Resolving Projections for the Colorado River Basin

Colorado River Board of California
September 9, 2009
Ontario, CA

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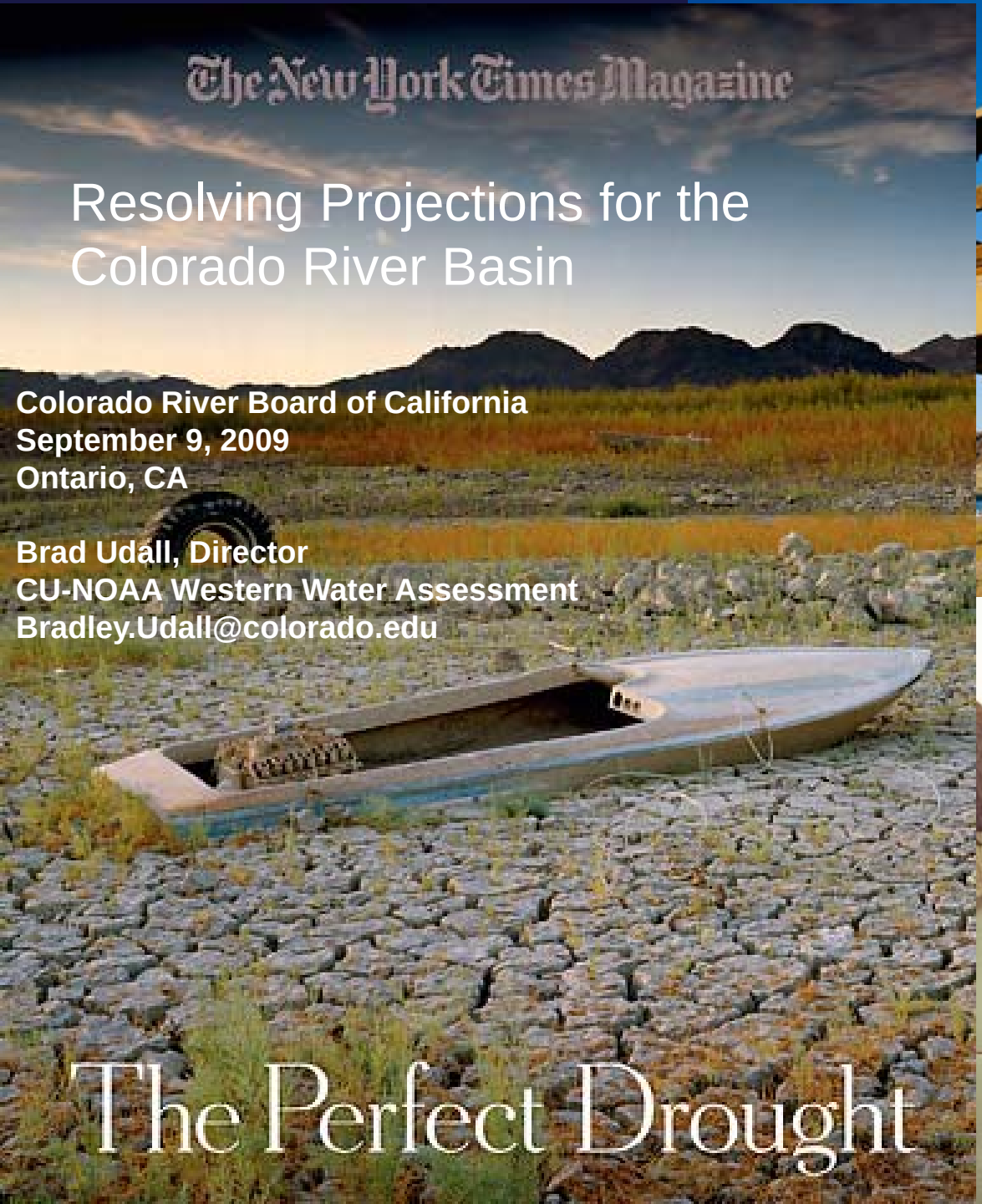

New York Times Sunday Magazine, October 21, 2007

Outline

- History of Colorado River Climate Change Studies
- Reconciling Disparate Projections
- Implications for the Basin

