has primarily worked on LCF projects involving sage-grouse, mule deer and golden eagle habitat suitability applied to Newmont Mining Corp. and Barrick Gold ranches. Badik is skilled in R coding, which he has used to perform stochastic weather generation and ecological departure analysis. He has also assisted with hydrologic and sediment transport modeling for the Upper Truckee River watershed. Recently, he has also led projects on native seed establishment. Badik earned his B.S. from Ohio Northern University and his Ph.D. in Ecology, Evolution, and Conservation Biology from the University of Nevada Reno.

Ms. Sarah Byer has been the Spatial Analyst for TNC since 2018. She is skilled in GIS, including R and Python coding, and uses remote sensing imagery and ancillary data to support LCF for land management planning in Nevada and Utah. She also designed and constructed geodatabases to store and distribute data describing GDEs in Nevada for the Nevada iGDE database and story map. Byer has a B.A. in Geography from Colgate University and a M.A. in Geography from University of California, Davis.

5. Anticipated products

We anticipate four key products from this effort: 1) The *Groundwater Requirements for GDEs Framework* will come in the form of an interactive web application (e.g., see ShinyR example here) and/or downloadable Excel spreadsheet that accepts user inputs of GDE type, climate, soils and potentially other information that can readily be obtained from maps or field observations and outputs model-predicted estimated ranges of plant groundwater use, vegetation productivity, and sensitivity of vegetation to changing groundwater. Options for exploring the effects of changing groundwater availability on output values will also be included; 2) an interactive web map application that provides the above-described outputs from the framework using mapped climate and soils attributes and user-defined GDE type as inputs. This application will be integrated with the existing Nevada Indicators of Groundwater Dependent Ecosystems (iGDE) database and story map hosted respectively by the Nevada Division of Natural Heritage and Nevada Department of Wildlife; 3) a journal article describing the biophysical and statistical modeling aspects of the project and application of results to the *Groundwater Requirements for GDEs Framework;* and 4) a journal article describing the application of modeling results to parameterize LCF state-and-transition models to examine long term responses of GDEs to changing groundwater availability.

D. Dissemination of Results

Our stakeholder advisory committee will be composed of several of our intended end-users, including state and federal agencies, counties, and water providers, thus project progress and results will be communicated to them throughout the project through organized workshops. We will work with this group to identify additional stakeholders and the best means for conducting outreach to other interested parties. This type of outreach will be in line with best practices of knowledge co-production[40] and enable us to incorporate feedback from interested stakeholders and end-users over the course of the project. By doing so, we are more likely to generate end products that are usable and used[41]. We will work with the stakeholder advisory committee to determine the best means of publicly distributing the *Groundwater Requirements for GDEs* framework (e.g., agency, DRI, or TNC website). The web map application will be available on the Nevada iGDE story map application that is already available through the Nevada Department of Wildlife. We will prepare papers for peer-reviewed publication (see Task 5) and will give webinars and conference presentations to publicize the work and availability of the framework and its applications.

E. Department of the Interior Priorities:

This project will contribute to ***creating a conservation stewardship legacy*** while ***utilizing our natural resources*** by providing scientifically defensible estimates of GDE groundwater use and responses to changing water availability that can be used to 'identify best practices' for water resource management amidst competing interests in NV and the Great Basin. The stakeholder-driven approach to research design and the resulting products from this project will help to ***restore trust with local communities*** by 'fostering relationships with conservation organizations advocating for balanced stewardship and use of public lands,' 'improving dialogue and relationships,' and 'expanding lines of communication with state natural resource offices, Fish and Wildlife offices, water authorities, county commissioners, Tribes, and local communities.' This work will also assist with ***striking a regulatory balance*** by providing a strong scientific foundation for understanding key GDE water needs for habitats in which many ESA species occur in Nevada so that water can be reliably provided to benefit people and nature.

