Impact of climate change on hydropower generation: implications to the re-licensing of hydropower units in California

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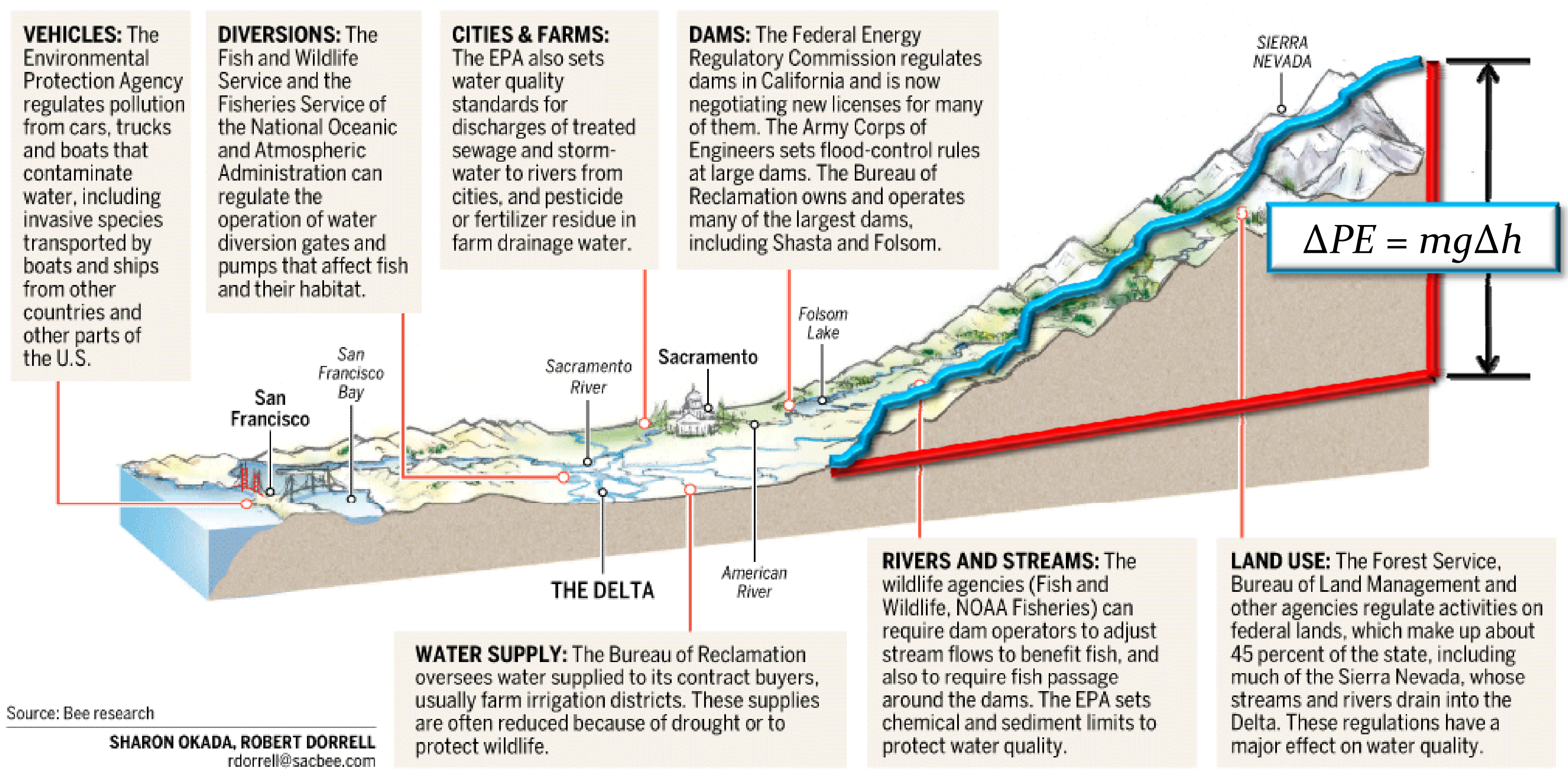
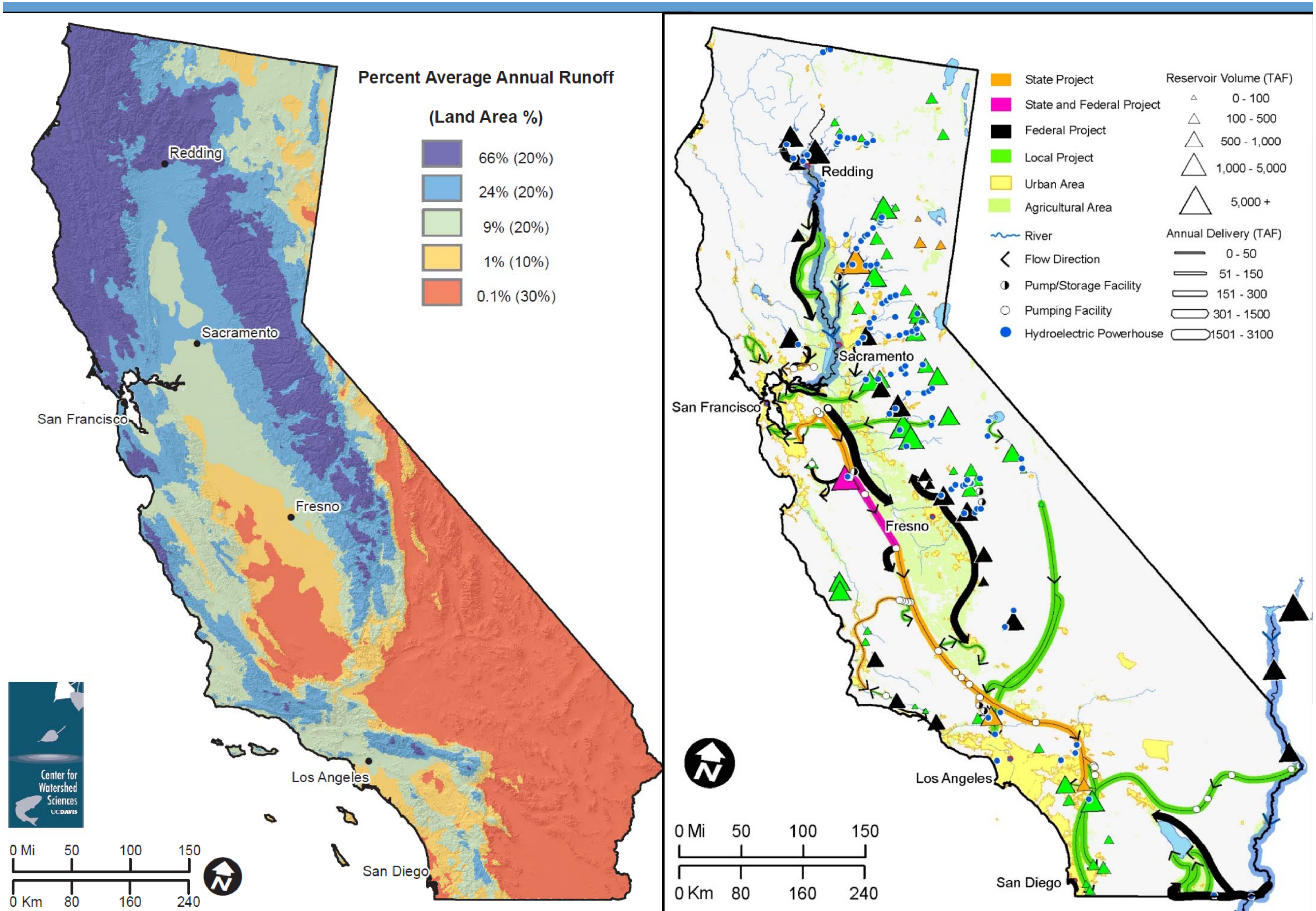
Vast Potential Energy *potentially at risk…*

