CALFED BAY-DELTA PROGRAM

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In cooperation with the

California Sea Grant College Program

FELLOWSHIP APPLICATION COVER PAGE

APPLICANT TYPE [X] Postdoctoral Researcher [ ] Ph.D. Graduate Student

PROJECT NUMBER ____________

PROJECT TITLE Investigating the Frequency and Magnitude of Floods in the Sacramento-San Joaquin Valleys under Changing Climate

FINANCIAL SUMMARY

First Year CALFED Funds Requested: 63,045

Total CALFED Funds Requested: 123,269

Duration: 2 years

Proposed Start/Completion Dates: 10/1/08 - 9/30/10

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Will animal subjects be used? [ ] Yes [X] No

APPROVAL DATE: ____________ PROTOCOL #: ____________ PENDING: ____________

Does this application involve any recombinant DNA technology or research? [ ] Yes [X] No

Investigating the Frequency and Magnitude of Floods in the Sacramento-San Joaquin Valleys under Changing Climate

A proposal to the CALFED Postdoctoral Research Program,

Dr. Tapash Das
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1. **Introduction/ Question/ Objectives**:

Natural calamities like flood continue to cause immense damages to the human society (for example, fiscal year 2003 in US the total estimated flood damage was almost $2.5 billion; Pielke et al. 2002). Pielke and Downton (2000) found an increasing trend over the past century in the flood damage. California suffered the second greatest damage in their early period of study (fiscal years 1955 to 1978), following only Pennsylvania. In their later period, fiscal years 1983 to 1999, the flood damage in Pennsylvania fell to 26th position, but the flood damage in California stayed in third place (Pielke et al. 2002). In California, most of the large historical floods have arisen from two general classes of mechanisms (Roos, 1997; 2006), including (i) winter general floods (covering a large area) and (ii) spring and early summer snowmelt floods (mostly from the higher elevation central and southern Sierra Nevada). The largest winter floods have historically been most catastrophic. For example, flood in 1997 caused billions of dollars in damages and was caused by a classic orographic event, with warm and moist winds from the southwest passing across the Sierra Nevada, and there was large amount of rain at the middle and high elevations (Roos, 1997). Floods in California are linked to winter-spring atmospheric circulation (Cayan and Riddle, 1992). The extremely largest floods are most probably associated with atmospheric rivers (Dettinger, 2004; Ralph et al. 2006; Neiman et al. 2008). These influences, and hence the floods they produce, are quite likely to be amplified in the coming decades as climate becomes warmer, which is projected by virtually all global climate models.

California has a long history of being challenged by floods. Considering these challenges and the tightening of water-supply options in the State, the California Water Plan Update 2005 finally identified integrated flood management actions as a crucial part of improved water supply management (DWR, 2005). Of more immediate concern here, CALFED must address flood mechanisms, frequencies and magnitudes to achieve its primary objectives: Most succinctly, floods are a long-term and continuing threat to levee stability and stabilization; future water supplies can be threatened severely by major levee-failure disruptions of the Delta, even as changing streamflow timings are likely to pit flood management increasingly against warm-season water reserves; potential flood-induced Delta disruptions threaten the Delta through threats specifically to its water quality; and we are increasingly aware that floods and floodplains will play a fundamental role in Bay-Delta ecosystem restorations. Thus, informed water-supply and ecosystem-restoration decision making will require both a better understanding of the primary causes of observed flood frequency changes and reliable projections of future flood statistics.

Many studies have documented recent changes in hydro-meteorological variables across the western United States (US). The main changes observed include a large increase of winter and spring temperatures (Dettinger and Cayan, 1995; Bonfils et al. 2008), a substantial decline in the volumes of snow pack in low and middle latitudes (Lettenmaier and Gan, 1990; Dettinger et al.

