"Water Sustainability and Climate (WSC)-Category 2: Toward Water Sustainability in an Extreme Environment"

A proposal to the National Science Foundation

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WSC-Category 2: Toward Water Sustainability in an Extreme Environment
Project Summary

Here we propose to evaluate the integrated water infrastructure (natural, engineered, social/network decision making structure, and economic/policy frameworks that influence resources use) of the arid, closed-basin Borrego Springs Aquifer System (BVAS) using a participatory science framework. Borrego Springs is an early crisis area in the context of future water sustainability and climate change and an excellent model system to evaluate integrated approaches to resource management. A long history of the research has documented a significant annual groundwater deficit providing estimates of significant water shortages for users within 15 years. Despite wide-spread acknowledgement of the problem and clear socioeconomic impacts, the community has not responded to the crisis and lack a coordinated approach to water management. Our motivating question is: *given that local stakeholders have had physical data on over-extraction for ~30 years, why haven't they acted to create a sustainable water use plan?*

In this proposed project, we focus on three levels of an integrative water infrastructure – the physical and ecological **"*hydroclimatology*"**, the sociocultural structures and behaviors we call **"*water socialities*"**, and the institutional and market forces that structure a **"*water economy*"**. These disciplinary activities include basic scholarship that will be used to holistically model the coupling of hydrologic and human systems. We have embedded integrative physical/social/econoimic questions within each research area that allow for idea iteration and disciplinary cross-talk. In the final research section of the proposal, we take advantage of the realities of existing governance by the State of California to combine our academic findings and activities together in the context of emerging issues and potential threats to sustainability. This allows us to 'circle-back' to our stakeholders and research questions associated with application of knowledge to a real water-crisis. Such an integrative approach to research is necessary to support the goal of water sustainability in a manner that does not preclude the very existence of a localized economy in such areas of crisis. Important deliverables of this project include: (1) a coupled human/natural model for sustainable decision-making and planning that can be used by a diverse group of stakeholders, with appropriate assumptions about socioeconomic behavior and future climate change; (2) an understanding of how climate variability and extremes influence water balance, (3) a sustainable definition and plan for coupled hydrological and socioeconomic sustainability, and (4) a collaboratively determined iterative process for arriving at this definition, plan, and its implementation.

Intellectual merit: There is no resource management issue of more importance to society than that of how water supplies are governed and how global change may influence future availability, yet our understanding of the issue from integrated approaches remains a challenge. Attempts to also include the context of a future uncertain climate within existing policy or governance frameworks are lacking. The BVAS is appropriately simple to allow for a comprehensive approach, but sufficiently complex to allow for the production of translatable knowledge, all while embedded in an on-going site of water conflict and crisis. This project directly tackles the grand challenge of understanding the coupling of physical and human systems in the context of creating science that supports decision making.

Broader impacts: The BVAS is a model system that is accelerated in the expression of challenges associated with water, climate and the environment relative to other settings throughout North America and in dryland settings throughout the world making the findings broadly applicable. In addition, this system is driven by extreme events and our effort represents an opportunity to consider how physical, social and economic systems integrate with respect to extremes surrounding resource management. This program will train early career scholars in stakeholder engagement and highly interdisciplinary settings and include educational programs that impact undergraduate students, graduate students, post-doctoral scholars, and teacher trainees. Borrego Springs includes many stakeholders from under-represented groups that will be engaged though this project in environmental decision making. In addition, this program will leverage existing programs at UCI and within NSF to broadly integrate concepts across diverse disciplines and settings.

1.0 Problem Statement and Overview –There is no resource management issue of more importance to society than how water supplies are governed and how global change may influence future availability (Vorosmarty et al. 2000; Branosky et al. 2012). Science has come to appreciate that water systems are influenced by many features, including climate, human engineering, and the social/ cultural/political/economic factors that affect resource use and abuse by different stakeholders (Gleick 1998). The pressures of a growing public, water resource over-extraction, and crises arising from climate change, such as more frequent fires / droughts or unanticipated feedbacks (e.g., McDonald 2010) make the study of water sustainability imperative. Increasingly, we recognize that the goal of resource sustainability requires further integration of physical, biological, social, political, and economic perspectives (Clark and Dickson 2003), and for that we need sufficiently simple study systems, where the coupling of potential forcing factors can be evaluated holistically, yet where simplicity does not preclude broad applicability to additional settings and contexts. Additionally, to best understand how to build knowledge that can be effectively used by society, we need to undertake this integrated, multidisciplinary research in the context of existing, real-world planning processes, mandated by standing governance systems (Ostrum et al., 1990, 2009).

We propose here to study the physical and human components--which we call the *integrated water infrastructure*--of the Borrego Valley Aquifer System (BVAS; **Fig. 1**), a closed-basin groundwater system in the eastern deserts of Southern California, USA. The BVAS is an exceptional model for evaluating climate change consequences, sociocultural features affecting decision making, and socioeconomic systems affecting water use, all that may impact future water sustainability. We will tackle questions such as: how do extreme precipitation events influence recharge (in the context of climate change, when the distribution of extreme events is likely to change); how are stakeholders vested in extremely pressured decision-making associated with water planning (in the context of different stakeholder currencies for valuation); and, how do threshold driven socioeconomic patterns influence stakeholder water use (and indicate which governance features may lead to sustainable resource extraction)? We will carry out these activities through a participatory science framework that brings the community into our research and works with them to provide stakeholder-determined decision-making tools. We leverage a State of California mediated process to develop a management plan to contextualize our science. The unique features of Borrego Valley make the proposed research timely, providing substantial broader impacts. At the same time, we maintain Borrego Springs is essentially an early responder to the increasingly extreme drivers that are likely to broadly affect water infrastructures throughout the United States and much of the developed world.

2.0 Research Team, Leveraged Activities and Results from Prior Experience

2.1 – Research Team: The researchers and collaborators assembled for this proposal is exceptionally well prepared to carry out integrated, multidisciplinary work in collaboration with stakeholders to advance our understanding of water sustainability in the face of a changing climate. **Huxman** has extensive project management experience in multidisciplinary settings that integrate community groups, diverse education programs / curriculum development, and environmental research activities surrounding water in natural ecosystems. **Sorooshian** has led several major efforts focusing on water resources and stakeholder driven science, including the NSF STC Sustainability of semi-Arid Hydrology and Riparian Areas (see below). **Olson** has a proven track-record of engagement with communities and socio-cultural research in the context of environmental crises. **Famiglietti** is an international leader in evaluating groundwater dynamics, sustainability of water systems, impacts of climate change, and public engagement in water issues. **Hsu** and **Thomas** bring substantial expertise to the remote sensing and groundwater modeling activities detailed in this proposal. **Elyachar** has guided the theoretical development of this project by focusing our activities around a socioeconomic perspective that is of key relevance to the issues that affect crisis in diverse settings. **McBride** brings experimental approaches to economics that will accelerate our understanding and communication of important system features that influence the long-term

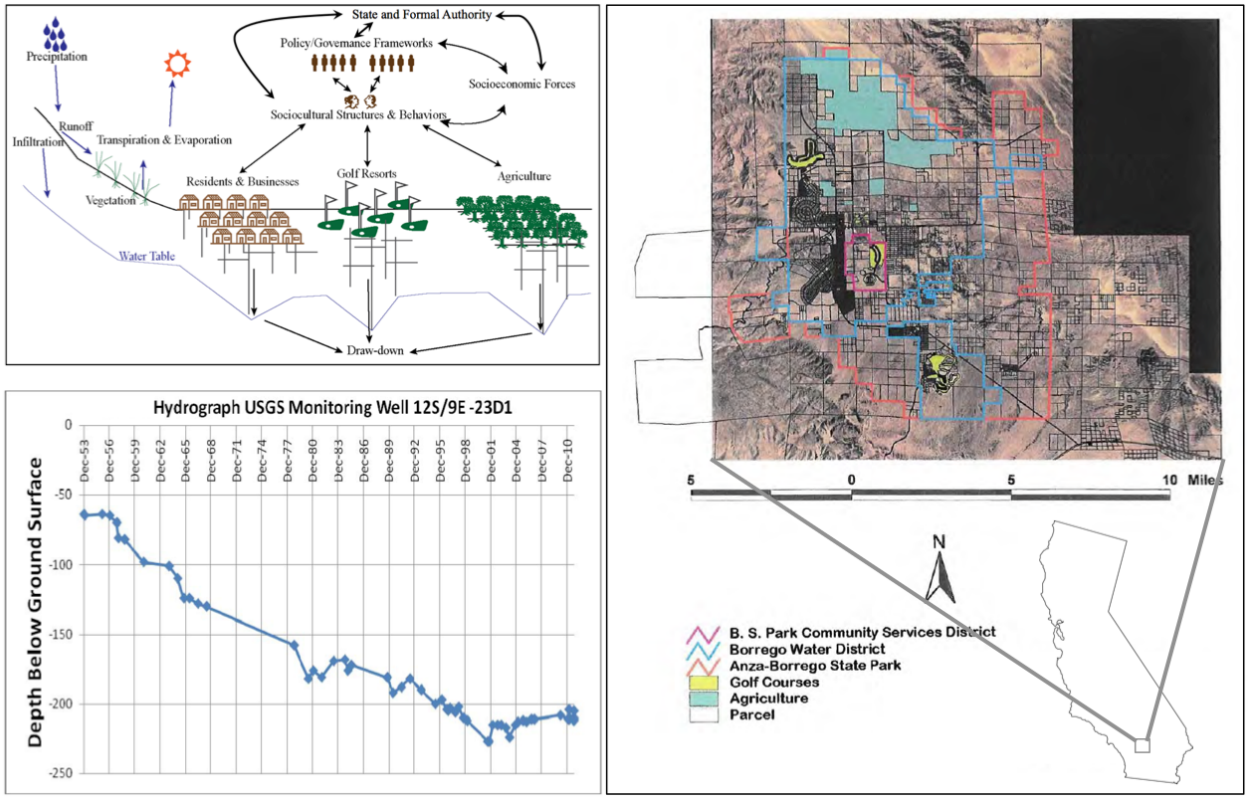

Fig 1 – Illustration of the *integrated water infrastructure* (**top left panel**), including biological and physical components (precipitation, infiltration & runoff, transpiration & evaporation, the water table), social components (multiple water users, policy/governance frameworks, sociocultural structures & behaviors), and economic (socioeconomic forces, including golf and agriculture); declines in groundwater elevation (**bottom left panel**; data from BWD & USGS); and the scope and dimensions of the Borrego Valley Aquifer System (**right panel**).

sustainability of water in Borrego Springs. **Mastnak** is a historian of political thought focused on ideas and assumptions that shape human behavior in ways that can ameliorate or exacerbate conflict. **Montoya** and **Feldman** are experts at stakeholder community engagement and evaluating consequences of policy and governance frameworks. **Coons and Brooks** have the skills to build the relationships among stakeholders that will set the stage for all our research by understanding the ethnography and water systems of Borrego Springs. In addition, our stakeholder community [represented by **Brecht** and the Borrego Water Coalition (see letter of collaboration), representing USGS collaborators, community groups, under-represented populations, and agency representatives] combine to create a team that connects our research activities to every important stakeholder or vested party that initially speaks to the water sustainability issue at hand (also see *Management and Integration Plan*).