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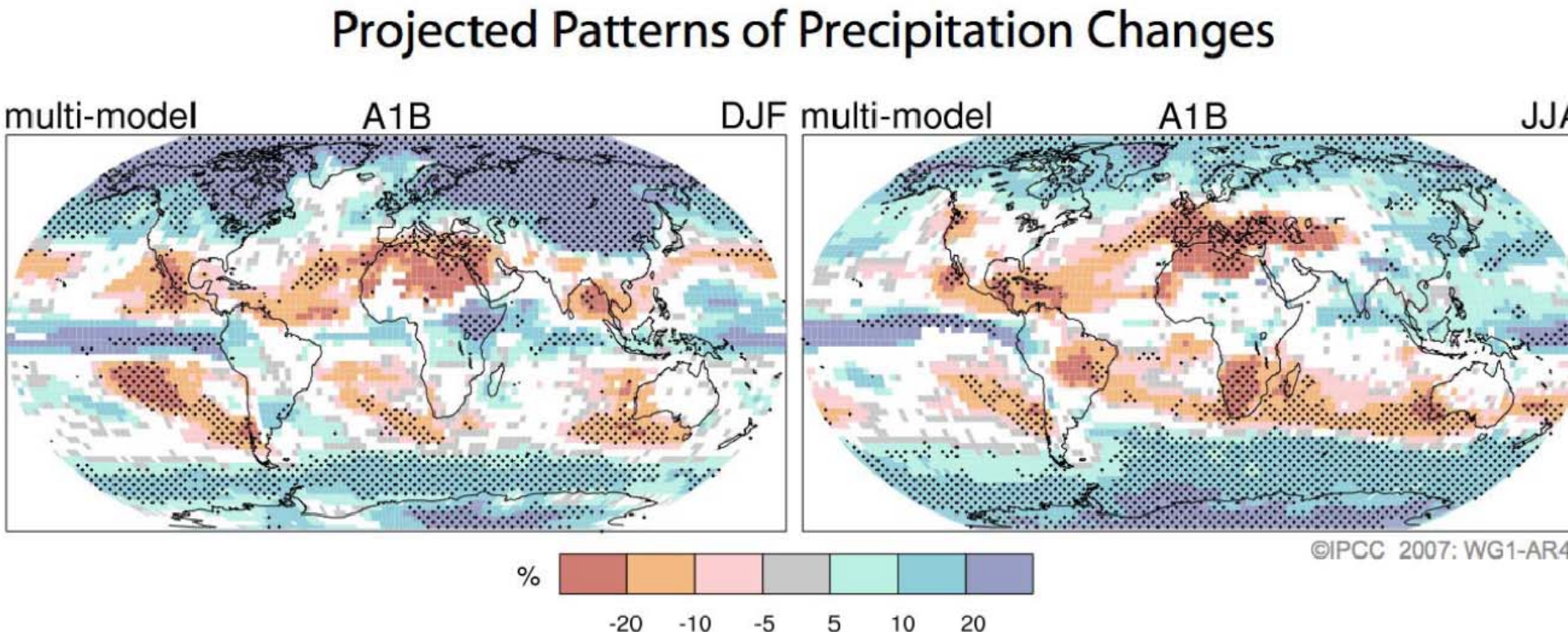
Colorado River Climate Change Studies over the Years