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Funding Plan

Desert Research Institute

SCIENCE • ENVIRONMENT • SOLUTIONS

Division of Hydrologic Sciences

October 24, 2019

Dept. of Interior – Bureau of Reclamation
WaterSMART – Applied Science Grants
FOA No. BOR-DO-19-F012

Project Title: WaterSMART: Quantifying environmental water requirements for groundwater dependent ecosystems for resilient water management
DRI PI: Christine Albano, Ph.D.

To Whom It May Concern:

This letter confirms that the Desert Research Institute (DRI) is pleased to submit a proposal in response to referenced Funding Opportunity Announcement. This letter serves as a commitment from the Desert Research Institute to provide the required 50% cost share for the referenced project. The total Federal amount of the project is $296,740, the DRI Cost Share amount is $146,195 and the subawardees cost share amount is $150,793 (see separate letters of commitment from these entities), for a total project cost of $593,728.

DRI's cost share has been secured and will be available at the time of the award. It will consist of $88,603 cash from non-federal/internal sources and $57,592 of waived indirect costs.

Sincerely,

Yvonne Rumbaugh

Yvonne Rumbaugh
Business Manager

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The Nature Conservancy
Nevada

Dr. Christine Albano
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512

October 16, 2019

RE: Match Contribution and Letter of Commitment for Funding Opportunity Number: BOR-DO-19-F012

Dear Dr. Albano,

On behalf of The Nature Conservancy's (TNC) Nevada Field Office, I am pleased to write a letter of commitment for the Department of the Interior, Bureau of Reclamation WaterSMART: Applied Science Grant proposal you are submitting entitled "*Quantifying environmental water requirements for groundwater dependent ecosystems for resilient water management.*" We are committed to working with the Desert Research Institute (DRI) and the University of Wisconsin-Madison on developing a framework for GDE water requirements to enable science-based decision-making for resilient water management in Nevada and the region. We will participate in all tasks for the proposal, and will lead workshop coordination, development of a web map application for the framework, and modeling of GDE transitions.

TNC's mission is *to conserve the lands and waters on which all life depends.* We work to provide tangible, lasting results using the best available science and a non-confrontational approach with innovative solutions to complex conservation problems at scales that matter and in ways that will endure. This project embodies that mission by providing a science-based means of quantifying the relationship between groundwater availability and water needs for groundwater dependent ecosystems, a critical piece that has been missing in making sustainable water decisions for people and nature for future generations.

This letter also serves as documentation and verification that TNC is contributing match in support of the above referenced grant. We will contribute in-kind services of $34,562 to match federal funds of $34,559. These funds are detailed on the attached spreadsheet.

Salaries and wages: Federal funds are requested for 315 hours for the Spatial Analyst (Ms. Sarah Byer), and 140 hours for the Rangeland Ecologist (Dr. Kevin Badik). Matching funds from TNC will be provided for 77 hours of the Director of Conservation Ecology's (Dr. Louis Provencher) time, 49 hours of the Rangeland Ecologist's time, and 224 hours of the Nevada Water Program Director's (Dr. Laurel Saito) time. A 2.2% annual cost escalator has been applied to all salaries based on the lowest of three recent Congressional Budget Office (CBO) projections for 2017-2022. Dr. Saito will be TNC's project manager and will lead Task 3 (development of web map application) and workshop coordination for the project. Ms. Byer will be responsible for most of the work on Task 3. Dr. Provencher will lead Task 4 (modeling of GDE transitions), and Dr. Badik will be responsible for most of the work on Task 4. All TNC team members will participate in all tasks for the project, including development of the Groundwater Requirements for GDEs Framework (Tasks 1-2), attending all workshops and meetings for the project, and preparing project reports and publications (Task 5).

Fringe benefits: The Nature Conservancy's negotiated fringe benefits rate for federally funded awards for FY 2020 is 40%. Fringe on match salaries will be charged to the match requirement for this project.

Supplies/Materials: Funds of $100 per workshop for 3 workshops are requested for copying and supplies for materials distributed at workshops.

Equipment: No funds are requested for equipment.

Contractual: No funds are requested for contracts.