2.2 Leveraged Activities – Major centers are leveraged in this proposal, including: The Center for Hydrologic Modeling (Famiglietti, director), Center for Environmental Biology (Huxman, director), Center for Global Peace & Conflict Studies (Elyachar, director), Center for Hydro-meterology & Remote Sensing (Sorooshian, director), and the Community Learning Project (Montoya, director). In addition, we will engage the Center for Land & Environmental Resources (see letter of collaboration) in policy and law educational workshops associated with our research topics, and we will use the facilities of the Experimental Social Science Laboratory (McBride, director) to conduct behavioral experiments, along with the Steele/Burnand Anza-Borrego Desert Research Center (Huxman, director) as a gathering place for the community; especially our existing stakeholder network (through the Borrego Water Coalition; BWC, see *letter of collaboration*). The central question of

this proposal aligns with the goals and research agendas of each of these areas of excellence at UCI, thus extending the broader impacts of our proposed activities.

2.3 Results from Prior NSF Support

T. Huxman (co-PI)–*Individual function and community processes in desert annuals*; DEB-0453781 & 0844780; $465,000 & $575,000; 2/1/2005 to 9-30-2013; This project found a general evolutionary trade-off between growth potential and stress tolerance within and between species of a model ecological community that dictated how ecological interactions interact with climate variability, resulting in long-term species coexistence and resilient biodiversity (summarized in Huxman et al., 2013). More than 25 undergraduates, 4 PhD students, and 4 post-docs participated in this project over the last 8 years, publishing 15 peer-reviewed articles to date.

S. Sorooshian (original PI & Director)–*Science and Technology Center for "Sustainability of semi-Arid Hydrology and Riparian Areas" (SAHRA);* EAR-9876800; $33,092,688; 1/1/2000 to 12/31/2010; The center focused on the Arid/Semi-arid Southwestern US through five scientific thrust areas: (1) spatial and temporal properties of hydrologic variables, (2) processes controlling water and chemical balances in catchments, (3) functioning of riparian systems, (4) integrated modeling of catchment-scale processes, and (5) water resources management. During the project period, more than 450 peer-reviewed manuscripts and over 130 theses and dissertations on fundamental and applied hydrologic science issues have been published.

J. Famiglietti (PI)–*A CUAHSI scoping workshop on a community hydrologic modeling platform in Washington, DC;* EAR-0814193; $40,600; 3/1/2008 to 2/28/2010; This proposal focused on a community project to produce a modeling platform that would advance hydrologic simulation capabilities for the collective field. The goal is a formal research proposal to the NSF for the development and implementation of the platform. Outcomes of these workshops have been disseminated to the community through a number of venues (e.g., Famiglietti et al., 2008).

J. Elyachar (co-PI)–*IBSS-EX: Comprehending and Regulating Financial Crises:* SMA-1328172; $249,928; 9/1/2013 to 8-31-2015; This recently awarded multidisciplinary project is focused on understanding the 2008 global financial crisis and regulatory responses. The project connects anthropology, economics, history, philosophy of science, physics, and sociology to address how the crisis is apprehended, how financial models are constructed, and how regulators attempt to construct solutions to crises.

V. Olson (PI)–DIG-06020442; $12,000; 7-1-2006 to 6-30-2007; This project was focused on understanding how astronautics has designated outer space as an 'extreme environment' that is connected to the future of Earth in vital ways that shape our view of technological response to environmental problems. A book detailing this investigation is currently in revision.

D. Feldman & M. McBride (co-PI & senior personnel)–*PIRE: Low energy options for making water from wastewater;* IIA-1243543; $1,876,164; 10/1/2012 to 9/30/2017; This recently initiated multidisciplinary project compares water sustainability issues in Australia and the U.S., funding graduate students in a number of fields with awards determined via a competitive process. The first cohort of students are in the process of finishing their first year of projects.

M. McBride (senior personnel)–*NCSS/W: Substantive expertise, strategic analysis and behavioral foundations of terrorism;* BCS-0905044; $149,885; 9/15/2009 to 9/14/2012; This project focused novel game-theoretic exercises and laboratory experiments on dark network dynamics. This work showed that increasing the probability of detection reduces network size, along with the increasing impact of any one arrest. The summary of the findings are presented in "Endogenous Formation of Dark Networks: Theory and Experiment" (currently under review) and yields new insights into the viability of different counterterrorist policies.

M. Montoya (PI)–*Transnationalizing gangs: expertise, advocacy, and the politics of policymaking*; SES-0851553; $12,000; 7/1/2009 to 6/30/2011; Gangs have been named a trans-national U.S. foreign policy issue, which has redefined the gang problem and in turn shaped proposed solutions in the U.S., Mexico, Central America and beyond. This dissertation project evaluated the micropolitics of this strategy in order to analyze the logic, which produces gangs as a transnational threat at the exclusion of other ways of framing the problem and its solution.

3.0 Background and Conceptual Framework

3.1 The Borrego Valley Aquifer System (BVAS) – The BVAS is a sole-source aquifer that is the only source of water for the community of Borrego Springs, serving robust agriculture and tourism (principally golf) industries in an area adjacent to several major population centers (San Diego, Orange County, Palm Springs; **Fig. 1**). Agriculture dominates fractional water use (>70%), as compared to tourism / recreation (~20%) and residential (~10%) consumption. Withdrawals, estimated at ~23,000 acre-feet per year (af/y), are greater than recharge estimates (4800 af/y: Moyle, 1982; 5670 af/y: Netto, 2001; 6170 af/y: Henderson, 2001) resulting in significant overdraft and marked declines in groundwater storage (BWD, 2002).

Physical aspects of the BVAS have been well documented, most recently by a USGS effort commissioned by BWD that produced an operational MODFLOW scheme. The three-tiered aquifer system is characterized by decreasing hydraulic conductivity and specific yield with depth (upper: 50 ft/d, 0.20; middle: 5 ft/d, 0.10; lower: 1 ft/d, 0.05 for hydraulic conductivity and specific yield, respectively). The upper aquifer consists of unconsolidated sand and gravel, the middle aquifer of finer sands and gravel, and the lower of poorly consolidated sandstone-conglomerate overlying granite/gneiss bedrock. BVAS's geometry is well constrained by bore-hole investigations (Moyle, 1982) and geophysical surveys (Agbabian Associates, 1996).

Water quality testing completed under the Groundwater Ambient Monitoring Assessment program (Mathany et al., 2013) identified good quality groundwater within BVAS. Previous reports (BWD, 2002; BWD, 2012) documented localized water quality issues due to total dissolved solids (TDS) and nitrate. BVAS water quality is generally assumed to degrade with depth where TDS concentrations can reach 15,000 mg/L (BWD, 2012). Uncertainty in water quality within the aquifer arises from the assumed water quality stratification that can be perturbed due to withdrawals (Bear, 1988).

An obvious question arises from this description: *Given that local stakeholders have had physical data on over-extraction for ~30 years, why haven't they acted to create a sustainable water use plan?* Despite the stakeholders' common reliance on the BVAS, viable long-term solutions for achieving water sustainability are missing. We propose, learning from recent studies, that an *integrative* approach that combines physical and social sciences, as well as *participation* from the stakeholders, is necessary for any effort to achieve this water sustainability. For example, the 2007 water district Expert Panel (comprised of natural scientists) concluded that, "There is no single investigative technique that can provide an answer to the question concerning the so called 'life' of the Borrego aquifer system" (IWRMP 2009). In 2011, USGS recommended that Borrego Springs focus on understanding the impending economic impacts of aquifer depletion (USGS Summary 2011). It may be these interconnections to other aspects of society that have complicated community response. For example, in addition to supporting the above human functions, the BVAS maintains significant biological diversity in riparian ecosystems located in Anza-Borrego State Park, fueling ecotourism that is highlighted by most stakeholders as a defining feature of their community identity. This points to important conflicts in management – between a traditional approach focused on 'safe yield' and an integrated approach which requires a 'sustainable yield'.

3.2 The unique opportunity presented by BVAS and Borrego Springs – Approximately 8,000 residents and ~500,000 State Park visitors draw from BVAS annually. To date, however, there

has been no systematic attempt to collect social and economic data by stakeholder groups or to integrate existing hydroclimatological and social data into a coupled system. Our preliminary research shows that *water-use stakeholders* historically include farmers, resident property owners, resort property owners, and local and state officials. There are also key groups not included in formal water use governance processes, including the seasonal residents ("snowbirds") and the resident farmworker and service industry population (estimated to be supporting up to 70% of the local school district's enrollment). All of these social groups are vitally interconnected in Borrego Springs, as BVAS users, and as part of a ~$100 million local political economy that includes State Park revenue ($42 million annually), resort infrastructure/activity (>$40 million), and fairly extensive, year-round agriculture.

In November 2012, as a community response to the above water issues, the Borrego Water Coalition (BWC) of stakeholders was established to develop a "collaborative, inclusive, transparent, and robust planning process" for developing a Groundwater Management Plan and Integrated Regional Water Management Planning proposal (IRWM; see BWC letter of collaboration). With guidance from the California Department of Water Resources (DWR), stated aims of BWC make visible and address implicit conflicts between stakeholder interest groups while leveraging new and existing community, government, and scientific partnerships to implement a long term participatory management plan. The BWC includes most members of the vested stakeholders and offers a unique opportunity to engage the local community in sustainability research carried out through UCI's new Steele/Burnand Anza-Borrego Desert Research Center. UCI has embedded a graduate researcher (E. Brooks, see *Management and Integration Plan*) in the BWC meetings as a liaison for the UCI research team and began holding meetings with stakeholders to align the university's research capacity and stakeholder needs.

3.3 The BVAS "integrated water infrastructure" and reframing the question – In this proposal, we use the overarching concept of "integrated water infrastructure" to bring together hydrology, ecology, sociocultural structures and behaviors, socioeconomic forces, and policy/governance frameworks (**Fig. 1**). Infrastructures are constructed networks that facilitate the flow of goods, people, ideas, and resources (Larkin 2013). Our conceptualization of infrastructures brings together both tangible systems and intangible processes. These interconnections tend to lie in the background, undergirding circulation of goods, people, ideas, and resources, becoming visible only when broken (Starr 1999); when the lights go out, the internet freezes, or water doesn't run. Social science has concentrated on water infrastructure in poor countries of African and South America, where the provision of adequate water has been in the forefront of daily concerns and political debate (Swyngedow 2004, Orlove 2012, Anand 2011). Evaluating the integration of these processes may provide a transformational view into the features that control resource allocation and planning in areas of potential crisis.

Our integrated water infrastructure concept encompasses not only aquifers and pipes, but also the engineers who design and install them, bureaucrats who regulate them, social networks of people who use them, and economic activities that rely on them. As such, we look at the entire network of people, things, and activities that are brought together through the medium of water. This framework motivates a reframing of the "obvious question" above (3.1) to: ***Given that physical investigations of BVAS have not alone resulted in a plan for long-term sustainable rates of water extraction, what human systems are essential to promote a resilient socio-hydrological system to impending climate change?*** Answering this question allows us to determine what features of the physical, social, economic or policy systems would encourage shifts to more sustainable patterns of water usage in a time of increasing uncertainties. Our work directly evaluates how extreme weather events and extreme socioeconomic pressures directly impact potential sustainable models of groundwater use. At the same time, this area of scholarship is an identified grand challenge (NRC 2013) and greater understanding would move society forward towards responding to our growing water crises (deBuys 2011). Together, the contained aquifer, the role of natural ecosystems, the impending

impacts of climate change, the scale of the stakeholder groups, the sufficiently simple economy, and the current community water planning and management activities constrained by real governance all make BVAS an exceptional case study to create integrative knowledge that would be highly transferable.

4.0 Major Research Areas and Driving Questions – Our focus is on building the basic knowledge that will lead to transformational changes in our understanding of integrated water infrastructures, and ultimately water sustainability. From a hydrological perspective, the BVAS water balance is dominated by patterns of *recharge* and *evapotranspiration,* principally a function of the physical and ecological system components, along with *water-use by extraction*, which includes the human systems. The field of hydrology has provided computational models that describe the underlying physics governing water balance for many basins, including Borrego Springs. However, the most broadly applied models have limitations in that they may be insufficient to capture the impacts of climate change (NRC 2009), they may not explicitly consider special, place-based issues associated with a particular basin (NRC 2009), and, crucially, they tend to leave human systems out of the model altogether (Baldassarre et al., 2013). Our proposal focuses in particular on the way in which human systems—political, economic, and social—must be integral to any adequate model of water sustainability.