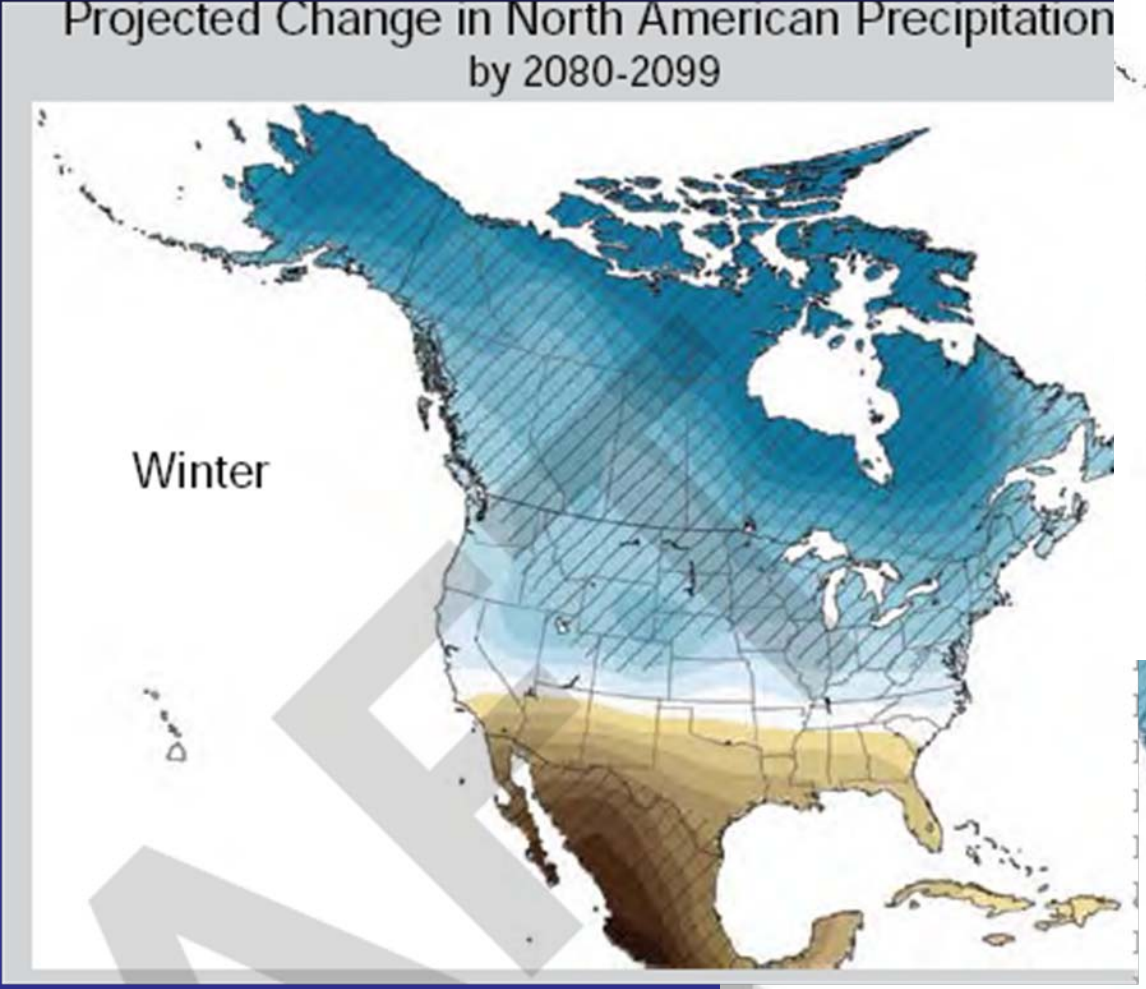
- Early Studies – Scenarios, About 1980
  - Stockton and Boggess, 1979
  - Revelle and Waggoner, 1983*
- Mid Studies, First Global Climate Model Use, 1990s
  - Nash and Gleick, 1991, 1993
  - McCabe and Wolock, 1999 (NAST)
  - IPCC, 2001
- More Recent Studies, Since 2004 – RANGE -5% to -45% BY 2050
  - Milly et al.,2005, "Global Patterns of trends in runoff"
  - Christensen and Lettenmaier, 2004, 2006
  - Hoerling and Eischeid, 2006, "Past Peak Water?"
  - Seager et al, 2007, "Imminent Transition to more arid climate state.."
  - IPCC, 2007 (Regional Assessments)
  - National Research Council Colorado River Report, 2007
  - McCabe and Wolock, 2007, "Warming may create substantial water shortages…"
  - Barnett and Pierce, 2008, "When will Lake Mead Go Dry?"
  - Barnett and Pierce, 2009, "Sustainable Water Deliveries From CR in changing climate
  - Rajagopalan, 2009, "Water Supply risk on the CR: Can management mitigate?"
  - Comments and Responses to B&P 2008

