Generation of Streamflows

As illustrated in Figure 3, the coverage area of the hydrologic model includes all major tributaries to the northern CVS. The contributing flow is summarized in the Figure 3 table insert, showing the relative importance of the Shasta and Oroville subbasins. The SAC-SMA-DS hydrologic model is used to simulate streamflow at 32 locations throughout the CVS watershed. As shown in Figure 10, these 32 streamflow simulations include:

> **Calibration Set I:** 12 rim inflows to major reservoirs throughout the CVS.
>
> **Calibration Set II:** 11 gauging station streamflow points important for calculating water-year types used for regulatory constraints, management, and operational decision-making.
>
> **Calibration Set III:** 9 subbasin inflows that account for a substantial portion of the rain in the system and represent "unimpaired inflows," as they are the modeling results of estimating the runoff that would have occurred had water flow remained unaltered in rivers and streams instead of stored in reservoirs, imported, exported, or diverted (Bay-Delta Office 2007).

As shown in Figure 11, the locations of the 11 stream gages in Calibration Set II are nearly identical to the locations of the basin outlets for the 12 rim inflows in Calibration Set I. This is because the historical data for the CalLite 3.0 rim inflows are derived from the 11 physical stream gages described in Calibration Set II. To validate the workflow shown in Figure 2 relative to the baseline run of the CalLite 3.0 simulation model, the SAC-SMA-DS model was calibrated directly to the streamflow in the CalLite 3.0 package (Calibration Set I). This is different than calibrating to historical observations, as the streamflow pre-loaded in the CalLite 3.0 package is the output of previous hydrologic modeling (Variable Infiltration Capacity [VIC]) project performed for the CVS.

To evaluate the quality of the original VIC hydrologic model output used in CalLite 3.0, and to gain the confidence associated with validation relative to historical observations, it was necessary to calibrate the SAC-SMA-DS directly to the observations at the 11 physical gages of Calibration Set II. The results of Calibration Set II were not used as input to CalLite 3.0 but were used in the determination of water-year type classification as described below.

Calibration Set III was developed when it was realized that Calibration Set I and Calibration Set II failed to account for a substantial portion (especially south and west) of the total CVS basin area shown bounded in red in Figure 11. The nine unimpaired inflow basins of Calibration Set III add information on CVS subbasins that are rain-dominated (as opposed to many of the 12 rim inflows, which are largely snow-dominated), and accounts for a substantial portion of the rain that falls within the CVS system. The nine basins of Calibration Set III are referred to as "unimpaired inflows," as they are the result of a modeling project that estimated the runoff "that would have occurred had water flow remained unaltered in rivers and streams instead of stored in reservoirs, imported, exported, or diverted" for 24 Central Valley subbasins and the Sacramento-San Joaquin Delta for October 1920 through September 2003 (Bay-Delta Office 2007). Whereas Calibration Set I was used as direct input to CalLite 3.0 and Calibration Set II was used principally as a check on Calibration Set I and in the development of water year type classification, Calibration Set III was used principally to add information to the process for generating other, minor hydrologic and non-hydrologic inputs to CalLite 3.0.

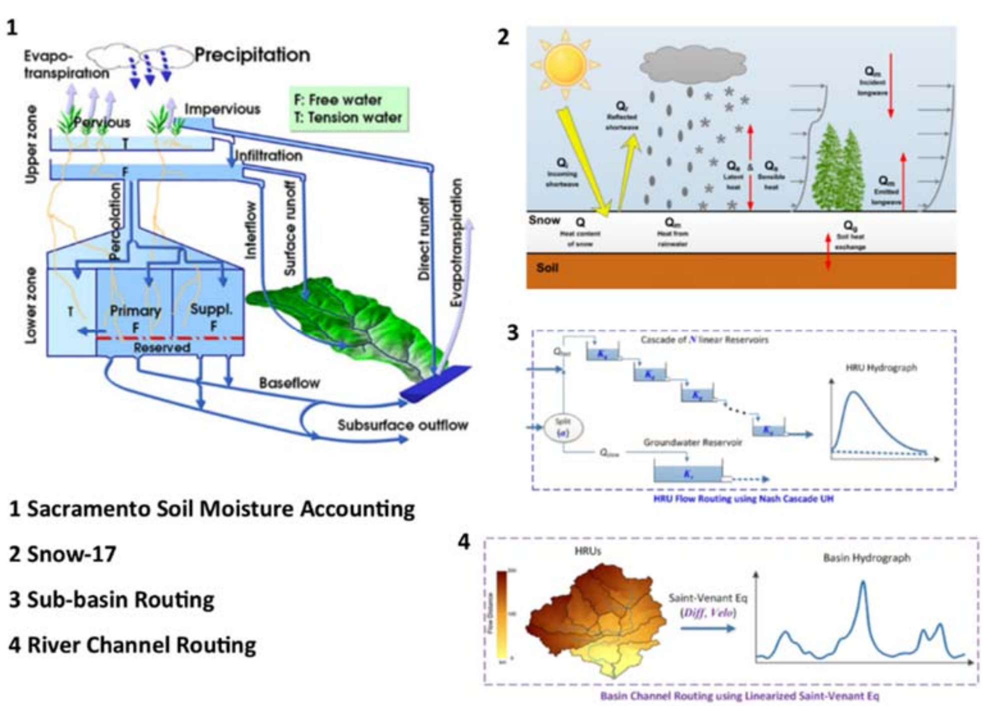
Box 1 Description of the SAC-SMA-DS Hydrologic Model