Even though human systems have generally been left out of hydrological models (but see Landstrom et al., (2011) for flood risk example), we propose that physical models are still shaped in important ways by implicit assumptions about human behavior (e.g., the assumption of rational actor). In this project, we bring human systems out from the background of hydrological models, analyze them in their economic, sociological, behavioral, and political aspects, and lay the groundwork for a fully integrated human/natural model of water usage. Only then can a more adequate process of modeling socio-politico-economic/hydrologic behavior be developed and applied to specific resource problems in real settings, in a context of rapid change and normalization of extreme events.

In this proposed project, we focus on three levels of an integrative water infrastructure – the physical and ecological "*hydroclimatology*" (5.1), the sociocultural structures and behaviors we call "*water socialities*" (5.2), and the institutional and market forces that structure a "*water economy*" (5.3). These activities give us the specific knowledge to holistically model how an inclusive hydrologic system is coupled to human systems. We have also embedded questions that integrate the physical/social/economic behavior of interest within each section. We use both a stakeholder engagement process for prioritizing research with our partners (which includes forming this proposal), and an iterative process to allow for disciplinary cross-talk and learning within our researchers and stakeholders (see *Management and Integration Plan*).

In addition to this 'basic scholarship integration' of principle interest to academics, we combine our findings and activities together in the context of emerging issues and potential threats to sustainability discussed in section (5.4). This allows us to 'circle-back' to our stakeholders and research questions associated with application of knowledge to a real water-crisis. We strongly assert that these integrative approaches to research are necessary if society wants to support the overarching goal of a sustainable water supply that does not preclude the very existence of human settlement and a localized economy in settings such as Borrego Valley.

5.0 Research Approach – Major Research Areas – We require a fully integrated human, physical, and biological component understanding of BVAS to assess potentially undesirable future change and long-term water sustainability. In the past, decision making has mainly been supported by physical science data, yet even these data have been limited, since an overwhelming focus of the past research has been on detecting and defining the BVAS overdraft (see above) based on available data from monitored wells (only 10-20% of total

extraction). First we require additional site-specific data to bring in more stakeholders and landscape forms, along with recharge and natural ecosystem extraction information to develop scenarios representing the future. We then tackle explicitly the assumptions about human systems, building first on the specific knowledge of BVAS's water sociality and water economy, integrating each research area in turn. Finally, we conclude with investigating the potential for collaborative future planning and decision making.

5.1 – What is the future hydroclimatology of Borrego Springs?

5.1.1 – How will groundwater recharge be impacted by extreme events? External forcing pressures on recharge are likely to increase due to uncertainty in potential climate variability and change that can affect precipitation distribution, snow cover, soil moisture and surface runoff all directly influencing groundwater recharge and storage. Climate variability on the time scales of inter-annual to decadal has substantial influence on recharge, discharge, and storage changes in aquifers. Variable groundwater behavior results due to coincident positive or negative phase in climate indices such as El Niño/Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) [Gurdak et. al., 2007; Hanson et. al., 2006; Stonestrom et al., 2007]. We will investigate the patterns of variability, such as droughts, rainstorms and snow cover, by evaluating the climate indices (e.g. ENSO, PDO) and their affect to groundwater recharge and water resources management. Such an analysis will characterize the resiliency of the physical water system to account for future hydrologic and water demand trends. We will also draw on methodologies used by our co-PIs (Elyachar, Olson) to model extreme events in finance, space, and oil spills, to integrate extreme events as integral to processes of water resources management.

5.1.1.1 What is the role of episodic events in driving recharge in this arid ecosystem, and how may this change in the future? A conceptual understanding of the relationship between precipitation and groundwater recharge, specific to this basin, is fundamental to the development of management objectives in Borrego Springs. Multiple approaches have been employed to characterize groundwater recharge [Scanlon et al., 2002]; in arid or semi-arid climates, however, groundwater recharge fluxes are not constant [Gee and Hillel, 1998; French et al., 1996]. This irregular pulse of recharge is termed episodic groundwater recharge [Lewis and Walker, 2002] resulting from excessive rainfall events. To evaluate historic and future episodic recharge for this project, we propose to use methods proposed by Nimmo et al. [2013]. The Episodic Master Recession (EMR) method [Nimmo et al., 2013] borrows methods commonly employed in streamflow analysis [Brutsaert and Nieber, 1977; Tallaksen, 1995; Nathan and McMahon, 1990] in the context of the Water Table Fluctuation method [Healy and Cook, 2002]. To evaluate historic recharge in the valley, we will use coincidental groundwater observations using approaches described by Taylor et al. [2012] to develop the characteristic EMR behavior. The EMR approach is advantageous for recharge predictions as compared to probabilistic forcing into recharge models [Ng et al., 2010] or from poorly represented recharge in groundwater simulations because the approach permits (1) characterization of a recharge to precipitation ratio (R/P) and (2) evaluation of the elasticity of episodic groundwater recharge [Schaake, 1990].

5.1.1.2 - What is the current and future cumulative basin distribution of rainfall events that result in recharge of water to the aquifer? Studies indicate widespread changes in precipitation intensity and distribution and increasing occurrences of extreme weather, including droughts and floods (Karl et. al., 2007). Average annual precipitation in Borrego Springs is around 5.80 inches; rainfall of the wettest year (1983) is 18.73 inches (El Nino year) while the amount for the driest year (1953) can be as low as 1.35 inches [Western Regional Climate Center]. Historical record has shown that, in semi-arid regions with deep aquifer water tables, recharge of surface water to subsurface can only reach to top soil layers, with most of the recharged

water returned to ET in a short period of time (Scott et al., 2008). BVAS records also show that only very limited extreme storm events result in changes in aquifer elevation impacts. Analysis of the historical data can provide information to obtain the relationship between rainfall and recharge. Climate variability in a warming episode will lead to dramatic changes in the snowfall and snowmelt dynamics. Increasing temperatures will accelerate the rate of spring snowmelt and shorten the overall snowfall season. Under conditions of high climate variability, quantifying effective recharge to the aquifer for semi-arid region environments is a challenge and requires historical bounding of potential extreme years of drought and heavy rainfall. We will use a minimum of 30 years of climate data record of precipitation and temperature variability from *in situ* and remote sensing measurements to characterize historical precipitation, and match that distribution to the products in 5.1.1.1. Climate projection of precipitation in Borrego Spring will be explored by using the climate model simulations of IPCC AR4 (e.g. B1: low emission and A2: high emission) and forthcoming AR5 scenarios [IPCC, 2007]. Trend and variability of precipitation and their impact to the groundwater recharge and storage will be investigated (in the context of the specific recharge mechanisms elucidated in 5.1.1.1). We will explore analysis of extreme events in this area also (as above).

5.1.2 – What is the role of vegetation and evapotranspiration of critical landscapes in this closed basin system? To determine both basin-wide and critical land-surface component evapotranspiration, we will rely on scaling estimates of net radiation partitioning into latent and sensible heat flux based on site water balance, such as soil moisture profiles and lysimeters, along with micro-meteorological techniques, such as eddy covariance, with derived indices from Moderate Resolution Imaging Spectoradiometer (MODIS) observations. At the simplest level, we will extrapolate these point measures to larger spatial scales based on vegetation classification or leaf area index (e.g., Nagler et al., 2007; Scott et al., 2008). We will build on these straight-forward exercises, with two different techniques. First, we will adapt an approach outlined by Anderson et al., (2013) and Jin et al., (2011), where we estimate net radiation using Moderate Resolution Imaging Spectroradiometer (MODIS) observations of surface albedo and land surface temperature. We will connect distributed radiation balance assessments within the basin to these MODIS (500 – 100 m resolution) evaluations using time-series of Landsat images (30 m resolution) that represent different vegetation classifications. We will use measures of incoming shortwave and longwave radiation measured directly by radiometers on existing micrometerological sites at eight locations in the basin and the Landsat images to help us spatially extrapolate our estimates to spatial scales sufficient to integrate with the MODIS product. This overall approach is ideal for capturing ET variations along an elevation gradient since changes in vegetated fraction and plant functional type will influence leaf area, albedo, and land surface temperatures. Second, we will constrain vegetation water-use with a flux model, such as in Ponce Campos et al., (2013), which is also driven by MODIS surface albedo. There are a number of existing flux data sets that will allow for water-use classifications by eddy covariance and functional responses connected to remote sensing.

5.1.2.1 – What critical habitat derives water for transpiration from groundwater (Bosque and Riparian Corridors) and how does natural vegetation change constrain the water budget? We will determine groundwater use by vegetation using stable isotope composition of evapotranspired components and the composition of the source waters (ground and surface water) using isotopic mass balance (Yakir and Sternberg 2000, Williams et al. 2004). Using both plant water and atmospheric flux sampling allows us to evaluate the source contributions effectively in arid systems and determine groundwater use (Yepez et al., 2005). Source waters will be sampled from small trenches, while groundwater will be from existing observation wells throughout the valley. When combined with the above evapotranspirational assessment, short- and long-term estimates of groundwater use by landscapes can be derived (Scott et al.,

2007), which can inform the decision making process in terms of the requirement for critical habitat and the management of vegetation types as a function of impact on the water budget.

5.1.2.2 – What are the water use patterns in the agriculture sector of Borrego Valley? What, if any, potentials for water efficiencies in this sector can be identified? Agriculture—almost exclusively irrigated citrus—is by far the main water-user in Borrego Valley. It is estimated that this sector uses 70% of the water of the BVAS. And yet, amazingly, there is little to no data on groundwater use, except that inferred by USGS MODFLOW exercises (see above). No sustainable water plan for BVAS can be approached without more accurate data for this sector. We propose that this lack of data is related to the historically constituted nature of decision making in BS, typical of many areas experiencing water crises. We will draw on two methodologies to build a better picture of actual water use and engagement of the agricultural sector. First, while it is cost prohibitive for us/our team to place new monitoring wells in these systems, remotely sensed efforts to estimate evapotranspiration from the crops is a highly effective means to bound the upper water use by this community and bound the MODIS and other modeling efforts. We will use the MODIS net radiation partitioning described above (section 5.1.2) to develop a 14 day product that can be used both in the integration of multiple data sources for the model and for understanding how weather drives different water-use patterns in the agricultural systems. This approach will be contrasted with the standard modeling approach described in Allen et al., (2004; using METRIC), which has been applied to water rights and use issues in the past. In our second approach, we will work as a team across research sections (5.1 to 5.3) to leverage the ethnography fieldwork with farmers and their knowledge about water usage. Combined, these two approaches will allow us to consider areas that most dramatically impact potential efficiencies of agricultural water use, and tell us whether this model of agricultural economic activity as a whole or its particular components need to be rethought. These research activities will be linked with our activities discussed below about regulatory models of water use and valuation models among farmers.

5.2 – What are the water socialities of Borrego Springs?

