Modeling the Flow of Water and Heat in the Central Valley to the Coastal Ocean

Water enters the Central Valley basin in the form of snow and rain and moves from watersheds through rivers and the estuary to the ocean. Throughout this domain there are two processes that govern most of the thermal hydrodynamics at local scales: advection (the movement of heat downstream with the water), and heat exchange (heating and cooling of the water with the environment). There are two primary drivers of these processes: flow dynamics and atmospheric forcings. Flow dynamics determine the rate at which heat is advected downstream (when and how much water is moved), and the rate of heat exchange. Atmospheric forcings and hydrology determine the amount of water entering the system (precipitation, evaporation, infiltration and either rain fed runoff or snow accumulation and snow melt) and the rate of heat exchange (solar radiation, evaporative cooling). The hydrologic processes influencing advection and heat exchange are well-understood and predictable phenomena. Atmospheric forcing and water resources operations (reservoir operations, water diversions, etc.) and the interactions between them are more variable and complex, and have important management, socio-economic, and environmental consequences.

The flow dynamics in the Central Valley have been fundamentally altered by the Central Valley Project (CVP) and State Water Project (SWP); a series of dams, reservoirs, and canals that were built to store and move water throughout the state. These projects have also significantly changed the spatial distribution and the timing of the advection and heat exchange processes. Reservoirs within the system were built to store water, forcing a lag in the timing of the movement of the water downstream. An unintended consequence of water storages is the associated alteration in the timing and magnitude of the advection of heat downstream. The statewide water budget model used for water management (CalSIM) was developed to move of water through actions such as reservoir operations and withdrawals, and does not have the capability to simulate heat and temperature processes.

The other key driver, atmospheric forcing, varies at multiple scales in the Central Valley, with daily to seasonal temperature and precipitation variation, seasonal to multi-year drought or pluvials, and expectations for long-term increases in air temperatures. In California, the majority of the water year’s precipitation occurs in the winter months, but the water is released from storage reservoirs during the summer and fall when the heat exchange is greatest. California is currently in a multi-year drought and air temperatures in 2014 and thus far into 2015 were the highest in recorded history.

While water temperatures do not directly impact the amount of water within the system, they can significantly influence water availability and distribution through restrictions driven by regulations such operating criteria based on ESA impacts. In 2015, for example, temperature compliance issues Sacramento River resulted in significant reductions in water delivery to Sacramento River Settlement contractors. Future climate warming and the related increase in drought frequency and severity will likely make temperature management an even more important regulatory factor in the future. Thus there is a clear need for a comprehensive, basin-scale heat flow model.

We propose to develop a coupled modeling framework to quantify the advection and heat exchange of water throughout the Central Valley basin, the San Francisco Bay/Delta, and the coastal ocean. There are five distinct zones that function under differing mechanisms and climate inputs that we refer to as process domains:

watershed, reservoir, river, estuary, and ocean. The overall framework consists of a series of fine scale, process-based models that link each process domain through water flow (Q) and temperature (T) and are driven by outputs generated by climate models, for full regional coverage (see figure). The process-models are all mechanistic with heat budget components: (watershed) VIC, a macroscale hydrologic model; (reservoir) CE-Qual-W2, a 2-D water quality and hydrodynamic model; (river) River Assessment for Forecasting Temperature (RAFT), a 1-D heat budget model; (estuary and coastal ocean) SCHISM (Semi-implicit Cross-scale Hydroscience Integrated System Model), a 3-D hydrodynamic model.

Water enters the framework through the precipitation and atmospheric forcings from from climate models. Heat is then advected (grey arrows) within and between domains (as a function of flow, Q, and temperature T), in the downstream direction only until the estuary, where tidal flow and diffusion become relevant. Heat exchange (black wavy lines) occurs within each domain, either adding heat, which is then advected downstream, or removing heat from the system through cooling. Heat can also be removed from the system through water withdrawals, such as in the estuary where a substantial proportion (up to 50%) of the water is exported for municipal and agricultural use. Examples of management options for each model are included (model subheadings).

The first three models, watershed-reservoir-river (grey layered boxes), would be repeated to capture the multiple inputs into the estuary. The project would be implemented in two stages: the first stage would include the development of linked process-modes for the Sacramento River (Shasta watershed, Shasta Reservoir, Sacramento River, Sacramento-San Joaquin Delta). The second stage (the full model) would incorporate the additional tributaries to the Sacramento (the Feather and American Rivers), and the San Joaquin River system (the Merced River, Tuolumne River, Stanislaus River and Mokelumne River).

Research Questions

A wide range of potential research questions can be addressed with the modeling tools developed in this project. These questions range from issues of basic thermal hydrodynamics (what is the overall heat budget for the CV?) to specific management driven questions (what are the thermal impacts of specific reservoir operations for the mainstem Sacramento River downstream and into the Delta?)

<u>Research Objectives:</u>

<u>1. Develop a process-based model for Watershed Thermal Hydrodynamics</u>

A quantitative description of where and when heat exchange occurs in the system, under past, current, and future climate and water management scenarios.

- What is the role of each process domain: contribution to total, variability, sensitivity, etc.?
- How much variability has there been in the past and how much will there be in the future?
- What is the capacity of the entire system to handle additional heat?
- What is the spatiotemporal extent of the thermal signature of freshwater in the estuary and coast ocean?

Operations and Management

Same as above but focused on the impacts of operations:

- How much capacity is there in the system to manage for heat (i.e. move water and heat around to meet temperature goals)?
- Environmental flows
- Optimality models for moving water and heat between different components of the system in order to meet multiple management objectives (including environmental flows and temperature targets for spawning/incubating/rearing/migrating salmon; water exports/deliveries for multiple user groups)

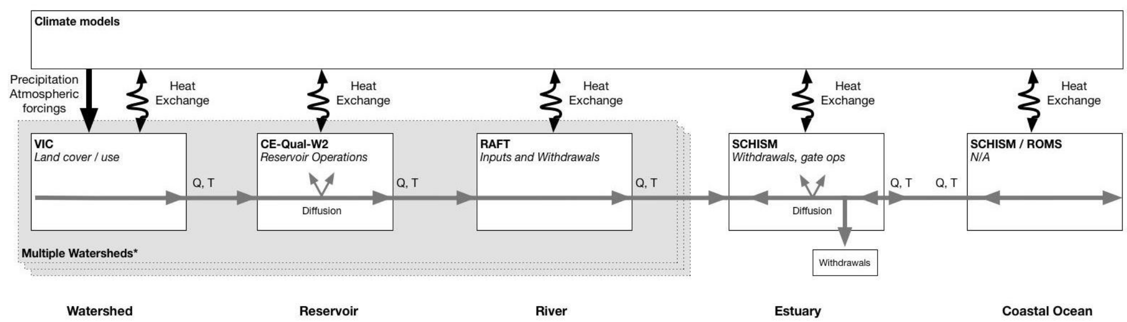

Figure 1. Model framework. The framework consists of five process domains: watershed, reservoir, river, estuary, and coastal ocean, each with a physical model (white boxes). Water enters the framework through the precipitation output from climate models. Heat is then advected (grey arrows) within and between domains (as a function of flow, Q, and temperature T), in the downstream direction only until the estuary, where tidal flow and diffusion become relevant. Heat exchange (black wavy lines) occurs within each domain, either adding heat, which is then advected downstream, or removing heat from the system through cooling. Heat can also be removed from the system through water withdrawals, such as in the estuary where a substantial proportion (up to 50%) of the water is exported for municipal and agricultural use.