Hydropower ~15% of California's Energy Supply (CEC)





Sierra Nevada supplies California with ~40% of its water supply and generates ~50% of its hydropower.

Change is taking place regionally, albeit with uncertainty at fine temporal and spatial scales

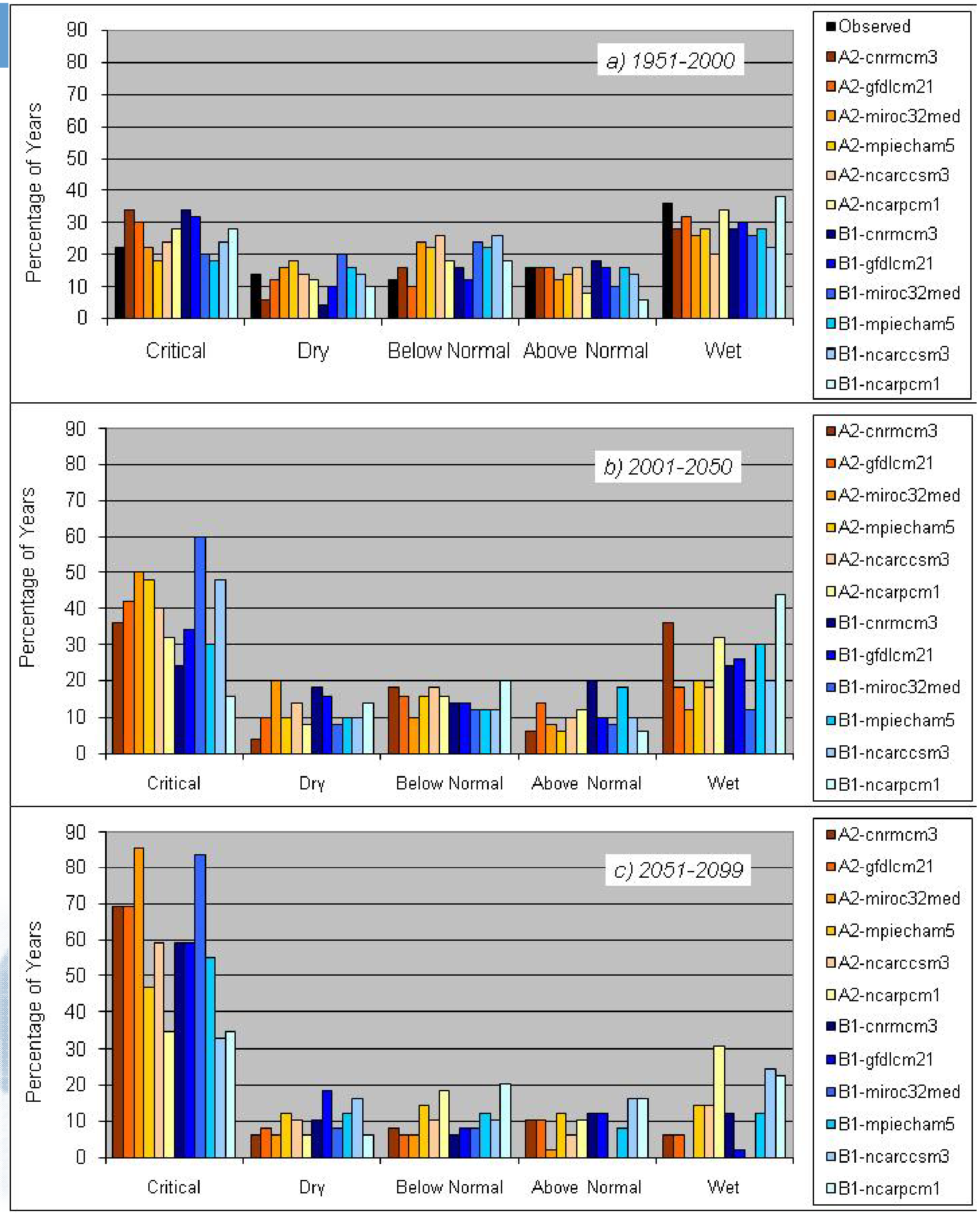
Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