2004; Knowles and Cayan, 2004; Hamlet et al. 2005), a significant decline in April 1st snow water equivalent (SWE) (Mote, 2003; Mote et al. 2005; Mote, 2006; Mote et al. 2008), and a reduction in March snow cover extent (Groisman et al. 2004). A shift toward more rainfall and less snowfall has also been observed (Knowles et al. 2006), as well as an earlier streamflow from snow dominated basins (Dettinger and Cayan, 1995; Cayan et al. 2001; Stewart et al. 2005; Regonda et al. 2005; Peterson et al. 2008), and a sizeable increase of winter streamflows as fractions of water-year totals (Dettinger and Cayan, 1995; Stewart et al. 2005). In accordance with these changes, model simulations show that winter runoff also occurs earlier in the year (Hamlet et al. 2006). Recently Barnett et al. (2008) performed a formal multiple variable detection and attribution study and showed how the changes over the mountainous regions of the western US in minimum temperature, SWE as a fraction of precipitation and center timing of streamflow for the period 1950-1999 co-vary. They concluded, with a high statistical significance, that up to 60% of the recent trends in those variables have been human-related and temperature related. In response to projected continuing anthropogenic increases in greenhouse-gas emissions into the atmosphere, the 21st Century temperature rise in California is expected range between +2^{o}C and +6^{o}C more by end of century. There is much less consensus regarding either the sign or magnitude of the attendant changes in precipitation patterns (Cayan et al. 2008a). Cayan et al. (2008b) noted that the changes in climate due to rise in atmospheric concentration of greenhouse gases might pose serious risks to California's health, economy and environment.

By now, quite a few studies have been performed to investigate the potential impact of continuations of these climate changes to California hydrology (for example, Lettenmaier and Gan, 1990; Wilby and Dettinger, 2000; Knowles and Cayan, 2002; Dettinger et al. 2004; Hayhoe et al. 2004; Maurer and Duffy, 2005; Maurer, 2007). In California, water is stored as snow in winter and starts to melt during late spring and early summer. Given all of the observed and predicted hydrologic changes across the Western US, it is reasonable to wonder whether there could be changes in the frequencies and magnitudes of floods. Hamlet and Lettenmaier (2007) identified increased flood risk tendency in warmer transient basins along the coast in Washington, Oregon and California using the precipitation and temperature data for the 20th century in combination with a hydrological model. The magnitude of 100-year floods estimated from the historical period is found smaller than the recent observed floods, suggesting that either the observed data considered to compute the 100-year floods is too short or that the changes associated with climate change (DWR, 2005; 2007). That is, there are larger flood inundations by the recent floods than were expected by the designed floodplain mapping (DWR, 2005; 2007). Furthermore, Anderson et al. (2006) confirmed the increasing trend in the magnitude of 100-year floods in six rivers in California. Dettinger et al (2004) evaluated future flood risks in specific California basins and found increased risks from warming alone. Thus it is useful to investigate how the extremes are likely to change under future climate as they will have impacts on water resources management, the environment and the ecology of the region. The estimation of potential changes in the frequency and magnitude of extreme events is important because this kind of events cause large scale damage and human sufferings. Miller et al. (2003) found increased likelihood of more floods in California under climate change. However in-depth evaluations of potential flood risks in California under changing climate have not been performed within a systematic framework. Milly et al. (2008) argued "now is an opportune moment to update the analytic strategies used for planning such grand investments under an uncertain and changing climate."

A preliminary analysis, already been started at Scripps Institution of Oceanography by the author and his colleagues as an outgrowth of the detection-and-attribution studies of Barnett et al. (2008). In particular, this is part of a more spatially detailed evaluation of where and when hydrologic trends can be detected in a variety of hydrologic variables across the western mountains. A comparison is being made of simulated daily streamflow extremes for seven California Rivers for the retrospective observational time period water years 1950 to 1999 with extreme flows from a very long-term control simulation of natural climate variability. As in the real world, most of the floods in California's Northern Sierra Nevada (NSN) have occurred from November to March (Fig. 1a). The largest floods occur during the winter (DJF), corresponding to events associated with the influence of an unusually strong Pacific jet that transports moisture and warm temperatures to the western US during days of accentuated low-pressure systems over western Canada and the Pacific cost (Fig. 2; see also Cayan and Riddle, 1992; Pandey et al. 1999; Ralph et al. 2006). There are two different kinds of floods in the Southern Sierra Nevada (SSN) according to whether it rains or not during the days of the flood (Fig. 1b). Thus there are "wet" or precipitation-dominated floods and "dry" or snowmelt-dominated floods. As in the NSN, the largest floods occur during the winter (DJF), corresponding to wet-day floods associated with the influence of the Pacific jet. Notably there are preliminary indications of a positive trend in the frequency of spring (MAM) flood events in the NSN. These results need to be explored more fully and then placed in context of long-term projected climate changes, as proposed here.

