The Use of Water System Models in the FERC Process: Opportunities and Motivations to Consider Climate Change

David R. Purkey, Ph.D.

US Water Group Leader

Stockholm Environment Institute-US Center

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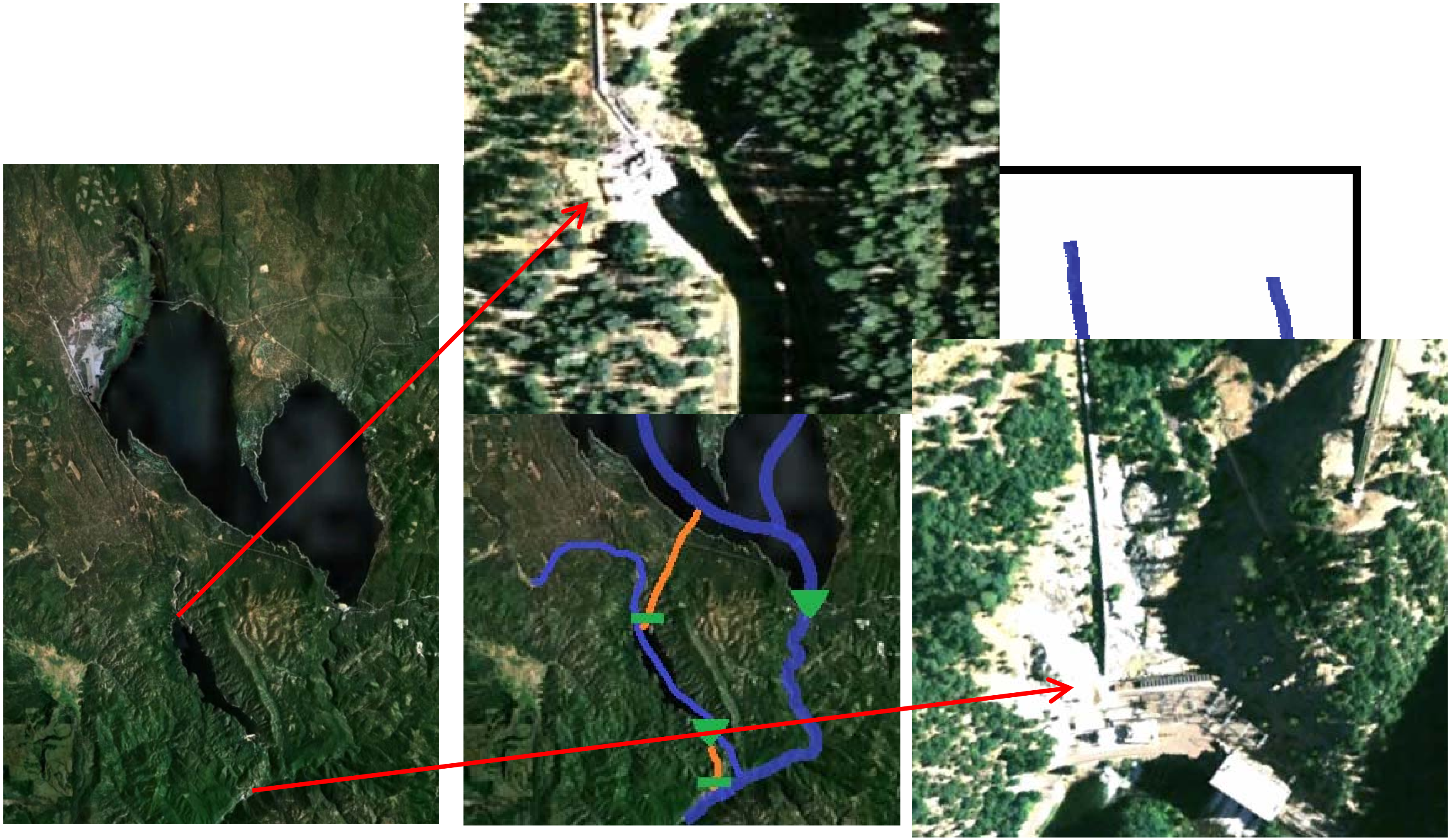
The Modeling Enterprise: From Reality to Representation



“The only PERFECT model of the world, perfect in every little detail, is, of course, the world itself.”

Paul Teller

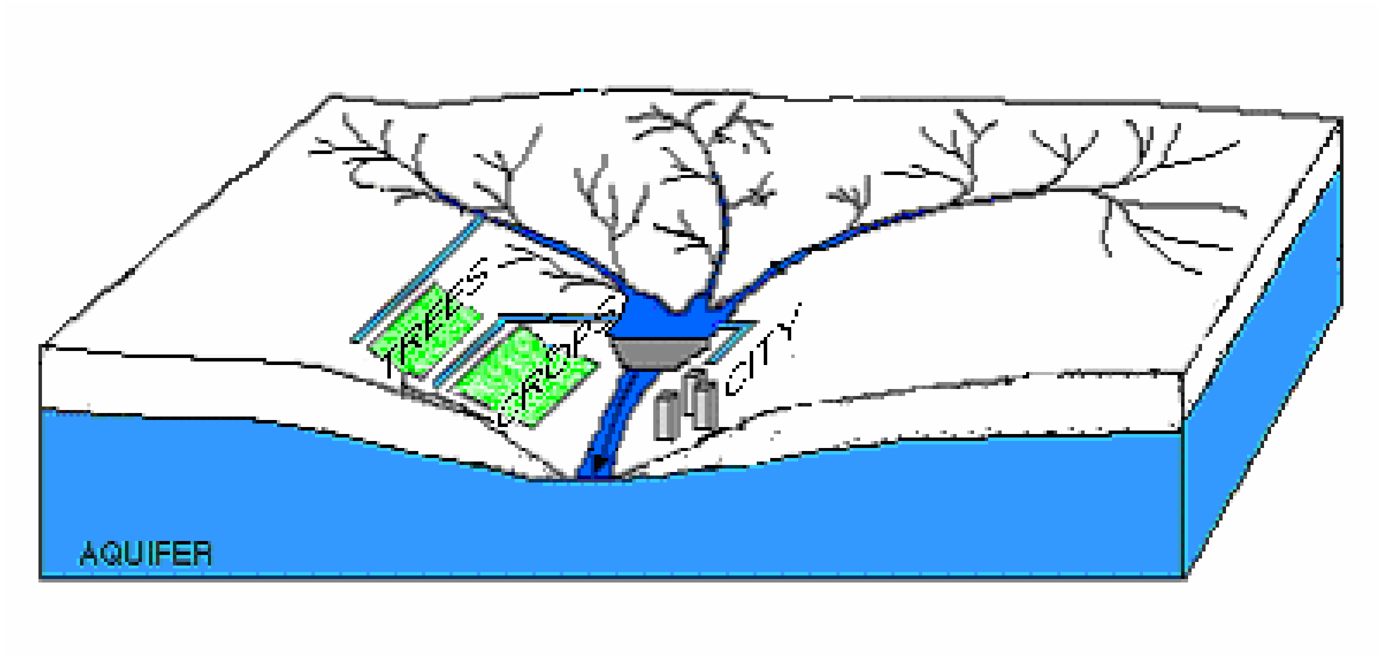
The Twilight of the Perfect Model

“All models are wrong, some models are useful.”

George E.P. Box

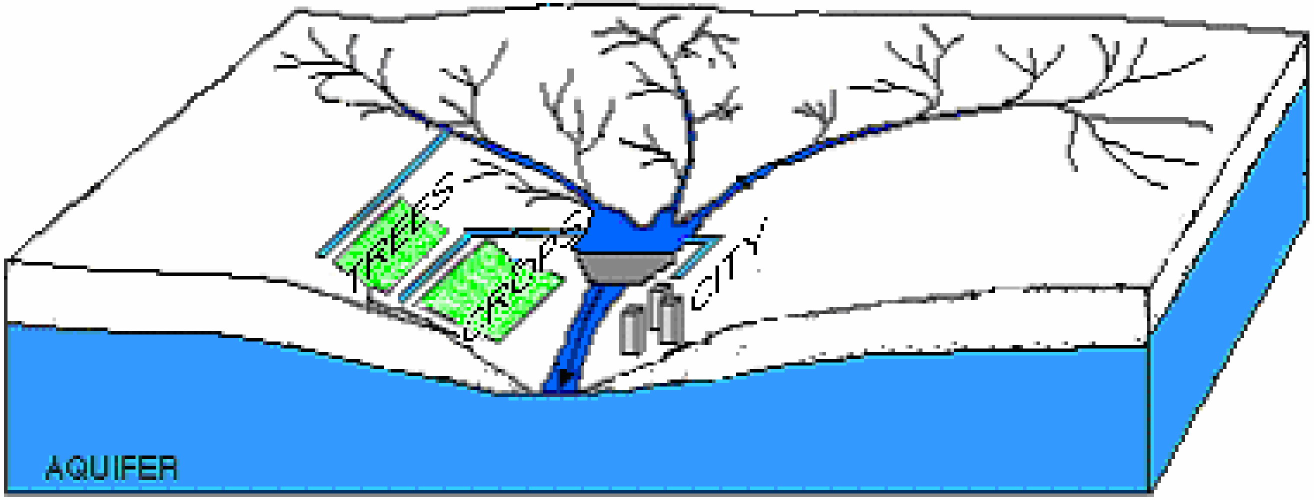
Robustness in the Strategy of Scientific Model Building