Milly et al. 2008

- Progressive negative shift in onset of spring snowmelt pulse
- Negative shift in center of mass
- Regional increase in average annual air temperature
- Continued intra- and inter-annual variability in precipitation

Water year type distributions are expected to push to extremes.

- San Joaquin Valley Index
- A2 and B1 SRES
- 6 GCMs
  - CNRM CM3
  - GFDL CM2.1
  - CCSR MIROC 3.2
  - MPI-OM ECHAM5
  - NCAR CCSM3.0
  - NCAP PCM1
- BCSD VIC streamflow estimates



Null & Viers *In Review* Nature Climate Change

Impact of Hydroclimatic Alteration on Hydropower Resources

Research Findings:

Total energy produced is mostly linear in response to total resource availability (i.e., less water = less energy).

Timing and amount of resource is critical for infrastructure and operations to compensate for alteration in resource availability.

Adaptation is possible, but contingent resource demands make it difficult to meet all needs and maintain generation levels.

Recent Research focusing on Sierra Nevada

Macro

All Facilities
Annual Summaries
Coarse Operations

- Medellín-Azuara et al. 2009
- Madani & Lund 2010
- Null et al. 2010

Meso

Many Facilities
Seasonal Summaries
Contigent Operations

- Vicuña et al. 2011
- Mehta et al. 2011
- Rheinheimer et al. In Review

Micro

Limited Facilities
Refined Timesteps
Seasonal Operations

- Olivares 2008
- Rheinheimer et al. In Prep

Null SE, Viers JH, Mount JF (2010) Hydrologic Response and Watershed Sensitivity to Climate Warming in California's Sierra Nevada. PLoS ONE 5(4): e9932.