5.2.1 – What social networks of water use operate within Borrego Springs? How do these networks participate (or not participate) in processes of planning and decision-making about water use and sustainability? In this set of activities, we look at the "water socialities" aspect of the human systems of BS. Our two-phase activity begins with baseline demographic and participatory social network information on BVAS water users employing a combination of existing data (census data, water district data) and *de novo* data collection. Using a stratified purposive framework to sample by "water use social group" (e.g., farmer, non-farming resident, farm-working resident, business owner dependent on tourism and recreation) we will enroll approximately 50 subjects to participate in two rounds of bilingual (Spanish/English) ethnographic social network surveys: one baseline and one comparative follow-up (see *Management and Integration Plan* for timing). Building on Faculty Associate Michael Montoya's model for understanding structures of community knowledge, surveys will collect data with which to map networks of knowledge sharing, water use, access to decision-making data and technologies, and roles in local and basin-wide water use decision making (Lane 2013). To make it possible to determine how (or if) these groups participate as recognized stakeholders in past and emerging water governance and oversight systems, we will use a qualitative research program to produce "water use sociograms" (a high-level graphical representation of social relations and association choices) to visibly represent distinct stakeholder networks of water knowledge production, interaction, trust, communication, and decision-making participation. In a pilot study in a land use management context (Beilin et al 2013) stakeholders reported that sociograms would be useful for understanding how their diverse place-specific networks functioned; however, researchers concluded that such a task should be

done by designated personnel (as we propose here) rather than local groups or government officials. In addition, we propose to do this activity twice, to make evident any changes in local social network systems as a result of knowledge transfer and decision-making support. We will present both sociogram outputs to participants and interested publics via such activities as our annual stakeholder meeting, project workshops, and the project web site.

5.2.2 – What local explanatory models of the socio-hydrological system are present in Borrego Springs? How do these models define, explain, and operationalize concepts like sustainability, water shortage risk, climate uncertainties, and resilience? Given the lack of existing data on sociocultural factors impacting water and sustainability decision making in Borrego Springs, this two-phase activity will research and analyze historical and contemporary explanatory models of socio-hydrological systems, using a variation on medical anthropologist Arthur Kleinman's explanatory model instrument adapted to an extreme environment context by Co-PI Olson in previous work on the BP oil spill crisis. First, the research team will use archival data (census data, government reports, planning documents, feasibility studies, and other historical materials from the past 100 years) to determine historical explanatory socio-hydrological models by "water knowledge stakeholder group" (including "water use social groups" described in 5.2.1 with the addition of UCI scientists). Using the sampling, linguistic, and administrative framework described in 5.2.1, we will conduct a baseline and follow-up collection of each group's explanatory models, emphasizing terms and ideas most relevant to contemporary socio-hydrological knowledge, including explanations of: water system structure and recharge, water shortage and overdraft, climatological uncertainty, and sustainability and resilience. Comparative content analysis will identify similarities and differences between stakeholder groups (past and present) on perceptions of socio-hydrological systems factors such as: causes and levels of concern about water shortage; key variables that influence social and environmental change; effects of water shortage on natural and social systems; and key water use problems and their solutions. We will analyze and describe (in English and Spanish) each social group's models and make them available by our dissemination activities. This exercise innovates explanatory model research and dissemination in three ways: by making results available to participants engaged in knowledge sharing and decision-making, by analyzing and publicly describing expert as well as lay explanatory models, and by seeing how and if participants change their models after seeing theirs and others represented visually.

5.3 – What is the 'water economy' of Borrego Springs?

5.3.1 – How is the Water Economy of Borrego Springs part of a broader water economy of the American Southwest? How was that water economy historically constituted and how does that history impact (or not impact) patterns and practices of water usage today?

In this set of activities, we look at the "water economy" of Borrego Springs as a crucial human system. Our activities will identify the essential characteristics of that water economy, including its historical constitution and regional context (Worster 1985; Resiner 1993; Blackburn and Anderson 1993; Fiege 1999; Anderson 2005; deBuys 2011). We will draw on archives, secondary literature, and oral histories to map out how natives and settlers in the region of Borrego Springs historically related to water, and the extent to which these patterns are typical of the water economy of the American Southwest or unique to Borrego Springs. We will document how property rights to water in the Southwest in general and Borrego Springs in particular were created and assigned, a story that appears to be surprisingly murky. (Stewart 1958, 1959a, 1959b, 1973; Barker and Ehrenfeld 1976; Sutton and Beals 1985) Water policy and politics in the American southwest have long been shrouded in contested and overlapping claims, power politics, and overlapping (or nonexistent) regulatory regimes (Espeland 1998). We will link this research to dilemmas of data gaps in water use patterns in Borrego Springs. We will supplement those historical and legal sources with research in archives located in

Borrego Springs, Sacramento, the University of California, and among individual families. We will also draw on research methodologies to outline contested patterns of jurisdiction and regulation among Native Americans of the Southwest (Maurer and Richland 2012) to see how these patterns map onto, or supplanted, native water economies in the region. Since, as Ingram and others have shown, "interest" in water has to do with much more than financial interest (Ingram et al., 2001), we will see how attachments of different stakeholders to the notion of ample water—emotional attachments, political attachments, community attachments, etc.—are part of a broader pattern in the region. This will entail the ethnographic research coordinated with our water socialities team about the meaning of "plentiful water" in the economic imaginary of residents of Borrego Springs and will be evaluated in the context of the mass balance produced by the hydrologic team. Throughout this process, we will delineate the ways in which these historic and regional patterns map onto attitudes and practices of water usage in Borrego Springs today and how these impede or support possibilities for a more sustainable water economy in the future.

5.3.2 What formal and informal systems of rights govern access to water today? What formal and informal regulatory mechanisms, if any, of water usage are mobilized by stakeholders in Borrego Springs? How have past policy and regulatory changes impacted on patterns of water usage, and what policy and regulatory changes could improve the chances that a water economy can continue to exist in Borrego Springs? Farmers, who use 70% of BVAS withdrawals, principally draw on private wells on their private property. As such, the state and water board have no regulatory authority over farmers' water usage, even though the entire system is directly impacted by farmers' individual patterns of water usage. This system of water rights was established in an era in which water was not seen in the United States as a scarce resource, after a period in which water use was not regulated at all (Fox 1985; Anderson 2005). Today, new kinds of water economies are being formed around the imperative of economizing water itself. Those could be stymied by the lack of a coherent regulatory regime for water. The lack of a coherent regulatory regime today does not mean, however, that there is no possibility of successful regulation at all. Research around the world has shown that even in the absence of direct state regulation of natural resources, community users often evolve their own effective mechanisms of resource regulation (Ostrom 1990). We will ask: Do such informal mechanisms of water regulation exist in Borrego Springs? If not, what factors in the structure of the water economy of Borrego Springs mitigate against their evolution? How might those factors be alleviated? How do we explain the lack of an overarching regulatory regime for water in BS initiated, backed, and enforced by public authority? What kinds of public authority could be effectively utilized as part of this overall regulatory regime? How might the mix of public authority and informal regulatory methods change over time in the face of increasing pressures on water quantity and quality?

In addition to our research on the secondary literature, we will also follow conflicts over access to good water, which have erupted into the public sphere in Borrego Springs, and in other areas of the American Southwest. There are blogs, websites, and public meetings through which problems of water usage and regulation are discussed and argued over. We will follow and analyze those public resources and conduct interviews with participants. We will also take oral histories and interview different stakeholders in BS to map out the formal and informal mechanisms of water regulation and conflicts over water. We have access to datasets about patterns of water usage in homes and some small businesses regulated by BWD and analysis of patterns produced in 5.1.2. Here, we can draw on methods of econometric analysis to study the extent to which changes in regulatory policies over the years have mitigated or contributed to the current water crisis. Finally, we will conduct ethnographic research, based in the homes of one or two farming families in Borrego Springs. This will allow us to open up the black box of most discussions of "agriculture" in Borrego Springs. This research area builds on all previous

areas to allow us to better understand how formal and informal methods of regulation impact on patterns of water usage among farming families, to suggest what kind of changes in policies and regulations might contribute to a more sustainable water economy in Borrego Springs, and to begin to model those changes in a way that can be tested through experimental economics and other kinds of projections. It also allows us to develop impact scenarios on the behavior of agriculture on other coupled components of the water infrastructure (riparian vegetation; tourism water use and availability, future water quality, etc.).

5.3.3 – What essential features shape the economic behavior and practices of individuals in the water economy of Borrego Springs? Given the fact that formal regulatory regimes impact only a small fraction of water usage (due to the prevalence of private wells), it is essential that we have a robust method for analyzing unregulated modes of behavior in the water economy. Not all forms of behavior regarding water usage are the object of decision making processes. We thus draw on well-established methods used previously by our economic team to elucidate and analyze patterns of behavior in the economic realm. One part of our investigation involves conducting economic experiments. This method places human subjects defined from our socialities work in 5.2 into well-defined social roles to study how they behave under changes to the social setting (Friedman and Sunder 1994; Guala 2005). The proposed experiments will directly incorporate the research from other parts of this project into a common pool resource experimental design (Ostrom et al., 1994). We will construct on-line simulations that are designed to incorporate the property rights structure identified in 5.3.1, the valuations described below, and the ecological features of the Borrego hydroclimatology system studied in 5.1. Via this simulation, the subjects will be placed into the roles of Borrego Springs stakeholders. We will exogenously control the framing and incentives to test the effectiveness of different policy interventions in the Borrego Springs water economy. Some experiments will be conducted at the UCI Experimental Social Science Laboratory. This laboratory maintains a large subject pool and provides a low-cost forum for conducting experiments. Other experiments will be conducted in Borrego Springs using actual stakeholders as subjects to provide external validity to the laboratory experiments. These experiments will be conducted over the course of the grant, with each experiment requiring multiple development phases, from software design and testing to data analysis. We will also use methods of ethnographic fieldwork, coordinated with the methodologies outlined in 5.2, in order to shed light on patterns of water usage and their economic logics among farmers in particular. In a highly charged climate such as Borrego Springs, research suggests that individuals are unlikely to directly voice how they would actually behave in social life. Ethnography is a good complement to experimental economics to study what people actually do, not what they say they do.

5.3.4 – What are different schema of valuation of water among different stakeholders of Borrego Springs? This research draws on methods of ethnographic research and content analysis to look into the different scales of "valuation" of stakeholders in Borrego Springs, but importantly incorporates a linguistic component. Ecology and hydrology use a language of "budgets" and "economies" in which the efficiency of concern is saving water. Farmers and business owners also talk about "budgets" and "economies," but tend to mean something completely different. This use of an apparently shared vocabulary masks drastically different schema of valuation among different stakeholders. In other words, different actors in BS have different implicit models of value and organize their economic behavior and practices regarding water usage (see 5.3.3) around different ends. We will analyze the language used in previous attempts to create a more sustainable water management plan for BS, and see how the different stakeholders mobilize metaphors from economics, and the different meanings they have. We will also map out, drawing on our ethnography, different valuation frameworks and temporal scales of valuation among different stakeholders in BS, including scientists, park officials, farmers, farmworkers, business owners, and residents.

5.4 – What context-specific modeling and integrative activities facilitate collaborative future planning and decision-making in Borrego Springs? – In this section, we apply the

above developed scholarship to the specific planning and visioning process governed by BWC and State of California mediated planning processes (IRWM) in order to 'circle-back' to the specific water sustainability issue at hand in the region with the learning that has taken place throughout the proposal and extend the activities to other settings. Thus, these areas of research are not only merited scholarly activities with specific learning objectives, but also activities that integrate our above scholarship, engage stakeholders in the research process, and disseminate our findings to potential users of that knowledge to evaluate resource management. Work in this area will take advantage of an on-line web portal to create summary products of our above efforts, dynamic exercises to allow for stakeholder involvement, and on-line community development to create additional pathways for learning and sharing.