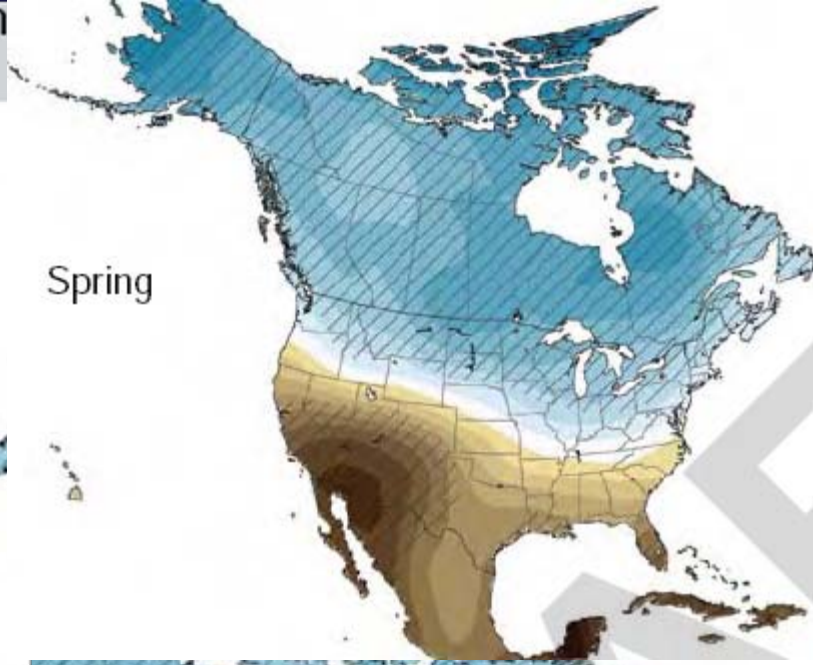
IPCC 2007 AR4 Projections

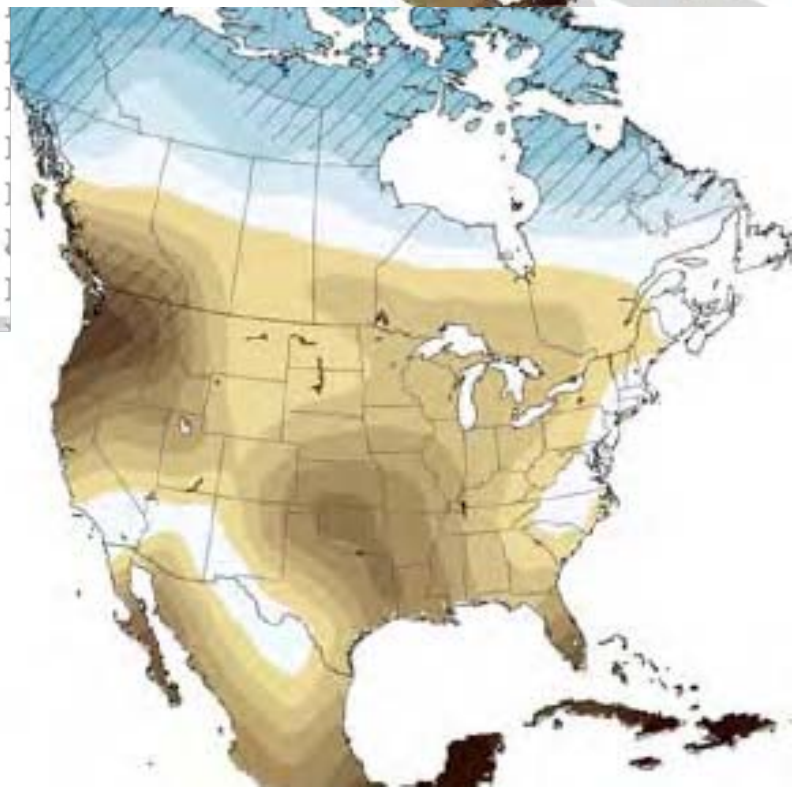
- Wet get wetter and dry get drier…
  - Part Increased Evaporation, Part Less Precipitation Due to Changes in Weather Patterns
- Southwest Likely to get drier – IPCC Findings