Uniform Warming

Average response over 20 WYs

+2°

+4°

+6°

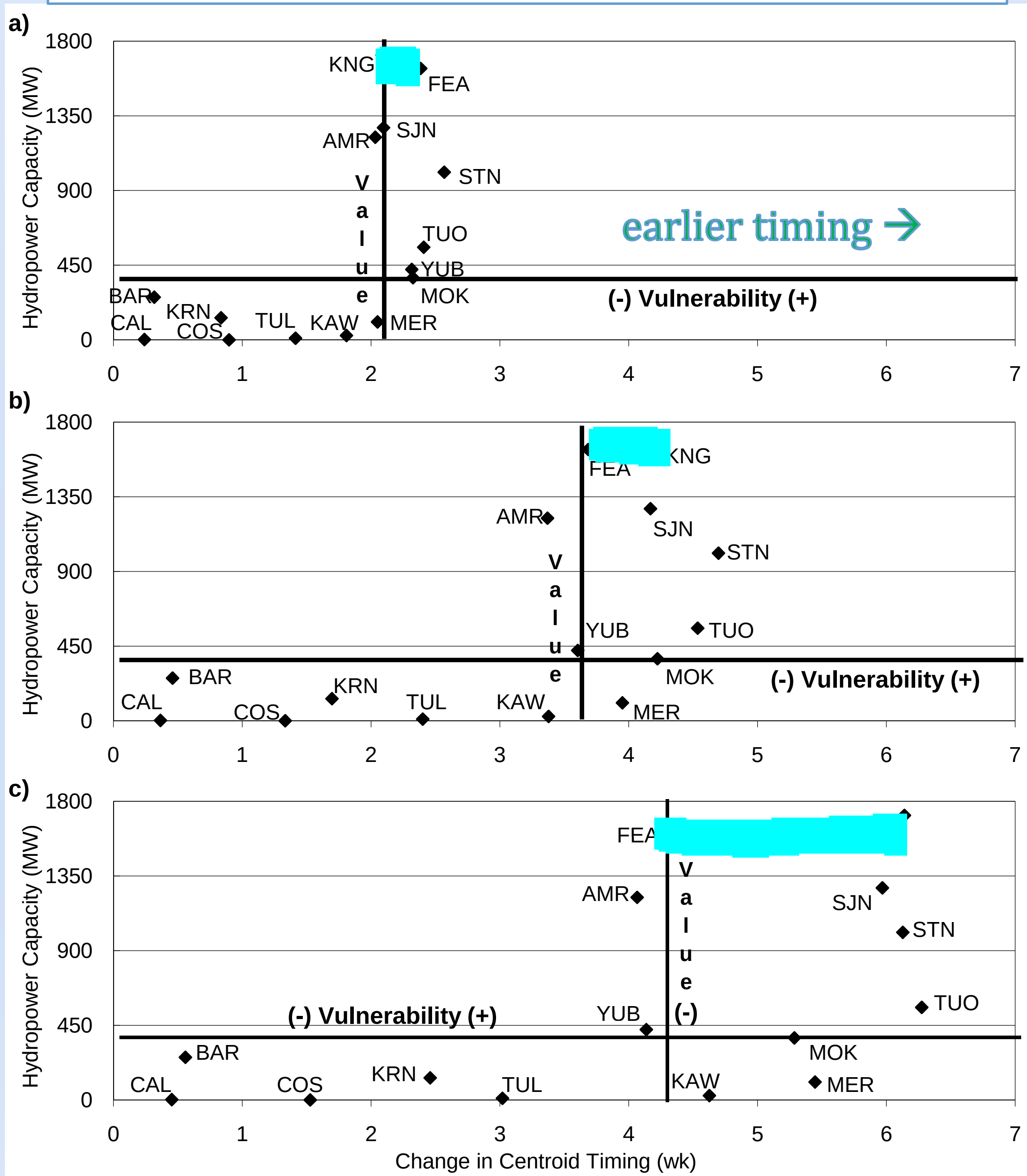


Table 5 Comparison of outputs for the two hydropower systems for various periods

Variable	Period	UARP System	Big Creek System
Energy generation in GWh[a]/year	Historical	1,976	3,580
	Early 21st C.	−2.1%	−0.6%
	Mid-21st C.	[illegible]	[illegible]
	Late 21st C.	−12.2%	−10.4%
Energy generation revenues in million $/year	Historical	130	212
	Early 21st C.	−1.3%	0.7%
	Mid-21st C.	−5.8%	−4.7%
	Late 21st C.	−8.5%	−7.8%
Average August power capacity in MW	Historical	654	1,034
	Early 21st C.	−0.2%	−0.1%
	Mid-21st C.	−0.2%	−0.1%
	Late 21st C.	−0.1%	−0.2%
Average Spills[b] in m^3/s	Historical	8	98
	Early 21st C.	19.2%	−0.5%
	Mid-21st C.	−1.8%	−17.3%
	Late 21st C.	10.8%	−21.8%

Vicuña et al. 2011

Climatic Change (2010) 102:521–538 527

Table 1 EBHOM's results (average of results over 1985–1988 period) for different climate scenarios

	Base	Dry	Wet	Warming-only
Generation (1,000 GWH/year)	22.3	17.9	23.6	22.0
Generation change with respect to the base case (%)		[illegible]	[illegible]	[illegible]
Spill (MWH/year)	130	96	1,112	735
Spill change with respect to the base case (%)		*−26*	*+755*	*+255*
Revenue (million $/year)	1,791	1,536	1,822	1,754
Revenue change with respect to the base case (%)		*−14.2*	*+1.7*	*−2.1*