Water Resource Systems Model



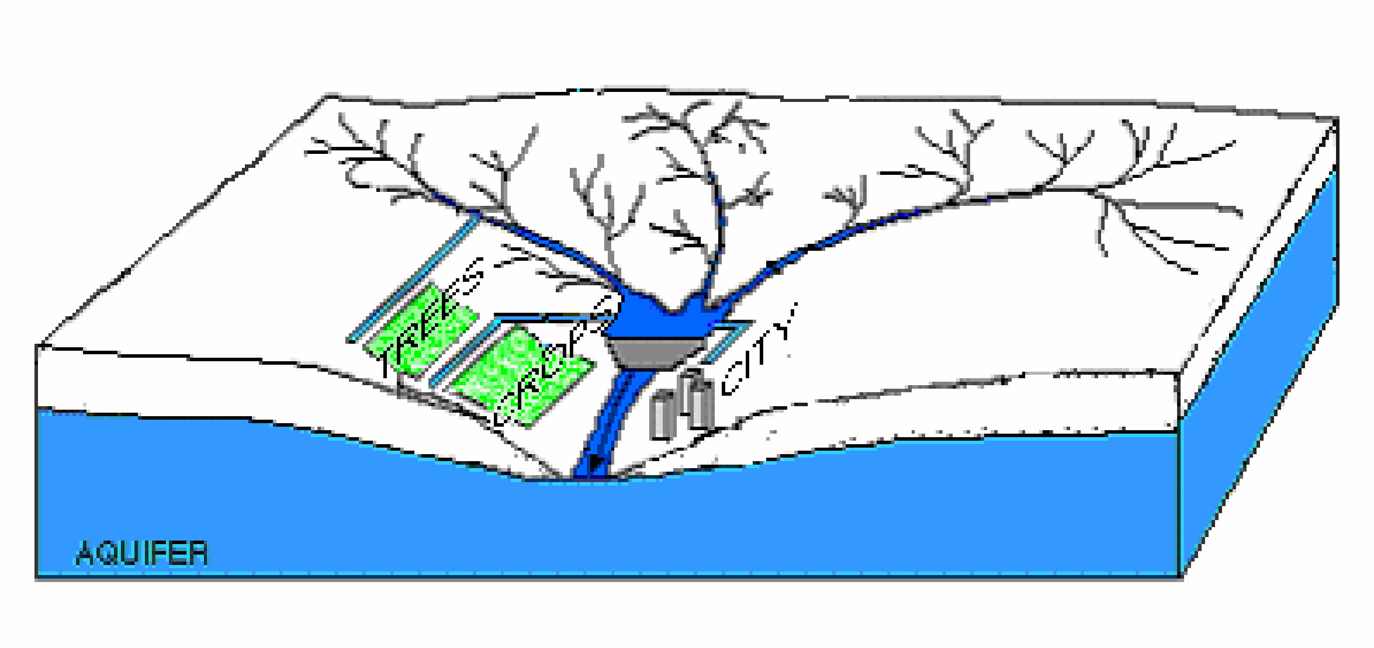
Critical questions: How should infrastructure in the system (e.g. dams, diversion works, powerhouse returns, etc) be operated to achieve maximum benefit?

Water Resource Systems Model



Critical questions: How can these operations be constrained to protect the services provided by the river?

Water Resource Systems Model

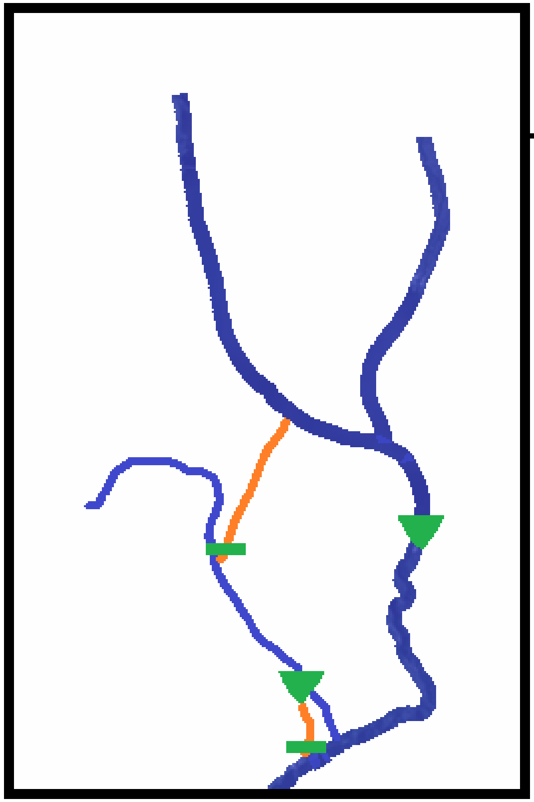


Critical questions: How will allocation, operations and operating constraints change if new management objectives are introduced into the system?

The FERC Modeling Process: More or Less

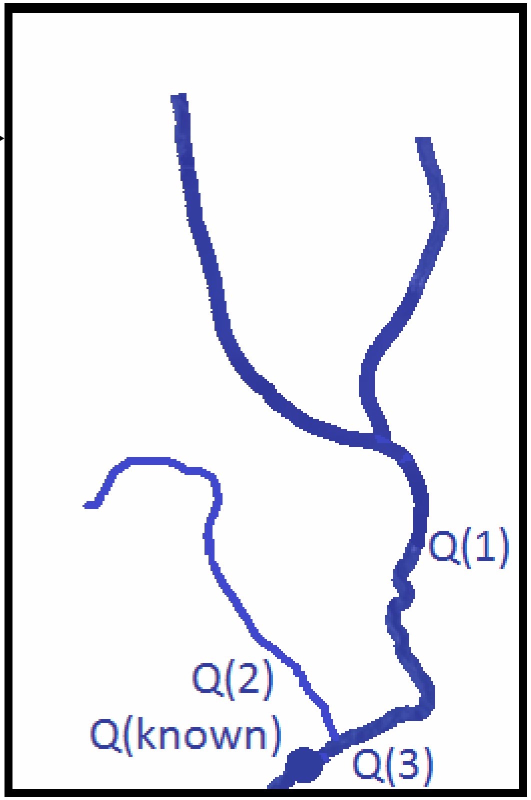
- Reconstruct the relevant unimpaired historical hydrology.
- Use this hydrology as input to a water resources systems model of the build infrastructure.
- Test implications of various management arrangements (e.g power generation, aquatic habitat conditions, recreations).
- Negotiate a license.

