New methods to support decision making during freshwater ecosystem service evaluation: The case of the Sacramento Watershed

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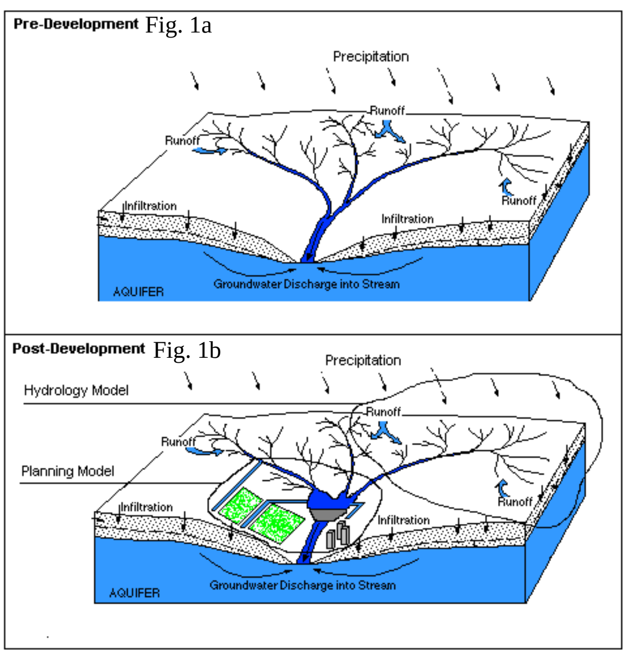
Background

This Assessment Initiative project uses the results from the Bayesian Statistical model of Tebaldi et al. (2004) to develop high-resolution, downscaled climate scenarios (Yates et al. 2003) for direct application within an integrated water resource planning model of the Sacramento Watershed of Northern California. This work is leveraged off a stakeholder guided, Environmental Protection Agency study that examines the combined effects of climate change and other stressors on the ability of the watershed to support important ecological resources and supply valued ecosystem services.

Our focus in the Assessment Initiative is to develop methods that can explicitly incorporate the uncertainties of climatic change and changes in land use and other watershed conditions on watershed response, coupled with the watershed management paradigm to address opportunities for expanding the beneficial use of regional water supplies (e.g. agricultural, urban, hydropower and ecosystems). Examples of management opportunities include the re-operation of existing water supply infrastructure, the construction of new facilities, investments in demand management initiatives, changes in allocation priorities and supply preferences, watershed improvement efforts, and changes in regulations regarding the management and allocation of available water supply. Uncertainty related to each of these changes, in both the physical and management systems, can be addressed through the internal organization and evaluation of multiple scenarios within a model construct known as the Water Evaluation and Planning (WEAP) Decision Support System (Seiber et al. 2004 and Yates et. al. 2004).

Water Resource Planning and Management Tools

Water resource planning increasingly occurs as part of complex, multi-disciplinary investigations that bring together a wide array of individuals and organizations with varied interests, technical expertise, and priorities. In this multi-disciplinary setting, successful planning requires tools that can clarify complex water issues (Loucks 1995). Factors related to the bio-physical system, namely climate, topography, land cover, surface water hydrology, groundwater hydrology, soils, water quality, and ecosystems, shape the availability of water and its movement through a watershed (Pre-Development, Fig. 1a). Factors related to the socio-economic management system, driven largely by human demand for water, shape how available water is stored, allocated and delivered within or across watershed boundaries (Post-Development, Fig. 1b). In general, individual water resource models have tended to focus on either understanding how water flows through a watershed in response to hydrologic events, or on allocating the water that becomes available in response to hydrologic events. Models that do both are less common and those that do generally make simplifying assumptions with regards to the physical hydrology.



The Sacramento Watershed of Northern California

Among others, WEAP has been developed within the context of the Sacramento Watershed because the Sacramento provides an excellent laboratory for such advancement, as is data rich and heavily managed. The study focuses on the riverine habitat for aquatic life and other services and strategically selected wetlands associated with its rivers. Other goals are to develop methods that can assess how global change-related alterations in surface hydrology, subsurface hydrology, water quality, water quantity and seasonality may affect these systems. A key component is the involvement of stakeholders who have an interest and a role in watershed management decisions in the San Francisco Bay area, in order that they may aid in the analytic design, analysis, evaluation and interpretation of information. Stakeholders have helped guide the selection and prioritization of analytic activities, helped establish project goals, share expertise, and provide information in a variety of areas including public values, equity considerations, and relevant decision processes. A selection of stakeholders engaged as part of this project and their water related decisions are presented in Table 1.