Travel: Workshops are planned to be held simultaneously in Reno and Las Vegas at DRI North and South campuses, so travel funds of $890 are requested for one TNC team member to travel to Las Vegas for a workshop in Years 2 and 3. Roundtrip airfare was estimated at $247 per trip, and per diem and lodging were estimated at $198/night.

Indirect costs: TNC negotiates a new indirect costs rate with the federal government each fiscal year. TNC's fiscal year runs July 1 – June 30. TNC's approved Negotiated Indirect Cost Recovery Agreement (NICRA) FY20 indirect cost rate is 24.34% of direct costs. This rate is applied to both federal funds and matching funds for budget purposes.

The Nature Conservancy appreciates working with DRI and the University of Wisconsin-Madison on this important project.

Sincerely,

Laurel Saito

Laurel Saito, Ph.D., P.E.
Nevada Water Program Director

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October 23, 2019

Christine M. Albano
Postdoctoral Fellow, Ecohydrology
Division of Hydrologic Sciences
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512

RE: UW Proposal #MSN234941 Professor Steven Loheide

Dear Dr. Albano:

The University of Wisconsin is pleased to collaborate with the Desert Research Institute in its submission to the Department of Interior, for the proposal entitled, "Quantifying environmental water requirements for groundwater dependent ecosystems for resilient water management" on behalf of Professor Steven Loheide in the Department of Civil and Environmental Engineering. The total amount requested for the subcontract is $116,230.00. The attached application has been administratively approved on behalf of the Board of Regents of the University of Wisconsin System and is submitted for your consideration.

The University of Wisconsin - Madison agrees to provide $116,230.00 to meet the agency's cost share requirement, as detailed in the project budget.

During the evaluation process we ask that you use the University's above-referenced proposal number in any future correspondence. For questions regarding administrative or contractual matters please contact Research and Sponsored Programs, 21 N. Park Street, Suite 6401, Madison, WI 53715-1218, Phone: (608)262-3822, Fax: (608)262-5111. The University of Wisconsin reserves the right to negotiate terms of this proposal prior to final award notice.

For questions regarding the technical nature of this application please contact: Professor Steven Loheide, UW-Madison, 1269c Engineering Hall, 1415 Engineering Dr, Madison, WI 53706, Phone: (608)265-5277, Email: loheide@wisc.edu.

Sincerely,

Ian M. Robertson, Dean
College of Engineering

Brenda Egan

Brenda A. Egan, Managing Officer
Research and Sponsored Programs

Budget Proposal

Table 1. – Total Project Cost Table

SOURCE	AMOUNT
Costs to be reimbursed with the requested Federal funding	$296,740
Costs to be paid by the applicant	$146,195
Value of third-party contributions	$150,793
TOTAL PROJECT COST	$593,728

Table 2. – Budget Proposal

DRI

		Year 1				Year 2				Year 3				TOTAL PROJECT	
		Federal		Match		Federal		Match		Federal		Match			
	Rate	**Units**	**Amount**	**Units**	**Amount**	**Units**	**Amount**	**Units**	**Amount**	**Units**	**Amount**	**Units**	**Amount**	**Units**	**Amount**
PERSONNEL															
Albano, Christine	6,129	3.00	18,387	5.00	30,644	2.80	18,019	3.20	20,593	2.00	13,514	2.00	13,514	18.00	114,671
TOTAL PERSONNELL			18,387		30,644		18,019		20,593		13,514		13,514		114,671
FRINGE															
Post Doc	33.8%		6,215		10,358		6,090		6,960		4,568		4,568		38,759
TOTAL FRINGE			6,215		10,358		6,090		6,960		4,568		4,568		38,759
TOTAL SALARIES			24,601		41,002		24,109		27,553		18,082		18,082		153,430
TRAVEL															
Trips to Wisconsin															
Airfare	700	0.50	350	0.50	350	0.50	350	0.50	350	0	0		0	2	1,400
Lodging per diem	102	2.50	255	2.50	255	2.50	255	2.50	255	0	0		0	10	1,020
Meals per diem	61	3.00	183	3.00	183	3.00	183	3.00	183	0	0		0	12	732
Transporation/gas	65	3.00	195	3.00	195	3.00	195	3.00	195	0	0		0	12	780
TOTAL TRAVEL			983		983		983		983		0		0		3,932
SUBAWARDS															
University of Wisconsin			37,299		41,165		38,765		36,797		40,166		38,268		232,460
The Nature Conservancy			2,561		9,337		10,640		12,672		21,357		12,554		69,121
Subtotal Subawards			39,860		50,502		49,405		49,469		61,523		50,822		301,581
TOTAL DIRECT COSTS			65,445		92,487		74,498		78,005		79,605		68,903		458,942
MTDC			53,145		41,985		35,732		28,536		29,881		18,082		207,362
ICR (ON MTDC)	65%		34,544		27,290		23,226		18,549		19,423		11,753		134,785
TOTAL COST			**99,989**		**119,777**		**97,723**		**96,554**		**99,028**		**80,657**		**593,728**