The hydrologic model is required to be extremely robust because of its essential role in the quantification of the available water on which water allocations to all water sectors are based. Hydrologic model residuals propagate through the modeling chain and contribute to a cascade of uncertainty (Wilby & Dessai 2010). This box describes the development of a distributed, physically-based hydrologic model capable of supporting subsequent phases of the climate change vulnerability assessment workflow.

The amount of usable water for the CVS can be approximated as the quantity of streamflow in the 12 largest rivers flowing from the northeast into the Central Valley. These are referred to as the *rim inflows*. To estimate those 12 streamflows, a unique version of the Sacramento Soil Moisture Accounting (SAC-SMA) model was developed.

SAC-SMA (Burnash et al. 1973), is a lumped conceptual hydrological model employed by the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA) to produce river and flash flood forecasts for the United States (Burnash 1995; McEnery et al. 2005). It was coupled with a river routing model (Lohmann et al. 1998) for application to the large, distributed CVS watershed system (consisting of approximately one thousand 1/8th degree grid cells). The coupled model is hereafter referred to as SAC-SMA-DS (Wi & Brown 2013), distinguishing it from the distributed version of SAC-SMA previously developed by NWS. SAC-SMA-DS has been applied to a number of case studies (e.g., Koren et al. 2004; Smith et al. 2004). SAC-SMA-DS (Box 1 Figure (a)) is composed of hydrologic process modules that represent soil moisture accounting, potential evapotranspiration (Hamon 1961), snow processes (Anderson 1976), and flow routing, and operates in grid formulation on a daily time-step.

(a) Distributed Hydrologic Model



Box 1 Description of the SAC-SMA-DS Hydrologic Model (continued)

The overall model structure of SAC-SMA-DS is depicted in Box 1 Figure (a) above. More details on the model components are provided in the descriptions for the modules additionally introduced to develop the distributed version of SAC-SMA.

Hamon Evapotranspiration Calculation

The potential evapotranspiration (PET) is derived based on the Hamon method (Hamon 1961), in which daily PET in millimeters (mm) is computed as a function of daily mean temperature and hours of daylight:

$$\mathrm{PET} = \mathrm{Coeff} \cdot 29.8 \cdot \mathrm{L_d} \cdot \frac{0.611 \cdot \exp\left(17.27 \cdot \frac{\mathrm{T}}{(\mathrm{T}+273.3)}\right)}{\mathrm{T}+273.3}$$

where L_d is the daylight hours per day, T is the daily mean air temperature (°C), and Coeff is a bias correction factor. The hours of daylight is calculated as a function of latitude and day of year based on the daylight length estimation model suggested by Forsythe et al. (1995).

In-grid Routing: Nash-Cascade Unit Hydrograph

The within-grid routing process for direct runoff is represented by an instantaneous unit hydrograph (IUH) (Nash 1957), in which a catchment is depicted as a series of N reservoirs each having a linear relationship between storage and outflow with the storage coefficient of Kq. Mathematically, the IUH is expressed by a gamma probability distribution:

$$\mathrm{u(t)} = \frac{\mathrm{K_q}}{\Gamma(\mathrm{N})}\left(\mathrm{K_q t}\right)^{\mathrm{N}-1}\exp\left(-\mathrm{K_q t}\right)$$

where Γ is the gamma function. The within-grid groundwater routing process is simplified as a lumped linear reservoir with the storage recession coefficient of Ks.

River Channel Routing: Linearized Saint-Venant Equation

The transport of water in the channel system is described using the diffusive wave approximation of the Saint-Venant equation (Lohmann et al. 1998):

$$\frac{\partial \mathrm{Q}}{\partial \mathrm{t}} + \mathrm{C}\frac{\partial \mathrm{Q}}{\partial \mathrm{x}} - \mathrm{D}\frac{\partial^2 \mathrm{Q}}{\partial^2 \mathrm{x}^2} = 0$$

where C and D are parameters denoting wave velocity and diffusivity, respectively.