Reconstructing Unimpaired Historical Hydrology

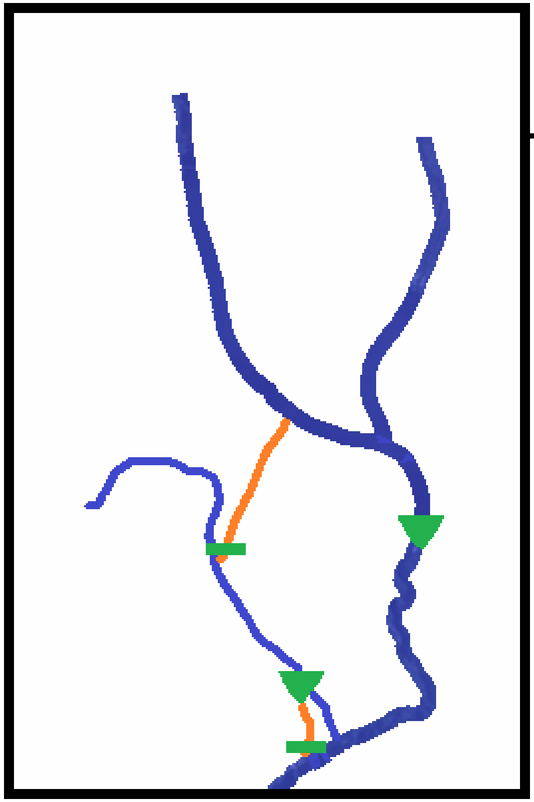


From the system…

…to the hydrology



Reconstructing Unimpaired Historical Hydrology



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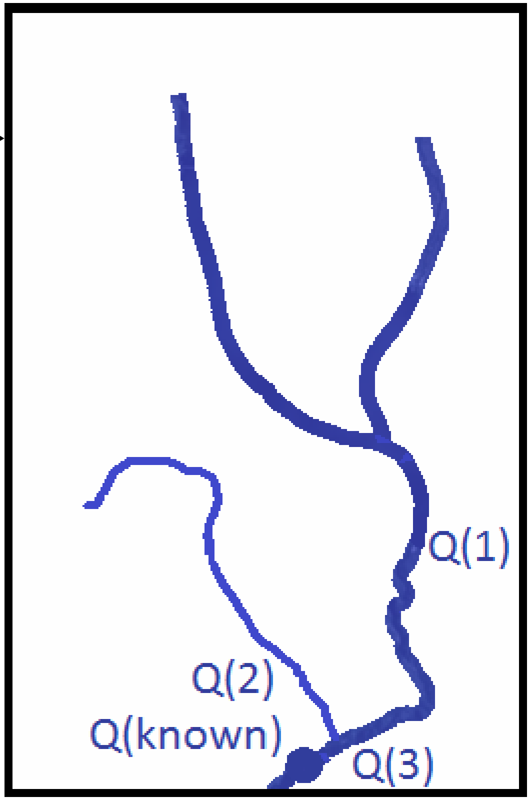
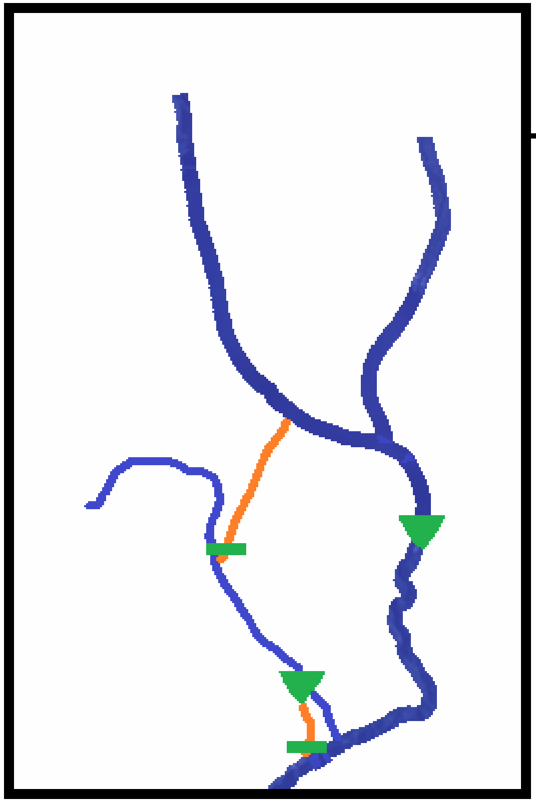


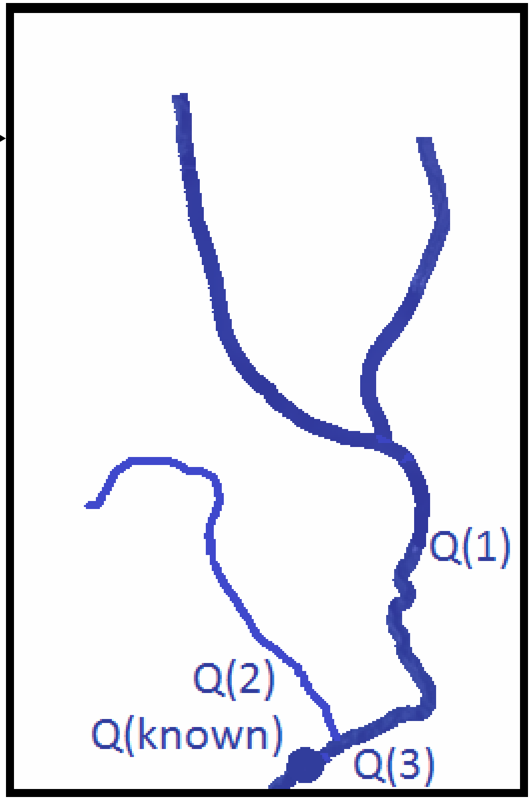
For Q(1) we might have a volume-elevation curve that can be used to estimate reservoir inflows from reservoir stage and release data and open water evaporation estimates

Reconstructing Unimpaired Historical Hydrology



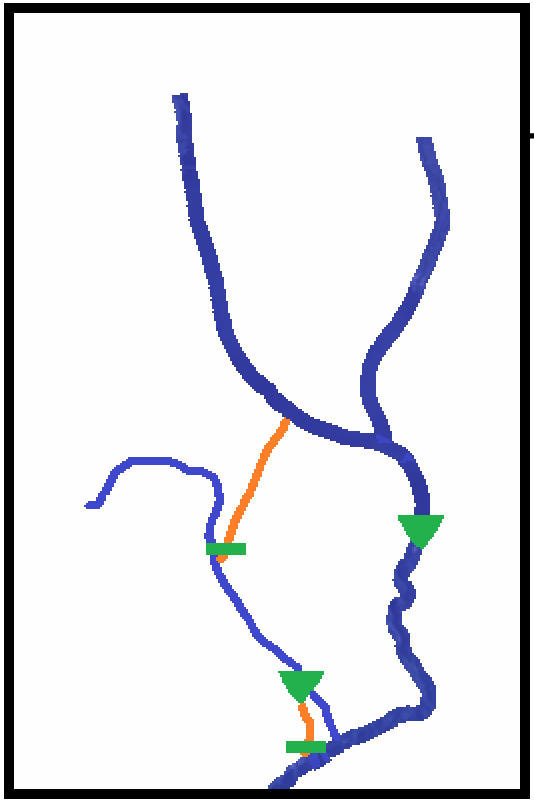
From the system…

…to the hydrology



For Q(2) we might be able to use watershed area scaling factors to estimate a valued based on measured flows at Q(known), corrected for the Q(1) estimate.

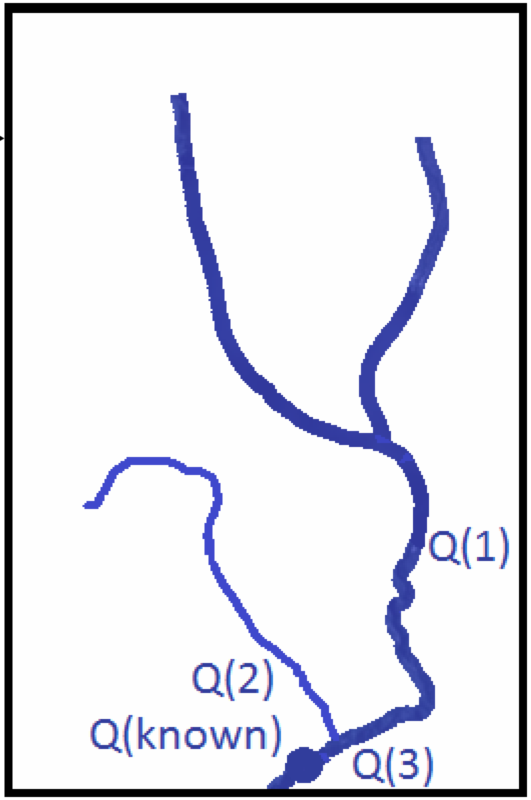
Reconstructing Unimpaired Historical Hydrology



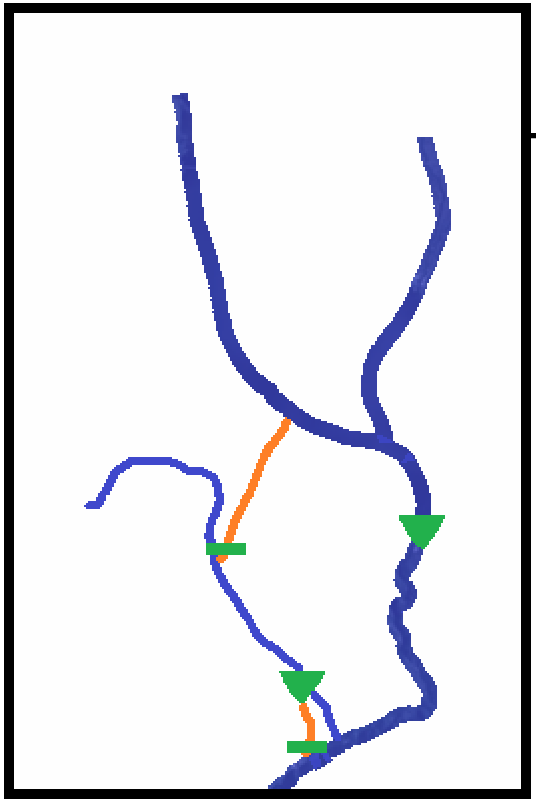
From the system…

…to the hydrology

For Q(3) we can estimate the incremental inflow downstream of Q(1) by subtracting the Q(1) and Q(2) estimates from measured flows at Q(known)