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

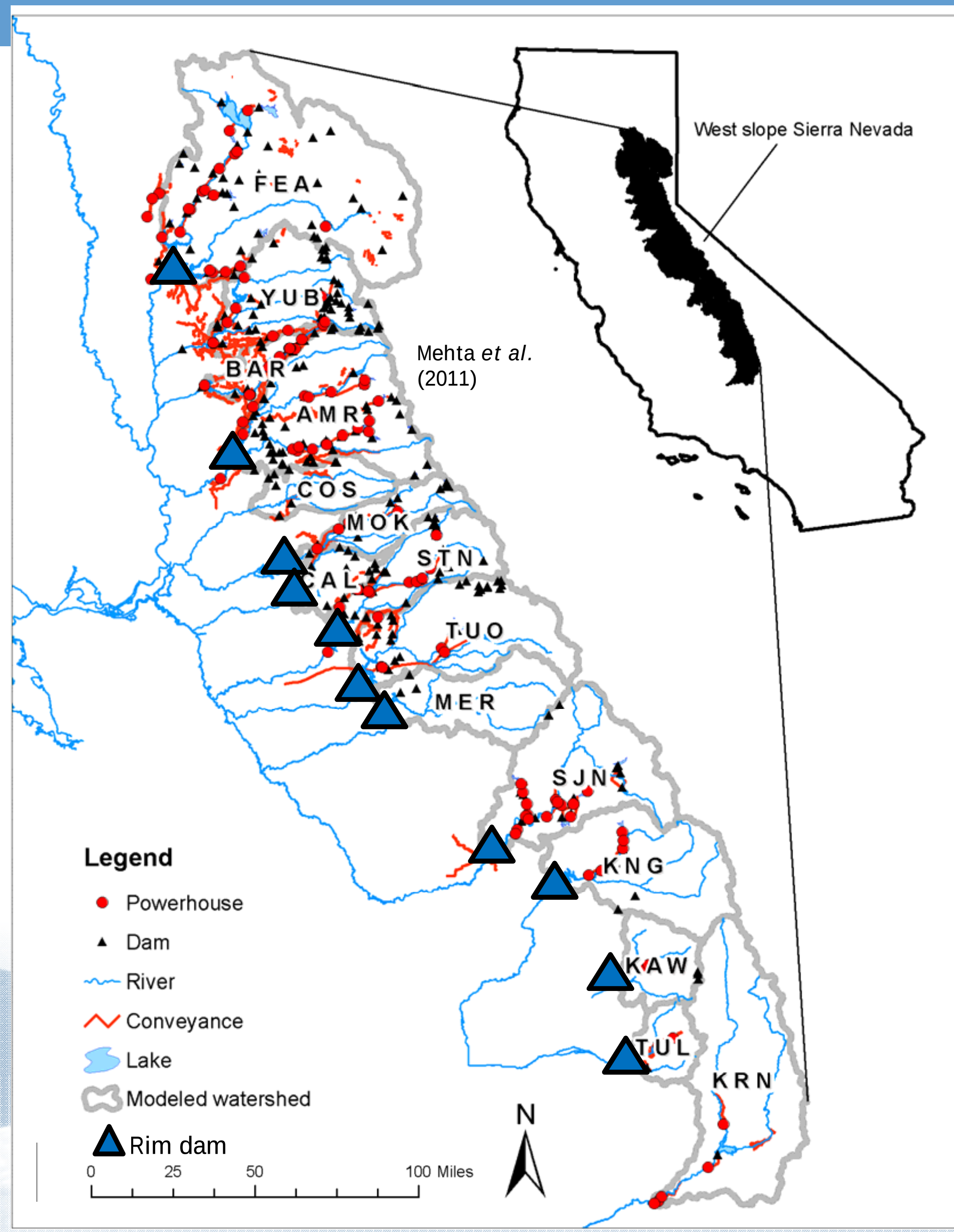
Madani & Lund 2010

SIERRA model

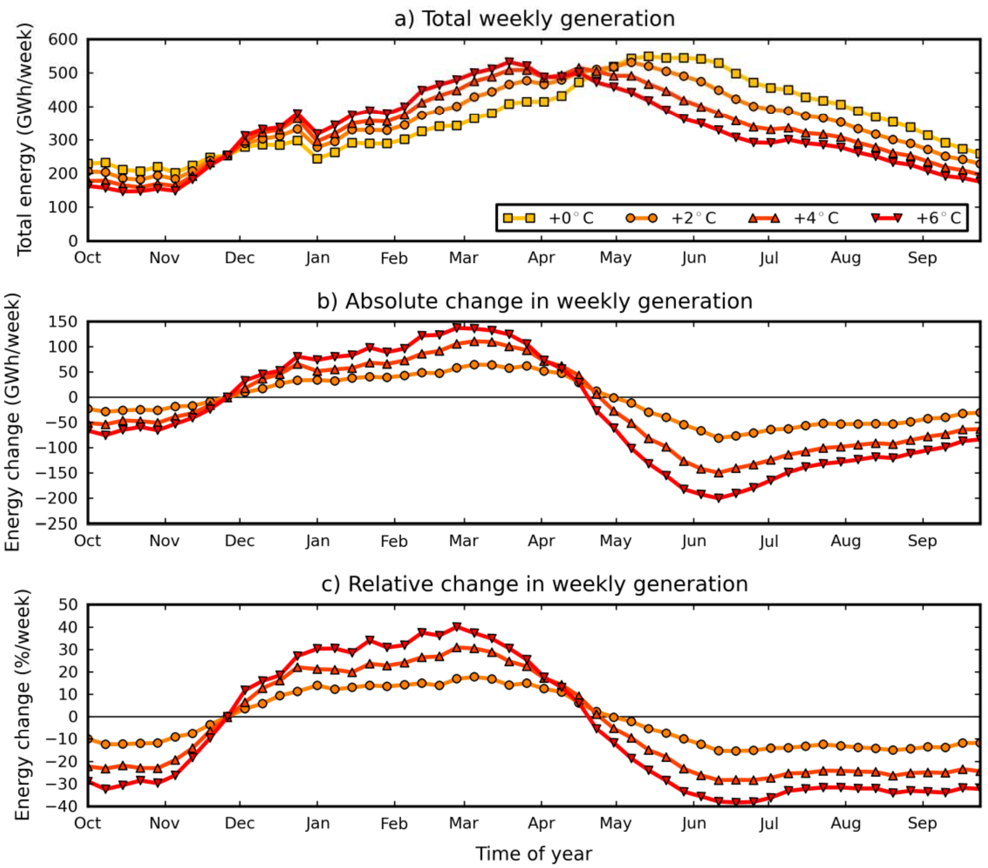
- **15 basins**
- **415 managed features:**
  - 56 reservoirs, 7.7 MAF
  - 85 run-of-river hydropower plants
  - 16 variable head hydropower plants
  - 125 diversion channels
  - 27 supply demands
  - 106 instream flow requirement points
- **Above "rim" dams**
- **Weekly time step**

Applied using:

- **20 years (1981-2000)**
- **Inflows:**
  Young et al., 2009
- **+0, 2, 4, and 6°C** uniform warming
- Modeled with WEAP21



Change in Weekly Generation



Mean weekly system wide energy generation with warming.

