Title:	**Hydrologic Response of Sub-Alpine Wetlands to Climate Change, Tahoe Basin**
Subtheme this proposal is responding to (choose only one)	Subtheme 5a
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Hydrologic Response of Sub-Alpine Wetlands to Climate Change, Tahoe Basin

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Relevant Theme: Theme 5, subtheme a: Managing for Climate Change.

Abstract

The proposed work will evaluate potential effects of climate change on the hydrologic regime that supports the occurrence and health of groundwater-sustained sub-alpine wetlands, also known as fens. A detailed study of two fens in distinctly different geomorphologic settings will be studied over two years. Field measurements will be used to evaluate the hydrologic flow system, including inflows and outflows such as evapotranspiration. A calibrated model that links surface water and groundwater interactions (GSFLOW) will be developed to help assess the potential impact of climate change on the hydrologic budget, water levels, and water available for fen vegetation. The sensitivity of the calibrated model to measurement errors made in the field will be addressed and incorporated into the assessment of the response to climate change. This proposal addresses subthemes 5a in the Request for Proposals. Since fens can be located in close proximity to rivers, lakes or ponds, they may be part of a single meadow or a meadow complex (Cooper and Wolf, 2006). As such, a better understanding of the groundwater flow system and hydrologic budgets in these environments will also provide useful information for stream and meadow restoration (subtheme 4a). The ability of large areas of riparian vegetation to reduce nutrient and sediment loads will also be addressed in part by this proposal (subtheme 2c).

Justification Statement

Fens are groundwater-sustained, sub-alpine wetland areas characterized by the accumulation of un-decomposed organic material (i.e., peat). Fens play an important role in plant and wildlife habitat as well as water quality. The groundwater chemistry in fens can be quite different than that of surface waters and often results in unique habitat for diverse riparian vegetation and wildlife. The high organic content of the soils may also help sequester nutrients, such as nitrogen and phosphorus derived from surrounding mountain slopes (Boomer and Bedford, 2008). The high density of vegetation and deep layer of litter also helps slow the runoff of precipitation and snowmelt, thereby promoting the deposition of fine sediment.

Recently the Forest Service has initiated a program to identify and assess fens and other wetlands in the Sierra Nevada. Recent work by Stuart Osbrack and Shana Gross in the Lake Tahoe Basin has focused on identifying potential fens using a combination of aerial photographs and IKONOS remote sensing data. Consideration of the geomorphic setting of these fens may provide critical information regarding their current health and their potential response to climate change.

The transient response of groundwater flow and storage are determined by the three-dimensional distribution of hydraulic potential (e.g., groundwater levels) and the physical characteristics of the subsurface materials through which it flows (i.e., hydraulic conductivity, storage coefficient, porosity). The transient response of the groundwater system can be quite different for different geologic materials. For example, fractures in otherwise impermeable crystalline rock may transmit water quickly down gradient while providing very little storage, while low permeability clays may transmit water very slowly while providing large storage capacity. The water table and hence vegetation in two hydrologic systems may have a very different response to the timing and amount of recharge. The thermal and chemical signature of groundwater traveling through a relatively deep fracture network may be distinctly different than that of groundwater traveling through the soil mantle (Manga, 2001; Feth et al., 1964).

Climate change in the Sierra Nevada will continue to produce thinner snow packs and greater proportions of precipitation falling as rain rather than snow. Response of fens to this phenomenon will depend not only on the groundwater storage characteristics of geologic materials immediately underlying the fens, but also on groundwater flow and storage in the upland, fractured-rock aquifers. Through modern methods of monitoring hydraulic, chemical, and thermal response of groundwater in the fens, the system hydrology can be characterized and modeled (e.g., Constantz and Stonestrom, 2003; Niswonger et al., 2008). The combined use of water level, soil temperature and water temperature measurements together with modern modeling and calibration tools will produce models that are sufficiently calibrated and constrained to provide useful answers regarding future response of the systems to climate change

Problem Statement

The proposed research will address how the groundwater flow systems and hydrologic budgets associated with fens may respond to climate change. Evaluation of the health of fens and their response to changes in climate requires sufficient understanding of the groundwater flow system, including the exchange of water between mostly fractured uplands and sedimentary-fill aquifers in the lowlands. Most of the work on fens in the Sierra Nevada has been based on ecological questions (e.g. Cooper and Wolf, 2006). However, there has not been substantial study of the hydrogeologic environment that gives rise to these wetlands, particularly in upland environments. Understanding how the groundwater flow systems may respond to changes in climate is crucial to evaluating the health and stability of these important riparian areas.

Goals and Objectives

The goal of this project is to provide quantitative information regarding the response of groundwater flow systems associated with fens to climate change. This will be accomplished by collecting high quality hydrologic and geologic data and constructing well-constrained and calibrated models that help explain current system behavior while also showing how more rainfall-runoff and less snow melt will affect timing of fen groundwater storage and hence the potential for sustenance of fen vegetation and peat. The field data and model will be used together to ensure efficient and meaningful data collection.