The goal of the proposed research is to investigate how extreme precipitation and flood events in model-simulated streamflows change under future climate scenarios in the Sacramento-San Joaquin Valleys. The results of the proposed project would provide important information on the potential floods under changing climate in the Sacramento-San Joaquin Valleys, which could guide CALFED management actions. The proposed research will address the following research questions:

- (i) To what extent do simulated flood statistics emulate historical observations?
- (ii) How and why do extreme events of simulated streamflows change under current projections of future climate?
- (iii) How does uncertainty in the GCM model results impact the extreme events statistics?
- (iv) How do uncertainties in hydrological model formulations influence extremes streamflow statistics?
- (v) To what extent are projected changes in flood frequencies and magnitudes being indicated in historical observations? How large would the changes need to be recognized as such?

We will investigate the physical mechanisms of the extreme streamflows (for example, which conditions of precipitation, temperature and antecedent watershed conditions enhance the extreme streamflow events).

2. **Approach/Plan of Work**:

2.1 **Tools:**

There are four tools at the core in the proposed research project: (a) historical records of extreme flows, (b) global climate models, (c) downscaling of climate models data, and (d) hydrological models. Fig. 3 shows a schematic diagram of the work flow which will be utilized to estimate changes in projected floods statistics. Each of the components is described below.

2.1.1 **Historical records**:

The historical records of extreme flows from the Sierra Nevada will be analyzed along with the climate conditions that gave rise to them. Observed records, dating back to at least 1948, of daily streamflows, temperaure, precipitation, humidity and atmospheric circulation will be employed. To the extent that records are available, observations from the pre-1948 period will also be included in order to increase the sample size and investigate key mechanisms. The observations will be used to describe the individual flood conditions—their intensity, duration, spatial extent and evolution. Conditions leading up to the floods, sometimes months prior to their occurrence will be examined. The observations will also be used for validation of simulated processes and changes, to better understand the particular vulnerabilities of California's flood regimes to climate change, for evaluations of basin-to-basin differences, and for estimation of future flood statistics, including illustrative examples of future flood-recurrence curves.

2.1.2 **Global climate models**:

Climate change projections for the 21st century will be obtained from coupled ocean-atmosphere GCM models. Dettinger (2005) favored to applying multiple GCM models for climate change studies. The author pointed out that uncertainties associated with future greenhouse-gas emissions are comparable with the differences among climate models, so that neither source of uncertainties should be neglected or underrepresented. Maurer (2007) observed some important differences in impacts of climate change (using two emissions scenarios A2 and B1 from 11 GCMs) on future low streamflows, water stored as snow pack, and the shift to earlier streamflow timing in the Sierra-Nevada watershed. In the proposed research, multiple GCM models will be used so that results will capture and describe some of the range of uncertainties in current GCM climate projections.

The El Nino-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) have important influences on the variability of California climate. The selection of the global models will be guided by several different factors, including having a good representation of typical patterns of ENSO and PDO and realistic representation of mean climate and its decadal variability over California. Another selection criterion will be the availability of daily precipitation and temperature data required to set up hydrological models to simulate future floods. The initial choices of the GCM models are CNRM-CM3 (Center National Weather Research, France), GFDL-CM2.1 (Geophysical Fluid Dynamics Laboratory, USA), NCAR-PCM1 (National Center for Atmospheric Research, USA), MPI-OM ECHAM5 (Max Planck Institute for Meteorology, Germany) and CSIRO Mk3.0 (Commonwealth Scientific and Industrial Research Organization, Australia); however the choices might be changed in time if availability changes and after more detailed evaluations.

