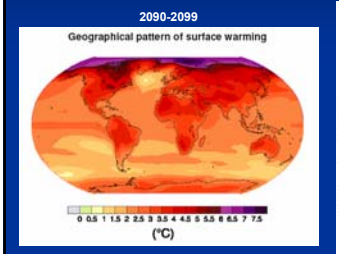
Response of California's Hydropower Rivers to Climate Change

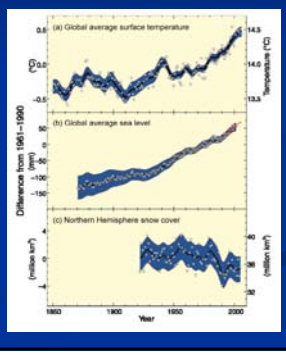
- Change is happening and will hurt some
- Adaptation and optimization reduces the financial costs
- Demand for ecosystem services beyond hydropower generation will be the greatest challenge

Acknowledgements

- *UC Davis*: J. Lund, J. Viers, P. Moyle, H. Doremus, K. Madani, M. Jenkins, et al.
- *Stockholm Environment Institute*: D. Purkey, C. Young, M. Escobar
- *Watercourse Engineering Inc*: L. Basdekas, M. Deas
- *Funding Provided by*: Resources Legacy Foundation Fund and California Energy Commission

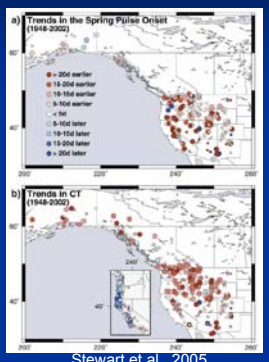
Global climate change science is consistent: we have warmed, are warming, and will warm

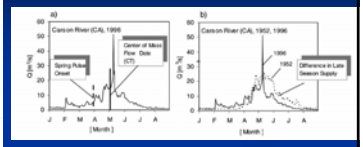




IPCC, 2007

Change is taking place regionally as well, albeit with less certainty about causes

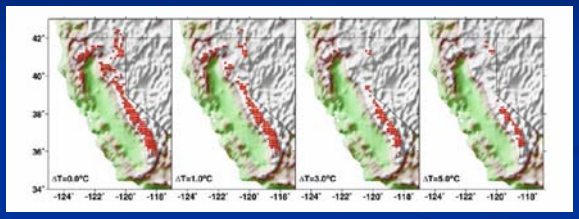




- Progressive negative shift in onset of spring snowmelt pulse
- Negative shift in center of mass
- Regional increase in average annual temperature

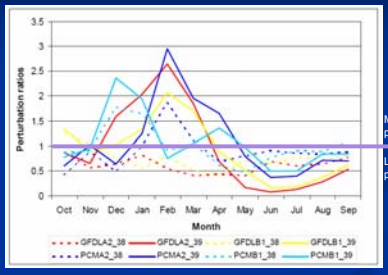
Stewart et al., 2005

A regionally-consistent prediction of a future with less snow/more rain

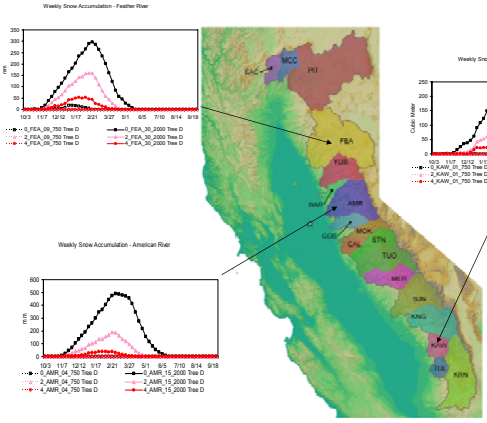


Snow-dominated regions under incremental temperature increases above 1961-1990 levels. Maurer et al., 2007

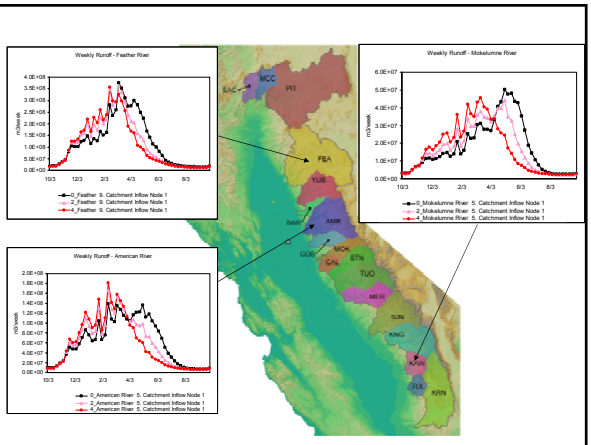
Spaghetti-diagrams dominate, reflecting proliferation of Global Circulation Models