Federal	**49.98%**	**FEDERAL**	**296,740**
Cost Share	**50.02%**	**COST SHARE**	**296,988**

Subaward – The Nature Conservancy

Federal	Non-Federal	Total
2,561.40	9,336.88	11,898.28
2,561.40	9,336.88	11,898.28

Year 1

1 Federal	2 Match		5 Total
$1,400.00	$5,363.68		$6,763.68
560.00	2,145.47		2,705.47
0.00			0.00
0.00			0.00
100.00			100.00
			0.00
			0.00
			0.00
2,060.00	7,509.15		9,569.15
501.40	1,827.73		2,329.13
$2,561.40	$9,336.88		$11,898.28

Federal	Non-Federal	Total
10,640.37	12,671.58	23,311.95
10,640.37	12,671.58	23,311.95

Year 2

1 Federal	2 Match		5 Total
$5,723.20	$7,279.34		$13,002.54
2,289.28	2,911.74		5,201.02
445.00			445.00
0.00			0.00
100.00			100.00
			0.00
			0.00
			0.00
8,557.48	10,191.07		18,748.55
2,082.89	2,480.51		4,563.40
$10,640.37	$12,671.58		$23,311.95

Federal	Non-Federal	Total
21,357.09	12,553.52	33,910.60
21,357.09	12,553.52	33,910.60

Year 3

1 Federal	2 Match		5 Total
$11,879.54	$7,211.51		$19,091.06
4,751.82	2,884.61		7,636.42
445.00			445.00
0.00			0.00
100.00			100.00
			0.00
			0.00
			0.00
17,176.36	10,096.12		27,272.48
4,180.73	2,457.40		6,638.12
$21,357.09	$12,553.52		$33,910.60

Budget Information - Non-Construction Programs

Section A - Budget Summary

New or Revised Budget

	Federal	Non-Federal	Total
	34,558.86	34,561.98	69,120.84
Totals	34,558.86	34,561.98	69,120.84

Section B - Budget categories

	1 Federal	2 Match		5 Total
a. Personnel	$19,002.74	$19,854.53		$38,857.28
b. Fringe Benefits	7,601.10	7,941.81		15,542.91
c. Travel	890.00			890.00
d. Equipment	0.00			0.00
e. Supplies	300.00			300.00
f. Contractual				0.00
g. Construction				0.00
h. Other				0.00
I Total Direct	27,793.84	27,796.35		55,590.19
j. Indirect	6,765.02	6,765.63		13,530.65
k. Totals	$34,558.86	$34,561.98		$69,120.84

