COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 04-23

NSF 05-515 **01/26/06**

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)

EAR - MAJOR RESEARCH INSTRUMENTATION

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NSF PROPOSAL NUMBER

0619947

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University of California - Merced
4225 N. Hospital Road
Atwater, CA. 953445142

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TITLE OF PROPOSED PROJECT **Development of a water-balance instrument cluster for mountain hydrology, biochemistry and ecosystem science**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 578,171	36 months	07/01/06	

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☐ BEGINNING INVESTIGATOR (GPG I.A)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.1.d)
☐ HISTORIC PLACES (GPG II.C.2.j)
☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.1)
☐ VERTEBRATE ANIMALS (GPG II.D.5) IACUC App. Date ________
☐ HUMAN SUBJECTS (GPG II.D.6)
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☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
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☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT

School of Engineering

PI/PD FAX NUMBER

209-724-4356

PI/PD POSTAL ADDRESS

PO Box 2039

Merced, CA 95344
United States

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME Roger C Bales	PhD	1985	209-724-4348	rbales@ucmerced.edu
CO-PI/PD Martha H Conklin	PhD	1986	209-724-4349	mconklin@ucmerced.edu
CO-PI/PD Michael L Goulden	Ph.D	1992	949-824-1983	mgoulden@uci.edu
CO-PI/PD Jan W Hopmans	PhD	1985	530-752-3060	jwhopmans@ucdavis.edu
CO-PI/PD Eric E Small	PhD	1998	303-492-6187	eric.small@spot.colorado.edu

Electronic Signature

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 04-23. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

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By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Appendix C of the Grant Proposal Guide.

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(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

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This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

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The undersigned certifies, to the best of his or her knowledge and belief, that:

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(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

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AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME **Jennifer Teixeira**	**Electronic Signature**	**Jan 26 2006 7:40PM**

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
209-381-4180	**jteixeira2@ucmerced.edu**	**209-724-2912**

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Development of a water-balance instrument cluster for mountain hydrology, biogeochemistry and ecosystem science

Quantitative information on the Southern Sierra water cycle is largely provided by a few operational precipitation, snowpack-storage and stream-gauging stations, and by limited, intensive research networks in selected headwater basins. Evapotranspiration, soil moisture and groundwater recharge/discharge are not measured and the spatial properties of energy-balance variables driving the mountain hydrologic cycle are poorly measured across the region. Understanding the mountain water balance in a much more quantitative way and at greater spatial and temporal resolutions is critical to research in biogeochemistry, ecosystem science, and water resources, in addition to being central to research in hydrologic science.

This project involves developing and deploying a prototype instrument cluster to make comprehensive water-balance measurements across the rain-snow transition in the Southern Sierra Nevada, in support of hydrologic and related research by multiple investigators. At the center of the cluster will be an eddy-covariance system (flux tower) for measuring water and carbon exchange with the atmosphere. Besides providing measurements of evaporative and turbulent fluxes, the eddy covariance tower serves as the measurement and communications hub of the instrument cluster. Micrometeorological measurements and an embedded sensor network to capture the spatial variability of snow depth, soil moisture, air temperature, soil temperature, relative humidity and solar radiation will be clustered around the tower. The instrument cluster is to be located at Wolverton, in Sequoia National Park (36.5956ºN, 118.7333ºW). Wolverton is a non-wilderness area at about 2170 m elevation, road accessible year round and in an area with complimentary long-term research measurements and investigations.

The scientific merit of this project derives from the clear need to develop data sets that will enable advanced modeling tools to influence quantitative hydrologic forecasting, probe system response to climate and land-cover perturbations, increase understanding of basin-scale water cycles and provide defensible scenarios for infrastructure planning. Four broad science questions motivate this research: (i) How do hydrologic systems that are subjected to multiple perturbations respond? (ii) How do pulses and changes propagate through the hydrologic system? (iii) What are the time lags and delays of stresses in different systems? (iv) How can the predictive ability for these responses be improved? Our basic hypothesis is that strategically placed instrument clusters, designed to complement satellite remote sensing information, together with models encompassing climate, surface- and subsurface-hydrology, and other components of the Earth system, provide the basis for more accurately and efficiently measuring and scaling water balance components, and thence basin-scale fluxes, than does an approach that relies on sparsely distributed measurements of the type now available.

There are three important broader impacts associated with this project. First, the development and deployment of an instrument cluster in the Southern Sierra will provide data and information that will enhance the science of multiple individuals and research groups. By building on the data and infrastructure already in the catchment it provides a much-needed test basin and data-rich research site for hydrology, biogeochemistry, ecology and related fields. Second, it provides for the design and evaluation of a much-needed prototype instrument, or instrument cluster, one that can then be replicated across the landscape as the community works to build large-scale environmental observatories. Instrument clusters will form the basis for observatory system design for water balance measurements; design guidance does not yet exist. Third, building research infrastructure helps build both graduate and undergraduate research at UC Merced and partner institutions. Based on its inaugural undergraduate class, UC Merced is provisionally classified as a minority serving institution.

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*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Project description

1. Introduction

Several recent reports, including Water 2025: Preventing Crises and Conflict in the West, highlight the need for new water information to enable better decision-making for water resources management, and for the myriad other decisions that are influenced by water. Explosive population growth and changing climate are combining to create supply-demand mismatches that threaten water supplies across the West. As water becomes a more valuable commodity, more accurate information than is currently available will be needed to support better estimates of natural water reservoirs (e.g. snowpack, groundwater); we will need more complete understanding of water and contaminant fluxes (e.g. evapotranspiration, groundwater recharge, erosion, mercury transport, salinity sources), improved hydrologic modeling (e.g. streamflow forecasting, water quality predictions), and better informed decision-making [*Bales et al., 2004*].

The Sierra Nevada provides about 40% of the runoff for California, and a much larger component for specific basins. The range serves water to over 10% of the U.S. population. Snowmelt and streamflow timing are advancing earlier each spring in response to general warming (as much as +2ºC in recent decades) [*Cayan et al., 2001*]. This seasonal shift implies increased risk of floods in springtime, and droughts and wildfires in late summer.

The changing water balance and water distribution patterns, in both space and time, will radically impact ecosystems and water supplies in the Sierra Nevada and other western mountains in coming decades. Yet the knowledge base for implementing sound hydrologic management in Western mountains is notably weak (*Bales et al., submitted*). Information about water demand is not easily accessible. The effectiveness of various water and land-management practices and restoration techniques are largely untested. Forecasting tools lack the measurement base to make major advances. Observation technologies in current use are decades old, and the blueprints for modernization are lacking in most cases.