Three greenhouse gas emissions scenarios will be employed (Cayan et al. 2008a), which represent a range of socioeconomic developments and associated emission rates, run under the recent Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment (IPCC, 2007). The emissions scenarios that will be used are (i) a lower emissions scenario SRES (Special Report on Emission Scenarios) B1, (ii) a medium-high emissions scenario SRES A2, and (iii) a higher emissions scenario SRES A1fi (whenever available in the selected GCM model) will be used. The A2 emissions scenario represents a differentiated world in which economic growth is uneven and the income gap remains large between now-industrialized and developing parts of the world; people, ideas, and capital are less mobile so that technology diffuses more slowly (in this scenario atmospheric CO_2 concentrations reach to about 850 ppm in the year 2100). The B1 emissions scenario presents a future with a high level of environmental and social consciousness combined with a globally coherent approach to a more sustainable development (in this scenario atmospheric CO_2 concentrations reach to about 550 ppm in the year 2100). The A1fi emissions scenario represents a future in which fossil-fuel, coal, oil, and gas will continue to govern the energy supply for the projected future (CO_2 concentrations reach to approximately 970 ppm in the year 2100 in this scenario).

2.1.3 **Downscaling of climate models data**:

Current GCMs simulate climate at coarse spatial resolutions (200-500 km); therefore they are unable to resolve climate variations at much finer resolutions (Maurer, 2007). The effect of fine-scale complex orography on precipitation and temperature cannot be adequately represented in coarse-resolution global climate models. Thus the coarse resolution outputs are not used directly for basin scale hydrological studies in California, where topography is very complex.

Downscaling methods are used to obtain local-scale surface weather from the regional-scale atmospheric variables that are provided by GCM. There are different techniques available to downscale large scale GCM data to fine spatial scales of interest, including statistical and dynamical downscaling methods (Wilby and Wigley, 1997; Pandey et al. 2000; Wilby and Dettinger, 2000; Snyder et al, 2002; Wood et al. 2004; Kim, 2005; Maurer, 2007; Hidalgo et al. 2008; Maurer and Hidalgo, 2008).

In the proposed study, we will apply a statistical downscaling technique, constructed analogues (CA, Hidalgo et al. 2008) to transform data from global models to the small spatial scale needed by the hydrological models. The CA method is an analogue-based statistical downscaling approach described in detail in Hidalgo et al. (2008). The method will be used to obtain daily precipitation, maximum temperature and minimum temperature at the fine spatial scales needed by the hydrological models. In the proposed study, daily GCM data will be downscaled using CA as opposed to use monthly GCM data in Miller et al. (2003) and Anderson et al. (2006). This will allow characterization of day-to-day variability, important for estimating floods frequency.

2.1.4 **Hydrological models**:

The core task in this study is simulation of likely changes in flood statistics in the 21st century. We will apply two hydrological models using the downscaled data coming from GCM to simulate daily streamflows that then will provide a basis for estimation of future flood frequency and magnitude. Considering uncertainties in hydrological model formulations, we propose to use two different hydrological models, the Variable Infiltration Capacity Model (VIC) and the Bay-Delta Watershed Model (BDWM), in this study.

a. **Variable Infiltration Capacity Model**
VIC is a distributed macro-scale hydrological model originally developed at the University of Washington and Princeton (Liang et al. 1994). It uses a tiled representation of the land surface

within each model grid cell and allows sub-grid variability in topography, infiltration and land surface vegetation classes (Maurer et al. 2002). The sub-surfaces are modeled using three soil layers with different thickness. Surface runoff uses an infiltration formulation based on the Xinanjiang model (Wood et al. 1992), while base flow follows the ARNO model (Liang et al. 1994). Sub-grid variability in soil moisture storage capacity is represented through the use of a spatial probability distribution function, and a nonlinear recession function is used to model the baseflow component from the lowest soil layer (Liang et al. 1994). The model's soil moisture simulations are in reasonable agreement with the few point measurements available, and VIC simulated streamflow validates well with observations when the model has been calibrated using streamflow data, giving us confidence that VIC results provides a useful depiction of hydrologic variability and change.