Subaward – University of Wisconsin

	Sponsor Year 1	UW Cost Share Year 1	Sponsor Year 2	UW Cost Share Year 2	Sponsor Year 3	UW Cost Share Year 3	Total Sponsor	Total UW Cost Share	Total Project
A. Senior Personnel									
1. Steve Loheide	$ 16,037	$ 19,725	$ 16,678.13	$ 17,529	$ 17,345	$ 18,230	$ 67,581	$ 74,903	$ 142,484
Total Senior Personnel	$ 16,037	$ 19,725	$ 16,678	$ 17,529	$ 17,345	$ 18,230	$ 67,581	$ 74,903	$ 142,484
Total Salaries & Wages A+B	$ 16,037	$ 19,725	$ 16,678	$ 17,529	$ 17,345	$ 18,230	$ 67,581	$ 74,903	$ 142,484
C. Fringe Benefits									
35.00% *A1	$ 5,613	$ 6,904	$ 5,837	$ 6,135	$ 6,071	$ 6,380	$ 17,521	$ 19,419	$ 36,940
20.00% *B1									
33.30% *B2									
21.00% *B3									
Total S&W + FB	$ 21,650	$ 26,629	$ 22,515	$ 23,664	$ 23,416	$ 24,610	$ 67,581	$ 74,903	$ 142,484
E. Travel									
1. Domestic	$ 1,100	$ -	$ 1,100	$ -	$ 1,100	$ -	$ 3,300	$ -	$ 3,300
Total	$ 1,100	$ -	$ 1,100	$ -	$ 1,100	$ -	$ 3,300	$ -	$ 3,300
F. Other Direct Costs									
1. Materials & Supplies	$ 1,314		$ 1,314		$ 1,314	$ -	$ 3,942	$ -	$ 3,942
10. Other	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Other Direct Costs	$ 1,314		$ 1,314		$ 1,314		$ 3,942	$ -	$ 3,942
G. Total Direct Costs	**$ 24,064**	**$ 26,629**	**$ 24,929**	**$ 23,664**	**$ 25,830**	**$ 24,610**	**$ 74,823**	**$ 74,903**	**$ 149,726**
H. Indirect Costs 55.0% MTDC*	**$ 13,235**	**$ 14,536**	**$ 13,836**	**$ 13,133**	**$ 14,336**	**$ 13,658**	**$ 41,407**	**$ 41,327**	**$ 82,734**
I. Total Costs	**$ 37,299**	**$ 41,165**	**$ 38,765**	**$ 36,797**	**$ 40,166**	**$ 38,268**	**$ 116,230**	**$ 116,230**	**$ 232,460**

Budget Narrative

Desert Research Institute

General: The methods used in estimating the costs for this proposal are consistent with those used in other projects of this type. This proposal is consistent with DRI's governing Federal cost principles, including the OMB Unified Circular.

Salaries and Fringe Benefits: The Desert Research Institute (DRI) is a non-profit academic research institution of higher education (as opposed to a degree granting entity). As such, DRI faculty salaries are funded solely from grants and contracts with no ability to obtain tenure.

Personnel
The project manager of the project is Christine Albano, Postdoctoral Fellow. A total of 18 months has been budgeted for Dr. Albano over the course of the project (hours broken down by year and tasks in the table below). Year 1 will consist of drafting the research design and framework, soliciting feedback from stakeholders, data preparation, and calibration and validation of the biophysical model simulations (Tasks 1 and 2). Year 2 will consist of modeling scenarios of changing groundwater availability, statistical analysis of simulation results, and soliciting feedback from stakeholders (Task 2), assisting with web app development (Task3), assisting with state-and-transition simulations (Task 4), and developing a manuscript on the modeling results and framework application (Task 5). Year 3 will consist of soliciting feedback from stakeholders and assisting with finalizing the web map application (Task 3), and manuscript development and project reporting (Task 5).

Labor Hour Estimates by Year and Tasks:

		Labor	Hours per Task					Total
Personnel		Rate	Task 1	Task 2	Task 3	Task 4	Task 5	
Albano, Christine	Year 1	$ 36.92	249	1,079	0	0	0	1,328
Albano, Christine	Year 2	$ 38.77	0	664	83	83	166	996
Albano, Christine	Year 3	$ 40.71	0	0	83	0	581	664
TOTAL			**249**	**1,743**	**166**	**83**	**747**	**2,988**

DRI does not pay its faculty and staff on an hourly basis, but rather a fixed salary amount monthly. Any hourly numbers provided are only estimates.