Table 1. A selection of water related decision makers, their decision time frames (Decision), and the timeframe in which their decisions have impact on the water system (Timeframe).

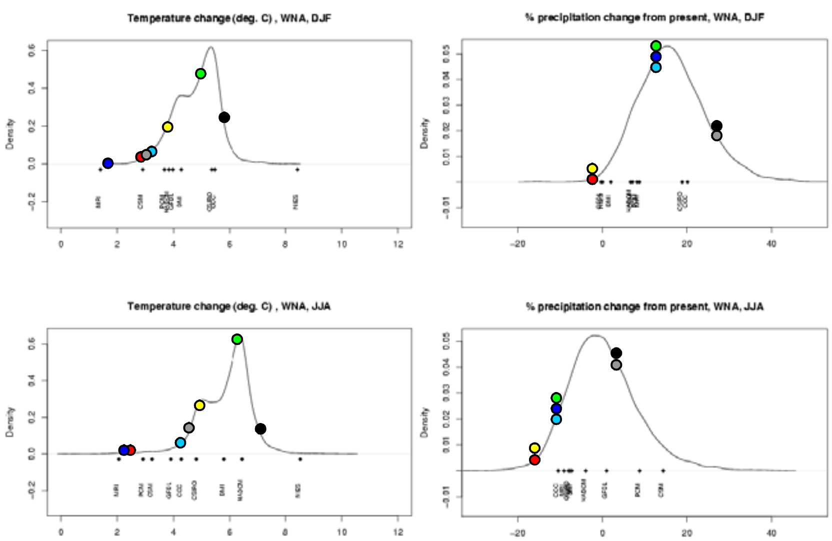
Organization	Function	Decisions	Decision (yrs)	Timeframe (yrs)
CALFED	Consortium of Federal and state agencies	Water use efficiency, Re-cycling, New storage to meeting Anticipated future demands; Ecosystem restoration needs	**3-5**	**30-50**
Department of Water Resources, Calif.	Bulletin-160 – A 5-year water master plan	Developing long-range plans as opposed to previous versions which project maximum anticipated demand and define supply options to	**1-5**	**5-50**
California Legislature	Select committee on California water needs and climate change	Recommends changes in laws, policy or funding to protect states water supply, taking climate change info. into account	**1-3**	**5-50**
Yuba, American, Bear Hydro-power Re-Licensing	Develop the re-licensing petition to the Federal Energy Regulatory Commission	Define the most economically and ecologically beneficial strategy for operation of reservoirs in the inter-connected upper Yuba, American, and Bear systems.	**3-5**	**30-50**

Bayesian Results for Western North America

Figure 2 presents the results from Tebaldi's Bayesian statistical model for Western North America (WNA). Their results suggest regionally wetter winters with a 15% increase in total winter precipitation in the later part of the 21st century (top-right), while the mean of the summer precipitation change is near zero (bottom-right). The bulk of the winter temperature increases are in the range of 4ºC to 6ºC (top-left), while summer warming is slightly higher (bottom-left). From these distributions, a *K*-nearest-neighbor (*K-nn*) resampling scheme (Yates et al. 2003) was run to generate both spatial (~20 km) and temporal (daily) high resolution datasets for use in the WEAP water model.

A summary of six downscaled scenarios is presented in Table 2, while Figure 3 summarizes the monthly average values of these scenarios for the entire Sacramento watershed based on the data from each of the 55 stations. These are stylized scenarios guided by the results of the Bayesian model, and include scenarios such as "Warmer and Drier" (abbreviated "WmDry") that is characterized by slightly drier winters, much drier late springs, and generally warmer conditions overall.

Fig. 2. Statistical distributions of seasonal change in temperature and precipitation for Western North America (WNA) and the representation of the downscaled scenarios in the density space: ● WmDry; ● WmDryT2; ● WtWnt; ● WtWntT2; ●WtWntT4; ●VWtWntr; ● VWtWntrT3



These scenarios generated with the *K-nn* model do not possess any exceptional drought or wet periods over their 40-year time horizon. The *K-nn* technique does allow for the creation of alternative scenarios with, for example, different measures of variance like intra annual and/or inter-annual variability. Nevertheless, while other scenarios could be generated with differing attributes, the six selected scenarios are only a sample, guided by the Bayesian model results, which themselves currently provide no information into changes in variability. Note that the relationship among variables is not currently preserved in the Bayesian model (e.g. there is no a joint distribution), thus there is no suggestion as to the magnitude of temperature change for a given precipitation change or vice versa. However, the scenarios derived from the *K-nn* downscaling do attempt to preserve the joint probabilities among variables. In Table 1, the ΔT's show in the *Scenario* column indicate the average incremental, randomly generated temperature change for that scenario relative to the base scenario of that same type, *Precipitation* is the seasonal average percent change and *Temperature* is the average incremental change, with both relative to the historic period 1961-1999.