5.4.1 – What indicators (in categories such as: natural science, business, governance/legal, cultural, economic) must be incorporated to resolve uncertainties in their decision making processes? This study follows the idea that participatory activities better inform collaborative environmental risk knowledge and mitigation activities (Liebow 2008). This will be critical in threshold-driven places like the Borrego Springs Valley where models predict extreme socio-hydrological change; we hypothesize that these will exacerbate existing patterns of unsustainable stakeholder decision-making. In order to evaluate how communities make future sustainable water use decisions in the face of uncertainty about water quantity, quality, and climate change, it is important to develop, through collaboration, specific and sensitive "decision making indicators." Community-based collaborative indicators development is being implemented to evaluate clinical and environmental health and sustainable conservation activities (Reed et al 2008), but has yet to be established for sustainable water use. The DELPHI survey process is a gold standard process for selecting key components or criteria for emerging processes with empirical and evaluative uncertainties, and has been used by experts to establish measurable criteria for environmental Adaptive Co-Management (Plummer and Armitage 2007) and clinical indicators (Hodge et al 2002), but not by experts and laypersons for selecting sustainability indicators across the sociocultural, socioeconomic, and natural science domains. This research will use a modified DELPHI expert panel process (Hodge et al 2002) through which the Borrego Springs Water Coalition and UCI researcher groups can collaboratively establish a suite of indicators for sustainable water decision-making. The process includes a literature review, surveys, and a final panel-driven indicators selection process. When complete, this process addresses problems of social exclusion (Burger 2009, Montoya 2011) from indicator selection, non-use of indicators by communities (Fisher et al 2001, Cook 2008), and risk of indicator invalidity due to lack of a collaborative process to mitigate inappropriate indicator selection (Reed et al 2008). This process will use a socially inclusive and facilitated consensus process to select indicators based on collaboratively defined criteria of validity, feasibility, and suitability for monitoring and evaluation. These indicators will be built into the IRWM planning process.

5.4.3 How does a focus on water quality change the dynamics of the Borrego Springs water infrastructure? This proposal has overwhelmingly focused on the issue of water quantity, but quality is an important coupled characteristic that can influence stakeholder dynamics. The BVAS will undergo significant changes in water quality as groundwater elevation changes, and this will influence socioeconomic dynamics within the water infrastructure. We will collaboratively tackle the issue of changes in how water quality influences the use efficiencies and supply / demand behavior within the different stakeholder components, the planned and projected changes in land-use by the human sector that will influence the water budget and quality, and the anticipated needs that require integration into the observation system for the community to support decision-making. We will use a series of stakeholder engagement workshops to develop the priority research questions for this section, carry out the preliminary

activities required to couple our understanding together in a model or integration process and then describe a common scenario in which water quality is analyzed.

5.4.4 – What educational activities influence behavior of the different stakeholder groups? We will engage in a number of 'informational workshops' that educate stakeholders on different aspects of the water balance problem in Borrego Springs and provide primers on aspects that we have not specifically addressed. Most of the research in this proposal is based on the assumption that stakeholder behavior can lead to effective planning for sustainability. However, there is a distinct probability that the process may not be successful and other options are employed to prevent catastrophic changes in the water balance, such as adjudication. Thus, we will engage the Center for Land, Environment, and Natural Resources (www.law.uci.edu/academics/centers/cleanr/) to hold an informational workshop on alternative solutions to the water problem from cooperative processes implied in this proposal. We will use survey data and metric data described in the management plan to evaluate the efficacy of these educational experiences.

5.4.5 – Can stakeholders develop true gains in efficiencies within the engineered hydrologic system of the Borrego Water District and coupled water infrastructure? Understanding the efficiencies by sector (household, small business, commercial, recreational, and agriculture) within the basin is important to understanding the future yields needed to account for in the water planning. Our evaluation will use publically available information including water use data from the BWD in addition to an evaluation of other external factors shown to influence water efficiencies, and the data collected throughout this proposal to collectively evaluate the true bounds of efficiency in this specific water system. Similar approaches have been employed in arid regions [Balling and Gober, 2007; Breyer et al., 2012] to assess patterns of water use due to climate and land use. Combined with the assessment of agriculture water use above, these data allow us to evaluate the engineered system and determine conservation strategies to leverage future water savings.

5.4.6 – What factors impeding the implementation of a more sustainable water plan for Borrego Springs are locally unique, and which are typical to other environments in which a shift in water economies is being attempted? While it is beyond this projects' scope to conduct a large comparative aspect outside the historical work, we will draw on the resources at our hands through residence of the PIs of this project in a controlled environment of "University Hills", a planned area for faculty at the University of California, Irvine, which has a similarly mixed property structure (private property, commons, and public lands owned by the state). A comparative approach with another setting will help us constrain our assumptions of the conflicting economic interests of stakeholders in Borrego Springs. What factors impede the implementation of a more sustainable water plan in an environment where residents do not have competing economic interests and tend to have high awareness of sustainability? In this neighborhood, some advocate for conversion to low-water usage landscape, while others advocate for the maintenance of green lawns and semi-tropical landscape. Through our project web site and reporting, this will allow BS stakeholders to see UCI scientists as participants in and objects of a similar research project, which can increase sympathy and buy-in, as opposed to previous projects in which some residents feel that researchers are preaching to them from above. Concretely, this activity will involve mini-interviews and auto-ethnography among residents, regulators, and administrators of University Hills, including the co-PIs of this study.

6.0 – Management, Timeline, Integration Activities, and Key Deliverables – This project is planned over four years (see *Management and Integration Plan* for other details and timeline). Much of the work in projects 5.1, 5.2 and 5.3 occur within the first three years, while the majority of activities in section 5.4 occur in years 2-4. We will manage this project with the use of an executive committee (chaired by the PI), research area leaders, designated stakeholder liaisons, and a Dean's council that will evaluate our project management and progress relative to our benchmarks. Our key entry into the stakeholder community is through the relationship

with the BWC, but we also have several mechanisms to include currently isolated or traditionally under-represented groups, such as local Native American tribes (see *letters of collaboration*). In our management plan we describe holding two symposia associated with bringing together researchers at the Beckman Center in Irvine tackling these integrated water infrastructure topics, two organized sessions at the American Geophysical Union Fall Meeting in the final years of this project, and a multidisciplinary conference at the Center for Global Peace & Conflict Studies. A key deliverable is an integrated human/natural model for sustainable decision-making and planning that can be used by diverse stakeholders in many settings outside BS in the context of climate change. Two specific outcomes of our project related to our overarching goal include: 1) an operational definition of sustainability and a plan for coupling hydrological and socio-politico-economic perspectives, and 2) a collaboratively determined iterative process for arriving at this definition, plan, and its implementation in the context of existing governance.

7.0 – Educational Programs and Outreach – The diversity of research projects and stakeholder engagement activities makes this project highly adaptable for integration into undergraduate degree programs, graduate student and post-doctoral professional development, K-12 curriculum / teacher training activities, under-represented group engagement, and the broad dissemination of research findings to many audiences. We will engage our graduate students and post-doctoral scholars in developing (collaboratively with the PI) a capstone experience for the existing Global Environmental Sustainability Minor undergraduate degree program based on case studies from our project (see *management and integration plan*). We will use the existing UCI CalTeach teacher training internship program and master teacher mentoring program to associate K-12 educators with the project, and cooperatively with the Borrego Springs School District (BSSD) to develop a project-based learning exercise for middle-school students. BSSD has a high proportion of under-represented students in their enrollment. The Post-doctoral community on UCI's campus holds a number of professional development activities each year and we will promote our training opportunities through these events (see *post-doctoral mentoring plan*). In addition, we will use a project web portal to both maintain up-to-date descriptions of our projects, blogs describing our recent accomplishments and to push our content to science media and educational networks that highlight biological, physical and socioeconomic issues. Our plans for stakeholder engagement (see management and integration plan) will result in up to six events annually in the Borrego Springs region that will disseminate our research products to a number of groups.

8.0 – Broader Impacts – We have detailed the transferability of our project throughout this narrative, as the issues associated with stakeholder conflict and issues of a change in climate on water resources currently occurring in Borrego Springs will likely be expressed throughout a growing area of the planet in the near future. In addition, the integrated water infrastructure concept and our approach translates to many other resource management issues. Finally, the use of science for decision-making, especially in the context of externally forced crises such as climate change, will benefit from our project findings. Finally, we will bring together several disciplines that approach issues such as extreme events, stakeholder engagement, participatory science, graduate education in different ways. The synergies that come from this interaction will be broadly enriching to our work. Probably the greatest broader impact this project will provide is to push our disciplines towards issues that deal with trade-offs between major sectors studied by different scholars, such as, "How can we maintain resource sustainability and not preclude a resilient economy?", and "How do we move beyond management principles based on 'safe resource extraction' to 'sustainable resource extraction'?"

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Other Supplementary Documentation
Management and Integration Plan

Principle Investigator (PI): Travis E. Huxman, UCI Professor, Ecology and Evolutionary Biology, Director, Center for Environmental Biology and Steele/Burnand Anza-Borrego Desert Research Center. *Co-Investigators (Co-I)*: Julia Elyachar, UCI Associate Professor, Anthropology, Director, Center for Global Peace and Conflict Stugies ; James Famiglietti, UCI Professor, Earth Science, Director, Center for Hydrologic Modeling; Valerie Olson, UCI Assistant Professor, Anthropology; Soroosh Sorooshian, UCI Distinguished Professor, Engineering, Director, Center for Hydrometerology & Remote Sensing; Kuolin Hsu, UCI Associate Professor in Residence, Civil & Environmental Engineering, Michael McBride, UCI Associate Professor, Economics; Tomaz Mastnak, UCI Visiting Scholar, Director of Research, Institute of Philosophy, Slovenia Academy of Sciences and Arts; Lyle Brecht, Director, Borrego Springs Water District. *Senior Personnel (SP)*: Susan Coons, UCI Academic Coordinator, Academic Affairs; Brian Thomas, UCI Postdoctoral Scholar, Center for Hydrologic Modeling; Michael Montoya, UCI Associate Professor, Anthropology and Chicano/Latino Studies, Director, Community Knowledge Project. David Feldman, UCI Professor and Chair, Dept. of Planning, Policy and Design, Professor, Political Science; *Associated Personnel (AP)*: Emily Brooks, PhD Graduate Student, Anthropology

Key collaborators: Borrego Water District, Borrego Water Coalition, Sacred Places Institute (see letters of collaboration) – These groups bring together all aspects of the stakeholder community in this aquifer system, including the vested scientific groups important to the development of science in the region (such as the USGS group, working collaboratively through BWD to build an initial MODFLOW representation of BVAS) and agency interactions (such as DWR participation in the regional water management activities through the BWC).

Management Structure: The PI will oversee planning, implementation and coordination of all activities and take on the responsibility of reporting activities to NSF, while also participating in several aspects of each research area. The project is broken into four distinct areas: three of these require specialized teams to tackle the disciplinary research projects [Hydroclimatological (5.1), Water Socialities (5.2), and Water Economy (5.3) – see project description], while the forth area is an integrated set of activities that will engage all project team members [Context-Specific Modeling and Intervention (5.4)]. Each area will be led by a designated project leader and have a team of researchers focused on the driving question:

Hydroclimatology:
Lead – K. Hsu; Team – J. Famiglietti, B. Thomas, S. Sorooshian, T. Huxman, post-doc (TBD)

Water Socialities:
Lead – V. Olson; Team – E. Brooks, S. Coons, M. Montoya, graduate student (TBD)

Water Economy:
Lead – J. Elychar; Team – M. McBride, T. Mastnik, graduate student (TBD)

Context-Specific Modeling and Intervention:
Lead – T. Huxman; Team – S. Coons, J. Famigliette, K. Hsu, B. Thomas, S. Sorooshian, V. Olson, E. Brooks, M. Montoya, J. Elychar, M. McBride, T. Mastnak, D. Feldman, L. Brecht, graduate student (TBD), post-doc (TBD)

The research leader will oversee the implementation specific projects and will be the point-of-contact for integration and coordination in the fourth area. The fourth area will draw on skills and projects that involve all team members along with external stakeholders. The PI will take responsibility of monitoring the academic progress of the graduate students and the professional development of the post-doctoral scholars in the context of the proposal (they of course will have an existing mentoring

framework from their schools). L. Brecht will assist with engaging the community stakeholders in Borrego Springs and the activities of important agencies associated with sustainability. The leaders of these four research areas, along with the PI and Brecht will form an executive committee (EC) that will meet monthly to discuss research progress and activity planning. The EC will monitor and assess progress against the anticipated timeline laid out in our initial plan (see below), adjust proposed activities based on input from stakeholder activities, integrate the educational and research objectives, review broader impact materials and activities, assist the PI in reporting to NSF and briefing / communicating with community stakeholders.