Projected Change in North American Precipitation by 2080-2099







Hatching Indicates Areas of Strong Model Agreement

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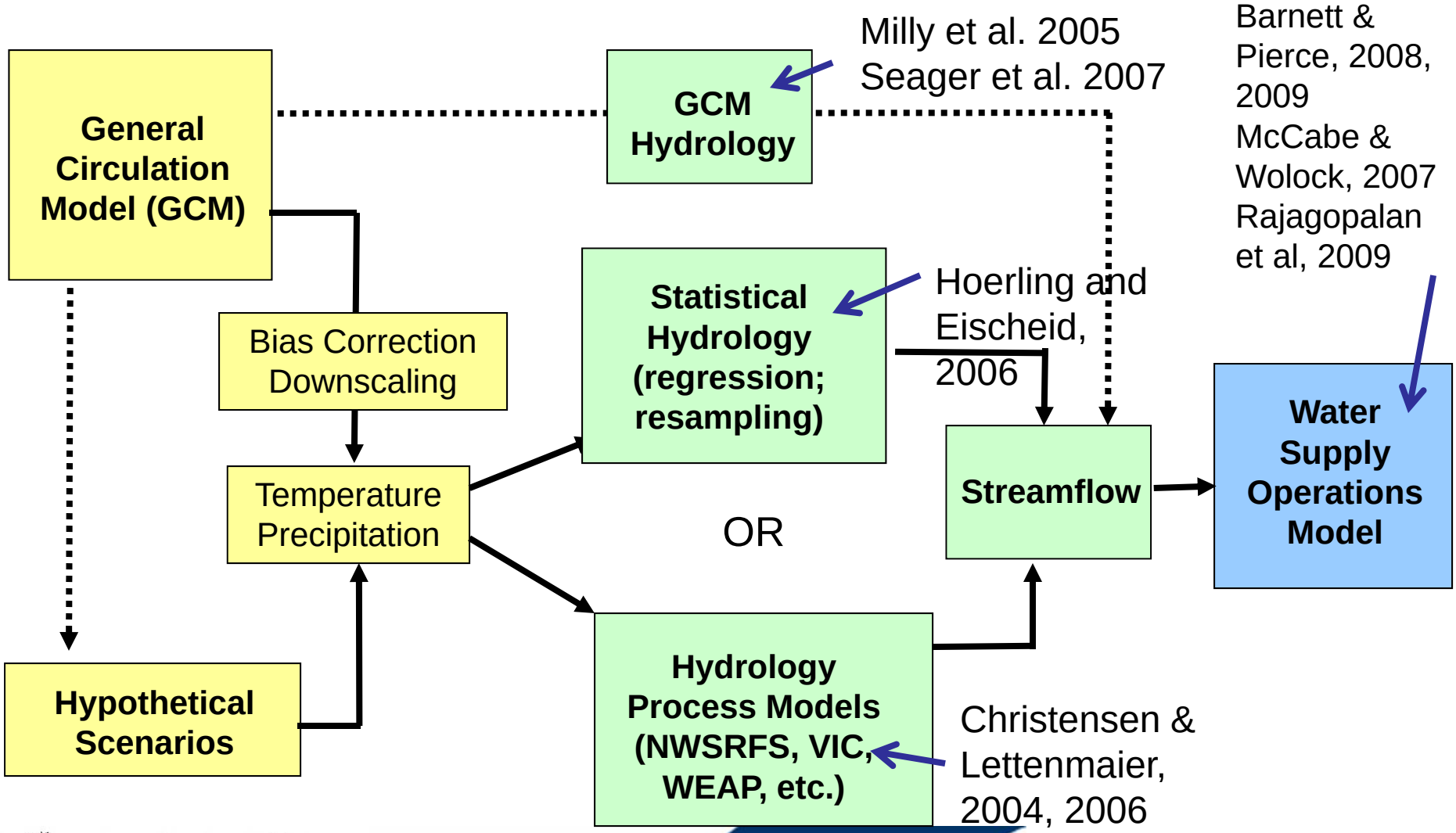
Progression of Data and Models in studies about the influence of climate change on streamflows in the Colorado River Basin



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Colorado
University of Colorado at Boulder