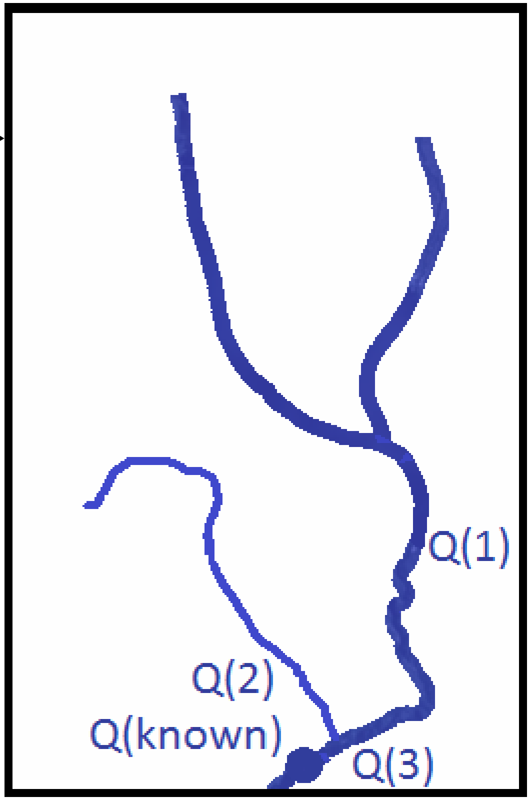


Reconstructing Unimpaired Historical Hydrology



From the system…

…to the hydrology



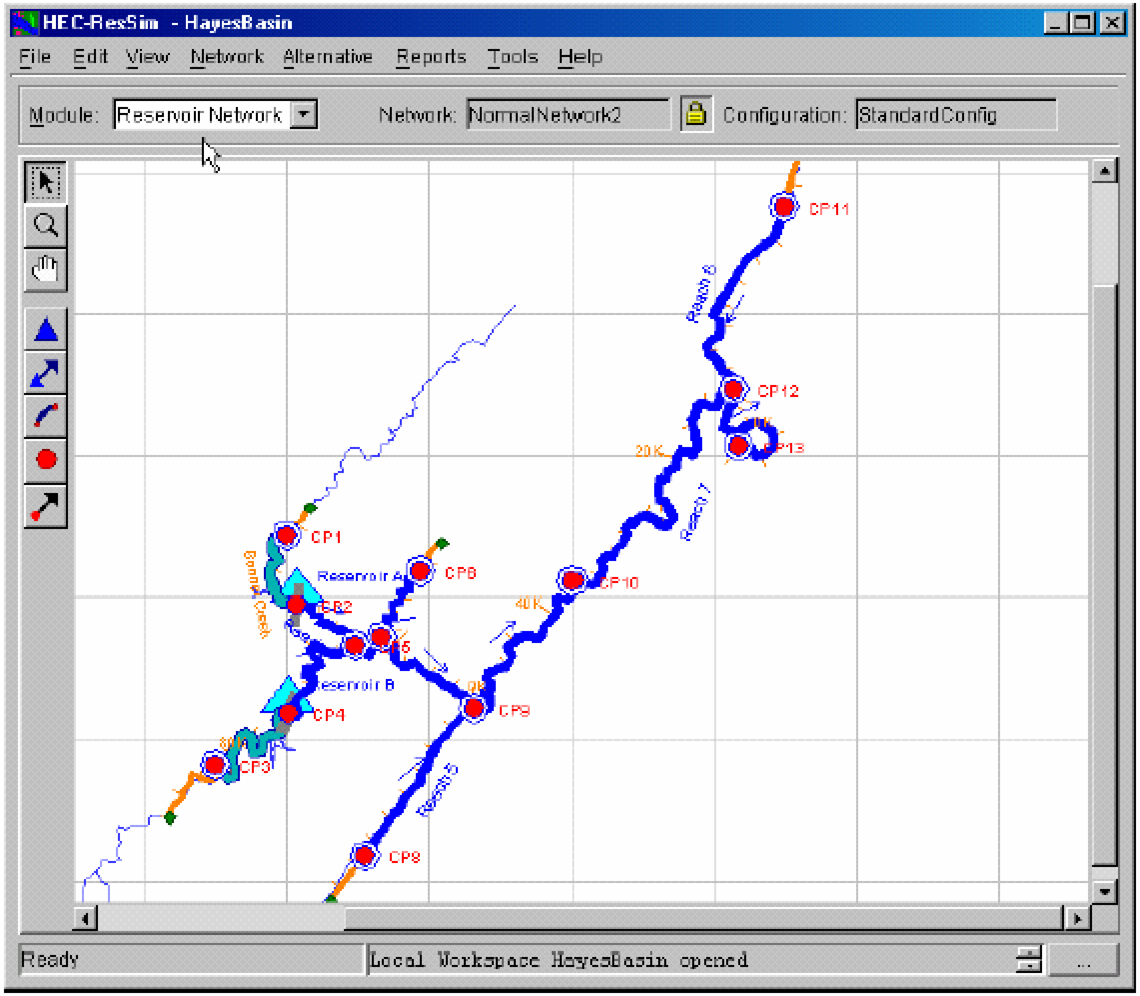
This process, in and of itself results, in a **model** of the unimpaired historical hydrology, not a measured set of streamflows.

“All models are wrong, some models are useful.”

George E.P. Box

Robustness in the Strategy of Scientific Model Building

Useful to FERC as input to Water Resource Systems Models



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Useful, but Still Appropriate?

POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.$500 billion (*1*).

An uncertain future challenges water planners.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now that has emerged from climate models (see figure, p. 574).

Why now? That anthropogenic climate change affects the water cycle (*9*) and water supply (*10*) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (*11*, *12*). Accounting for the substantial uncertainties of climatic parameters estimated from short records (*13*) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (*12*, *14*).

Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of climate models. The global pattern of observed annual streamflow trends is unlikely to have

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Modeling Hydropower Generation

$$\text{Maximize } Z = \sum_{i=1}^{12} P_i \times G_i \quad (1)$$

subject to

$$S_1 = 0 (\text{initial condition}) \quad (2)$$

$$S_i \leq Scap\,(\text{energy storage capacity}),\ \forall i \quad (3)$$

$$S_i = e_{i-1} + S_{i-1} - R_{i-1} (\text{conservation of energy}),\ \forall i \quad (4)$$