2. Research activities

This infrastructure project derives from the clear need to develop data sets that will provide a process-level understanding of controls on the mountain water cycle, establish a foundation for detailed geochemical and ecological studies, and improve the predictive ability of models of the Earth system. It will enable advanced modeling tools to influence quantitative hydrologic forecasting, probe system response to climate and land-cover perturbations, increase understanding of basin-scale water cycles and provide defensible scenarios for infrastructure planning. Besides supporting a range of research projects from multiple investigators, the development, i.e. design, deployment and evaluation, of the proposed instrument cluster is also research. We are not aware of any such intensive and integrated measurement system in a mountain basin that will serve as a template, though we have previously used most of the sensors that will make up the proposed instrument cluster in more limited mountain deployments.

Our basic hypothesis is that strategically placed instrument clusters, designed to complement satellite remote sensing information, together with models of climate, surface and subsurface hydrology, and other components of the Earth system, provide the basis for more accurately and efficiently measuring and scaling water balance components, and thence basin-scale fluxes, than does an approach that relies on sparsely distributed measurements of the type now available. Within this overall context this infrastructure proposal has itself three primary objectives:

1. Develop measurement strategies for accurate estimation of snowpack amount, soil moisture, snowmelt and partitioning of snowmelt/rain into runoff versus infiltration and evapotranspiration (ET) in mountain basins.
2. Demonstrate the applicability of an integrated satellite and ground-based measurement strategy through deployment of a prototype system employing emerging technologies.
3. Provide measurements needed to accurately estimate mountain water fluxes and reservoirs, and related biogeochemical cycles, in a representative southern Sierra Nevada basin.

While a number of science questions are addressed by the overall design, there are many additional science hypotheses driving the development of a prototype measurement system.

- Increased accuracy in the spatial estimation of snow water equivalent (SWE) at scales of 1-1,000 km^2 is possible with sensors placed to capture the variability in slope, aspect, radiation and landcover.
- Soil moisture patterns will follow the patterns for snowcover accumulation and depletion. Soil moisture measurements will also help to discriminate snow versus rain.
- Spatial variations in tree canopy cover are as important as slope and aspect for variability in snowcover and soil moisture.
- Accurate estimates of changes in spatial SWE across a basin can be developed using subpixel satellite snow covered area (SCA) and albedo plus canopy information and distributed energy balance modeling, with only limited ground-based SWE measurements.
- The reduction in uncertainty for a spatial average from additional nodes within a sensor web diminish slowly after a relatively small number of nodes is in place, i.e. measurement saturation will occur.
- Evapotranspiration is a dominant component of the water balance, greater than deep infiltration/runoff. It is greatest following spring snowmelt and is lowest in late summer and fall after the soil dries.
- Evapotranspiration (and carbon exchange) continues through the winter at a significant rate, and increases in response to temperature during the snow-covered season and in response to soil moisture (precipitation) during the snow-free season.
- Measurable groundwater recharge occurs in meadows.

In support of hydrologic and related research by multiple investigators, this project involves developing and deploying a prototype instrument cluster to make comprehensive water-balance measurements across the rain-snow transition in the Southern Sierra Nevada. Examples of the research planned by the co-investigators, and other cooperators who intend to use data from the proposed instrumentation follow. Note that while there is overlap between the aims of different investigators, in many cases they take multiple approaches and most have worked collaboratively in the past.

Basin scale water balance. Many of the collaborators on this proposal are interested in integration of satellite data, other spatial information, point flux tower data and sensor web data to estimate the spatial water balance (Bales, Conklin, Guo, Hopmans, Marks, Maxwell, McConnell, Miller, Molotch, Rice, Small). Research involves both developing and evaluating a strategy and approach that can be scaled beyond this pilot area, as well as estimating the actual water fluxes and reservoirs for the basin where the instrument cluster will be located. The combined patterns of snowfall, snowmelt and snowmelt-infiltration dictate soil water availability and therefore influence evapotranspiration rates during the growing season as well as deeper recharge to groundwater. Conversely, vegetation dramatically alters land-surface/atmosphere energy exchange and therefore the distribution of snowmelt and soil moisture. Improving understanding of these feedbacks is a necessary effort for accurately simulating the timing and magnitude of runoff and for predicting hydrologic response to ecological perturbations.

Soil moisture and evapotranspiration. Using both the tower and sap flow we will examine above and below canopy fluxes of water at the instrument cluster site, with some emphasis on the transition period from snowcover to no snowcover. Measurements of soil moisture, soil water potential, sap flow, and ET will be integrated to quantify how soil water controls ET. Shallow soil water (top 15 cm of the profile) is the primary source for bare soil evaporation. Soil water at greater depths, depending upon the root distribution of vegetation, is the source of transpiration. Soil moisture and potential vary greatly through space (horizontally and vertically), so only a distributed network of probes can provide the information required to understand the temporal fluctuations in ET measured by eddy flux tower measurements, which integrate over an area ~10,000 m^2. As transpiration and carbon assimilation are linked (through water use efficiency of vegetation), spatio-temporal variability of the soil water reservoir also controls carbon fluxes.

Sap flow velocity measurements, performed in junction with the flux tower studies, are part of the overall effort to close the water budget. Although relatively few sap flow velocity measurements have been made in snow-dominated terrain, measurements of transpiration in natural stands of conifer trees in the Jemez Mountains (Valles Caldera, NM) by J. McConnell suggest that tree transpiration accounts for ~60% of the combined ET in that sub-alpine environment. Measurements indicate that transpiration continues throughout much of the year, although rates of transpiration are highest during spring and early summer. In contrast, at Mt. Bigelow (Santa Catalina mountains, AZ) transpiration shuts down during the post-snowmelt, pre-monsoon dry period. Tower measurements of carbon and water fluxes will be used to interpret the sap flow velocity measurements and to quantify the amount of water transpired through trees throughout the year. Comparisons to meteorology, snowpack, and soil moisture and temperature will be used to better understand the effective controls on tree transpiration. Understanding tree transpiration is critical to closing the water balance and to understand how the hydrologic cycle changes in response to changing vegetation.

The same data will address multiple other questions. For example, the proposed instrument cluster compliments work by D. Marks' group in the Reynolds Creek (Idaho) experimental catchment using eddy correlation systems. A primary interest of that group is parameterizing canopy effects on meteorological forcings in snowcover energy balance models.

Spatial snow properties. Spatial snow depth for the areas with ground measurements will be estimated by interpolation of point measurements, including operational snowcourse and snow telemetry data [Molotch et al 2005a]. This analysis will yield relationships between snow depth and independent variables (topography, landcover, radiation and other derived variables). At the scale of a sensor web ($\leq$ 1 km) this analysis will yield estimates of the minimal and optimal placement and number of individual pods to provide both spatial average snow estimates and estimates of sub-grid variability (related to independent variables). At the scale of the instrument cluster ($\leq$ 10 km) it will provide guidance on the number and placement of individual sensor webs, and the potential gain in information from adding instrumentation or covering additional variability in the landscape. At the scale of the upper Marble Fork ($\leq$100 km) it will yield estimates of uncertainty in snow depth and provide guidance for broader measurement network design. Note that in all cases the interpolated snow products will be masked with SCA from MODIS, to provide a blended product that is corrected for fractional SCA [Dressler et al., in press; Bales et al., in preparation].