Rheinheimer, Viers, et al. In Revision

Seasonal and Annual Changes in Generation

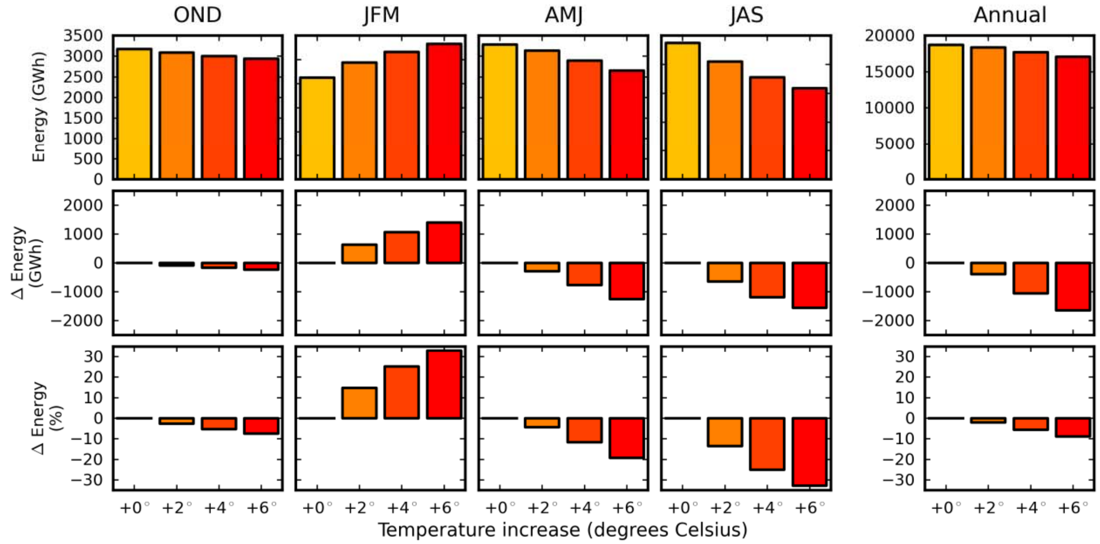


Figure 11: Seasonal and annual hydropower generation with warming.

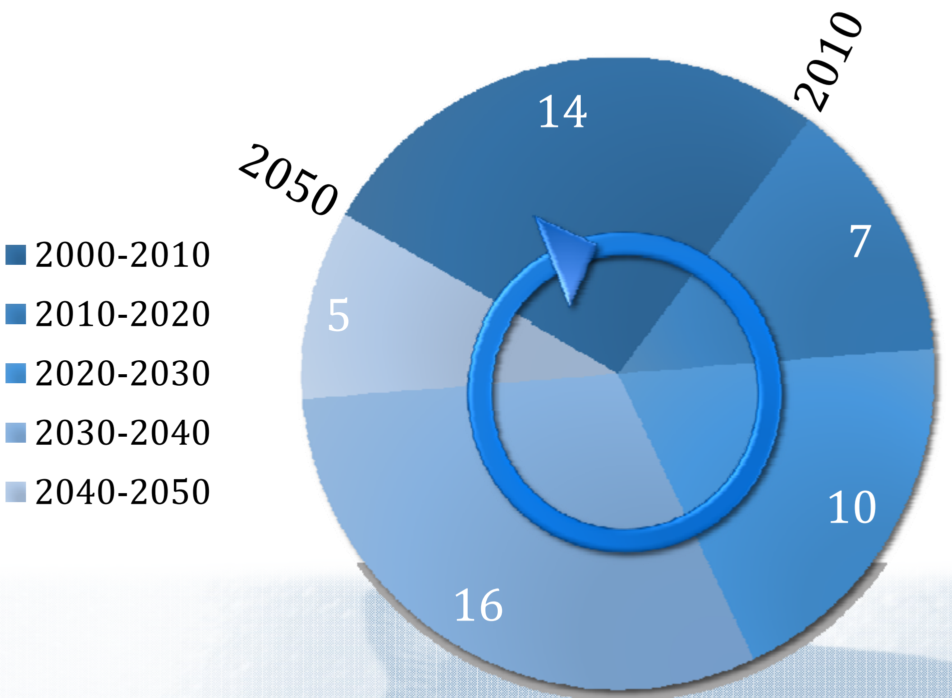
Generation	Warming scenario	OND (Fall)	JFM (Winter)	AMJ (Spring)	JAS (Summer)	
Total (GWh)	dT0	3,157	4,271	6,584	4,724	18,735
	dT2	3,066	4,902	6,268	4,089	18,325
	dT4	2,969	5,334	5,785	3,548	17,636
	dT6	2,897	5,662	5,298	3,177	17,033
Change (GWh)	dT0	--	--	--	--	--
	dT2	-91	631	-316	-635	-410
	dT4	-188	1,063	-799	-1,176	-1,100
	dT6	-260	1,391	-1,286	-1,547	-1,702
Change (%)	dT0	--	--	--	--	--
	dT2	-3%	15%	-5%	-13%	-2%
	dT4	-6%	25%	-12%	-25%	-6%
	dT6	-8%	33%	-20%	-33%	-9%