Approach, Methodology, and Location

Location

Two fens will be selected for this study based on their geomorphic setting. The groundwater fed wetlands located on the south side of Grass Lake Research Natural Area are characteristic of a “basin fen” as defined by Cooper and Wolf (2006). The location of the second study site will be based on current work being conducted by Lake Tahoe Basin Management Botanists to identify potential fens throughout the Lake Tahoe Basin using GIS data and field verification. The second study area will be selected to represent a “sloping fen” that is characterized by the presence of groundwater flow through bedrock. Sites currently under consideration include wetlands in Third Creek, Incline Creek, or wetlands located southeast of Echo Peak.

Field Measurements

Every attempt will be made to incorporate existing data into the model development and calibration. Forest Service records on the Grass Lake Research Natural Area will be reviewed for any information pertaining to surface water and groundwater. Collaboration with Lake Tahoe Basin Management Unit (LTBMU) hydrologists, botanists, and soil scientists will be sought in order to ensure consistent and efficient collection of field data. For example, floristic variations are sensitive to water chemistry (surface vs. groundwater) and are in part controlled by the water table depth (Marini et al., 2008; Cooper, et al., 2005a). As such, existing vegetation data and/or interaction with Forest Service specialists will be used to determine the potential significance of flora to the study of groundwater in the area.

Additional field measurements will be required to properly calibrate the model. The number and types of field measurements will be based on field observations of groundwater expressions and consideration of the sensitivity of the model parameters. The specific sampling locations will be determined based on geomorphic and floristic variations within the fen. The largest component of the hydrologic budget is evapotranspiration, which we will measure with energy balance and water vapor flux methods under the guidance of UC Davis Cooperative Extension Specialist in Biometeorology, Dr. Richard Snyder.

Nested drive point piezometers will be installed to facilitate subsurface field measurements including: groundwater levels, temperature profiles, stable isotope concentrations, water pH, and ion concentrations. Solinst remote loggers ("leveloggers") will be installed in approximately 20 piezometers per study site to measure water level and temperature fluctuations. Onsight temperature probes ("Tidbits") will be installed in other piezometers to monitor temperature fluctuations. The piezometers will be sampled periodically for pH, major ion concentrations and stable isotope composition. The subsurface stratigraphy will be evaluated by hand augering.

Temperature profiles can help constrain the depth of groundwater flow and differentiate between deep fracture controlled flow and shallow flow through soil. The interaction of heat and groundwater flow is especially important to consider in mountainous regions, where high-relief terrain can enhance groundwater flow to depth where elevated temperatures are encountered (Forster and Smith, 1988a; Constantz and Stonestrom, 2003). The stable isotope concentrations will help constrain the elevation of recharge and differentiate between deep groundwater and groundwater from upland areas.

The use of precise measurements of subsurface temperature profiles can be used to help constrain models of the groundwater flow regime. Shallow subsurface waters can be 1 to 2°C warmer or cooler than mean annual air temperature due to seasonal heating and cooling of the land surface (Anderson, 2005). Figure 1 presents data collected by Jim Trask (a student and post-doc of the PI) at Big Meadows in the Lake Tahoe Basin that shows this effect clearly. Below a certain depth however, temperatures are not influenced by diurnal fluctuations and remain near the mean annual air temperature (bottom of Figure 1). As such, the temperature of groundwater may be used to differentiate between shallow groundwater and deeper groundwater. High precision measurements of the temperature profile in wells can also detect temperature inversions that result from zones of localized groundwater (figure 2). Furthermore, areas with elevated deep groundwater flow can perturb the geothermal gradient below the bottom of the well and result in offset temperature profiles. This effect can be used to detect deep groundwater flow beneath the study area (Manga, 2001).

Saturated hydraulic conductivity of surrounding soil units will be evaluated using a modified constant head permeameter developed by Woody Loftis at the Natural Resources Conservation Service. Other measurements will include: precipitation, snow surveys, air temperature, surface flow into and out of the fen, and estimates of evapotranspiration.

Field sites will be visited on a monthly basis for repairs and data collection. Monthly measurements will include: water level, water chemistry, pH, subsurface temperature profiles, and stream flows.

Numerical Modeling

GSFLOW will be used to model the hydrology of the study area. GSFLOW is a finite difference numerical model developed by the United States Geological Survey. GSFLOW is capable of modeling three-dimensional, spatially explicit groundwater and surface water interactions. GSFLOW simulates snowmelt, rainfall, runoff, infiltration, stream routing, interactions between streams and groundwater, and evapotranspiration. GSFLOW couples the Precipitation-Runoff Modeling System (PRMS) with the Modular Ground-Water Flow Model (MODFLOW-2005), both USGS programs (Markstrom, et al., 2008). The model and documentation can be found on the USGS website: http://water.usgs.gov/nrp/gwsoftware/gsflow/gsflow.html.