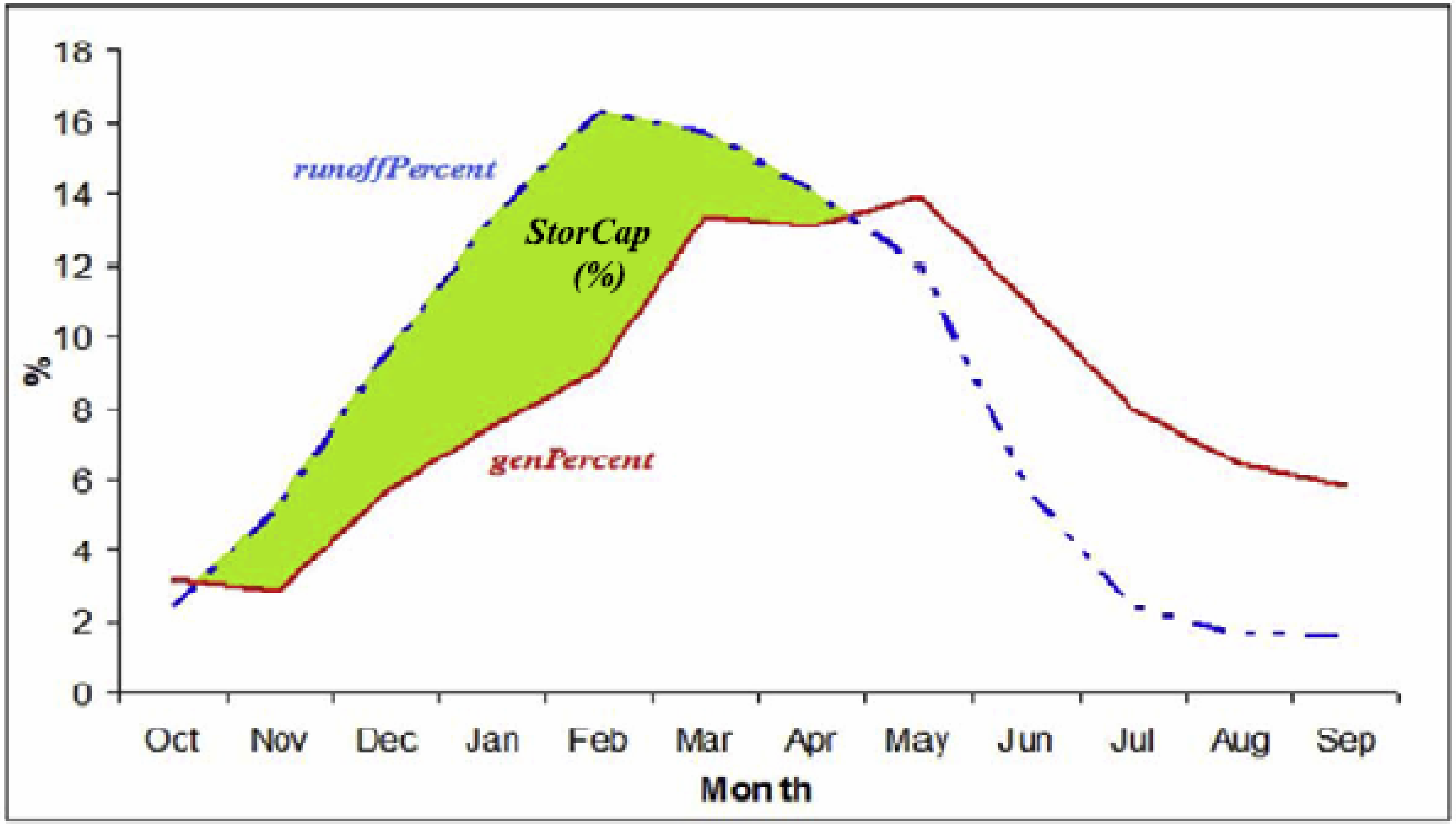
$$G_i \leq R_i,\ \forall i \quad (5)$$

$$G_i \leq Gcap\,(\text{generation capacity}),\ \forall i \quad (6)$$

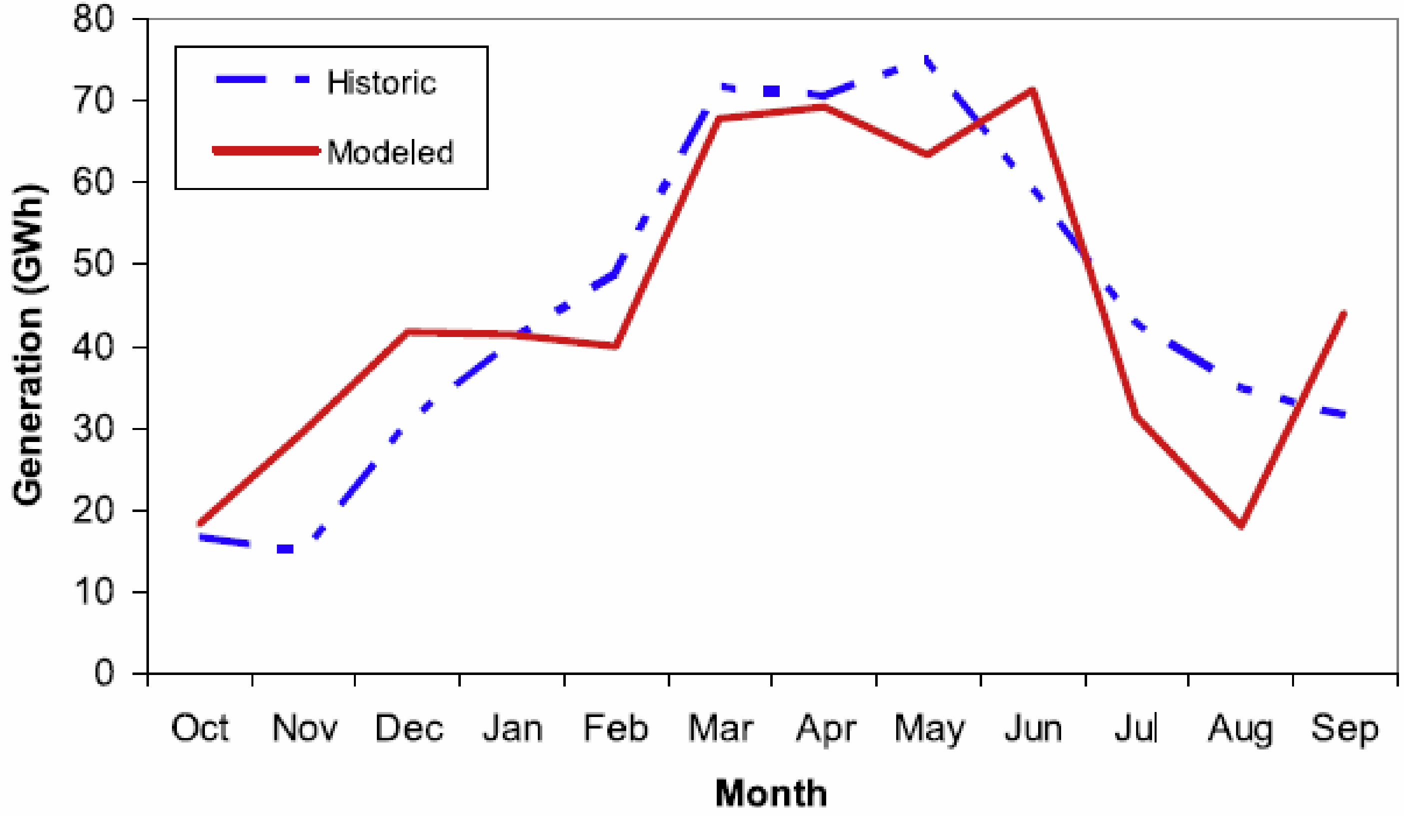
$$G_i, S_i, R_i \geq 0\,(\text{nonnegativity}),\ \forall i (i = 1, 2, 3, \ldots, 12) \quad (7)$$