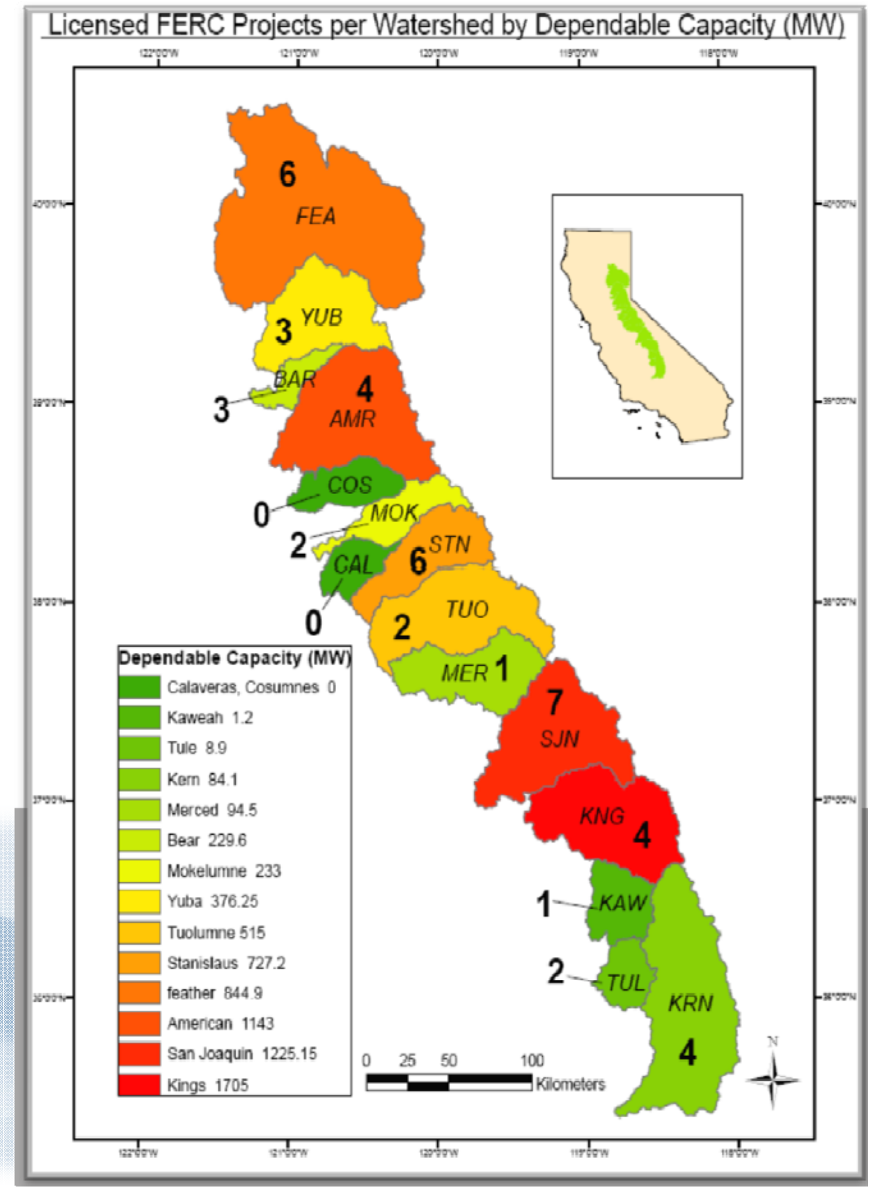
dT6 -8% 33% -20% -33%

Rheinheimer, Viers, et al. In Revision

FERC (Re)Licensing in the coming decades…

~60% of licenses remain up for renewal by 2050.





Hydropower is also a renewable source of energy that does not emit greenhouse gases through generation, and presently contributes to 15% of California's total power system supply (California Energy Commission, 2008).

FERC does presently consider climate change in hydropower project relicensing

Project Nexus

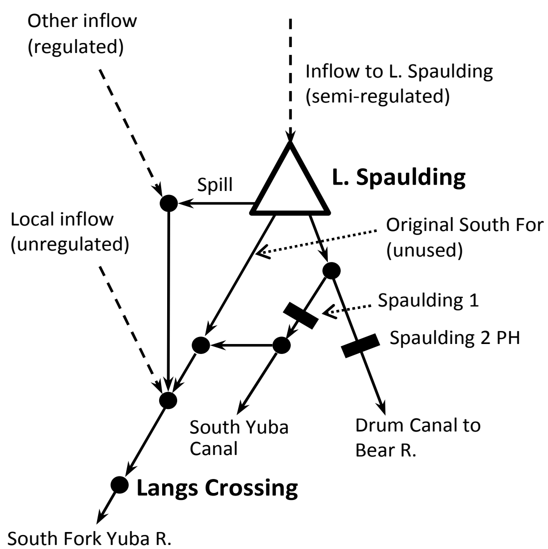
§5.9(b)(5) Explain any nexus between project operations and effects (direct, indirect, and/or cumulative) on the resource to be studied, and how the study results would inform the development of license requirements;

"Although there is consensus that climate change is occurring, we are not aware of any climate change models that are known to have the accuracy that would be needed to ***predict the degree of specific resource impacts*** *and serve as the basis for informing license conditions."*

Office of Energy Projects, in *Study Plan Determination for the Yuba-Bear, Drum-Spaulding, and Rollins Projects (February 23, 2009)* Federal Energy Regulatory Commission, Ed. (Washington, DC, 2009), pp. 32.