Christensen & Lettenmaier, 2006
Colorado River Projections - Mean Results

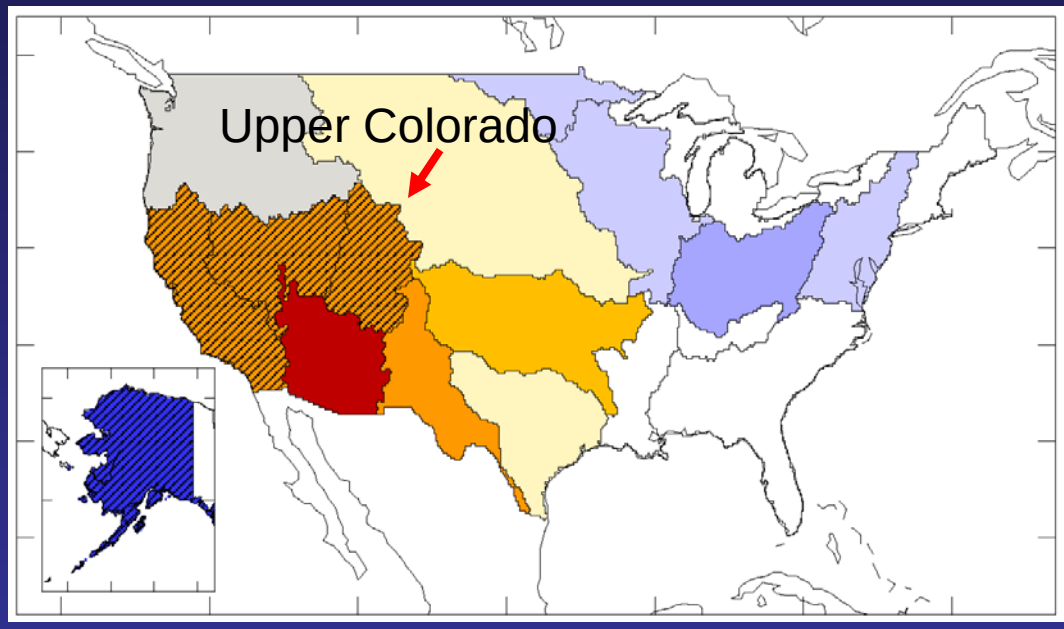
- 11AR 4 Models, 2 Scenarios B1(Low) & A2 (High)
- Different results from C&L, 2004
- Increased Winter Precipitation important
- Caveats: Does hydrology model understate summer drying?

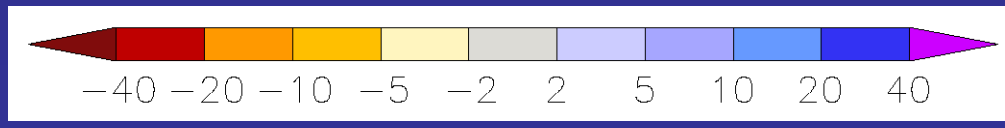
	P1 = 2010-2039		P2 = 2040-2069		P3 = 2070-2099		
	B1	A2	B1	A2	B1	A2	Comments
Temperatures	1.28	1.23	2.05	2.56	2.74	4.35	in C
Precipitation	-1%	-1%	-1%	-2%	-1%	-2%	Relative to Historic Run
SWE	-15%	-13%	-25%	-21%	-29%	-28%	Relative to Historic Run
Runoff	0%	0%	-7%	-6%	-8%	-11%	Relative to Historic Run

Milly's Results – Nature 2005

"Global pattern of trends in streamflow and water availability in a changing climate"

- 10 to 20% Less Upper Basin Runoff in 2041-2060 relative to 1900-1970 baseline.
- > 90% of Models Agree
- Decreases in runoff due to temperature increases, perhaps small precipitation declines
- Dryness consistent with world-wide poleward movement of deserts from ~30 N/S Latitude
- Warning: GCMs have relatively crude hydrologic cycle