Table 2. The six downscaled scenarios.

Scenario	**Quantitative Summary (relative to historic)**	
	Precipitation	***Temperature (C)***
(1) Warmer and Drier Slightly drier winters, much Drier Late Springs, Moderately warmer (WmDry)	WES = -6%; LSES = -45% SLF = -34%; ANN = -11%	WES = +1.4; LSES = +2.8 SLF = +2.2; ANN = +1.9 C
(2) Same as (1) w/ ΔT+2 (WmDryT2)	Same precipitation sequence of Scenario 1	WES = +3.2; LSES = +4.7 SLF = +4.5; ANN = +3.9
(3) Wetter Winters, Drier Springs, and Warmer Summers (WtWnt)	WES = 21 %; LSES = -46 % SLF = -2 %; ANN = +15%	WES = -0.1; LSES = +2.4 SLF = +1.7; ANN = +0.9
(4) Same as 3 w/ ΔT+2 (WtWntT2)	Same precipitation sequence as Scenario 3	WES = +2.2; LSES = +4.7 SLF = +4.0; ANN = +3.2
(5) Same as 3 w/ ΔT+4 (WtWntT4)	Same precipitation sequence as Scenario 3	WES = +4.2; LSES = +6.7 SLF = +6.0; ANN = +5.2
(6) Very Wet Winters, Dry Springs, Much warmer Summers, Warmer Winters w/ (VWtWnt)	WES = +31 %; LSES = -41 % SLF = +15 %; ANN = +25%	WES = +2.1; LSES = +4.9 SLF = +4.2; ANN = +3.2
(7) Same as (6) w/ ΔT+3 (VWtWntT3)	Same precipitation sequence as Scenario 6	WES = +5.1; LSES = +7.9 SLF = +7.2; ANN = +6.2

Winter and Early Spring (WES); Late Spring and Early Summer (LSES); Summer and Late Fall (SLF); Annual ANN

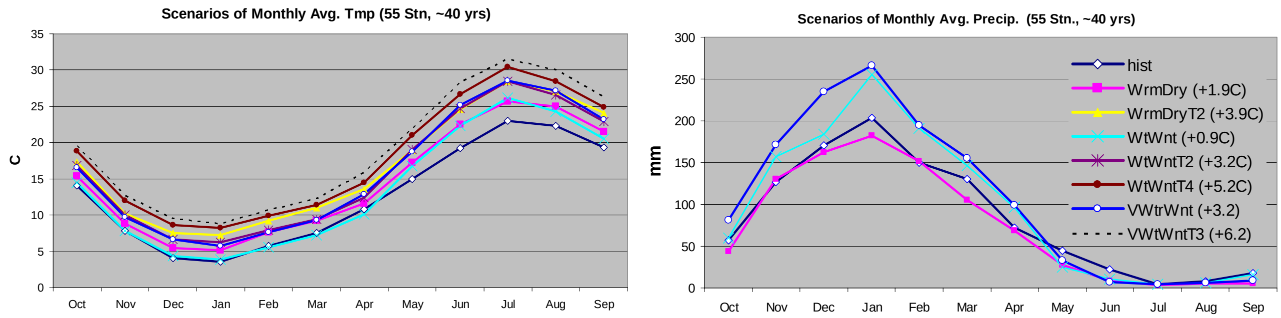


Figure 3. Monthly average Sacramento air temperature (left panel) and precipitation (right panel) from historic data (hist) and the 6 scenarios.

A simplified schematic of the Sacramento Watershed as represented in the WEAP modeling framework is given in Figure 4 and includes the major river network, demand centers, tributaries, demand nodes, reservoirs, groundwater nodes, diversions, instream flow requirements, etc. The inset box in Figure 4 shows the northeast corner of the Sacramento Watershed which was reproduced in greater detail and shows a computer generated image of the Graphical User Interface of the model building space of WEAP.

