Annual impact of climate change in Upper Merced basin, CA

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INTRODUCTION:

During 2012 water year, the California Department of Water Resources conducted snow surveys that revealed less than normal snow amounts and continuing dry conditions. As a result, the DWR reduced the State Water Project allocation of water for more than 25 million Californians and over nearly a million acre-feet of farmland.

Like for California, snowpack is of special concern for many other states in the west since it provides a natural "frozen reservoir" that stores the water that will eventually be used during dry, warm weather months. With such importance, numerous studies on long term April 1st snow water equivalent (SWE) (Mote , 2003) have found declining trends which is influenced mainly by warming temperatures. Taking the analysis one step further, Howat and Tulacyzk, 2005 included the effect of elevation and conducted a similar study in California and found that at stations above 2300 meters, April 1st SWE increased by an average of 12% while stations below 2300 meters saw Apr 1st SWE decreasing by an average of 13%.

Based on the results found in these previous studies examining snowpack, this study attempts to assess streamflow response due to climate change in a Sierra Nevada mountainous watershed.

METHODS:

Study Area

This research was carried out in the 5,253 km² Upper Merced watershed in the Sierra Nevada Mountains of California. The elevation of the watershed highly varies from 17 m at the outlet to 3,979 m at the top and about two third of the watershed lies within 17 and 1,500 m. Land cover is mostly dominated by forest areas with vegetation cover consists of 41% evergreen forests, 28% rangeland, and 16% of grasslands. (Fig. 1).

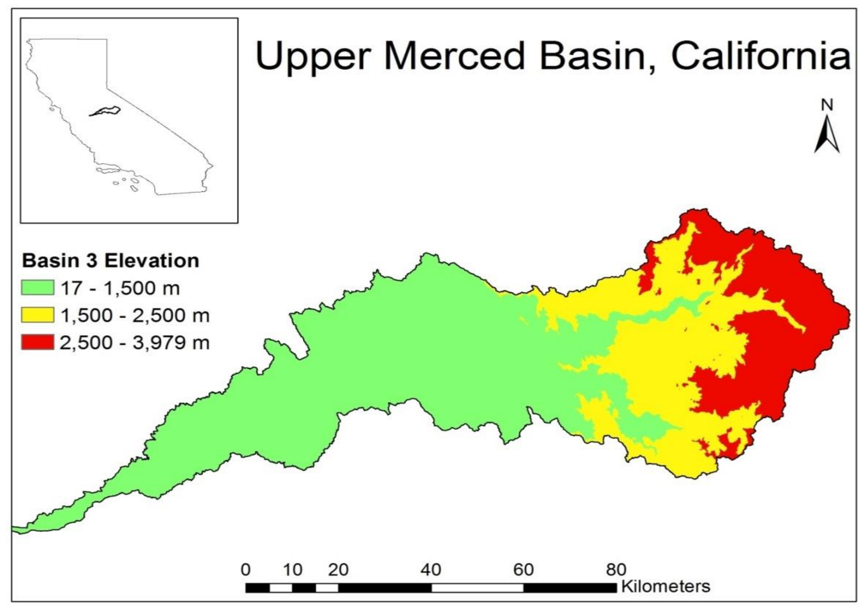

Figure 1. Upper Merced watershed in California

Model

The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) is a physically based continuous, long-term, distributed-parameter watershed scale simulation model. The model subdivides overall watershed into sub watersheds that are connected with the river network.

Table 1. Data and sources

Data Type	Data Sources	Scale	Description
DEM	USGS	Grid cell (100 m)	Elevation
Land Use	USGS	Grid cell (100 m)	Classifies land use as forest, water, etc.
Soil	NRCS	Vector	Classifies soil's physical properties
Weather	NCDC	-	Precipitation and temperature
Streamflow	USGS	-	Streamflow discharge

Data

Each subbasin is divided into hydrologic response units (HRUs) each representing a unique combination of land use, soil properties and slope. SWAT model has been used in several mountainous watersheds to simulate streamflow from snowmelt. In this study SWAT is applied at the Upper Merced watershed to study spatial variations in snowpack and snowmelt and potential changes in streamflow with change in future precipitation and temperature peak values. The model was simulated from Oct 2003 to Sep 2011 period.