Viers, JH. 2011. Hydropower Relicensing and Climate Change. *Journal of the American Water Resources Association*

PIER Case study: Yuba River Watershed



Selective withdrawal

- Reservoirs seasonally stratify:
  Completely mixed in winter, stratified in summer
- **Selective withdrawal**: multiple outlets at different elevations

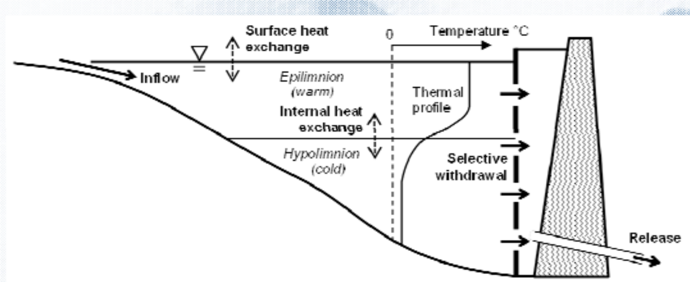
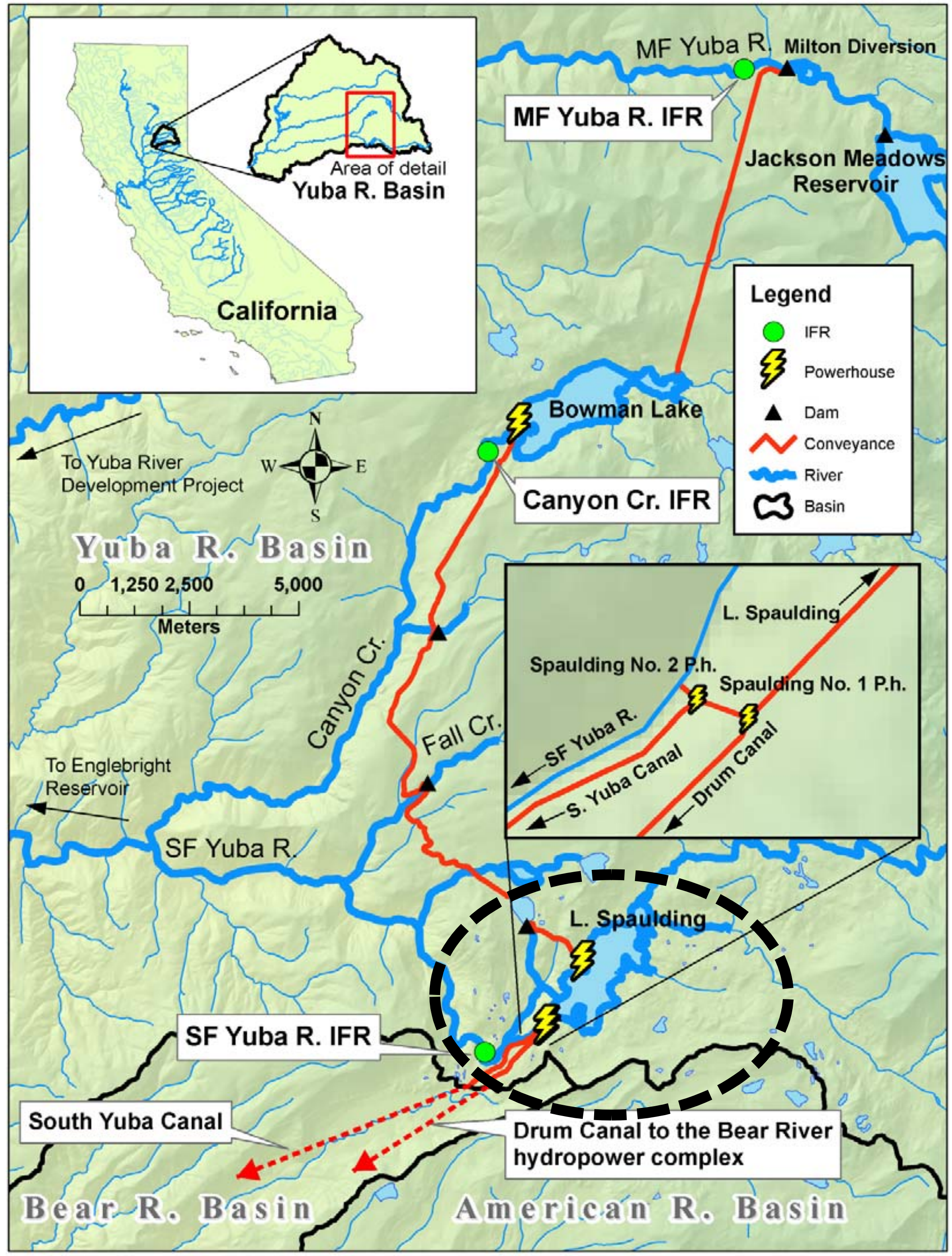


Figure adapted from Fontane et al. (1981).



Potential FERC Remedies

- Aggregation of Licenses
  - minimize cumulative effects of serial flow manipulation
  - minimize direct liability by any one licensee
  - <u>include federal dams</u>
- Escrow Accounts
  - third-party administration
  - intended to remove partiality of licensee hired consultants
  - improve standardization across study plans
- Regionalization
  - specific projects and water resources are assessed for their marginal benefit to the public trust
  - Basin "specialization" becomes important: water delivery, flood control, aquatic ecosystems, recreation evaluated beyond project boundaries
- Climate Adaptation
  - embrace uncertainty
  - enable flexibility
  - employ policy feedbacks

Adapt yes, but how exactly?

> . . . By contrast, the issues lying at the heart of climate change concern dynamics and disequilibrium – how long will it take for people to perceive changes in climate and respond to them? Will they refuse to acknowledge such changes when they occur, or will they quickly anticipate them? [redacted] (Fisher and Hanemann, 1993).

- <u>What is likely?</u> ››
  - *reactive* adaptation: local, single actor, short run decisions, private domain
- <u>What is needed?</u> ››
  - *anticipatory* adaptation: regional, multiple actors, middle & long run decisions, public domain

- Legal framework based on surety; “re-openers” rare
- “Adaptive management” both unsure and without precedent

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