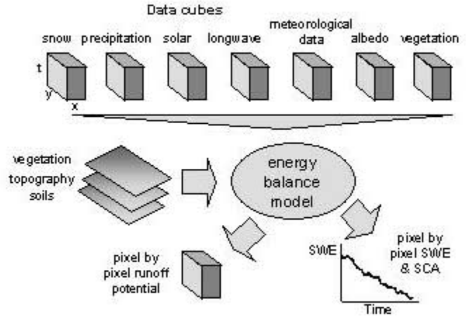

Figure 1. Approach for estimation of time series of pixel-by-pixel snowmelt, SCA and SWE from energy balance data.

Spatial energy balance and snowmelt. It is planned to assess the snow and energy mass balance, and the consistency between them, across the different scales of the study area. Consider the data cubes (x-y-t) illustrated on Figure 1. This data cube concept can be translated across scales with the proposed instrument network enabling investigations from both top-down and bottom-up scaling approaches. From the top-down perspective, we plan to model the distribution of energy fluxes across the Upper Marble Fork (135 km^2) and evaluate model performance across carefully selected grid elements containing ground measurements of varying intensity. For the analysis of daily snowmelt we will start with the approach that we recently used in the adjacent 19 km^2 Tokapah basin (elev 2400-3500 m, largely above treeline), with the turbulent energy terms lumped into a melt factor [*Brubaker and Rango, 1996; Molotch et al., 2004*]. With instrument clusters designed specifically to represent grid element fluxes in a variety of physiographic environments, we will be able to evaluate uncertainty in the basin-scale model over landscape types that are not currently part of the operational network. At the intermediate scale, we will be able to evaluate the basin-scale model within the Wolverton basin – where our instrument clusters and basin-integrated hydrologic observations will enable us to close the water balance with small uncertainty. In addition we will perform similar top-down model evaluations using leveraged observations such as those located in the above-timberline Tokopah basin.

From the bottom-up perspective, the instrument clusters will enable us to develop an improved understanding (and parameterizations) of snow-vegetation interactions, as well as groundwater recharge. Canopy effects on the distribution of solar radiation will be measured both at the tower and over different canopy types and canopy densities within the scale of a sensor web. This will allow us to develop improved parameterizations of vegetation-induced shortwave radiation extinction – information that has not been developed over snow-covered forests at these latitudes. Using the available vegetation (canopy opening, NDVI) information we will be able to apply these parameterizations over the basin-scale. The proposed instruments will allow for similar parameterizations to be developed for snow-surface albedo and for the distribution of longwave radiation.

Spatial scaling of vegetation properties. Spatial variability of vegetation and terrain features greatly influences energy, water and carbon fluxes over a range of scales [Shen and Leclerc, 1995; Cosh and Brussaert, 2003]. The scaling process involves taking spatial, temporal and process information at one scale and using it to derive information at another scale [Jarvis, 1995]. Using the proposed multi-scale measurements – flux tower, sensor array and remote sensing products – to derive information across a catchment and at scales in between is a major challenge facing the research community. To address this we will first extract various vegetation properties (e.g. leaf area index, tree height, and tree crown size) and terrain properties (e.g. slope, and aspect) from existing geo-datasets together with a range of geospatial techniques such as GPS, remote sensing, leaf area meters, and laser rangefinders; then, we will evaluate the use of different scaling methods (interpolation methods, multivariate regression to process-based ecological and hydrological models).

Hydrologic modeling. A number of different hydrologic and land-surface models will be used to help integrate measurements and provide estimates of derivative quantities. One approach will be to use PRMS/MMS [*Leavesley et al.*, 1996], which has recently been modified to assimilate spatial snow data [*Dressler et al*., in press]. Information from flow paths and residence times will be used to help calibrate the model parameters related to flow paths and validate the model performance at basin scale. PRMS will provide derivatives such as spatial snowmelt infiltration rate and evapotranspiration rate and thus test the effectiveness of the instrument cluster design. Under a project that will begin in 2006 we also plan to use of the observations (remotely sensed data, other spatial information, and instrument cluster data) to evaluate more advanced models, including the LLNL climate/hydrology model, and to find optimum values for key parameters within that model. The coupled land-surface-groundwater model is a dynamic, two-way coupling of an LNL-developed groundwater code (ParFlow) [*Ashby and Falgout*, 1996; *Jones and Woodward*, 2003] with a fully-integrated overland flow capability [*Kollet and Maxwell*, 2005] and a widely used land surface model, the Common Land Model (CLM) [*Dai, et al.*, 2003] as described by Maxwell and Miller [2005].

Water flow paths and residence time. Information on flow paths and residence times is crucial for understanding water balance, partitioning of snowmelt, and the links between snowmelt, subsurface flow and streamflow discharge in snow-dominated regions. Acquisition of this information is affected by and affects the monitoring design in measuring the water balance components, developing and parameterizing hydrologic models (e.g., how soil water and overland flow modules should be configured in predicting stream flow discharge at a designated scale). An instrument cluster design for water balance measurements in combination with synoptic sampling/measurement at larger scale provides an excellent prototype for testing the changes of flow paths and residence times over catchment scales and geographic settings and the effectiveness of the instrument cluster in a water balance study. Physical measurements (stream sensors, meadow groundwater and soil moisture sensors), combined with isotopic and chemical tracers will determine flow paths and residence times at three scales: hillslope/meadow, headwater/tributary catchment and larger sub-basin scale. Using samples from streams, soil water, groundwater and snow, sources of groundwater and flow paths of stream flow will be determined using diagnostic tools of mixing models [*Hooper*, 2003] and end-member mixing analysis [*Christophersen and Hooper*, 1992] as demonstrated in *Liu et al*. [2004; in press] across all scales. Four hypotheses will be tested: (i) overland flow is insignificant at all scales, (ii) soil water is disconnected with streamflow at all scales, (iii) there is significant groundwater recharge, and (iv) information obtained at the instrument cluster and smaller scales will improve parameterization of hydrologic models that simulate streamflow at the basin scale.

Research that builds on water balance. A number of additional studies that will build on the water balance research are also planned. Only a few examples and investigators are given here and in the attached letters (Green, Goulden, Meixner, O'Day, Sickman, Traina).