In all, this WEAP implementation for the Sacramento River includes the major tributaries; the main alluvial aquifers of the Central Valley; the major diversion from the Trinity; the major reservoirs (McCloud, Trinity, Shasta, Black Butte, Oroville, Almanor, Buzzard, and Folsom); the primary irrigation canals and their demand centers (e.g. Cottonwood Irrigation canal, Tehma Canal, the Colusa Canal, and others) and aggregated minor irrigation districts; and the major and aggregate minor municipal and industrial demand centers. Three flood conveyance systems are also included: the Yolo Bypass, the Sacramento Weir Bypass, and the Sutter Bypass.

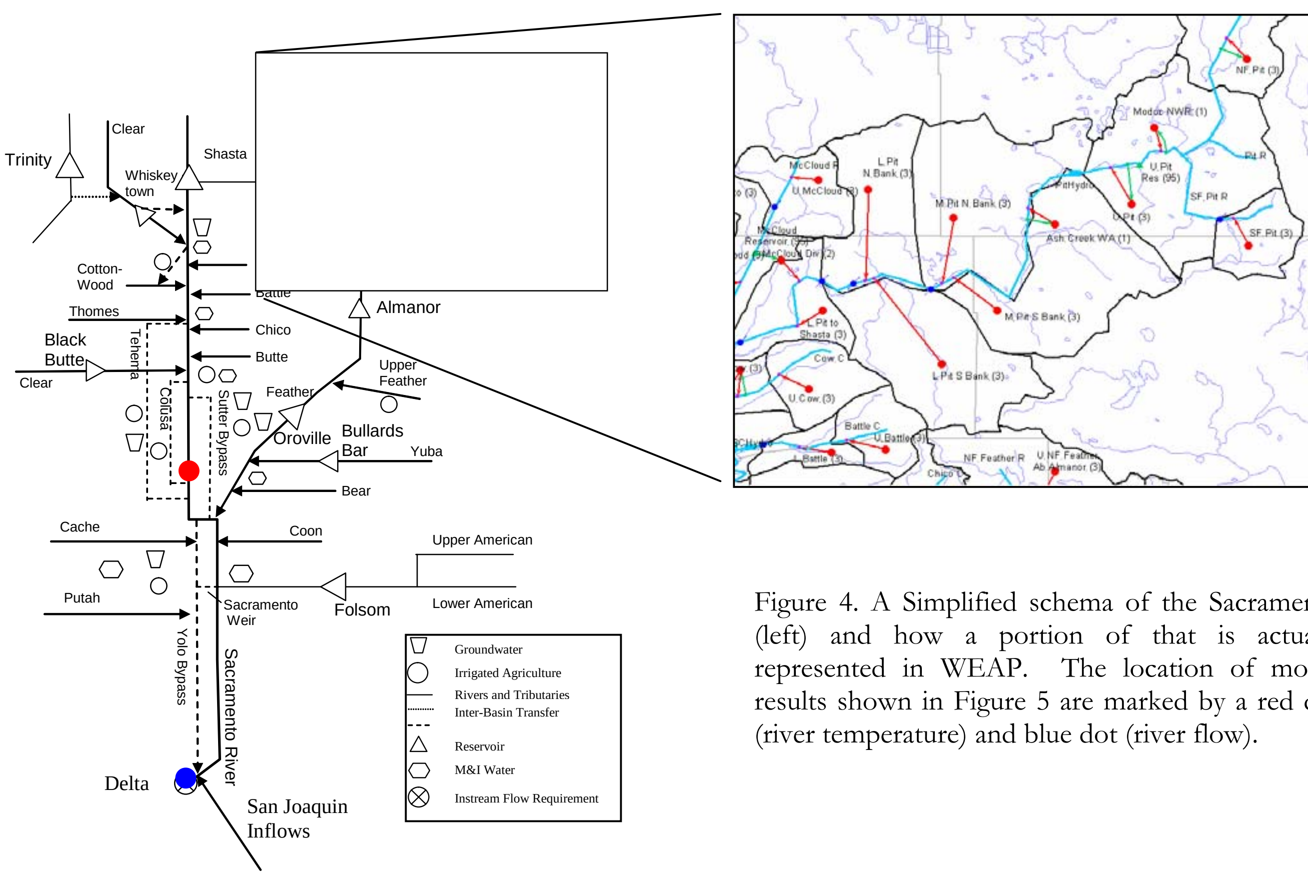


Figure 4. A Simplified schema of the Sacramento (left) and how a portion of that is actually represented in WEAP. The location of model results shown in Figure 5 are marked by a red dot (river temperature) and blue dot (river flow).