MT3DMS was developed to interface directly with MODFLOW, and hence GSFLOW. MT3DMS is capable of simulating heat and mass transport based on the results of the GSFLOW model. (Although MT3DMS is for modeling solute transport, its equations are fuctionally the same as the saturated groundwater and heat flow equations, so the code can also be used to model heat flow in groundwater.) A conceptual model will be developed using MT3DMS to explore the thermal aspects of groundwater flow at the study sites. A sensitivity analysis will be conducted using UCODE to evaluate the interplay between recharge in the surrounding uplands, the depth of groundwater circulation, and the temperature profiles in the fen. This conceptual model will be used to enhance data collection and characterize the groundwater flow regime.

A preliminary model will be developed using existing digital elevation data, soils maps, geologic maps, climate data from nearby weather stations, and estimates of evapotranspiration from the Lake Tahoe region. Measurements of stream flow made by Norman and Parsons (1997) will be used during the initial sensitivity analysis of the model. The sensitivity analysis will be done using the inverse modeling code, UCODE (Poeter and Hill, 1999; Hill and Tiedeman, 2007). Through an iterative process, UCODE provides a statistically based assessment of how well the model fits observations for a given set of model parameters. UCODE provides a framework to quantitatively evaluate the sensitivity of a complex model to various parameters and provides valuable information for effective data collection. Field data will be incorporated into the model as it becomes available and the data collection needs will be evaluated regularly to ensure effective data collection.

Strategies for Engaging with Managers

This project will involve interaction with Shana Gross and Stuart Osbrack, the Botanists currently working on the fen inventory in the Lake Tahoe Basin. The PI and the graduate student executing the research plan, Wes Christensen, will join them for field visits to several fens to discuss the floristic and geomorphologic variations between sites. Frequent feedback regarding their findings and the hydrologic data from this project will help inform both projects. A field visit by interested land managers and other personnel will be coordinated through Shana Gross and Stuart Osbrack once the installation of the sites is complete and applicable data is available.

Deliverables

This project will provide a rich hydrologic data set for two fens in the Lake Tahoe Basin, including the Grass Lake Research Natural Area. The data will be summarized in a concise report written in a style that is intelligible to an informed reader and not restricted to specialists. Suggestions from hydrologists, botanists, and soil scientists from various agencies will be considered to ensure the information is clearly presented.

A three-dimensional model for groundwater and surface water interaction will be developed for these sites. The model will be calibrated using field observations of the physical parameters of the system, as well as the response of the system to variations in the timing and amount of precipitation. The calibrated model will be used to predict the response of these systems to changes in the timing and amount of precipitation. Although no model predictions are ever guaranteed, quantitative model statistics will be generated using UCODE in order to evaluate the validity of these predictions. The model predictions and accompanying statistics will be presented in a concise report that is intended for the informed reader, yet not restricted to specialists.

Table 1: Schedule of work.

Milestone/Deliverables	Start Date	End Date	Description
Submit quarterly reports and/or presentations	June 2009	January 2011	Submit brief progress report to Tahoe Science Program coordinator by the 1st of July, October, January, and April.
Install field equipment	Summer 2009	Summer 2009	Install piezometers, rain gauges, temperature sensors, and other equipment
Preliminary model development	December 2008	June 2009	Use existing data to develop and calibrate a preliminary 3D GSFLOW model for sensitivity analysis
Install field equipment	July 2009	October 2009	Install and maintain additional equipment as necessary based on sensitivity analysis
Calibrate model	October 2009	June 2010	Use field data to recalibrate the model based on physical parameters and the systems response to precipitation events
Remove field equipment (?)	October 2010		If no further use of the equipment is identified
Final report	June 2010	January 2011	The final report will be submitted and a presentation will be made if requested