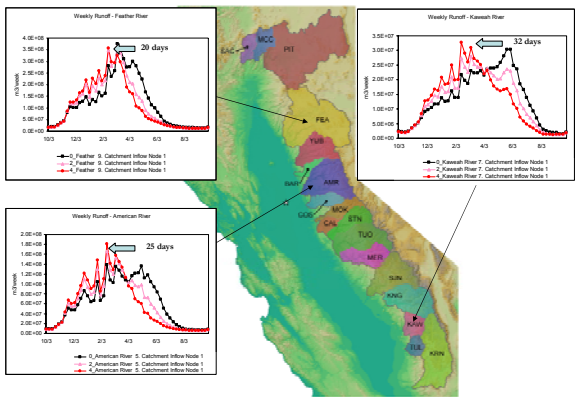
2007-2099 American River Flow Change Based on downscaled GCMs. Vicuña et al., 2006



UC Davis/SEI Sierran Rainfall-Runoff Model



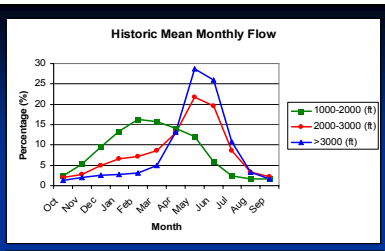
UC Davis/SEI Sierran Rainfall-Runoff Model

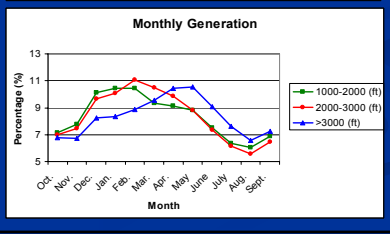


UC Davis/SEI Sierran Rainfall-Runoff Model

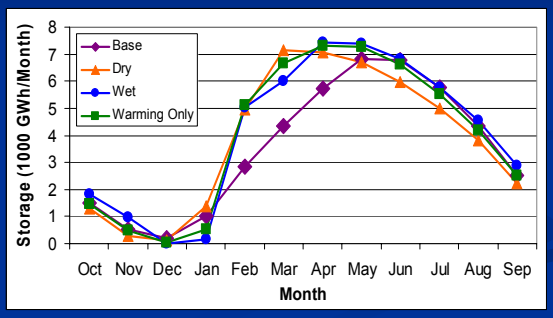
Impacts of Climate Change on Hydropower Operations

1. Energy demand
2. Timing of water availability
3. Quantity of water available
4. Availability of hydropower to import
5. Thermal generation efficiency

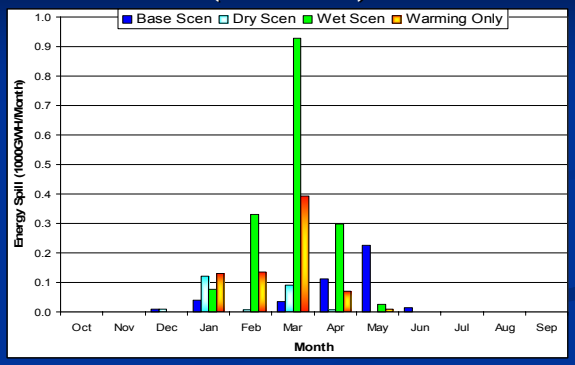




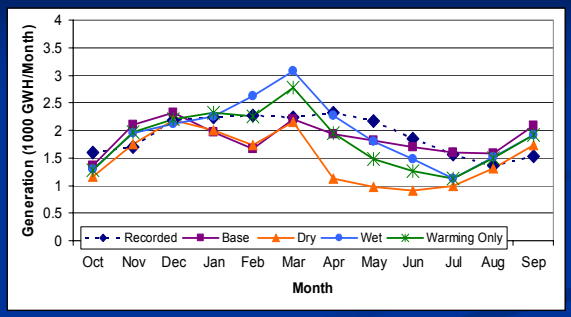
Optimized average total end-of-month energy storage (1984-1998)



Average monthly total energy spill (1984-1998)



Monthly Generation (Optimized)