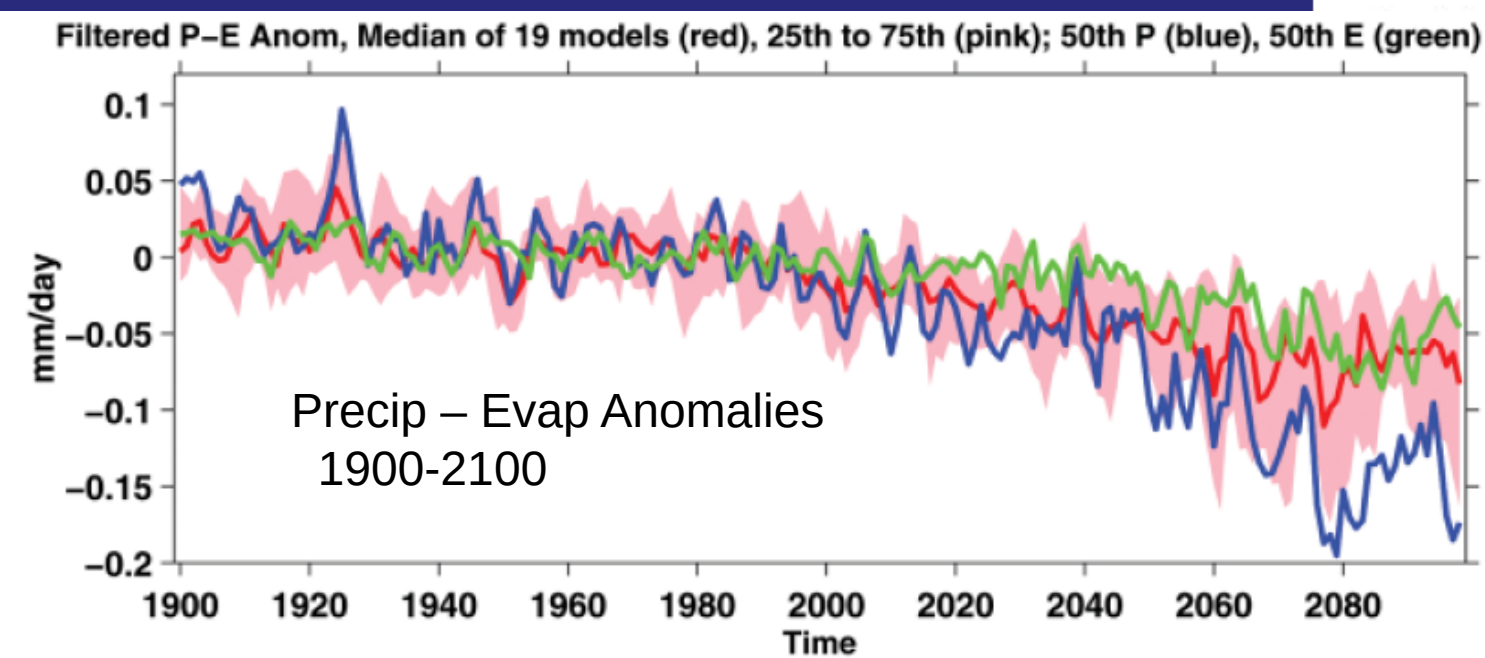


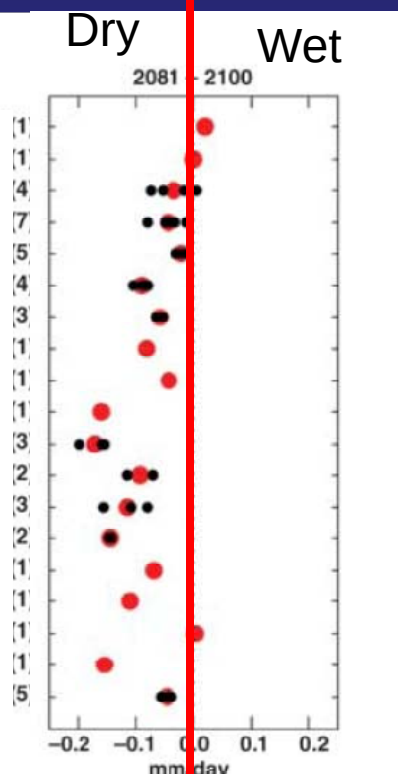
(After Milly, P.C.D., K.A. Dunne, A.V. Vecchia, Global pattern of trends in streamflow and water availability in a changing climate, *Nature*, **438**, 347-350, 2005.)

Seager's Results – Science 2007

"Model projections of an Imminent Transition to a more arid climate in Southwestern North America" – Science, 2007

- Climate models project drying in SW US
- Likely that this is already occurring
- Recent drought may become normal
- Only 1/19 Models Have Wet Trend
- -16 % Reduction by 2050 (??)
- Caveats: Large scale models, crude 'runoff' "SW" is huge