Fringe Benefits: DRI's fringe benefits are calculated annually based on actual costs from the prior year. The rates are subject to Department of Health and Human Services (DHHS) audit. The FY20 rates are 47.5% for professional employees, 33.8% for post docs, and 3.8% for hourly student employees. Fringe benefits for professional employees include retirement, health insurance, Medicare, Workman's Compensation Insurance, unemployment taxes, and accruals for sick and annual leave. See included federally approved rate agreement from DHHS.

Domestic Travel:
Funds are budgeted for the program manager to attend 1-week collaboration meetings with Dr.

Loheide in Wisconsin in Years 1 and 2 of the project. The cost of the trip is based on a 21-day advance airfare ($700), current GSA per diem rates ($102/night for lodging and $61/day for M&IE – Madison, WI), and $65/day for transportation (rental car and gas).

Subawards:
Subawards will be issued to two collaborative institutions as part of this proposal – The Nature Conservancy and University of Wisconsin. TNC's role will be to organize and lead workshops, coordinate with stakeholders (Tasks 1-3), lead state-and-transition simulation modeling (Task 4) and assist with project reporting and manuscript development (Task 5). University of Wisconsin's role will be to collaborate on research and framework design and model simulations (Tasks 1-2) and manuscript development (Task 5) and to assist with workshops and framework applications. Please see separate budget narratives from each institution.

Indirect Costs: DRI calculates indirect costs based on a percentage of Modified Total Direct Costs (MTDC) in accordance with OMB Circular A-122 Cost Principles. DRI's indirect rates are negotiated with the Department of Health and Human Services, Division of Cost Allocation, 50 United Nations Plaza, San Francisco, CA 94102, and the provisional FY2020 rate of 65% is being used for this proposal. The indirect costs are based on salaries, benefits, expenses, and equipment used for Institute operations and maintenance of offices, laboratories and buildings; providing administrative support for grant and contract activities, human resources, accounting, budgeting and regulatory compliance as stated in the OMB Uniform Circular. See included federally approved rate agreement from DHHS.

Cost-Share
Mandatory cost-share will be met through salary, fringe and F&A at established institutional rates above.

The Nature Conservancy

1. Salaries and Wages

Fringe and annual increases were included and were based on the lowest of three recent Congressional Budget Office projections (2.2% per year).

Below is list of each position to be funded out of the grant with a description of the work they will do on the grant proposal. The number of hours per year proposed for each is shown by year and varies according to need for SOW task work.

- Dr. Laurel Saito is the <u>Nevada Water Program Director</u> and will be a Co-PI on the project. She will be the project manager for TNC efforts and will lead workshop organization and coordination with stakeholders for the project and the development of the web map application (Task 3). She will also assist with developing the Groundwater Requirements for GDEs Framework (Tasks 1-2), modeling of GDE transitions (Task 4), and reporting and publications (Task 5). The current hourly rate for this position is $55.62, and she will work 70 hours on the grant in each of the first two years, and 98 hours on the grant in Year 3. **All of Dr. Saito's time will be charged to match for the grant.**

- Dr. Louis Provencher is the <u>Director of Conservation Ecology</u> and will lead Task 4 on the modeling of GDE transitions. He will also assist with developing the Groundwater Requirements for GDEs Framework (Tasks 1-2), the web map application (Task 3), and reporting and publications (Task 5). He will attend all workshops and project meetings. The current hourly base rate for this position is $63.78, and he will work 14 hours on the grant tasks in Year 1, 28 hours in Year 2, and 35 hours in Year 3. **All of Dr. Provencher's time will be charged to match for the grant.**

- Dr. Kevin Badik is the <u>Rangeland Ecologist</u> and he will be responsible for state-and-transition modeling for the modeling of GDE transitions (Task 4). Dr. Badik will also assist with developing the Groundwater Requirements for GDEs Framework (Tasks 1-2), the web map application (Task 3), and reporting and publications (Task 5). He will attend all workshops and project meetings. The current hourly rate for this position is $41.24, and he will work 14 hours on the project in Year 1, 35 hours in Year 2 and 140 hours in Year 3. **Dr. Badik's hours in Years 1 and 2 will be charged to match for the grant.** We are requesting funding from the grant for Year 3 for Dr. Badik's time.