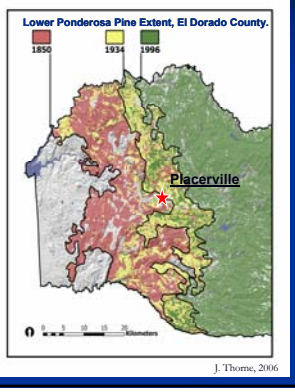


Model Results

	Scenario			
	Base	***Dry***	***Wet***	***Warming-Only***
Generation (1000 GWH/yr)	22.3	18.0	23.4	22.0
Generation Change with Respect to the Base Case (%)		- 19.3	+ 4.8	- 1.4
Spill (MWH/yr)	433	224	1,661	735
Spill Change with Respect to the Base Case (%)		- 46.0	+ 283.9	+ 58.8
Revenue (Million $/yr)	1,449	1,271	1,483	1,435
Revenue Change with Respect to the Base Case (%)		- 12.3	+ 2.3	- 0.9

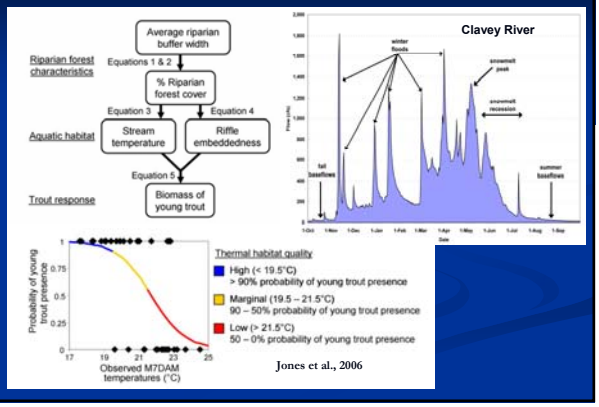
average of results over 1984-1998 period under four climate scenarios

Ecosystem Services



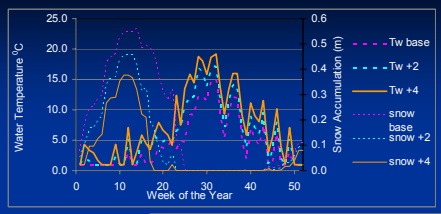
- Potentially significant shifts in ecological conditions
- Listed species and ecosystem service demands increase
- Tendency to seek "restoration" rather than "transitions"

Stresses on hydropower operations: maintenance of temperature and natural flow regime

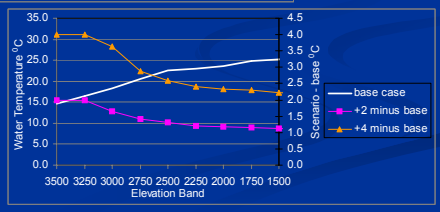


Jones et al., 2006

Kaweah River at 3500m elevation band

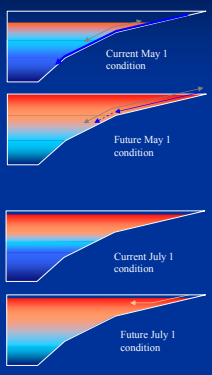


Kaweah River longitudinal change in temperature due to warming

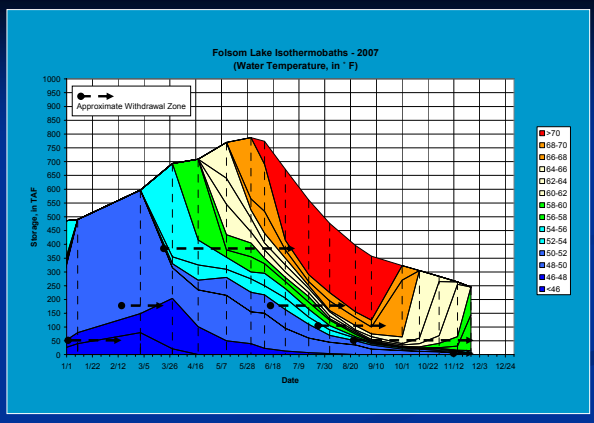


UC Davis/Watercourse Engineering Inc. Temperature Model

Cold Pool Management Challenges



- Increase storage to expand cold pool
- Construct new facilities for cold water storage
- Improve existing facilities (temp gates, etc.)
- Adapt facility operations



Climate Change: There's Something in it for Everyone

- Continued change, with no definitive answer to "how much"
- Optimization strategies significantly reduce the costs
- But these will be constrained by ecosystem services demands (FERC)