The downscaled precipitation, maximum temperature, minimum temperature and climatological wind speed will be used as primary inputs to VIC. A number of variables, including runoff, baseflow, soil moisture at three soil layers and SWE will be produced. The VIC simulated runoff and baseflow will be routed using a procedure described in Lohmann et al. (1996) to obtain model simulated streamflows in the 21st century.

b. **Bay-Delta Watershed Model**

BDWM is a physically based distributed model which simulates dominant components of the hydrological cycle over all of California (Knowles, 2000; Knowles and Cayan, 2002; 2004). The model simulates snow accumulation, evolution and ablation using the Utah Energy Balance Snow Accumulation and Melt model described in Tarboton and Luce (1996). The BDWM model has two vertical soil layers for each model computation grids. The river routing component integrates streamflow from throughout the watershed to generate total outflow (Knowles, 2000). The important feature of the BDWM is that the model parameters can be determined from considerations of catchment physiographic characteristics (for example, soil properties, land cover, and topography) with minimal calibration effort and the process calculation is computationally inexpensive. Thus this model is well suited for climate change scenarios studies (Knowles and Cayan, 2002; 2004). As in VIC, the downscaled precipitation, maximum temperature and minimum temperature from different climate scenarios data will be used as input to the BDWM to obtain future floods. BDWM has been applied successfully in the Sacramento-San Joaquin valleys for several purposes, including climate change studies (Knowles 2000; Knowles and Cayan, 2002; 2004).

2.2 Tasks:

In this study, we will go through the following steps, utilizing the core tools described earlier, to accomplish the proposed research questions.

a. Historical evaluations and model validations: We will compile the observed streamflows from multiple locations of the Sacramento-San Joaquin Valleys and will describe mechanisms using guidance from prior studies (e.g. Weaver, 1962; Neiman et al. 2008) and evaluate extreme streamflows statistics. As our aim is to examine future extreme streamflows statistics, we will evaluate how well simulated extreme streamflows are captured by VIC and BDWM from the retrospective model runs. The application of two hydrological models (VIC and BDWM) will provide information on the uncertainty in the hydrological model simulations (capability to capture extreme streamflows) due to uncertainty in model formulations. Observed flood characteristics and statistics will also provide a basis for ground-truthing flood-process results at basin by basin levels.

b. Evaluations of downscaling and hydrologic-model uncertainties: The daily precipitation, maximum temperature and minimum temperature from GCM simulations with historical greenhouse gas concentrations will be downscaled using the CA method to a spatial resolution needed by the hydrological models.

   i. As a part of evaluation of how well extremes are captured by the downscaled method (CA method), we will compare extreme precipitation events emerging from applications of the CA method to GCM-scale NCEP/NCAR Reanalyzed (observational) data fields (Kalnay et al. 1996) with observed precipitation at key locations and weather stations.
   ii. The downscaled variables will be used as input to hydrological models. The simulated streamflows will be used to estimate the floods frequency statistics.
   iii. The extreme streamflows statistics obtained using the historical climate simulations will be evaluated and compared with the statistics developed from hydrological-model runs forced by actual weather observations.

c. Projections of future floods, with uncertainties: To obtain the future floods statistics, the three greenhouse gas emissions scenarios (i) SRES B1, (ii) SRES A2, and (iii) SRES A1fi (whenever available in the selected GCM model) will be downscaled. The downscaled variables will be used as input to hydrological models to obtain a future flood statistics. The use of multiple GCM simulations will provide an important understanding to the uncertainty in the GCM simulations.