WATER RESOURCES RESEARCH, VOL. 45, W09413, doi:10.1029/2008WR007206, 2009

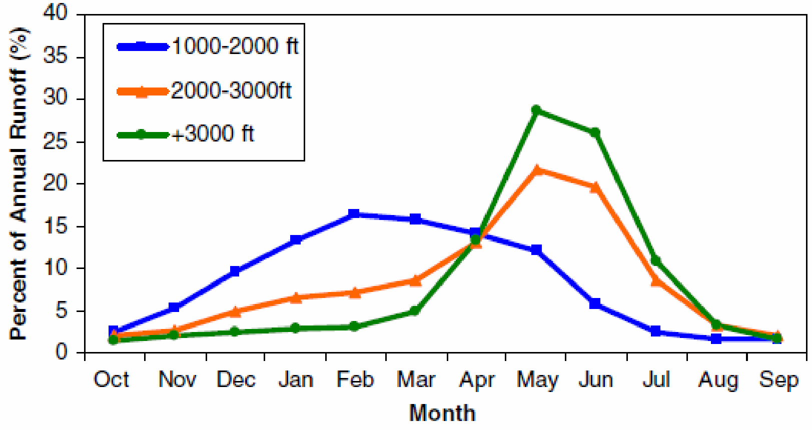
Estimating the Storage Capacity

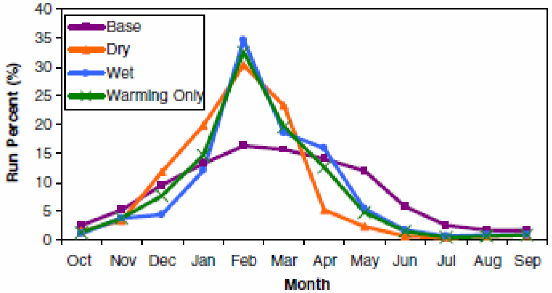


Model Calibration Results

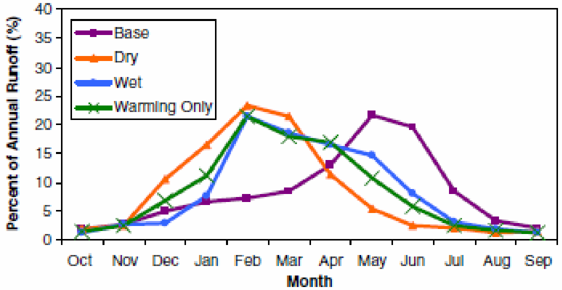


Now Introduce Climate Change

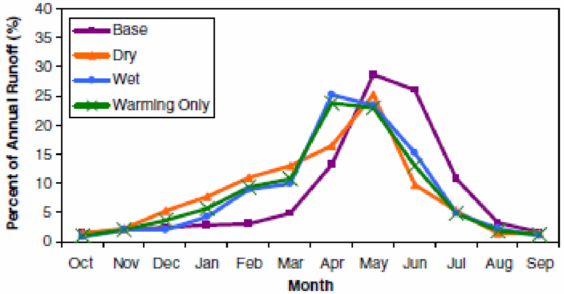




a) 1000-2000 ft



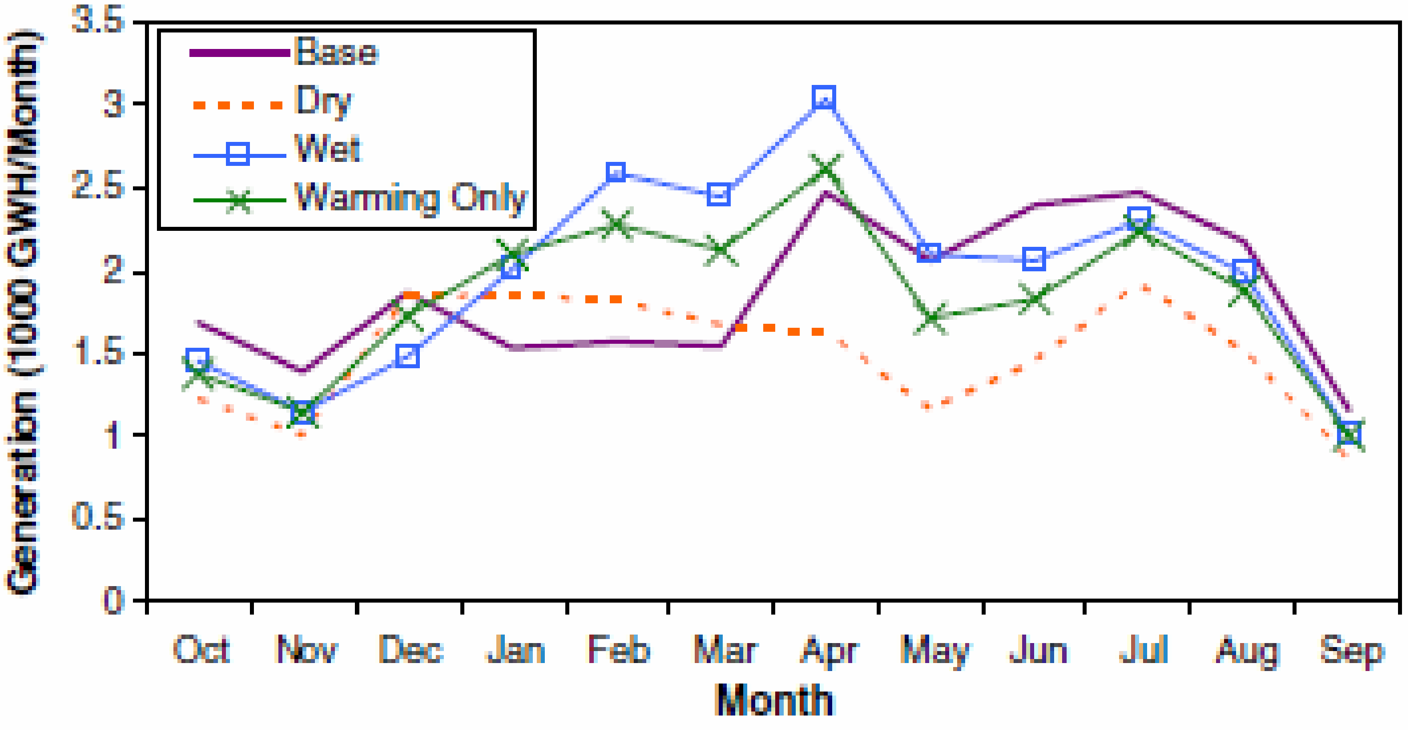
b) 2000-3000 ft



c) + 3000 ft

Climatic Change
DOI 10.1007/s10584-009-9750-8

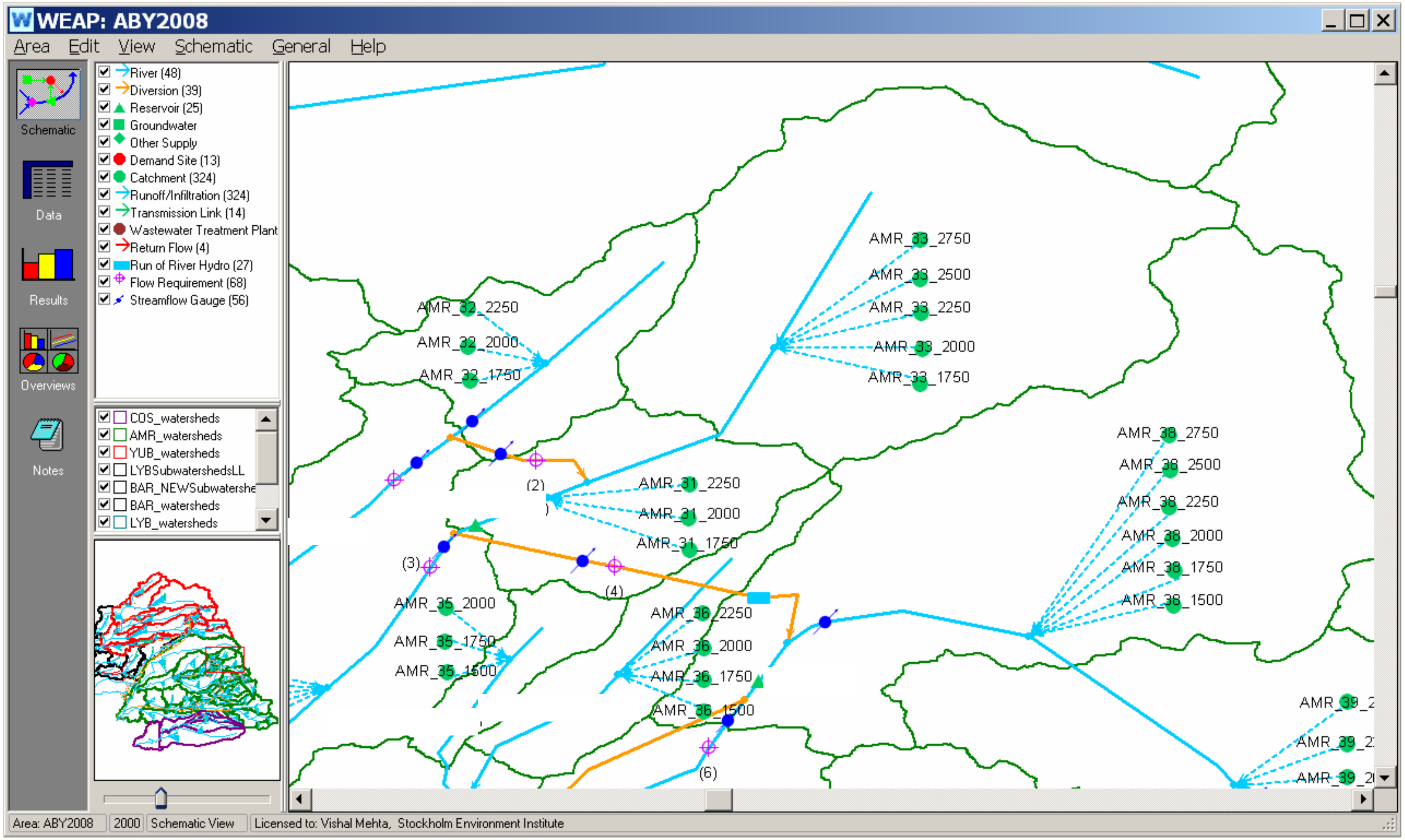
Change in Generation: 137 California Facilities