Carbon fluxes and soil carbon. The proposed flux tower will extend the California Carbon Study (M. Goulden, PI) to a major Sierra Nevada ecosystem. Five overarching science questions are driving that long-term project: (1) How much carbon is released and taken up by California? (2) How much confidence should we have in our carbon budgets? (3) How do our carbon budgets compare with previous budgets? (4) How much, and why, does California's carbon balance vary from year to year? (5) What processes control the CO_2 concentration of air leaving California? (6) Where does the CO_2 emitted by California go? The proposed instrument cluster will contribute directly to that multi-investigator program.

In addition, S. Traina's group is doing laboratory studies on the surface chemistry of black carbon (BC) particles in soil matrices. In particular these investigators are isolating black carbon from soil matrices, characterizing the surface functional groups on the BC particles with FTIR and C- K-edge spectroscopies, dating the C particles with accelerator mass spectroscopy and correlating the extent of surface weathering of BC with age and pedogenic environments. These studies require extensive knowledge of the water balance of all field sites used as sources for BC particles. The Traina group is also initiating a number of studies of soil C dynamics in natural systems. Three types of sites have been chosen for these activities, a series of coastal marine terraces near Santa Cruz California, a series of Sierra foothill terraces ranging in age from 10,000 to 3,000,000 y bp, and selected meadows in the Sierra Nevada. The first set of sites is already heavily instrumented to collect meteorological and soil-water data. The proposed installation in Sequoia National Park would provide a location for the mountain portion of this research.

*Biogeochemical cycling***.** The twenty-three year record of biogeochemical research in the nearby Tokapah basin clearly demonstrate that hydrologic variability, particularly with respect to snow regime, strongly influences cycling of carbon and nitrogen in soils. In turn, variability in C and N cycling in soils affects downstream lakes and streams by controlling the timing and amount of available nutrients for primary production. Nitrogen cycling is particularly sensitive to changes in snow regime. Stream nitrate levels in years with deep, late-melting snowpacks are double those in low snow years, thereby increasing surface water acidity and nutrient supply to phytoplankton [Sickman et al., 2003]. The Wolverton instrument cluster will extend this data set and understanding to the rain-snow transition zone to better understanding of how climate change is affecting ecosystems of the Sierra Nevada.

In addition, P. O'Day's research interests include mineral-aqueous interface geochemistry, chemistry and mobility of contaminants in the environment, and geochemical and biogeochemical applications of spectroscopy and microscopy, in particular synchrotron X-ray methods. She is interested in extending research to mercury and selenium cycling in the Sierra and Central Valley, with a focus on quantifying inputs and their speciation from atmospheric deposition versus terrestrial sources, and examining how co-contaminant speciation may influence bioavailability. Quantification of the mountain water balance will provide critical baseline data for designing studies aimed at understanding multiple contaminant inputs and their biogeochemical cycling.

Microbial ecology. The instrument cluster provides a platform for a rich set of soil microbial investigations. For example, J. Green will use the soils in the vicinity of the instrument cluster to study biological diversity and questions about patterns in the distribution and abundance of species. Specific attention will be directed to exploring patterns and principles that may be common to microbes, plants and animals. Relationships between soil microbiota, temporal-spatial patterning, plant community structure, and ecosystem function will be explored.

Sensor network design. T. Harmon is interested in using the proposed Wolverton water balance instrument as a setting for field testing sensor and sensor networking technology that he is developing in the contaminant observation and management thrust area of the Center for Embedded Networked Sensing (CENS). Both T. Harmon and R. Bales are interested in the site as a testbed and an integral cluster of a regional observatory effort being planned through NSF's NEON, CUAHSI and CLEANER initiatives. Harmon has a CLEANER planning grant, Bales has been coordinating a group planning of a CUAHSI observatory and both are involved in NEON planning (see also attached letter from M. Allen, chair of the CalEON planning group).

Prior NSF support for instrumentation. Roger Bales (NSF-OPP 0116674. Development of a System for Measurements of Soluble Chemical Species in Ice Cores. Nov 2001 - Oct 2004). This project involved construction of a new instrument for continuous measurement of soluble species in ice cores in the laboratory and field. It is composed of: (i) a system to continuously melt and deliver liquid to a continuous flow analysis system, (ii) eight modular continuous flow detectors, which use spectrofluometric and spectroscopic methods, and (iii) a data acquisition and processing system to calculate concentration versus depth from the measurements. Field performance of system components during deployments in both Greenland and Antarctica was excellent, providing data for two Ph.D. dissertations (J. Burkhart and M. Frey). The normal suite of analytes includes: hydrogen peroxide, formaldehyde, calcium, nitrate, ammonium, chloride and electrical conductivity. In comparison to the first-generation melter system, also built in our laboratory, we have improved detector sensitivity, monitoring and control of melt rate, and ease of use. Further deployments are planned.

3. Research instrumentation and needs

The work plan for this proposal involves developing a prototype of instrumentation that could form the backbone of a range-scale environmental observatory, and will provide essential data for a broader observatory design, as well as provide important data in one important basin within the southern Sierra Nevada. Conceptually, the approach involves developing one instrument cluster, anchored by an eddy-correlation flux tower but with ground measurements extending 1-2 km from the tower. The flux tower will provide point measurements of water, energy and carbon exchange with the atmosphere, which will be extended outward using the meteorological, snow/soil, remotely sensed and other spatial data. The proposed instrument cluster will include three embedded sensor networks, one located in the vicinity of the tower, one at a lower elevation with cold-season precipitation a mix of rain and snow (~2000 m) and one at a higher snow-dominated elevation (~2600 m).

The proposed location for the prototype instrument cluster is the Marble Fork of the Kaweah River Basin, in Sequoia-Kings Canyon National Park. The proposed location for the flux tower is in the vicinity of Wolverton, (36.5956^{o}N, 118.7333^{o}W). Wolverton is a non-wilderness area at about 2170 m elevation, road accessible year round and in an area with complimentary long-term research measurements and investigations (Figure 2). Wolverton is on a bench that extends on the order of 1 km in multiple directions, and is about 2 km below the ridge separating the Marble Fork from the Middle Fork of the Kaweah River. The largely forested (mixed conifer), 8 km^2 Wolverton basin is nested within the 135 km^2 Marble Fork. Before selecting this site the Co-PI's visited and analyzed several alternate sites in the same elevation range (Crane Flat in Yosemite National Park, Teakettle Experiment Area and the Kings River Experimental Watersheds in Sierra National Forest, and various University of California Natural Reserves in the American River Basin). Wolverton was chosen based on topography, vegetation, hydrologic features, history of past research in the area, access, availability of electricity/telephone on site and a commitment from Sequoia-Kings Canyon National Park to provide year-round research and lodging space at the site. Wolverton was formerly the site of a ski lift and stables; both have been abandoned but the structures that supported these activities remain and are largely unused. There is a small but active rock quarry in the area, and the water treatment plant for the Lodgepole Visitor center is at Wolverton; but those operations will not interfere with the proposed research. The water treatment plant withdraws a relatively small flow (relative to baseflow in Wolverton Creek) from a spring at the north edge of the basin. We have applied for