d. Evaluation and interpretation of results: The simulated changes in flood characteristics (seasonality, magnitudes, locations) and statistics will be analyzed in key basins, in key altitude ranges, and in terms of atmospheric circulation patterns and mechanisms and simulated water and energy budgets, in order to evaluate the mechanisms that are causing the changes. Where necessary to understand the relative roles of various processes, additional simulations with arbitrary changes to inputs or model parameters will be made, to best understand the simulation results.

e. Results of this research will be presented at the CALFED Science Conference and other science venues in a suitable format (poster or oral). Approaches to evaluating and presenting the projected flood-statistic changes will be coordinated with the Community Mentors. One or more journal articles describing the research results will be prepared, including most likely an article for the online journal, San Francisco Estuary and Watershed Science.

A schedule for meeting the objectives during the requested time period of support is depicted in the time lines of Fig. 4.

3. **Output/Anticipated Products and/or Benefits**:

In the first year we will select and downscale the majority of the GCM runs. We will set up two hydrological models (VIC, and BDWM). We will compute and compare floods statistics from observed streamflows, model simulated streamflows using observed-meteorology runs and downscaled historical-condition GCM runs. We will develop an Internet website to disseminate our results to the interested public.

The downscaling of the rest of the greenhouse gas emissions scenarios from selected GCM will be carried out in the second year. The downscaled data will be evaluated and used to estimate future floods statistics. We expect to develop future floods frequency curves which will be valuable for engineering purposes and to evaluate the dominant sensitivities that result in the changed statistics for California.

My research interests are land surface modeling, climate variability and climate change studies. I have experience in land surface modeling from my doctoral study. Presently I am enhancing this knowledge and expanding my experience as a postgraduate researcher at Scripps Institution of Oceanography, UC San Diego. I believe the proposed project will provide an excellent opportunity to establish a body of knowledge that is relevant to CALFED objectives (see below). My research mentors, Drs. Michael Dettinger (U.S. Geological Survey/Scripps Institution of Oceanography) and Daniel R. Cayan (Scripps Institution of Oceanography/U.S. Geological Survey) are established hydrologists and climatologists, respectively, with commanding knowledge in regional and larger scale water resources and climate change studies. An external collaborator, Dr. Noah Knowles, of the US Geological Survey in Menlo Park has also expressed interest in this project and will provide guidance in some key hydrologic modeling elements. Their knowledge and experience of the Sierra Nevada will be invaluable assets for my proposed research. Also, the discussions with my community mentors, Dr. Michael Anderson (State Climatologist at Department of Water Resources, Division of Flood Management) and Mr. John T. Andrew (Department of Water Resources) will be invaluable to put the results of the proposed research into their most useful contexts.

The proposed research is relevant to CALFED's mission and objectives. Specifically the proposed research is related to:

a. Levee Stabilization:

i. The Delta Vision Task force has lain out a vision of the Delta with different levee systems (and responses to floods) in different areas: armored levees where inundation is unacceptable (e.g., urban areas), overtoppable levees where occasional flooding is acceptable or even useful (e.g., agricultural areas), abandoned, or breached levees where ecosystems will benefit. CALFED will need to know how to design and operate this, with better knowledge of future flood patterns, frequencies, and risks.

ii. Levees historically have breached during floods or flood prone seasons, so that any plans for levee stabilization will ultimately depend on best information about flood statistics, especially changes in flood statistics.

b. Ecosystem restoration:

i. Native Delta ecosystem and species are adapted to flourish when currents, salinities, and floodplain inundations vary widely in time and space. As a result, CALFED approaches towards ecosystem restoration are leaning more and more towards harnessing extreme events, tides, geomorphic engineering, etc, to favor or allow such variations to more closely approximate natural ranges as part of restoration.

ii. Many invasive species are better suited to heavily managed flows, quality and temperatures than are native species.

iii. Occasional floods may play a central role in the developing strategies for ecosystem restoration in the Delta. Thus flood management may prove to be as important for ecosystem restoration as for other goals.