- Ms. Sarah Byer is the <u>Spatial Analyst</u> and she will be responsible for developing the web map application (Task 3). She will also assist with developing the Groundwater Requirements for GDEs Framework (Tasks 1-2), the modeling of GDE transitions (Task 4), reporting and publications (Task 5), and she will attend most workshops and project meetings. The current hourly rate for this position is $40.00 and she will work

35 hours on the project in Year 1, 140 hours in Year 2, and 140 hours in Year 3. We are requesting funding from the grant for all of Ms. Byer's time.

(*A 2.2% annual cost escalator was utilized based on the lowest of three recent Congressional Budget Office (CBO) projections for 2017-2022: Core CPI @ 2.2%, CPI @ 2.3%, and Employment Cost Index @ 3.5%. See: https://www.cbo.gov/sites/default/files/cbofiles/attachments/EconomicTables.pdf.)

2. Fringe Benefits

The Nature Conservancy's negotiated fringe benefits rate for FY 2019 is 40%. Fringe Benefit Rate Components for TNC U.S. Payroll Fringe Include:

NAME	PERCENTAGE
ACCRUED VACATION EXPENSE	7.64%
SICK LEAVE	2.34%
HOLIDAY & ADMIN	3.48%
MEDICAL INS CLAIMS	9.56%
LIFE INSURANCE	0.25%
ACCIDENTAL DEATH/DISMEMB	0.04%
DISABILITY INSURANCE	0.35%
WORKERS' COMPENSATION	0.48%
FICA TAX	8.04%
PENSION PLANS	7.45%
STATE UNEMPLOYMENT TAXES	0.37%
Total	**40.00%**

Budget Supporting Documentation is TNC's federally negotiated provisional fringe rate for TNC fiscal year 2020 is presented in the FY20 Negotiated Indirect Cost Recovery Agreement (NICRA) letter in the appendix following this budget narrative. TNC's fiscal year is July 1 – June 30.

Below is a table showing year 1 base hourly rate, hourly fringe, and total hourly rate plus fringe for each staff person.

Position Title	Base Hourly Rate (yr. 1)	Fringe @ 40%	Hourly Rate + Fringe (yr. 1)
Nevada Water Program Director	$ 55.62	$ 22 25	$ 77.87
Director of Conservation Ecology	$ 63.78	$ 25.51	$ 89.29
Rangeland Ecologist	$ 41.25	$ 16.50	$ 57.74
Spatial Analyst	$ 40.00	$ 16.00	$ 56.00

Below is a total personnel budget table, based on the total hourly rate plus fringe from the table above and the hours described for each position in section 1 (Salaries and Wages). Wages shown in the budget below are based on the 2019 wage (in the table above) plus annual increases of 2.2% based on the lowest of three recent Congressional Budget Office (CBO) projections of 2.2%* per year.

(*A 2.2% annual cost escalator was utilized based on the lowest of three recent Congressional Budget Office (CBO) projections for 2017-2022: Core CPI @ 2.2%, CPI @ 2.3%, and Employment Cost Index @ 3.5%. See: https://www.cbo.gov/sites/default/files/cbofiles/attachments/EconomicTables.pdf.)