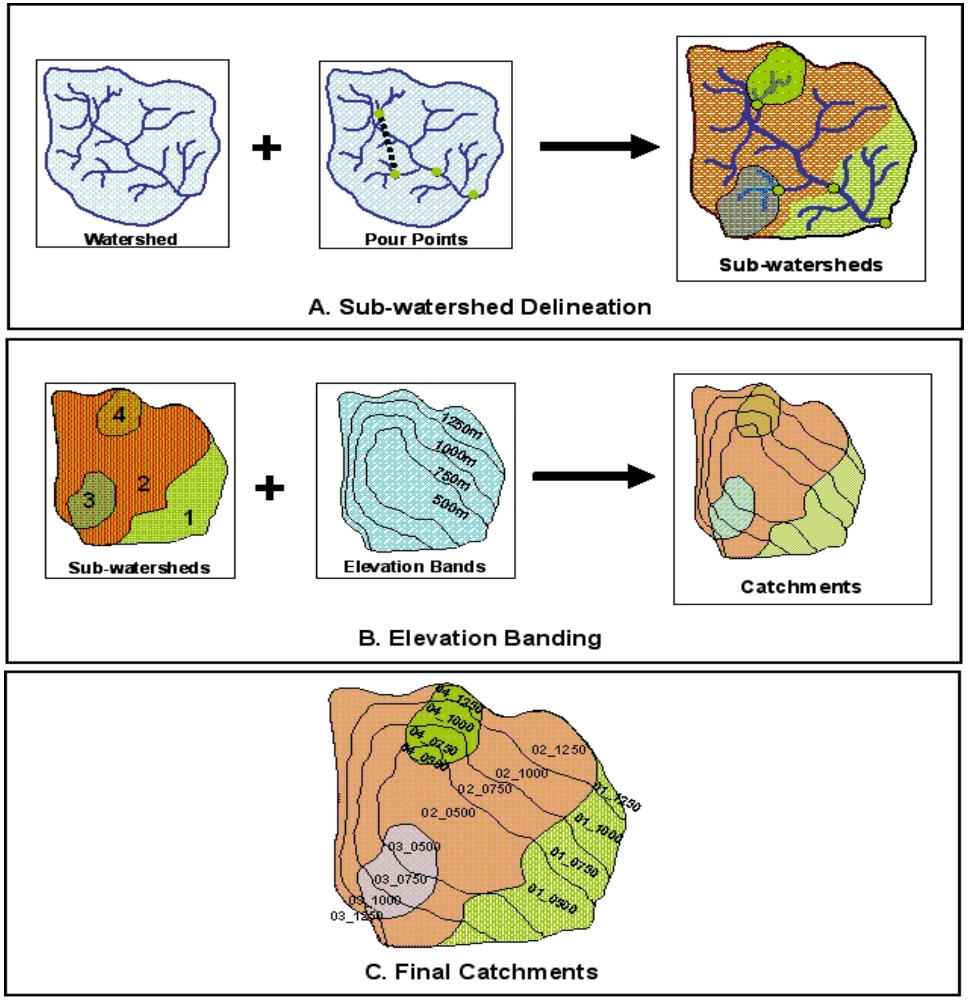
Assumptions

- Used perturbation of historical hydrology.
- Assumed that reservoirs completely fill over on annual cycle.
- Assumed that not spill occur.
- Assumed that all releases passed through generating facilities.

A More Refined Approach



Characterizing a Watershed



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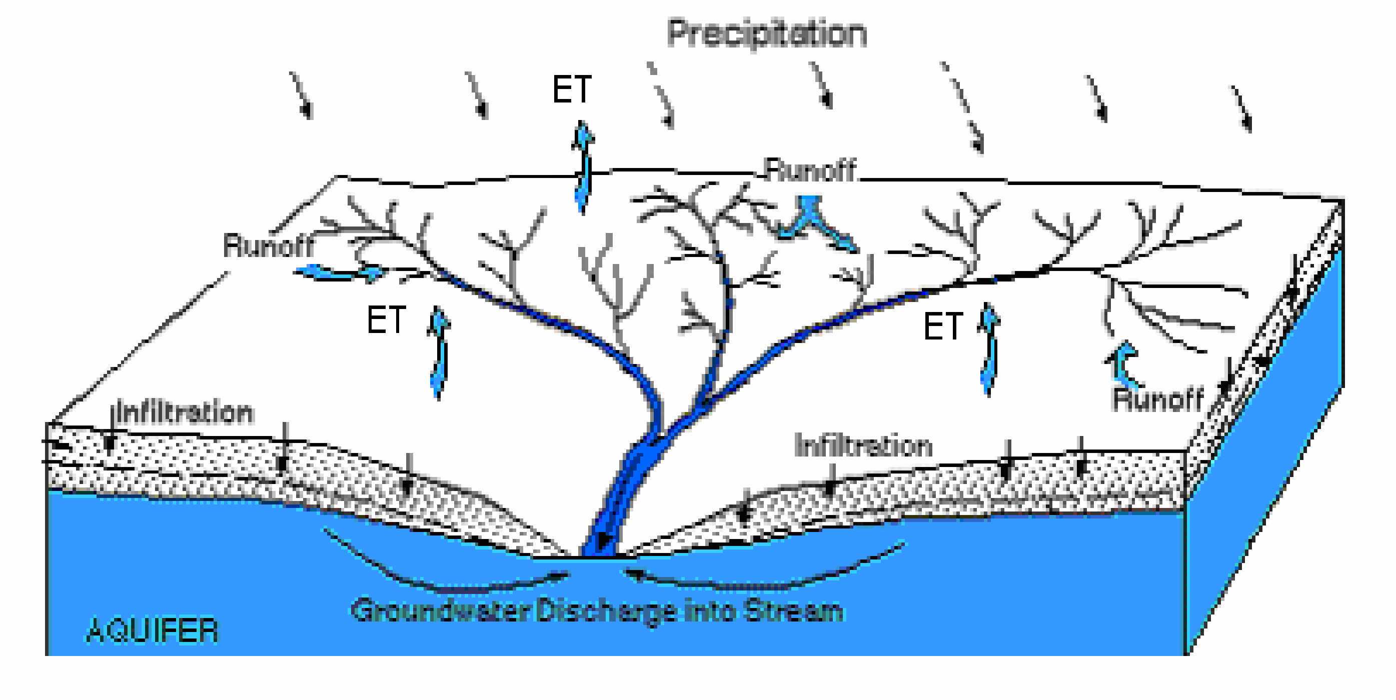
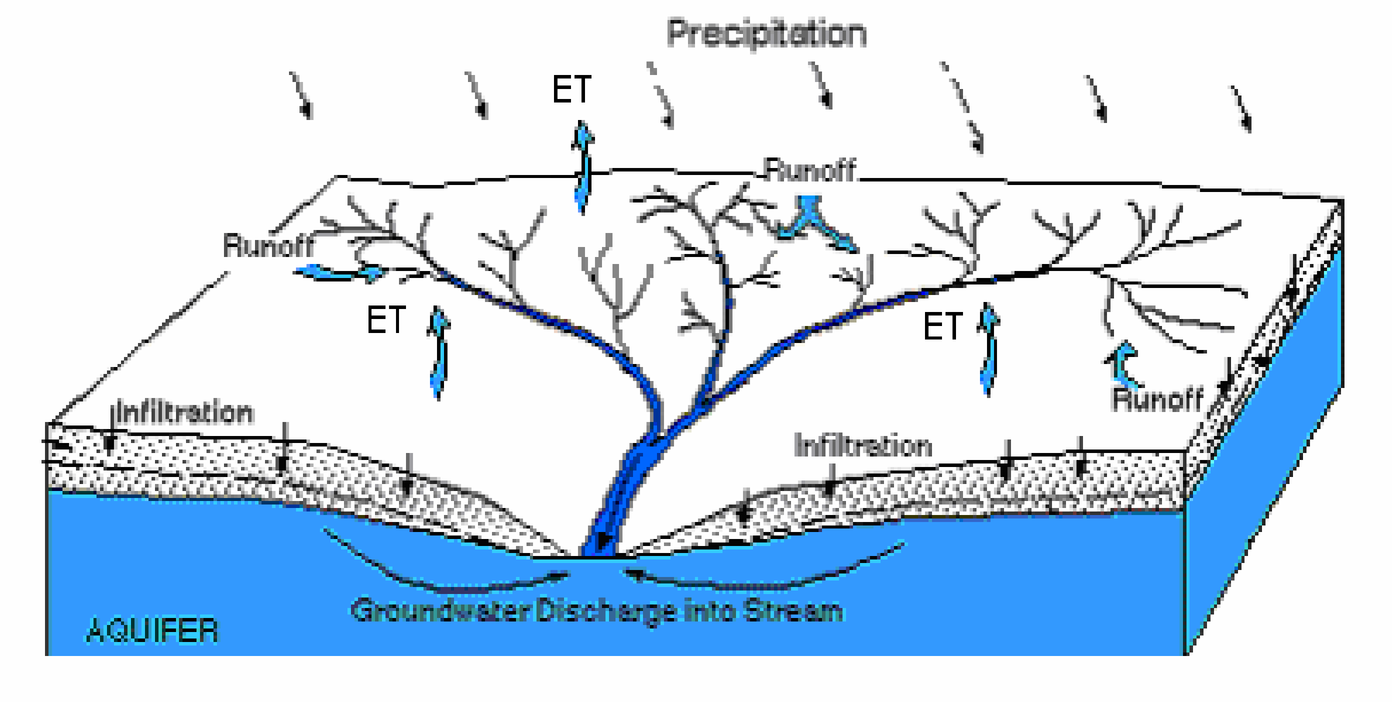
Hydrology Model