c. Water supply:

i. Water supply reservoirs are also used for flood control for half of the year. Thus changing flood frequencies pose significant operational challenges to the California's water supply system.

ii. The Central Valley was home to large and widespread floods in the past but people have gotten used to living right out on the floodplains; now floods of historical magnitudes could cause huge property (and human life) loses.

iii. Disruption of multiple levees and flooding of Delta islands during floods (for example, Florsheim and Dettinger, 2007) would threaten to change the hydrodynamics and water quality of the Delta in ways that could stop water supply exports for many months at a time. Thus planning for floods and their mitigation are key to sustaining or improving water supply reliability.

d. Water quality:

i. The potentially catastrophic impact of future floods on levees and the Delta islands and thus on the State’s water supplies arise because of the impact such a catastrophe would have on the water quality in the Delta (by allowing much more sea water much deeper into the Delta).

ii. The interactions between flood flows and sea level rise will play a crucial role in determining the extent, duration, and frequency of freshwater extremes in the Delta, episodes best suited for extraction of high quality waters for export to water users elsewhere.

iii. Overall water quality of the Delta depended on occasional flushing of brackish waters and various wastes, nutrients and other chemicals from the channels and surroundings by major freshwater floods. Targets for water quality restoration in the Delta may ultimately depend on the future of floods there.

(a) Northern Sierra Nevada (b) Southern Sierra Nevada

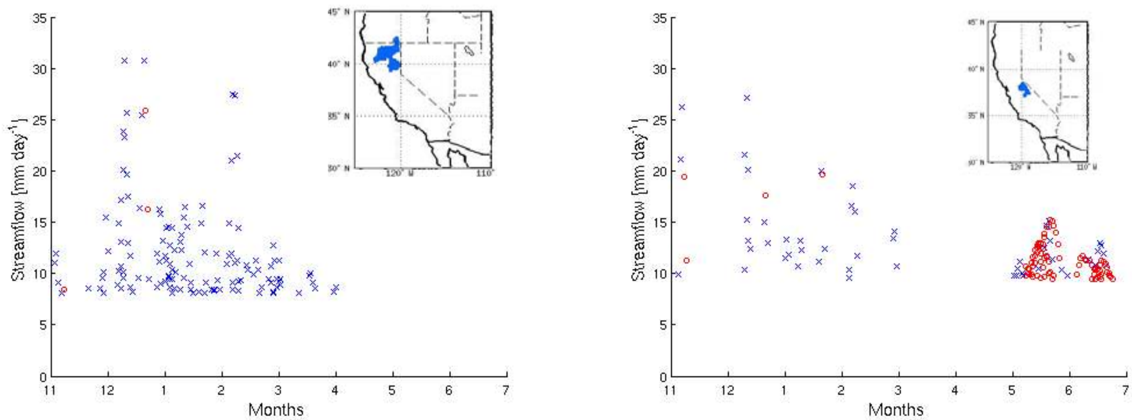

Fig. 1 Floods in California's Northern Sierra Nevada (a) and Southern Sierra Nevada (b). In the figures “X” symbols are precipitation-driven floods and red circles indicate snowmelt driven floods. The basin contributing areas are also shown.