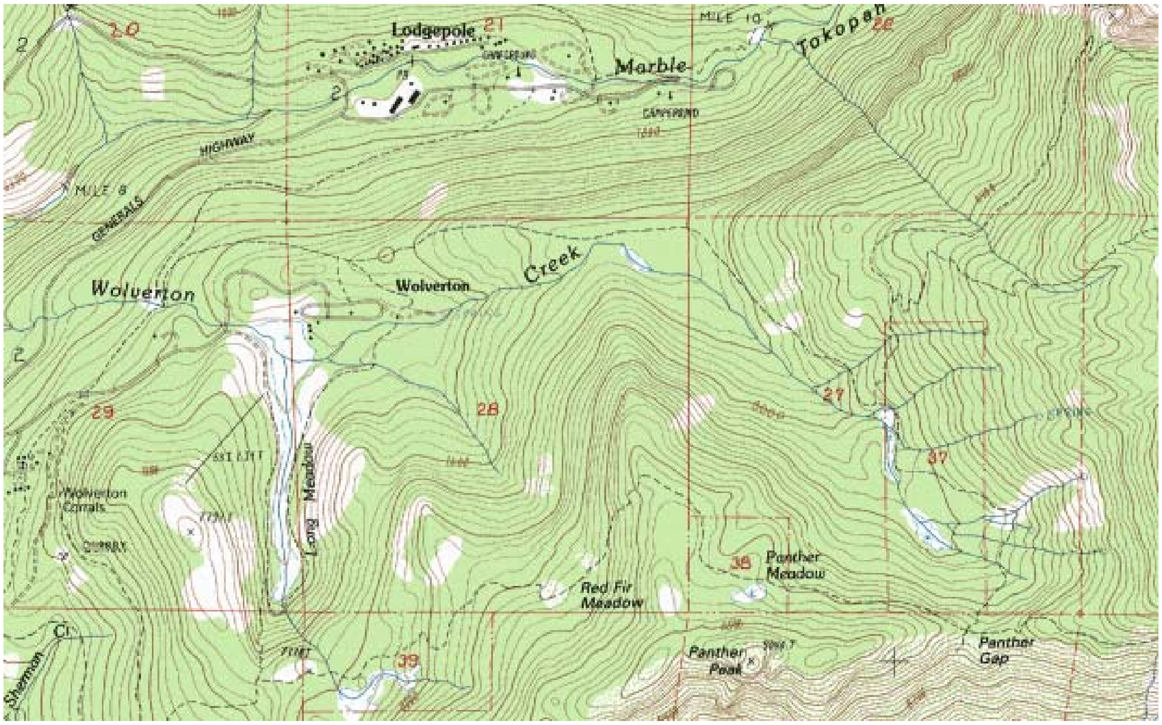

Figure 2. Wolverton catchment and vicinity

and received a National Park research permit to establish the instrumentation and carry out research in this area (copy appended).

Flux tower. An eddy covariance tower will be established for measurement of water, energy and carbon fluxes (Table 1). Besides providing important measurements of evaporative and turbulent fluxes, it serves as the measurement and communications hub of the instrument cluster. Micrometeorological measurements and an embedded sensor network will be clustered around the tower.

Table 1. Tower sensors

Eddy and storage fluxes
Sonic anemometer (Campbell CSAT 3)
Eddy flux CO2-H2O (LI-7000)
Profile CO2- H2O (LI-7000)

Meteorology
Wind speed and direction; MetOne cup
Wind speed and direction; ATI sonic
Air temperature; Aspirated thermistors
Net radiation; REBS Q*7.1
Up and down solar rad; K&Z 6B
Up and down terrestrial rad; K&Z CG2

The terrain at the proposed site is similar in complexity to a tower that R. Bales and colleagues located at Mt. Bigelow, AZ, 2573 m elevation, on a small plateau within a saddle area (http://www.sahra.arizona.edu/research/TA1/towers/) (Brown-Mitic et al., submitted). Water vapor, carbon dioxide, sensible heat and momentum fluxes were measured using an eddy covariance flux system. The saddle has slopes of 10-17^{o} for 1-2 km in all directions. Four micrometeorological stations equipped with wind, air temperature, relative humidity, surface and soil temperature, net radiation, precipitation and soil moisture sensors were installed in the vicinity of the eddy covariance tower, to characterize the variability in both atmospheric and surface characteristics.

Individual sensors on the proposed tower will be similar to that installed at Mt. Bigelow, and at seven sites that M. Goulden is establishing along a 150-km transect in Southern California (coast to San Bernardino mountains). Wind velocity and virtual temperature will be measured with a three-dimensional ultrasonic anemometer and CO_2 and water vapor measured with an open-path infrared gas analyzer. Incoming and outgoing shortwave and longwave radiation components will be measured above the canopy by a four-way radiometer and net radiation by a net radiometer. The tower will also be instrumented to measure micrometeorological data at three vertical levels. Infrared thermometers will measure the skin temperature of the ground and canopy. Data from the eddy covariance system will be sampled at 10 Hz, and five-minute average values recorded for all other hydro-micrometeorological variables.

Electricity is available at Wolverton, and we plan to extend it about 100-150 m to the tower site. At that distance one can run 110 volt power without the need for a higher-voltage line. Limited solar/battery backup will be provided on the tower. At Mt. Bigelow, operations on the tower are powered by four solar panels charging deep-cycle batteries, which is an option for the Wolverton tower if problems arise in extending electricity to the site. Experience at Mt. Bigelow shows that systems such as these can operate through winter snows and sub-freezing temperatures with only small losses of data. Riming has been an occasional problem at Mt. Bigelow, but sensors recover when ice melts.

Vegetation at the Wolverton site is mixed conifer, with areas nearby dominated by white fir and Ponderosa pine. Near the meadow canopy height is on the order of 30 m, with trees over 40 m on ridges away from the meadow. The physical tower will extend on the order of 5 m above the tallest part of the canopy, and 10-15 m above the average canopy (~40-45 m total).

It is also proposed to include measurement of carbon fluxes on the tower. Though not the main driving force for this science proposal, such measurements will be a quite valuable addition to the growing measurement network in California, and will provide the highest elevation site in the Sierra Nevada. There is essentially no incremental cost involved in adding the carbon measurements since the same instrument measures both water and carbon.

Data will be logged and stored on site and telemetered to our laboratory in near-real time. We continue to evaluate three options for real time data transmission: 1) GOES satellite uplinks 2) RF telemetry/spread spectrum, and 3) telephone line. The preferred option is telephone.