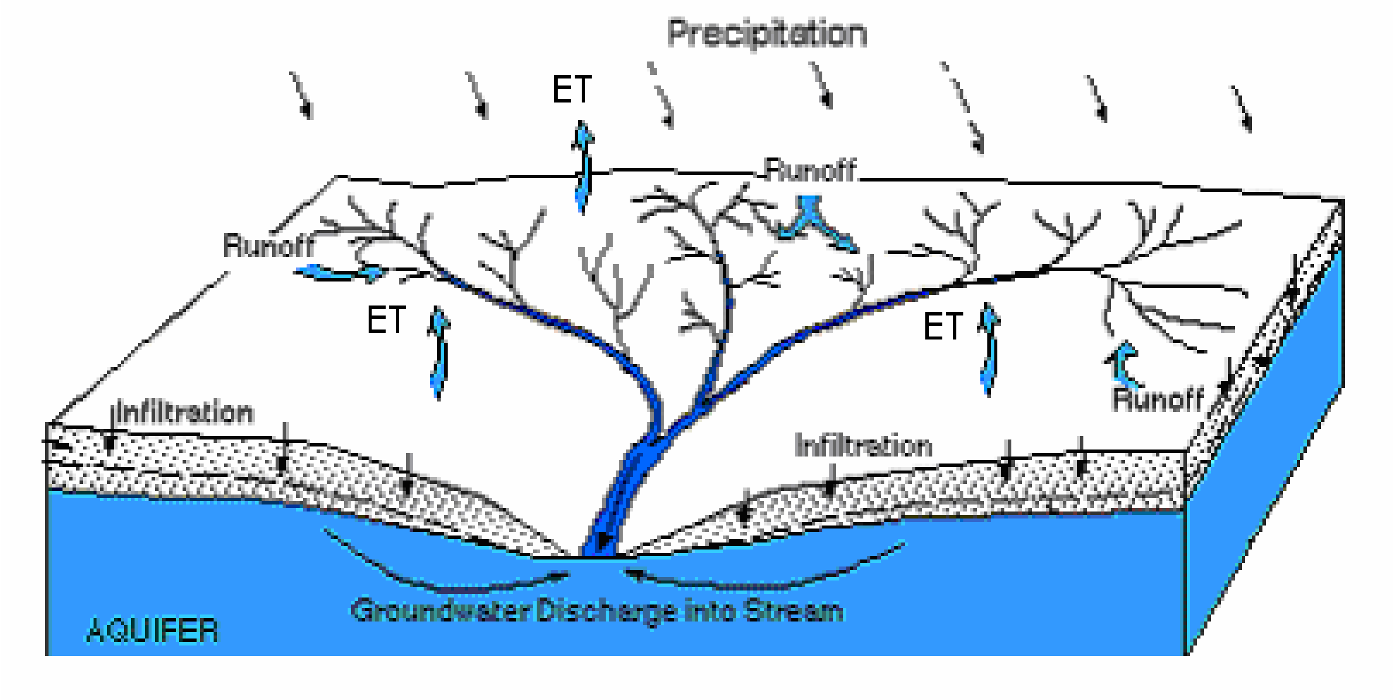
Critical questions: How does rainfall on a watershed translate into flow in a river?

Hydrology Model



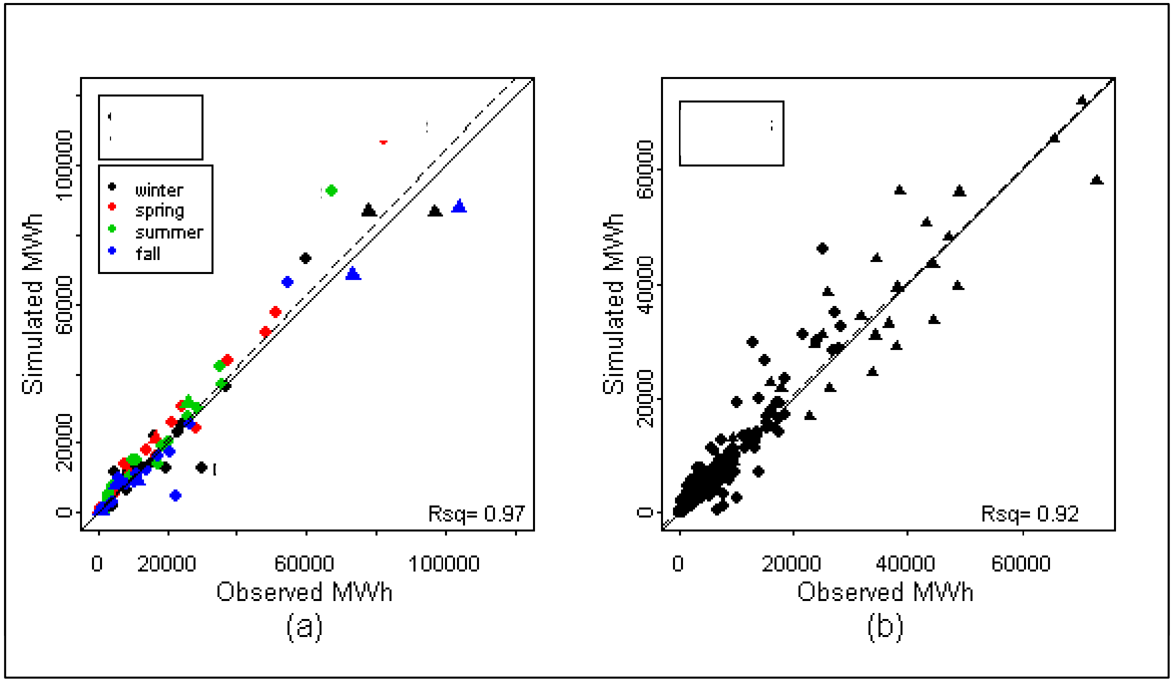
Critical questions: What pathways does water follow as it moves through a watershed?

Hydrology Model



Critical questions: How does movement along these pathways impact the magnitude, timing, duration and frequency of river flows?

Model Calibration Results



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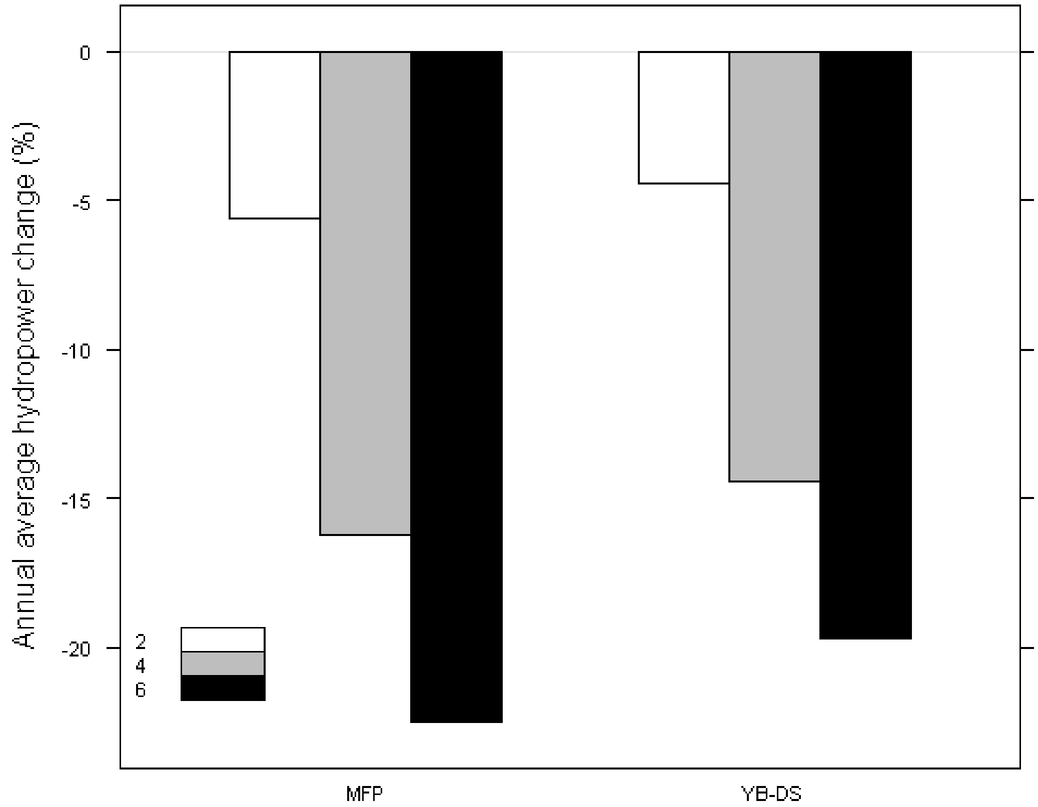
Simulated Changes in Generation



1. Is the science suggesting that hydrology will change in the future?

Yes, particularly in the West where snow plays such a critical role.

2. Does the science suggest that alternative future hydrology will influence the amount of hydropower that can be generated?

Yes, particularly if we maintain static operating objectives.

3. Does the science suggest that river ecosystem could be negatively impacted by climate change?

This is the subject of the next presentation.

4. Are all of these potential changes relevant to the FERC re-licensing process?

This is the topic of this workshop.

5. Do I have any ideas on how climate change could be integrated into the FERC process?

1. Introduce the concept of ‘acceptable risk’ into the negotiations.
2. Continually update the definition of water year types as hydrology changes.
3. Set ecosystem targets that factor in climate impacts on river ecosystems.