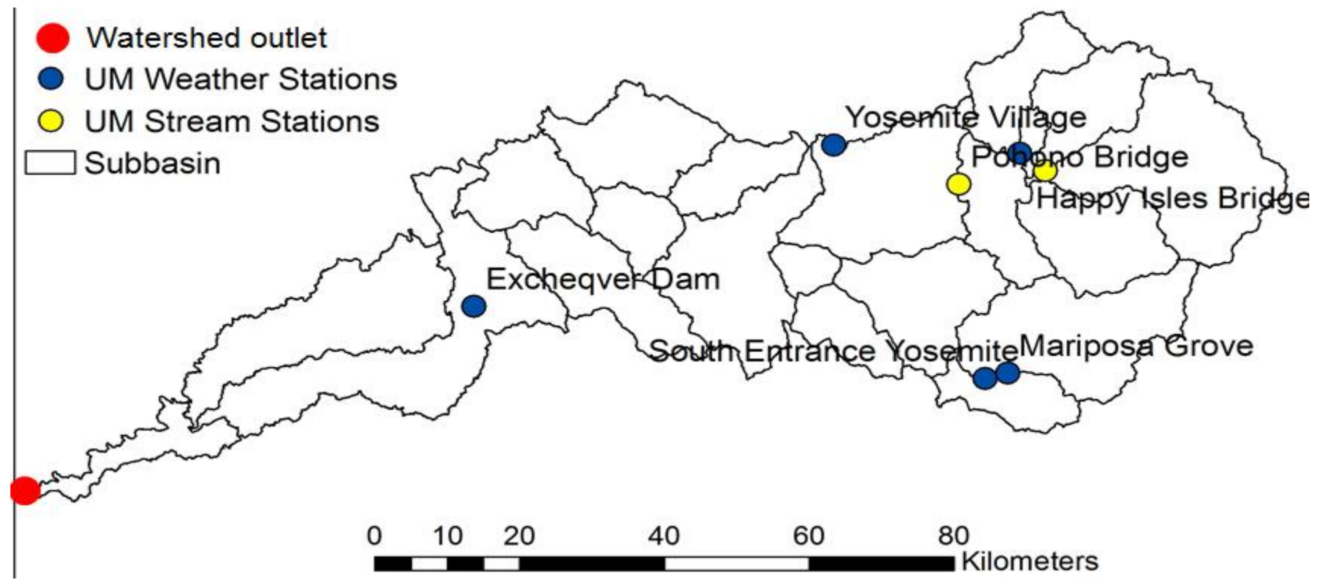

Figure 2. Weather stations and stream gauge location map

CALIBRATION:

The model parameters are calibrated by Sequential Uncertainty Fitting (SUFI2) technique (Abbaspour et al., 2007) using SWAT-CUP calibration model. The model parameters are calibrated at monthly time scale. The model was calibrated from Jan 2001 to Dec 2006 using streamflow data at UGGS stream gage *Pohono*.

Table 2. Calibrated parameters and their optimized value

Parameter	Description	Range	Optimized Value
ESCO	Soil evaporation compensation factor	0, 1	0.36
EPCO	Plant uptake comepnsation factor	0, 1	0
SLSUBBSN	Overland flow length	10, 150	10
HRU_SLP	Average slope steepness	-1, 1	0.6
OV_N	Mannings roughness coefficient	0.01,30	28.64
SURLAG	Surface lag coefficient [days]	1, 4	28.65
SNOEB	Initail snow water content in elevation band [mm]	0,600	240.89
SNO_SUB	Initial snow water content [mm]	0, 150	150
TLAPSE	Temperature lapse rate [°C/km]	-10, 10	-4.26
PLAPSE	Precipitation lapse rate [mm H_2O/km]	0, 10	4.31
TIMP	Snow pack temperature lag factor	0.01, 1	0.276
SMFMX	Melt factor for snow on June 21 [mm H2O/°C-day]	0, 10	2.12
SMFMN	Melt factor for snow on December 21 [mm H2O/°C-day]	0, 10	0.94
SFTMP	Snowfall temperature [°C]	-5, 5	5
SMTMP	Snow melt base temperature [°C]	-5, 5	4.1
CN2	Initial SCS curve number II for moisture	0, 100	+/-10%
ALPHA_BF	Base flow recession constant	0, 1	0.299
GW_DELAY	Groundwater delay time [days]	0, 500	500
RCHRG_DP	Deep aquifer percolation fraction [%]	0, 1	0.155
GWQMN	Threshold depth in shallow aquifer for return flow [mm]	0, 5000	1978.511
GW_REVAP	Ground water re-evaporation coefficient	0.02, 0.2	0.2
REVAPMN	Threshold depth in shallow aquifer for re-evaporation [mm]	0, 500	124.76