Embedded sensor network. As part of the instrument cluster we will deploy three sensor webs, which are in-situ, spatially distributed instruments consisting of cooperating observational sensor pods, each with sensors to record the seasonal evolution, accumulation through ablation, of snow depth, soil moisture, air temperature, soil temperature, relative humidity and solar radiation (Table 2). One distributed sensor web will be co-located with the flux tower, with the other two at elevations lower and higher than the tower. In this way the instrument cluster will cross the rain-snow transition. The sensor web associated with the tower will also have sap flow.

Table 2. Sensor network

Snow: Judd Communications ultrasonic depth sensor
Soil moisture & temperature: Decagon TDR & Watermark
Wireless pod (RH, temperature, radiation): JPL

This distributed sensor web network will take advantage of the varying topography to characterize the spatial variability of water-balance components at sufficient points to both develop and evaluate relationships between snow/soil measurements and topography, landcover and radiation features.

Site selection of pods within an instrument cluster is of primary importance to the overall success of the proposed project. A statistically unbiased approach for selecting the most representative locations for observations is critical. Small-scale (1-16 km^2) snow distribution studies have shown that the relationships between snow accumulation and independent variables are nonlinear [*Elder et al., 1998; Molotch, 2005b*]. While similar analyses for soil moisture in mountains are lacking, as a starting point we will use the same (horizontal) measurement strategy. Soil moisture will be measured at 2-4 depths at each point. We are evaluating this strategy at a new, small-scale deployment (1 km^2) in the Valles Caldera (Jemez Mountains, New Mexico) on which Bales, Small and Molotch are Co-PI's.

The basin-wide statistical distribution of physiographic variables for the upper Marble Fork of the Kaweah River basin will guide the site selection for the spatial distribution of the sensor networks and the pods within them.

A unique aspect of this instrument cluster is our use of sensor web technology to enhance the science product and explore new methods for hydrologic analysis. The sensor web is a collection of interacting sensor pods (Figure 3) that communicate wirelessly to form a single, spatially distributed instrument (*Delin, 2002*). Because the pods share their data with all other pods in the network, the sensor web allows for an embedded, autonomous, distributed GIS instrument that can also react and adapt to changing environmental conditions. In addition, real-time streaming data will be available on snow depth and temperature, as well as soil moisture, via the Internet. This communication link via the internet will allow a bi-directional link allowing not only for real-time viewing, but also real-time commanding of the system. Sensor Web systems have been fielded in a wide variety of harsh environments (http://sensorwebs.jpl.nasa.gov/), including the Central New Mexico desert and Antarctica, for many months and even years *(Delin et al., 2003)*. Data processing will occur on site and data will be telemetered to our lab as noted above.

Figure 3. One pod in sensor web that was installed in January 2005 to measure snow depth over a 20,000 m^2 study area at Gin Flat, Yosemite National Park. Depth sensor is on right and wireless pod on left.

Sensor web network installations will be similar in design to our pilot network array at Gin Flat, along Tioga Pass Road, Yosemite National Park, which focuses on snow distribution. In this design pods are placed in an elongated rectangular area, which both captured the variability in the area and kept instruments in a non-wilderness corridor along Tioga Pass Road. At the Valles Caldera, the 1-km^2 deployment area was more square. Because sensors are connected with wires rather than wireless technology at Valles Caldera, the arrangement was constrained to minimize wire runs to the data logger. It is our experience that the wireless pods can be placed at up to 100-m spacing, with each pod communicating with at least two other pods providing a reliable and robust network.

Most sensors will be sampled hourly. Hourly temporal measurements are of sufficient resolution to capture accumulation rates without the dampening affects of settlement. Monthly site visits during the winter and spring will be used to verify accuracy and perform any necessary maintenance. At our ongoing Gin Flat pilot study accuracy was better than 3% for any given sensor, with no systematic bias (http://faculty.ucmerced.edu/rbales/Alpine).

Within each of the sensor web clusters, a pod will be placed at randomly selected points to capture multiple trees and open spaces between trees. Since snow accumulation, densification and melting is affected by trees, it is necessary to sample distances from tree trunks and canopy in order to develop parameters to describe the local distribution of snow as a function of vegetation type and tree density. We will follow the protocol that we used at the Valles Caldera, where pods were deployed randomly in 3 areas: under canopy, at crown edge and in the open between trees. While that system was only placed in operation in summer 2005, early data confirm expected differences in soil moisture with placement relative to tree crown. Manual snow depth surveys will be done in the general area of each cluster during the site visits to evaluate the representativeness of the sensor locations.

Having 12-15 pods within a cluster also provides for replication. Even within relatively homogeneous sites snow depth and soil moisture vary. We found that for snowcourse data at Gin Flat, having 8 replicates in a flat, open meadow was only slightly better than having 3 replicates [*Rice and Bales , 2004*]. That is, for purposes of estimating spatial averages in varied terrain, uncertainty increased below 3 measurements. But for estimating spatial patterns, which is important for the research deployment outlined in this proposal, we have found the need for at least 12-15 pods per cluster.

We will use the heat diffusion method for measuring sap flow velocity in a number of evergreen trees at the flux tower site. Two or more sap flow velocity probes will be installed in up to sixteen trees at the site. Each probe consists of two 30 mm long needles that are installed into small diameter holes (1.2 mm) drilled into the tree trunk just below the bark (http://www.dynamax.com/). The holes are separated by 40 mm. Both needles in the probe contain a thermister for measuring temperature. The upper needle also contains a heater. Sap flow rate is proportional to the temperature difference between the two needles. Cables to provide power to the probes and to monitor the temperature difference will extend from a datalogger enclosure to the individual trees. These cables will likely be contained in PVC pipe to protect them from wildlife and research activities in the area. The probes will be relocated on the trees periodically. Measurements of sap flow velocity in all trees will be recorded every 10 minutes.

At the sensor web and instrument cluster scales it is planned to deploy sufficient sensors to provide redundancy and allow subsetting data for both estimation and evaluation. From previous field surveys we have developed guidance for sensor placement (*Molotch and Bales, 2004*). In cases where evaluation data were limited we have used a jackknifing procedure for evaluation (*Cadle, 1996; Cadle et al., 1997*).

Soil moisture measurements will be made using two methods: Watermark soil moisture blocks and probes that measure dielectric constant. We are currently evaluating the Decagon TE probes, which measure soil moisture and temperature, plus electrical conductivity. Following our Valles Caldera setup, we plan on measurements at 2-4 depths per node, depending on soil depths; most of the Wolverton catchment has shallow soils.