Preliminary Results

A model-based reproduction of the seasonal Sacramento River temperature regime, particularly for the portion of the river from the Shasta Reservoir downstream below the City of Sacramento, was developed to investigate, among others, the potential impacts of climate change and other stressors on Chinook salmon. The Chinook are under increasing anthropogenic stress, resulting in major population reductions. The greatest contributors to this have been the construction of dams blocking access to spawning habitats, sedimentation of spawning gravel beds, and water diversions resulting in low flows and higher water temperatures at critical stages of the fish life histories. Consequently, the primary spawning habitat of the Chinook has effectively shifted downstream into the Central Valley and away from the smaller tributaries. Prior to the 1966 construction of the Red Bluff diversion dam on the Sacramento mainstem, it was estimated that only 5 percent of the spawning activity occurred below this point, while more recent data suggests that over half of natural spawning now occurs below the Red Bluff diversion. Since it is a cold water fish, avoiding freshwater areas where water temperatures exceed their physiological requirements, Chinook may be vulnerable to the new threat of global climate change and warming. It is possible that rising water temperatures could adversely affect the ability of salmon to find suitably cold breeding habitats.

Figure 5 provides a brief summary of average monthly river flows (below Sacramento) and temperatures (above the Tehema and Colusa canal return flows) estimated with the WEAP model (see Fig. 4). The red-dotted line indicates the general temperature (~17C) above which salmon reproduction is challenged. To appreciate the role of irrigation and storage, the model was run assuming no storage reservoirs or irrigation anywhere in the watershed (left panels), while the results in the right panels reflect the model run with all storage infrastructure and irrigation demands in place. Differences in river temperature under these two assumptions are striking, and suggest that the massive cold water pools stored behind reservoir like Shasta could be strategically operated to offset the impacts of climate change.

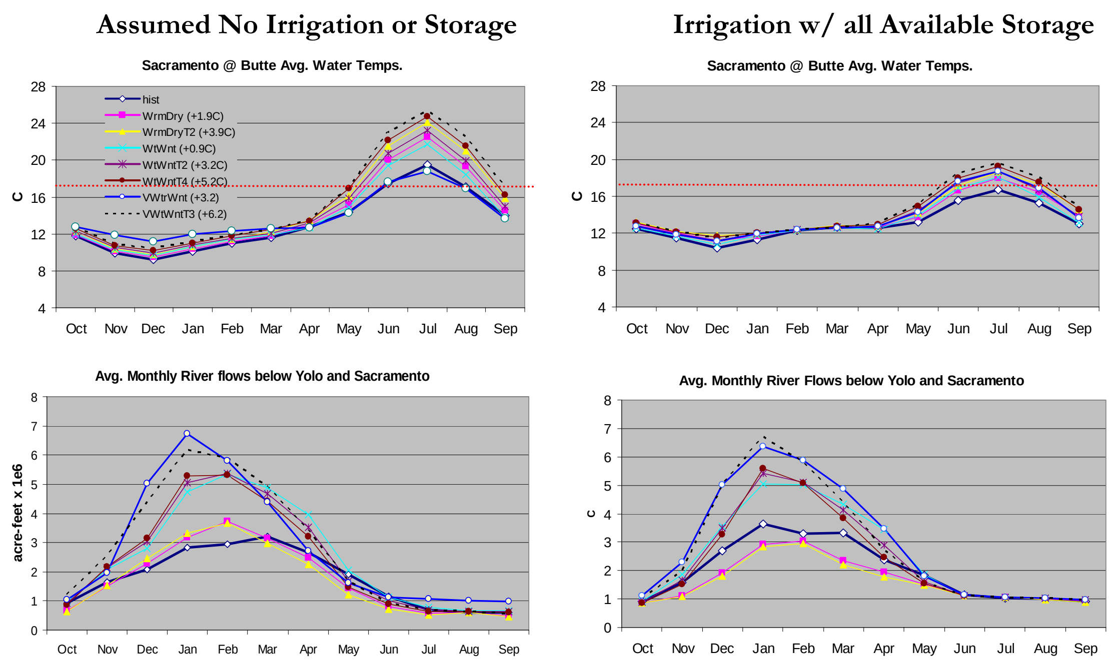


Figure 5. Monthly average river temperature (top panels) and river flow (bottom panels) under the six climate scenarios and assumptions of a "natural watershed" (e.g. no reservoir storage or irrigation) and a "managed watershed".

References

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