RESULTS:

To understand effect of future climate change, SWAT model was simulated using future weather data (precipitation and temperature). For future climate scenarios, we have used GFDL and CNRM global climate model data downscaled at 1/8° grid resolution for the 50 year period from 2015 to 2064. This data is bias corrected and is downloaded from http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/.

Two future Representative Concentration Pathways (RCPs)- RCP 4.5 and 8.5 were selected for this study. RCP 4.5 assumes peak radiative forcing at ~ 4.5 W/m² by 2100. The global mean temperature will be less than 2.4°C. On the other hand, RCP 8.5 assumes radiative forcing will increase to 8.5 W/m² by 2100 by raising global mean temperature to 5-6°C by the end of the century.

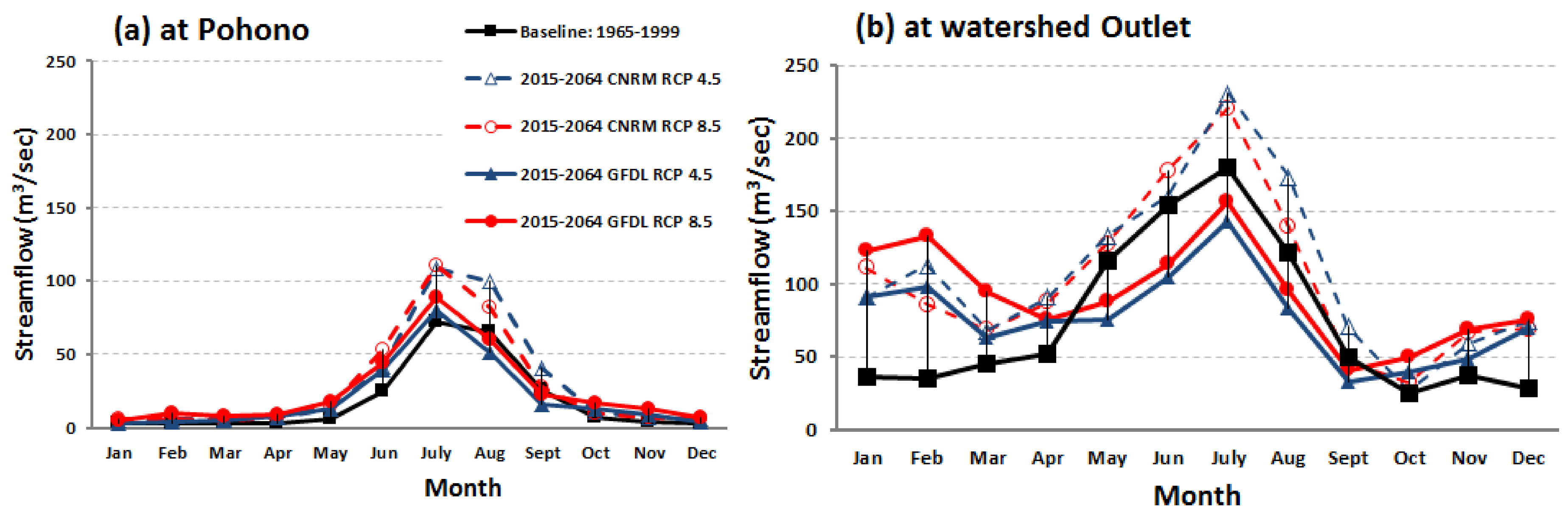

Figure 4. The projected average monthly streamflow compared with the average monthly streamflow of baseline period (1965-1999) at (a) the USGS stream gage Pohono, and (b) watershed outlet.