Our approach to integrating the soil moisture data will follow that for snow. To our knowledge this sort of spatial estimation has not been done for a mountain environment. Soil heat flux will be measured using soil heat flux plates buried 2-cm deep in close proximity to the soil temperature probes. At our Valles Caldera site we have deployed a combination of thermocouple psychrometers and water content reflectometers. With current funding we will also deploy a set of these sensors at the site in summer 2006, along with the Watermark and Decagon sensors. This side-by-side evaluation in the field will allow us to develop some field data before a final decision is made about which to include in the instrument cluster deployment a year later. But based on our lab evaluations to date, plus data from a multi-year deployment of TDR probes at Teakettle Experimental forest, just north of Sequoia-Kings canyon National Park, we expect the Watermark and Decagon sensors to be best for this deployment.

Table 3. Leveraged instrumentation

Stream stage, temperature, EC (Seabird), 5 sites
Water level piezometers, transect of 12 in meadow
Soil moisture vertical profiles, 2 sites using water content reflectometers, thermocouple psychrometers, time domain reflectometry & Watermark sensors
Meteorological stations, 2 sites
Precipitation (Ott Pluvio), 2 sites

Leveraged instrumentation. In addition to the instrument cluster described above, which will consist of a flux tower and three embedded sensor networks, we will deploy several additional sensors that are needed to provide a more complete water balance for the basin. These instruments are already planned for deployment in summer 2006 with other funding (Table 3).

We will deploy two heated, shielded precipitation gages, to compliment the operational measurements already in place in the Park. Two micrometeorological stations similar to that used at our Mt. Bigelow site will be placed in the Wolverton basin, with sensors for air temperature, relative humidity, wind speed and direction, incoming solar radiation, soil temperature and soil moisture. Data from these stations, plus the precipitation gage, will be telemetered to our laboratory as noted above. The instrument cluster to be developed under this proposal will use the same communication protocol.

A set of 12 piezometers with self-logging pressure transducers will be placed in the 1.4-km long meadow (Long Meadow) that is part of the Wolverton basin. Deployment will be both along and across the flow direction. They will be installed to accommodate a fluctuating water level, and will have continuous monitoring of water level and water temperature. Two of the wells would also have continuous conductivity measurements

Stream stage, temperature and electrical conductivity will be measured at five locations in the basin: in Wolverton Creek and two tributary streams where they drain to the main Wolverton bench, one upstream location on the tributary draining to the meadow and one downstream location on Wolverton Creek. These sensors will be self logging (Seabird), and we are currently evaluating telemetry options.

4. Impact of infrastructure projects

This project is a critical step in addressing the woefully inadequate observational infrastructure and understanding of mountain water balances. It provides important data for one area in the southern Sierra Nevada that is especially vulnerable to climate change (lower snow zone), but more importantly addresses broader questions of measurement strategy for larger basins and for the range as a whole. It addresses important water-balance questions, and provides data for a wide range of questions that cooperating researchers plan to address.

Broader impacts. There are at least three important broader impacts associated with this project. First, the development and deployment of an instrument cluster in the Southern Sierra will provide data and information that will both enhance the science of multiple individuals and research groups. It will also enable new science for which no adequate infrastructure currently exists. By building on the data and infrastructure already in the catchment it provides a much-needed test basin and data-rich research site for hydrology, biogeochemistry, ecology and related fields. Over 50 researchers have contributed directly to the community planning that identified the Sothern Sierra as a location for new water-balance measurement infrastructure, and most have expressed an interest in using the data when the system becomes operational.

Second, it provides for the design and evaluation of a much-needed prototype instrument, or instrument cluster, one that can then be replicated across the landscape as the community works to build large-scale environmental observatories. Instrument clusters will form the basis for observatory system design for water balance measurements; design guidance does not yet exist.

Two fluxes (precipitation and streamflow) plus snowpack storage are the main components of the Sierra Nevada water balance that are currently measured at selected locations. None of these are measured adequately for basin-scale or range-scale water-balance models or studies, and other important reservoirs (soil moisture) and fluxes (evapotranspiration, groundwater recharge/discharge) are not measured. While a single instrument cluster can only sample these water-balance measurements on the scale of only a few km^2, it provides the basis for scaling to basins on the order of 100's to 1000's of km^2.

Most of the sub-basins draining from the Sierra Nevada into the Central Valley of California and thence into the Sacramento-San Joaquin Delta are on the order of 1,000-5,000 km^2 above the mountain front. The Kaweah River is one of the smaller sub-basins (1,450 km^2), and has considerable area above treeline. It is expected that this instrument cluster will provide sufficient information to address the water balance at the scale of the Wolverton Creek basin, which is on the order of 8 km^2. It is nested within the 135 km^2 Marble Fork, which contains a second 19 km^2 well-instrumented headwater research basin, the Tokapah basin. The Tokapah basin, which lies mostly above the treeline, has been the site of continuous hydrology and biogeochemistry research since the 1980's [e.g. *Meixner et al., 2004; Sickman et al., 2003*]. Together with available lower-elevation measurements, and existing instrumentation in the Tokapah basin, addition of the Wolverton instrument cluster will offer an excellent opportunity for scaling from the Sierra Crest down toward the mountain front.

Thus the proposed instrument cluster provides both a prototype for a mountain water balance instrument cluster and also a prototype for how to deploy instrument clusters within a larger basin. The Co-I's on this proposal and other collaborators hope to eventually develop instrument clusters along both altitudinal and latitudinal transects in the Sierra Nevada, as part of a larger Sierra Nevada environmental observatory. In response to programs initiated by the Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI) (http://www.cuahsi.org/) a planning group formed in 2003 to plan a Sierra Nevada Hydrologic Observatory (SNHO; https://ucmeng.net/snri/snho). There is also an active National Ecological Observatory Network (NEON) planning group in California (http://www.caleon.org/) that plans to propose a NEON node that will include a snowline instrument cluster in the Southern Sierra Nevada.

It is proposed to broadly disseminate both the data from the proposed instrument cluster, and our experience with system operation and design. It provides a much-needed testbed for both new technology and sensor deployment. Raw, quality-checked data will be made available as soon after collection as is feasible to both the project collaborators and the broader community. Data coming into our laboratory from the field instrument cluster will undergo automatic range and continuity checks, and be made available through a digital library adapted from that initially designed by the CUAHSI Hydrologic information Systems group (http://whitney.ucmerced.edu). The same system has been implemented at the Santa Margarita Ecological Reserve in southern California. Persons using the data will also be asked to provide copies of their processed data through the digital library, at the time it is published.

We have also discussed the possibility of doing one or more instrument design workshops in cooperation with the CUAHSI Hydrologic Measurement Technology group. Future funds will be sought to hold two small workshops on site during the final year of development of the instrument cluster.