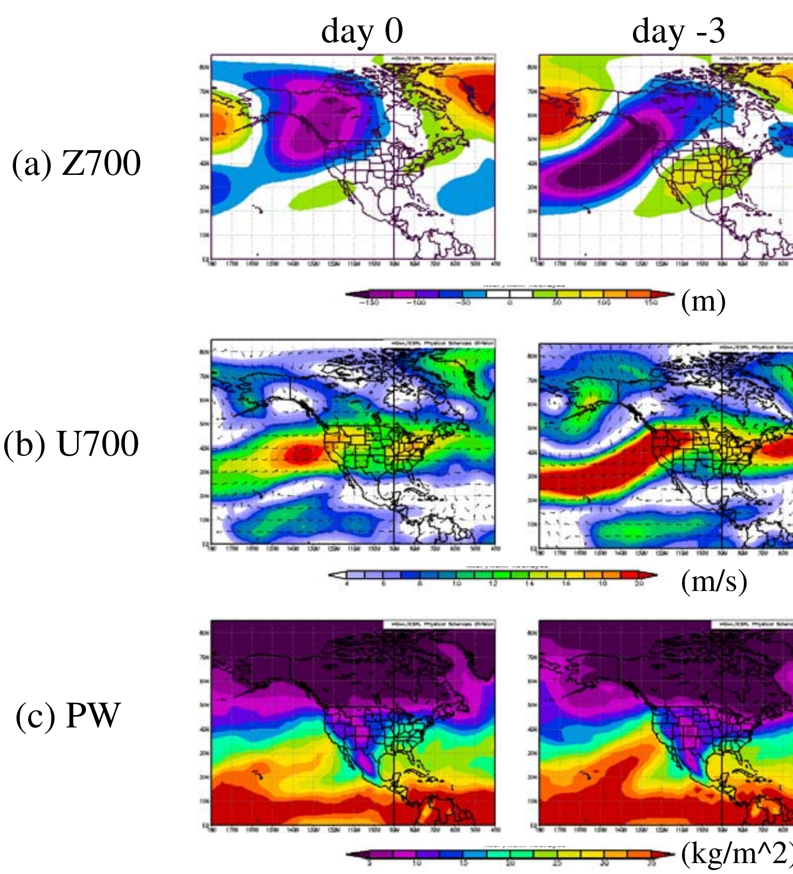

Fig. 2 Composites of the 10 most extreme streamflow events occurring in DJF for the Northern Sierra Nevada: 700 hPa geopotential hight anomalies (Z700) (a), 700 hPa mean wind speed (U700) (b), and mean surface precipitable water (PW) (c). In the figures, day 0 indicates the day of the flood event and day -3 indicates three days before of the event. Figures created using tool from NOAA's Climate Diagnostics Center.

Fig. 3 Future floods statistics (uncertainty from GCM models and hydrological model formulations)

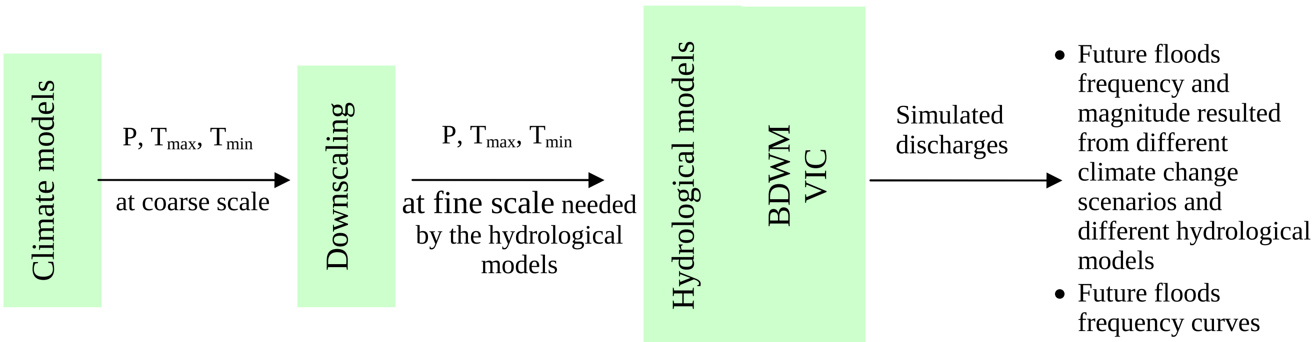

Fig. 4 Approximate time plan to carry out the major tasks

Tasks	2008	2009				2010		
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS
Setup VIC/BDWM	■	■						
GCM models selection	■							
Historical floods characteristics		■	■	■				
GCM downscaling		■	■	■	■			
Future floods characteristics					■	■	■	■
Manuscript preparation and submission								■

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