CONCLUSION:

- CNRM RCP 4.5 and 8.5 show increase in summer streamflow at Pohono as well as at the basin outlet.
- GFDL RCP 4.5 and 8.5 project increase in July streamflow followed by decrease in August streamflow at Pohono.
- At the basin outlet, both GFDL RCP 4.5 and 8.5 predict increase in winter but decrease in summer streamlow.
- Agricultural water demand will rise with increased urbanization. Therefore, water resource managers have to identify how to utilize increased volume of winter streamflow during low flow summer seasons.

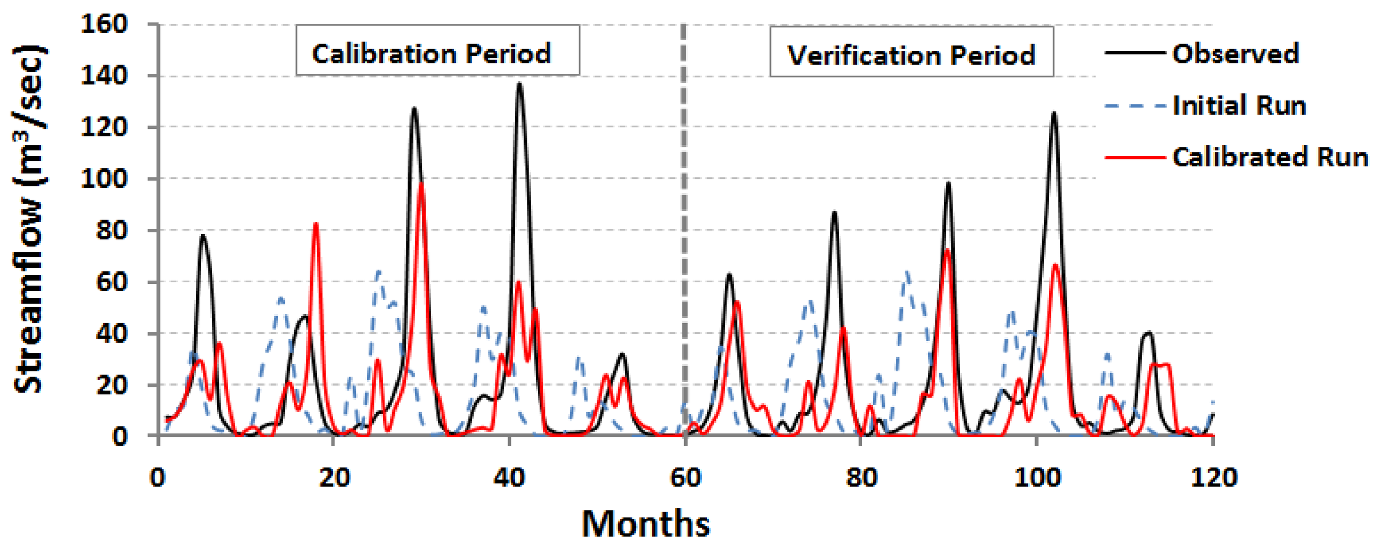

Figure 3. Observed and simulated model run at Pohono USGS stream gage for the period Jan, 2003 to Dec, 2012.

Coefficient of Determination

$$R^2 = \frac{\left[\sum_i (Q_{m,i} - \overline{Q_m})(Q_{s,i} - \overline{Q_s})\right]}{\sum_i (Q_{m,i} - \overline{Q_m})^2 \sum_i (Q_{s,i} - \overline{Q_s})^2}$$

Nash-Sutcliffe Efficiency

$$NSE = 1 - \frac{\sum_i (Q_m - Q_s)_i^2}{\sum_i (Q_{m,i} - \overline{Q_m})^2}$$

Percent Bias

$$PBias = \frac{\sum_i (Q_{m,i} - Q_{s,i})}{\sum_i Q_{s,i}} \times 100$$

Table 3. Model performance evaluation at Pohono

Parameter	R^2	NSE	Pbias
Initial Run	1.289	-0.2889	-28.4
Calibrated Run	0.266	0.7337	-26.1
Validated Run	0.594	0.516	-50.75

FUTURE STUDY:

- Future streamflow characteristics will analyzed statistically.

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