The third important broader impact of the proposed research infrastructure will be to help build both graduate and undergraduate research at UC Merced and partner institutions. This site will become a focal point for studies by UC Merced and cooperating researchers.

UC Merced has a special commitment to diversity, and we will take advantage of emerging efforts that will help recruit under-represented groups, particularly in California's San Joaquin Valley. Based on its inaugural undergraduate class, UC Merced is provisionally classified as a minority serving institution. Of the 974 students who accepted UC Merced's offer of admission for its inaugural undergraduate class (fall 2005) 47% identified themselves as first-generation college students and 23% as first-generation college students who come from families earning less than $30,000 annually.

UC Merced is also committed to recruiting graduate students from under-represented groups, and we will take advantage of those emerging efforts. Two graduate students joined R. Bales research group in fall 2004; one is Hispanic, from the San Joaquin Valley, and will pursue a Ph.D. The other is female.

As part of UC Merced's outreach efforts in the San Joaquin Valley, R. Bales, and the other UC Merced Co-I's give short research talks to groups of prospective students, community college and high school educators and many other groups. Many focus on mountain hydrology, climate and California's water resources and water quality. Being a small university, UC Merced also does frequent press releases highlighting faculty research. For example, last spring R. Bales did four follow-up press, radio and television interviews to a press release about mountain snowpack. One aim of these outreach efforts is to raise the awareness of the UC system in a population that is potentially eligible for UC admission, but is under-represented in the applicant pool. It is our experience over the past few months that including Earth and environmental science research talks in these recruiting efforts is an effective way to promote dialog, interest students in UC Merced, and encourage K-14 educators in preparing their students for a UC education. A side benefit is to raise the awareness of the participants about climate research, climate issues and related topics. Involving undergraduates in research will also contribute to retention of the students from under-represented groups that we do recruit.

Leveraging opportunities. Two important leveraging opportunities will amplify the impact of the proposed infrastructure. First, complimentary data from other activities in the Wolverton basin, from long-term research in the Tokapah basin, from satellite remote sensing, and from operational monitoring in the Kaweah basin are available. As noted above, we plan a number of sensor deployments at Wolverton this summer, which will build upon the past and ongoing long-term measurements in support of biogeochemistry and water balance studies carried out in the adjacent Tokapah basin since the mid 1980's (e.g. *Huth et al., 2004; Meixner et al., 2004; Sickman et al., 2003*). Fractional snow-covered area and albedo for the Kaweah basin will come from Moderate Resolution Imaging Spectrometer (MODIS) surface reflectance data, with products developed and delivered through our NASA-funded REASoN project, Multi-Resolution Snow Products for the Hydrologic Sciences. R. Bales is Co-I with responsibility for product applications. A limited number of LANDSAT Thematic Mapper (TM) scenes will also be available. Snow density, snow water equivalent, and additional depth measurements will come from operational snow measurement sites in the Wolverton basin and in nearby Giant Forest.

The second main opportunity comes from the research and related activities planned in the basin. It is important that operation and maintenance of the proposed instrument cluster be maintained over many years. UC Merced has a cooperative agreement with Sequoia-Kings Canyon and Yosemite National Parks for research, education and outreach in the Parks. Under this agreement UC Merced's Sierra Nevada Research Institute (SNRI) has established a year-round field station in Yosemite National Park (Wawona), and discussions are underway for both a year-round field station in Sequoia-Kings Canyon (Wilsonia) and a summer field station in

Wolverton. SNRI has just hired a Ph.D. scientist as field station manager, and it is expected that this individual will take some responsibility for managing infrastructure such as proposed for Wolverton. The presence of these field stations is already stimulating additional research by UC Merced and other scientists in the Parks. In the future, multiple and active research grants will depend on and thus help maintain the long-term continuity of the data stream from the proposed instrument cluster. In short, we are developing a site that UC Merced plans to sustain and build up as part of its commitment and mission to Sierra Nevada research.

5. Management plan

Each of the co-principal investigators has agreed to take responsibility for designing and overseeing installation of one or more components of the instrument cluster and to set up the data processing to establish a continuous, quality-controlled data stream from the system (Table 4).

On the tower, UC Merced personnel will handle routine maintenance, with annual visits by UC Irvine staff for calibration and major repairs or upgrades. To help assure continued operation of the system, backups of key equipment items will either be purchased or be available from M. Goulden's inventory. Q. Guo will work with M. Goulden in these efforts, and will eventually assume primary responsibility for the data.

Table 4. Co-I responsibilities

Tower installation: Rice, Bales
Flux tower sensors: Goulden, Guo
Embedded sensor network design: Bales, Small, Molotch, Marks
Snow sensors: Rice, Molotch
Soil moisture sensors: Hopmans, Small, Marks
Stream sensors: Conklin, Bales
Meadow water-level sensors: Conklin, Liu
Meteorological stations: Rice, Bales

R. Bales, N. Molotch and E. Small will design the embedded sensor network, building on the prototype sensor layout that they cooperated in designing and installing at Valle Caldera (New Mexico), and the prototype sensor network that R. Bales and R. Rice deployed at Gin Flat in Yosemite. The Valles Caldera system was implemented under the NSF Science and Technology Center for the Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA), centered at U. Arizona. R. Bales was deputy director of the SAHRA prior to moving to UC Merced in 2003.

Two web interfaces with different purposes will be established to distribute data. First will be access for the raw, unprocessed data, aimed mainly for internal project personnel but available to other researchers upon request. Most of these data will be available in near real time (e.g. daily) through telemetry and automatic checking and archiving. This interface will be important to track tower and sensor web operations, make adjustments and report on network performance. The second interface will be to distribute data to users, through the digital library.

Much of the first year will be devoted to system testing, with the instrument cluster being built in our lab during year 1, deployed to the field in year 2 and evaluated/revised during year 3 (Table 5).

Table 5. Schedule

Year 1	
Jul 06	Start project.
Aug 06	Refine instrument cluster design.
Sep 06	Begin bench testing/setup of prototype sensors
Oct-Dec 06	Develop and complete system design.
Jan 07	Order instrumentation and supplies.
Feb-May 07	Integrate and bench test all components and communications prior to field deployment.
May 07	Prepare detailed layout of instrument cluster
June 07	Field deployment: construct flux tower.
Year 2	
Jul-Aug 07	Field deployment: construct and instrument flux tower. Deploy instrument cluster.
Sep 07	Bring all instrumentation on-line and troubleshoot.
Oct 07-Apr 08	Monitor and perform QA/QC on data and system.
May-Jun 08	Repair and redesign system as needed.
Year 3	
Jul 08	Midcourse workshop.
Jul-Sep 08	Repair and redesign system as needed.
Oct 08-Apr 09	Monitor and perform QA/QC on data and system.
May 09	Repair and redesign system as needed.
Jun 09	Wrap-up workshop.

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