Plan for Integration of Research Components: The most intriguing aspects of this research program originate with the highly diverse interactions that may occur across the disciplines represented from physical and biological sciences, social sciences, humanities and economics. The overarching issue of sustainability ultimately falls on questions that can only be addressed by developing scholarship that crosses these major areas and fosters learning or new action in stakeholders (see participatory science figure in project description). Our focus is thus on developing our research team's opportunities for integration and learning across these divides and creating opportunities for interactions with stakeholders to have impact. We will rely heavily on regularly scheduled planning, coordination and reporting meetings (EC monthly), team-based project specific meetings (section 5.1-5.4 team specific meetings, quarterly), community engagement meetings associated with the three major research areas (topical stakeholder-team meeting biannually), whole project community engagement receptions and symposia (all stakeholder groups annually), and an annual project specific retreat and reflection (two different items below), where fixed pieces of the agenda include discussions of learning, access (to each other's resources) and potential road-blocks for progress. These and other, task specific meetings are identified on the research time-line. The EC will take the responsibility of coordination of these meetings and monitoring progress within each through time.

Parts of our program rely on stakeholder engagement to help prioritize questions and create a participatory science process. The logistics of meeting, planning and prioritizing will be managed by the PI (in assisting individual teams and planning the annual stakeholder meeting). Huxman has extensive experience from previous efforts building collaborative programs at the University of Arizona in both highly diverse research settings and community integrated education and outreach programs that he will apply to this current project. Team members include faculty, students, researchers, and professionals at many different stages in their careers. The team representation creates an excellent opportunity for professional development across the disciplines (learning from each other), but also a potential challenge to effectively carrying out the research plan (because different personnel with different skills are distributed across the task list). To mitigate this risk and exploit the potential opportunity, we will hold an annual retreat, not only focused on the specific tasks and progress of our project, but with the focus on growing our team based on lessons learned from our activities and documentation of best practices.

Advisory Structures: While it is beyond the scope of this project to establish a formal advisory board to engage in a steering process, we will take advantage of the existing infrastructure at UCI to help with oversight. The project will lean on experienced UCI scholars to evaluate annual progress on our research agenda from a high-level perspective. This will take place in the form of a council of deans [Dean of Social Sciences (Bill Maurer); Dean of Social Ecology (Valerie Jenness); Dean of Biological Sciences (Al Bennett); Dean of Henry Samueli School of Engineering (Gregory Washington); and Dean of Physical Sciences (Kenneth Janda)] that will recommend important, year-to-year changes in our structure and activities that may lead to greater growth. The project will present findings annually to the council in the form of a formal short-report, followed by rapid personnel interviews (by the council) representing the primary research areas. Feedback will be discussed and a formal response will be provided by the EC.

Timeline of Major Activities:

Project Schedule for "Assessing the functionality of decision making for water sustainability in a closed arid basin"

Tasks	Responsibility				Timeline															
					Yr 1				Yr 2				Yr 3				Yr 4			
					Sum	F	W	Sp	Sum	F	W	Sp	Sum	F	W	Sp	Sum	F	W	Sp
	PI	EC	RL	DC	2014	2014	2015	2015	2015	2015	2016	2016	2016	2016	2017	2017	2017	2017	2018	2018
Team Management Activities																				
Executive Committee Meetings	X	X																		
Team Based Project Meetings		X	X																	
Community Engagement Meetings	X		X																	
Annual All-Stakeholder Meeting	X	X																		
Annual All-Hands Retreat	X	X																		
Grad/Post-doc Meetings	X		X																	
Annual Project Evaluation				X																
Hydroclimatology RA																				
Precipitation Classification			X																	
Episodic Event Evaluation			X																	
Evapotranspiration Evaluation			X																	
Critical Habitat Water Balance			X																	
Agricultural Water Balance			X																	
User-Group Efficiencies			X																	
Socioalities RA																				
Social Network Baseline			X																	
Social Network Follow-Up			X																	
Explanatory Models Baseline			X																	
Explanatory Models Follow-Up			X																	
Socioeconomic RA																				
Historical & Comparative H2O Economies			X																	
Water Policy Evaluation			X																	
Experimental Water Economies			X																	
Valuation and Behavior			X																	
Context-Specific RA & Interventions																				
Collaborative Indicators		X	X																	
Water Quality Assessment		X	X																	
IRWM Documentation		X	X																	
Water Topic Workshops		X	X																	
Stakeholder Synthesis & Best Process		X	X																	
Broader Impacts, Education & Dissim																				
Online Portal and Inform. Manage.																				
Sustainability Seminar (development)	X																			
Sustainability Seminar (delivery)	X																			
NAS Symposium		X	X																	
AGU Session & CGPACS Conference			X																	
Papers, Presentations	X	X	X																	
Teacher Training / Engagement	X	X	X	X																

PI - principle investigator; EC - executive committee; RL - Research Leaders; DC - Deans Council

Sum - Summer; F - Fall; W - Winter; Sp - Spring

Plan for Dissemination and Sharing: We will disseminate and share data, models, tools and ideas, including dissemination to the research community through, (1) publication of peer reviewed journals, with a focus on interjecting interdisciplinary ideas into disciplinary forums, (2) producing reports, white papers, comments, blogs, and other written material on individuals who oversee planning processes for sustainability, (3) holding workshops and meeting, together with our stakeholders for water practitioners and researchers from other settings, (4) developing a capstone curricular experience for UCI undergraduates, (5) coordinating with programs such as UCI's CalTeach program that connects research to teacher training programs to provide appropriate content to young teachers as they develop their curricular 'tool-box', and (6) by traditional means through data arching and data-base linking (see *Data Management Plan*).

Our research team acknowledges that there are many important efforts in water sustainability occurring throughout the country, and especially in regions that are experiencing pointed issues in water availability and use (for example, - John Sabo's project). We propose a symposium to be hosted at the Beckman Center of the National Academy of Science, that will bring together several of these research projects early in our planned program. This will both connect us to important ideas occurring the field and also help in steering our scholarship part way through the program. Finally,

we propose to lead a series of proposals at the American Geophysical Union Fall meeting in years 3 and 4, which would bring back researchers from these different groups and place our developments in stakeholder-engaged sustainability into a wider audience. In addition, we will use the lecture series and annual conference framework for the CGPACS to integrate our activities, including in the context of external speakers to help us reach synthesis.

Quality and Expected Significance of Educational Program: Guided by the EC, the PI will also oversee a formal student and post-doc educational experience, focused on sustainability scholars with highly diverse skill sets. This will happen in two ways – biannual meetings with these early-career scholars will allow for important personnel feedback and a collective curriculum development activity that will result in a unique educational experience. Using the project-based experiences of the students and post-docs in the current projects, the PI/post-doc/graduate student team will develop a series of one-quarter capstone seminars for our Global Environmental Sustainability Minor (http://www.ess.uci.edu/undergrad/gs). In addition, we will partner with the UCI program, CalTeach, which has a formal internship program to place master teachers and training teachers in research settings to assist in their development of curricular materials (administered through the Center for Environmental Biology – uciceb.com). CalTeach is administered by the Deans of our major schools, which connects programmatically our research project to the assessment activities we'll ask the Deans to take on here.

Mechanisms to Assess Success: On-going evaluation within program components – we will use our regularly scheduled team meetings to report on progress in individual research projects. Benchmarks will include planning, scheduling, activity accomplishment, synthesis and summation. Included in this team-based evaluation will be quarterly reporting from key graduate students and post-doctoral scholars on their projects, along with their feedback on support received from the team and identification of barriers impeding progress.

Measuring output and assessing success – The team will document the engagement activities of our scholars directly related to this project or on themes that overlap with this project, including: research presentations, consultations with stakeholders, white paper production, briefings to agencies, non-profits, and other community stakeholders. We will also evaluate communication forms to general audiences, such as the bloging and web content provided by our researchers, media output, public seminars and conferences. All of these metrics can be compared to the activities historically carried out by our researchers on this team (pre-program baseline).

In addition, we will document the use of findings attributed to this project in decision making and policy development, or the participation of groups affiliated with this project in decision making and policy development on associated topics. Along with these items that highlight impact, we will document any use of our program findings or descriptions in education and outreach activities. Many of these items and processes are being promoted by the National Socio-Environmental Synthesis Center (sesync.org) and other programs involving stakeholder driven science. Several members of our research team are involved in projects that have evaluated stakeholder activities (Huxman, Olson, Sorooshian, McBride, Feldman), and we will reach out to SESYNC upon funding for feedback on our process.

Evaluating success of participatory activities and decision making processes – A key impact of our project is documenting the specific process of planning associated with an Integrated Regional Water Management Plan. As such, we will document the dialog associated with the many meetings of this process, including when specifics of our project are mentioned or intervene in the process. A specific research component of our overall plan tackles this issue (see *project description*).

Supplementary Document: Data Management Plan

Data management will play a crucial role in this multidisciplinary research project. The different activities associated with the project will generate large numbers of data sets for analysis, storage, documentation, and secure archiving. Our data management plan responds to these needs as also to the goals of making them easily searchable and accessible to project and other researchers. In addition, since our project takes a participatory science framework, engagement with our current (and prospective) stakeholders is important. As such, we will focus on access to data, synthesized data, and process / activities in our management efforts.

Types of Data

The principal materials and data generated by the proposed networking and research activities fall into three major categories – hydroclimatological science and water-balance process datasets; social and economic science datasets, and mixed social, economic and physical science datasets. In addition to data, we will also produce model outputs and outputs or examples from experimental economic games. We anticipate developing the following data sets as part of the hydroclimatology research and networking efforts: regional 10-m fractional vegetation cover, regional greening phenology, seasonal albedo distribution, multi-year surface skin temperature, stream flows, multi-year tracking of monsoon activity, multi-year spatiotemporal distribution of precipitation, temperature and humidity, topographic relief, multi-year projections of vertically- and temporally-resolved soil water content, and multi-year data streams for principal atmospheric state variables (surface pressure, vertically-resolved temperature and humidity, cloud density, and radiation loads), along with outputs from the MODFLOW exercises described in the proposal. In the hydroclimatology research, both continuous and discrete data types will be generated in the course of the project. This project will produce a real-time data display from multiple online instruments and sites to describe the hydroclimatology of Borrego Springs, similar to our network descriptions in Orange County on another project (see http://128.200.14.200/index.html#).

The social science datasets will include information from surveys, interviews, publicly available records, records available from the project network, and laboratory and field experiments that will be digitized and coded. Survey and interview questions will solicit subject identifiable data such as demographic markers, employment information, contact information, and work and life history. Subjects' contact information will be maintained in a secure database for the duration of the study, and shared only with authorized study personnel for purposes of follow-up data collection. Interviews will be transcribed and de-identified within four months of collection. Identifiable data will be de-identified and/or stripped from individual records before storage. Case study data will be used and analyzed with permission from producers of case studies. Information about data quality will accompany each datasets. In addition to survey and case data, we will also undertake substantial data integration efforts by drawing upon census and other officials datasets produced by country statistical offices in the different countries where the project will function. All data will be publicly available on the project web site (see below) or available from the researchers upon request in accordance with approved IRB protocols.