Position Title	Total Fed	Total Match	Year 1	Year 2	Year 3
Nevada Water Program Director		$17,853	$ 5,451	$ 5,571	$ 6,832
Director of Conservation Ecology		$ 7,069	$ 1,250	$ 2,555	$ 3,264
Rangeland Ecologist	$ 8,443	$ 2,874	$ 808	$ 2,065	$ 8,443
Spatial Analyst	$ 18,161		$ 1,960	$ 8,012	$ 8,189
Total Project Personnel	$ 26,604	$27,796	$ 9,469	$18,203	$26,728

3. Travel

Domestic Travel: Workshops are planned to be held simultaneously in Reno and Las Vegas, so we have budgeted for one person to travel to Las Vegas for a workshop in Years 2 and 3:

Trip to Las Vegas for workshop

1 trip x 1 person @ $247 airfare	=	$ 247
1 days per diem x $64	=	$ 64
1 nights lodging x $134	=	$ 134
Total	=	$ 445

4. Equipment

No equipment is requested for this proposal.

5. Supplies

Supplies for the project are associated with workshops that will be conducted to interact with stakeholders. Costs associated with each workshop include $100 per year in copying and supplies for materials distributed at the workshops.

6. Contractual

No contractual costs are associated with this project.

7. Construction

No construction costs are associated with this project.

8. Other

No other costs are requested for this project.

8. Indirect Costs

TNC negotiates a new indirect cost rate with the federal government annually; TNC's fiscal year runs July 1 – June 30. A copy of the FY20 Negotiated Indirect Cost Recovery Agreement (NICRA), showing the current rate of 24.34% is included as Supporting Budget Documentation. The rate varies from year to year but is usually between 22% and 25%. The current rate of 24.34% has been used for all three years in the budget estimate. Indirect was applied to all direct costs in the budget proposal as all proposed budget items are allowable per the NICRA. Indirect will be charged at the current rate available for each year of the grant in accordance with annual approved Indirect Rate letters.

University of Wisconsin

Senior Personnel
Steven Loheide, Ph. D. (effort = 1.0 summer month all years) Dr. Loheide will collaborate with PI Albano to expand and apply the concept of 'groundwater subsidy' to a variety vegetation types throughout the Great Basin to quantify water use by groundwater dependent ecosystems in the region and determine the water requirements for maintaining healthy ecosystems. Loheide will provide guidance and assist with model adaptation for each of these environments. Loheide will assist with development and interpretation of scenarios to identify salient features of groundwater regimes that control the groundwater dependency across gradients of soil texture, vegetation type and climate. Loheide will collaborate with PIs Albano and Saito to engage stakeholders from water and conservation agencies during both research design and result dissemination phases. Loheide will assist with developing materials for and organization of stakeholder workshops.

A base salary escalation rate of 4% has been calculated over years 2-3 for personnel above.

The University of Wisconsin does not pay its faculty and staff on an hourly basis, but rather a fixed salary amount monthly. Any hourly numbers provided are only estimates and there is not an audit system in place to verify specific hours.
Total salary: $50,060

Fringe Benefits
Fringe benefits are calculated in line with established UW fringe benefit rate agreement at 35% for faculty and academic staff.
Total Fringe: $ 17,521

Travel
$1,100 per year is requested to fund domestic travel for PI to Reno, NV to meet with stakeholders and collaborators. $1,000 per year includes round trip airline ticket $500 + per diem $50 * 2 days + Lodging $200 * 2 nights + Ground transportation/parking $100.
Total Travel: $3,300

Other Direct Costs
Materials and Supplies: $1314 per year is budgeted to purchase Comsol software annual subscription and license fees including Matlab livelink and subsurface modules.
Total materials/supplies: $3,942

Total Other Direct Costs: $3,942

Indirect Costs
F&A is calculated according to the University of Wisconsin's federally negotiated rate agreement (effective 5/14/18) of 55% Modified Total Direct Cost (MTDC) for FY20 and 55.5% FY21 and FY22.
Total indirect costs requested: $41,407

TOTAL FEDERAL PROJECT COST: $116,230

Cost-Share

Mandatory cost-share will be met through salary, fringe and F&A at established institutional rates above.
PI: Steven Loheide, 1.23 academic month year 1, and 1.05 academic month yrs 2-3

Match salary/fringe:	$ 55,484
Match F&A:	$ 19,419
Total Match:	$116,230

TOTAL PROJECT COST: $232,460