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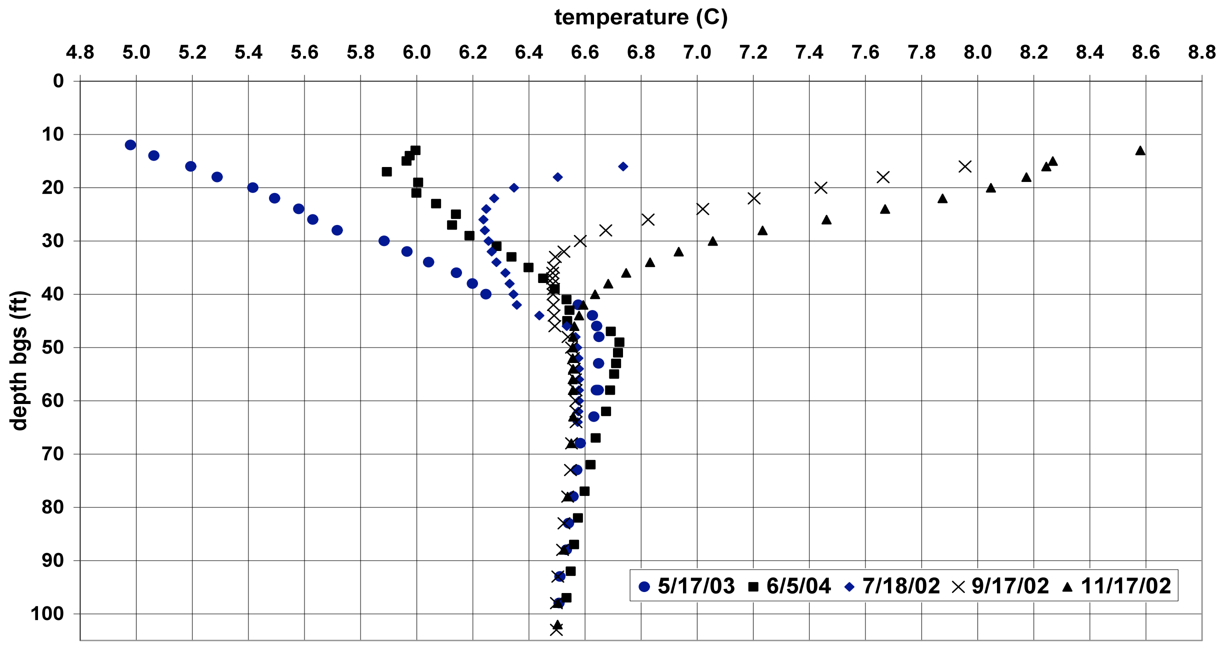

Figure 1: Temperature profiles with depth recorded at Big Meadows, Lake Tahoe Basin, CA. The affect of seasonal heating and cooling can be clearly seen.

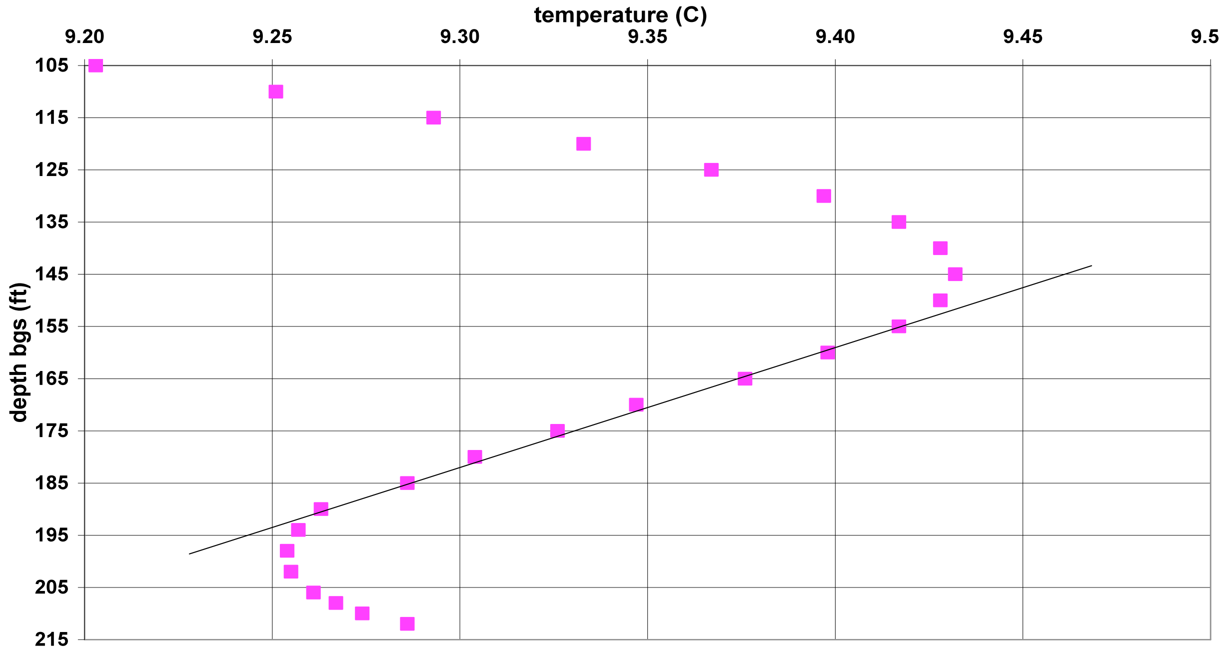

Figure 2: Temperature profile from a well in Christmas Valley, Lake Tahoe Basin, CA. The inflow of cooler water at depth results in the deflection of the thermal profile.