Data and Metadata Standards:

All data relating to human subjects will conform to federal and university procedures for informed consent and protection of privacy and we will engage all our team in clear education on the topic (e.g. UCI's online tutorial for all staff participating http://128.200.14.200/index.html#). The researchers involved with the project have substantial, long-term experience with large datasets, and have ensured that their research group members and laboratory researchers and students have completed human subject training. For new projects associated with the proposal, we will obtain approval as necessary prior to the beginning of relevant phases of the research.

To enable data discovery and re-use, all data generated by the project (including models) will be documented by metadata based on community standards. These include the Data Documentation Initiative (DDI), which is an international metadata standard adopted by widely recognized social science archives such as the Inter-University Consortium for Political and Social Research (ICPSR), the ISO 19115 international standard for describing geospatial data, and the Overview, Design concepts, and Details (ODD) protocol used in the OpenABM repository for describing simulation models. In addition to metadata standards, we will use Linked Data concepts and ontologies to relate data in a network of resources that also links data to researchers and scholarly papers. Our team has experience in managing data with community partners in this context.

Many components of our project involve comparison and synthesis of data already in the public domain or associated with other projects within our network. Where these data are not accompanied by data and metadata standards we will request information and permissions from data producers to provide accurate descriptions of data standards and metadata to ensure quality of data used, and for making data available through our data interfaces. Metadata will be based on the Ecological Metadata Language (EML) and will be generated by using "Morpho", available for free download at http://knb.ecoinformatics.org/morphoportal.jsp. Data quality control procedures from the LTER (http://www.lternet.edu/) will be implemented for newly collected data. Raw, quality controlled, and derived data as well as metadata will be stored and distributed as binary files and/or delimited text files generated by the commercial equipment and archived for future analysis at UCI.

Data Storage, Access, Sharing, and Reuse

We will establish a research project web site maintained at the University of California, Irvine. The web site will serve as a portal for access to all data and modeling platforms. We have requested funds for data management staff for the project. The technical staff will be responsible for organizing and posting all data spreadsheets and for linking with all the network members. Data (public and private) will be uploaded and stored in an operational database and managed by a database developer and administrator and accessed through out research portal. Information derived from database monitoring will be used to evaluate the efficiency and efficacy of database access and to prevent unauthorized database access. All developed data will be distributed on the internet via the project website using web services to query the database or as delimited text files and instrument specific binary files together with metadata which include methods, locations and processing descriptions. We will hold the data initially private to allow for student and postdoctoral researchers the opportunity to first analyze and publish their work. We have a successfully implemented this type of system in other collaborations (see www.ecodataportal.org; a commons associated with our collaborations throughout Orange County, CA). The distributed data files will be easily utilized by common statistical and data analysis software (Microsoft Excel, Matlab, JMP, SPSS, etc.). The project website will be updated to include an overview of the project, student, post-doc and faculty researcher biographies, and research action photos. In addition, curriculum for middle school activities generated during the CalTeach interface, curriculum from the undergraduate capstone experience in our Global Sustainability Minor, and public outreach documents, will all be included on the webpage, along with all project related presentations and posters. The data and associated metadata will be transferred to a data depository such as the NSF funded National Center for Ecological Analysis and Synthesis data depository (NCEAS) or other similar collection sources for appropriate disciplinary efforts. Private data users will be required to acknowledge the NSF/WSC funded program and invite the data owner(s) as coauthors in any documentation and/or publications, and will be required to inform the data owner(s) of any data use,

collaboration and publication plans. Users having access to private data will not be permitted to provide these data to any other party without explicit documentation in the form of written consent from the data owner(s). The user of data must agree to not resell or redistribute shared data and will be made aware that, while efforts will be taken to ensure that the data are of the highest quality, there will be no guarantee of perfection for the data and that the possibility of errors exists.

Long Term Preservation

The digital assets of the project will reside in and be available to the public through its dedicated project website as described earlier in this section. We will partner with existing data archiving and long-term storage facilities to ensure that the data generated through the project is available beyond the life of our project. Our hydroclimatic-social-economic research will involve both survey data and physical field measurements that result in research instruments containing complex relationships that are best represented as a relational database to handle the multi-way relationships between entities. We will archive our relational databases using a stable format so that future researchers will be able to access the data without the need to maintain or migrate proprietary software platforms. We will also make available records from the project network collected in non-digital form with the UCI Science Library.

Other Supplementary Documentation
<u>Postdoctoral Researcher Mentoring Plan</u>: Toward Water Sustainability in an Extreme Environment

Post-doctoral scholars engaged in this program have an extraordinarily opportunity to grow their careers in an exciting interdisciplinary setting. In addition, these scholars will have the opportunity to work in a setting where basic scholarship is put forward on equal footing as activities that serve decision making for sustainability. This area of research and our prior successes with training groups of postdoctoral researchers will result in a new brand of scholar that can tackle interdisciplinary, basic research on issues of resource sustainability, while also participating in a stakeholder-engagement framework. Mentoring post-doctoral researchers is a tremendous responsibility, but a great opportunity for the institutions and mentors in designing a program to advance individual careers and interdisciplinary research. We are responsible for helping postdocs develop research skills, new knowledge and professional networks, mentoring capabilities, written and oral presentation, communicating with stakeholders and collaborators from diverse disciplines, engaging in curriculum development and outreach, and learning to producing knowledge in a networked collaborative setting. Our research group must foster publishing scholarly papers and for constructive, but critical feedback.
Oversight: Day-to-day mentoring roles will be provided by the research leaders associated with the theme on which the post-doc is working. The responsibility for oversight of the entire mentoring plan and progress of the cohorts of scholars will be the responsibility of the PI, who will ensure that each area of research is providing sufficient opportunities for academic, professional and personal growth. We will hold quarterly meetings with these early career scholars to make sure that they are receiving resources significant to advance their careers.
Recruitment: Our project will conduct national searches using organization databases, e-mail networks and meetings, such as Fluxnet e-mail network and EANTH (Environmental Anthropology) listserv, NSF-funded RCN e-mail networks, ecology-l and climate-l, and postings in newsletters and annual meetings of the ESA, AGU, AAG, AMS, and AAA (the American Anthropological Association). While individual searches will focus on candidates who have the skills and knowledge to work with the topical research area, we seek to recruit postdocs with new perspectives, those that are driven to interact across both the natural and social sciences.
Training: Postdocs will receive training in scholarship, teaching and mentoring, along with service. Our flagship activity will be a capstone seminars led by a combination of participating graduate students, the PI and all postdocs, to take place within the existing Global Environmental Sustainability Minor program. This seminar will involve reading key interdisciplinary papers (and opportunities to discuss them with authors), and will allow for us to include advanced undergraduate students in our research. We will additionally hold meetings to help post-docs with networking, reviewing draft papers and reports, and other professional development skills in communication, proposal writing, stakeholder engagement etc. Postdocs will be encouraged and supported to participate in special courses. Examples include, the two-week stable isotope course in ecology at the University of Utah, Amazon PIRE type courses, Flux Observations and Advanced Modeling course, and opportunities with the Sustainability Science Program (SSP) fellows program at Harvard. Finally, the scholars will be integral parts of our research project and, as such, will interact directly with collaborators in the partner organizations, and will take part in activities associated with education and public outreach. Post-docs will have resources to attend at least one national scientific meeting a year in order to present their research results.
UCI Campus Postdoctoral Environment: UCI's Postdoctoral Scholar Association (PDA) is the primary organization for helping postdocs connect with peers and campus and community resources. The PDA offers a variety of social, recreational and professional development activities throughout the year, and meets regularly with UCI officials. Additionally, the Graduate Resource Center provides a gathering place for resources, services and activities to enrich the intellectual and professional lives of all graduate students and postdocs, and includes ongoing professional development opportunities in career planning, entrepreneurship, grant writing and communications. The UCI Postdoctoral Scholars Webpage (http://www.grad.uci.edu/postdoctoral-scholars/index.html) and UCI PDA Facebook page (https://www.facebook.com/groups/36821901035/) provide an extensive list of resources

Facilities, Equipment and Other Resources

Office and Laboratory:

UC Irvine provides office space for all faculty, staff and student researchers and lab space as needed for funded projects. In addition, our community partners have access to space for periods of collaborative activity at the Steele/Burnand Anza-Borrego Desert Research Center (described below). Excellent library and on-line research support is provided through the campus and university system libraries. Specialized resources and facilities that will be used in this project are described in greater detail below.

The senior personnel on this project span the Departments of Earth System Science, Ecology and Evolutionary Biology, Anthropology, Civil and Environmental Engineering and Economics. As such, their respective office and laboratory spaces are spread across the main campus, and primarily within John V. Croul Hall, Biological Sciences 3, Engineering Tower, Social Science Plaza, Steinhaus Hall and Social Ecology 2 – all within a 5 minute walk from each other.

Steinhaus Hall – Travis Huxman has laboratory and office space in Steinhaus Hall (approximately 1,500 square feet) sufficient for carrying out research on the ecological and environmental physiology of plants. Huxman's laboratory has typical ecophysiological equipment, including plant and soil gas exchange analyzers, micrometeorological equipment, plant water relations equipment, and standard ecological field equipment. Huxman has sufficient computing capacity for up to five graduate students and three post-doctoral scholars. Huxman has access to a field vehicle through the Department of Ecology and Evolutionary Biology. In addition, Huxman has built an extensive plant growth facility in the basement of Steinhaus hall with multiple stand-alone environmentally controlled growth chambers.

John V. Croul Hall - Croul Hall opened in 2003, and is a 68,000 square foot, state-of-the-art research facility. It was built through a successful private-public partnership. Croul Hall houses the Department of Earth System Science, including faculty and staff offices, laboratories, and conference rooms. Famiglietti and Thomas space within Croul Hall and adjacent buildings.

The Instrumentation Development Facility is located within Croul Hall and provides electronic engineering and instrumentation support. The facility assists in the maintenance, development, and field deployment of analytical instrumentation, and is overseen by a full time professional instrumentation engineer. This facility will be heavily leveraged for the extensive instrumentation required in this project. In addition, the stable isotope facility is located in Croul Hall.

Biological Sciences 3 –Bio Sci 3 also serves as the home of the Center for Environmental Biology (Director, Huxman), the administrator of this project, and has adequate and modern meeting spaces for interdisciplinary interactions.

Engineering Tower – Engineering faculty on this proposal have their office space in the Engineering Tower. These offices have a variety of supporting equipment; e.g., Intel Xeon

Workstation running Linux, which runs Portland Group Fortran and Tecplot to support modeling studies, a dual-processor Windows workstation running Compaq Fortran, Matlab, ArcGIS, and Tecplot as well as a Windows laptop that is used for basic computing purposes as well as programming and analysis. Offices are supported by departmental communication services: printing, scanning, faxing, internet and phone. Visiting researcher space is located on both the 8th and 9th floors Engineering Tower, which is also supported by departmental communication services.

Social Science Plaza - Experiments will be conducted at the UC Irvine Experimental Social Science Laboratory (ESSL), an interdisciplinary facility of the UCI School of Social Sciences. This 40-computer lab provides faculty and graduate students a low-cost forum for conducting experiments with a diverse human subject pool of over 2000 UC Irvine students. Co-PI McBride is the founding ESSL director and already has IRB approval (HS#2011-8378) to conduct experiments.

MAJOR EQUIPMENT

Center for Isotope Tracers in Earth Sciences

The UC Irvine Center for Isotope Tracers in Earth Science (CITIES) facility in the School of Physical Sciences houses a range of sophisticated analytical instrumentation. This includes four stable isotope mass spectrometers (IRMS), capable of measuring air, water, soil, plant, and rock samples, and a new High-Resolution Inductively Coupled Plasma Mass Spectrometer (HR-ICP-MS) that is utilized for measuring elemental and isotopic tracers in natural samples. The HR-ICP-MS (Nu Instruments AttoM) was acquired in 2009 with an NSF Major Research Instrumentation grant to Kathleen Johnson (co-PIs Saltzman and Trumbore). The AttoM can be utilized for high-precision analysis of nearly every element in the periodic table in both inorganic and organic solution matrices for a wide range of applications. ICP-MS is the most flexible analytical technique for elemental analysis and has become the preferred tool for research as well as routine analyses in a wide variety of areas. It is a fast, multi-elemental technique that offers significant advantages over other elemental analysis techniques, such as ICP-AES and GF-AAS, including lower detection limits, higher sample throughput, the ability to handle both simple and complex matrices, and the ability to measure isotope ratios.

High Resolution Mass Spectrometer for Trace Gas Analysis

This facility is a high-resolution triple-sector mass spectrometer. It is used for the identification and quantification of hydrocarbons and halocarbon trace gases in atmospheric samples, and air extracted from polar firn and ice cores. The facility was established with a Major Research Instrumentation grant from the Division of Atmospheric Sciences of the National Science Foundation. This instrument is one of only three such mass spectrometers currently utilized for atmospheric samples. It provides extremely high sensitivity and exact mass capabilities for analysis of air. The facility welcomes scientific interaction with investigators in the atmospheric chemistry community.

W.M. Keck Carbon Cycle Mass Spectrometer

The Keck Carbon Cycle Accelerator Mass Spectrometer facility (CCAMS) specializes in using radiocarbon as a tracer of the global carbon cycle. The facility analyzes ^{14}C in carbon from natural waters, soils, sediments, the atmosphere, and biota.

OTHER RESOURCES:

Key UCI Partnerships

UCI currently has partnerships with several organizations and agencies in southern California, that may bear on this current proposal, including the California State Parks, the Anza Borrego Foundation, both through the Steele Burnand Anza-Borrego Desert Research Center in Anza Borrego Desert State Park. These projects and facilities provide opportunities for research and education in conservation biology, restoration, ecosystem services, and land management. At the core of these projects is communication and collaboration between the academic community and stewards of natural resources.

Center for Environmental Biology

The Center for Environmental Biology (CEB) in the School of Biological Sciences was established in March 2010 to facilitate research, education, and outreach in biological science to help develop innovative new solutions to environmental problems. The mission of the CEB is to link academic research with ecosystem management and stewardship of natural resources, and to educate the next generation of environmental biologists and stewards. Participating faculty are from the Departments of Ecology and Evolutionary Biology, Earth System Sciences and Civil and Environmental Engineering. Professor Travis Huxman, PI on this project, is also the Director of the CEB. This project will be administered by the CEB.

Center for Hydrometerology and Remote Sensing

As an informal interdisciplinary group, the Center for Hydrometerology and Remote Sensing (CHRS) currently brings together faculty and researchers from the departments civil and environmental engineering and Earth system science in the University of California, Irvine. Our group jointly conducts research aiming to advance the knowledge of the water and energy cycle at scales ranging from the local watersheds to continental scales. Our main focus is land-surface hydrologic processes, their spatial and temporal variability, and the use of remote sensing information and computer models to improve both our understanding of these processes and our ability to model them in order to predict the impacts natural and anthropogenic variabilities on water resources. The majority of CHRS research activities are funded by NASA, NOAA, and NSF.

UC Center for Hydrologic Modeling

The University of California Center for Hydrologic Modeling (UCCHM) is an initiative across nearly all the UC campuses and affiliated laboratories to create a state-of-the-art, integrated model of California water resources. The Center functions as an open, community-based modeling effort where a team of faculty, researchers, and students work on developing and supporting models, and where collaborators, practitioners, workshops, short courses and outreach are hosted; a partnership with several UC campuses, national laboratories and state agencies, that collectively works towards building a comprehensive suite of hydrological model components

and integrated water cycle models for California to support critical research and applications for our state.

Center for Unconventional Security Affairs

Established in 2003, the UCI Center for Unconventional Security Affairs includes two research labs—the Environmental and Security Research Group and the Transformational Media Lab. The former conducts field-based research on security issues related to climate change including violent conflict, public health challenges and development setbacks. It has been a regular advisor to the United Nations, and to the US Departments of Defense and State as well as many non-governmental organizations. The latter conducts research on how complex science can be effectively communicated to the public to support or catalyze behavioral change. The Center has over forty students engaged in data collection, coding and analysis, over forty faculty affiliates, and over fifty advisory board members from academic and practitioner communities around the world.

Urban Water Research Center

The Urban Water Research Center's (UWRC) mission is to advance the understanding of the distinct characteristics of the urban water environment in order to assist people and institutions in their effort to promote health, enhance the efficient use of water resources, and protect environmental values. The Center is a partnership with over 70 faculty members and a variety of departments at UC Irvine. This partnership provides research, graduate education, and conducts public information programs. The Center pursues research that addresses topics such as water supply, demand and distribution, water quality issues for drinking and recreational use, how wetlands can reduce pollutants entering our streams and rivers from urban runoff, and how the acquisition and distribution of water and wastewater affect urban ecosystems, urban water reuse and public policy. Working together, we are able to effectively address the multitude of interdisciplinary water problems that people are facing in the modern urban environment.

Community Knowledge Project

The Community Knowledge Project (CKP) is a practice that explicitly addresses the systems and structures of inequality in which all humans and non humans live. The Community Knowledge Project is inspired by the Environmental Justice Movements around the globe where expertise itself is challenged and redefined. Coburn (2006) nicely details the promise of local knowledge for a new generation of scholars that seek a connection rather than domination or mastery over their subjects/objects of interest. His is an introduction and a doorway into a situated knowledge making practice that includes, on equal footing, expert and local knowledge makers. Neither takes an upper hand for Coburn. Rather, expert and local knowledge practices share many qualities that make the dichotomy only useful as a mnemonic, not as epistemological or ontological truism.

UCI Law Center for Land, Environment, and Natural Resources (CLEANR)

The Center for Land, Environment, and Natural Resources (CLEANR) strives to make UC Irvine School of Law a nationally recognized site for scholarship, education, community outreach, and public engagement on environmental, natural resources, and land use law. The center is a key part of a vision, building on UCI Law's strong environmental faculty, to the interdisciplinary

study of environmental problems. The mission of the center is to promote innovative thinking and engagement about environmental and land use law.

UCI Sustainability Initiative

The UCI Sustainability Initiative is creating a robust framework at UCI for crosscutting sustainability-related research, education, and community engagement. Strengthening this infrastructure enables UCI to elevate established and emerging collaborations, maximize public impact of research, and augment the campus's role in addressing intractable sustainability challenges in Southern California and around the globe. Such efforts help meet the University of California's commitment to exercise leadership in accelerating the shift to sustainability on campus, in our communities, and throughout society.

The Research Program supports campus strengths in a variety of applied disciplines, including alternative energy, hydrology, appropriate technology, social computing, alternative finance, public health, and sustainability science, as well as policy-oriented domains, including international relations, sustainable development, demography, migration, peace building, development economics and law, human and gender security and global humanitarianism. The Sustainability Initiative develops programs to assist researchers from across UCI departments and schools to identify and meet common objectives in the areas of research development, research integration across fields, and broadening research impact (including impact on policy, students, curriculum, workforce, and relevant community stakeholders).

The Education Program aims to make climate neutrality and sustainability part of the curriculum and other educational experience of all students, both inside and outside the classroom. A diverse task force is designing new formal education programs in sustainability for UCI undergraduate and graduate students alike. To reduce institutional barriers, the Initiative provides ancillary program support such as internship placement and informal advising to allow these interdisciplinary education efforts to thrive. Outside the classroom, the Initiative delivers co-curricular sustainability education through the Global Sustainability Resource Center (GSRC) by supporting graduate and undergraduate learning, leadership, and innovation through programs in education, career development, and community building.

Through the Engagement Program, the Initiative facilitates technical assistance to civic and community partners. On campus, we contribute staff expertise to conferences, student competitions, committees, and start up faculty initiatives; and host and co-sponsor sustainability programming. In partnership with UCI Government Relations, the Initiative works with faculty to communicate research results broadly through campus seminars, workshops, local community presentations, legislative outreach, and media placement. In the community, the Initiative fosters dialogue between UCI and the region on sustainability-related issues, laying the foundation for potential research partnerships and joint sustainability leadership initiatives. Work with tribal communities on environmental issues is building UCI's reputation as an innovative leader in interdisciplinary community-engaged research, aiming to position the Steele/Burnand Anza-Borrego Desert Research Center as a system-wide example of best practices in community engagement within the statewide UC Natural Reserve system.

The Community Partner Fellowship program bring together UCI's research, teaching, and engagement strengths in the fields of sustainability and development. The fellowships aim to bring to UCI Community leaders, activists, writers, artists and others who play a crucial role in developing paths toward lasting solutions to the problems faced by communities. The program is designed to leverage the research, educational, and service resources of the campus for the benefit of global community partners and promote sustained research partnerships.

UCI Center for Global Peace and Conflict Studies (CGPACS)

The UCI Center for Global Peace and Conflict Studies (CGPACS) is a multi-disciplinary program, housed in the School of Social Sciences, dedicated to promoting scholarly, student, and public understanding of international peace and conflict. Founded in 1983 CGPAS has fostered diverse and outstanding contributions from the UCI community as scholars, students, and citizens, to the promotion of global peace and to innovative and rigorous analysis of the factors shaping global conflict. CGPACS affiliated faculty from 7 schools across campus, guest speakers, and affiliated graduate students work on the military/strategic, economic/environmental, and cultural/normative motives, processes, and consequences of both peace and conflict. At CGPACS, we recognize that each of these aspects of peace and conflict needs to be studied in isolation as well as through their interconnections. As a result, our research programs encompass intra-disciplinary as well as interdisciplinary work.

Over the next three years, CGPACS will dedicate its programs to the theme *Thinking past the Unthinkable: Opportunities and Challenges for Global Peace*. We approach this broad theme in three related areas: *Biosecurity and the New Realities of Global Warming*; *Financial Crisis: Peace and Conflict in the New Normal*; and *Rethinking Peace and Conflict after the Arab Spring*. In all cases, we will draw on expertise across the schools of UCI as well as the expertise of local, regional, and international experts, and mutually impactful discussions in each category will impact the approach to the others. While other themes and topics will undoubtedly emerge, these three for the base of a coherent, interconnected and multidisciplinary program that will sustain and innovate upon CGPACS's legacy of excellence in forward-thinking research on conflict and peace. Outcomes will include peer-reviewed journal publications; online postings of articles; collaborative, curated discussions in existing and new online forums; interdisciplinary UCI grant applications; and collaborative, cross-school activity on the UCI campus.

Biosecurity and the New Realities of Global Warming, the first CGPACS sub-theme, is particularly relevant to this Water Sustainability and Climate proposal to NSF. Global warming poses a challenge to received wisdom about peace and conflict in the world. We are facing not only a problem of "peak oil," but also of "peak water." In times of high temperatures, research from the distant and more recent past shows, conflict rises dramatically. These new forms of conflict rewrite established maps of peace and conflict. The Southwest of the United States, for example, is grouped together with poor countries of Africa in global discussions of how we will face resource depletion. Drawing together our considerable expertise on the UCI campus, in partnership with national and international experts, we will look at the numerous challenges to peace and potential for conflict posed by peak water and peak oil.