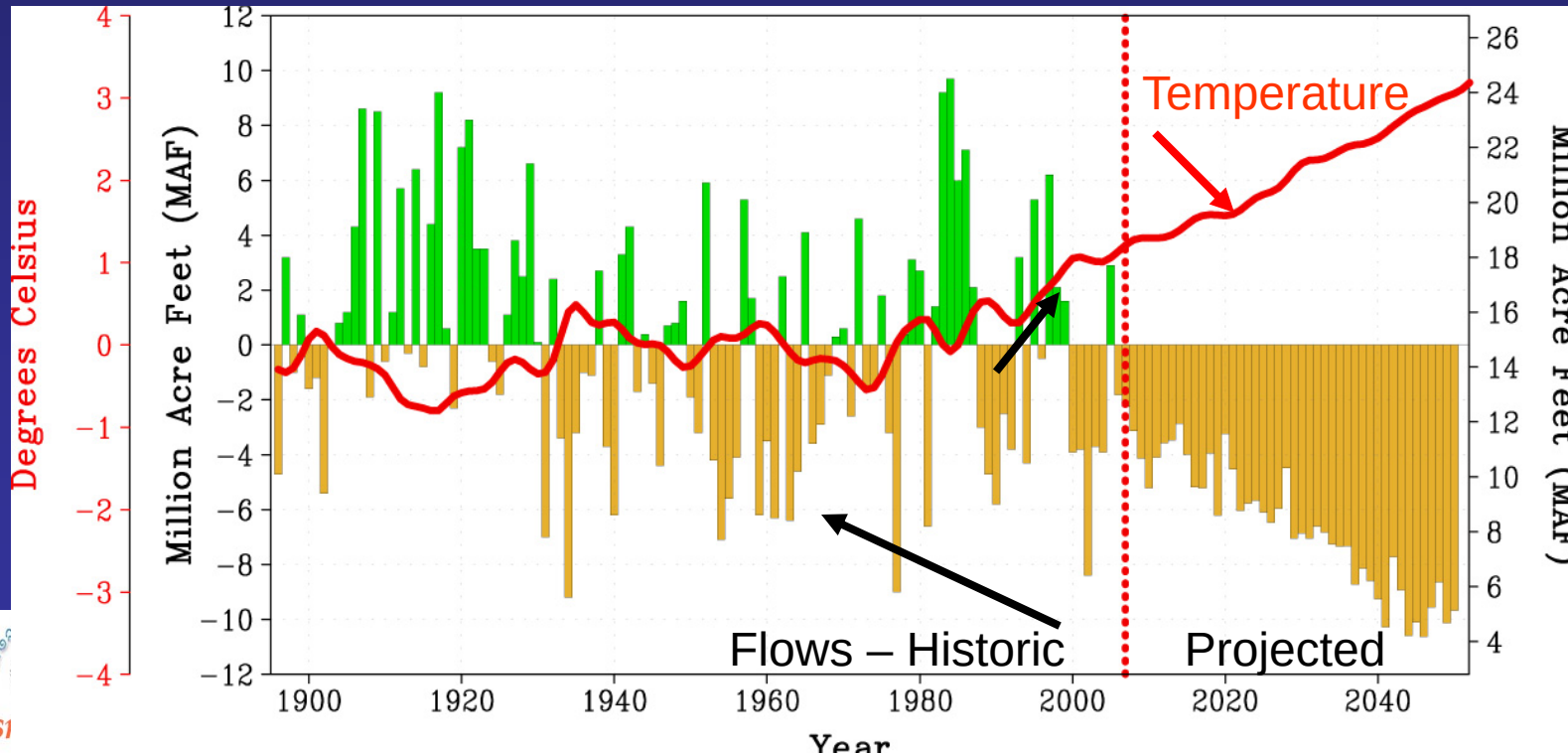


Historical and Projected Lee Ferry Flows: Hoerling and Eischeid, 2006

Bottom Line: -45% Reduction by 2050

Caveats: A very simple 'hydrology model' using a scale too big to effectively model the mountains in the basin

Hoerling now believes this overstates the future losses



Western Water Assessi

Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation

Lead Authors

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Authors

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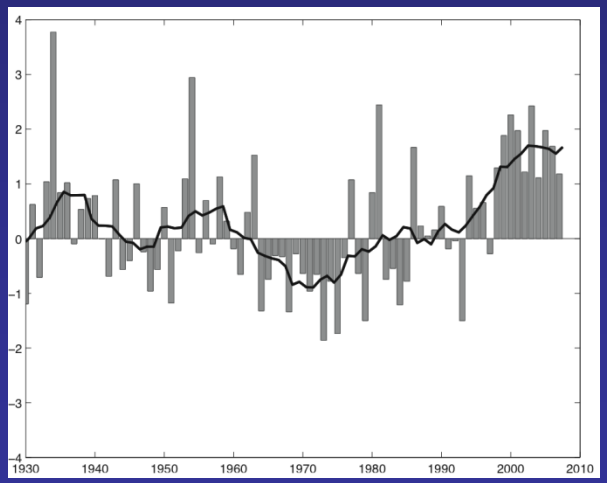
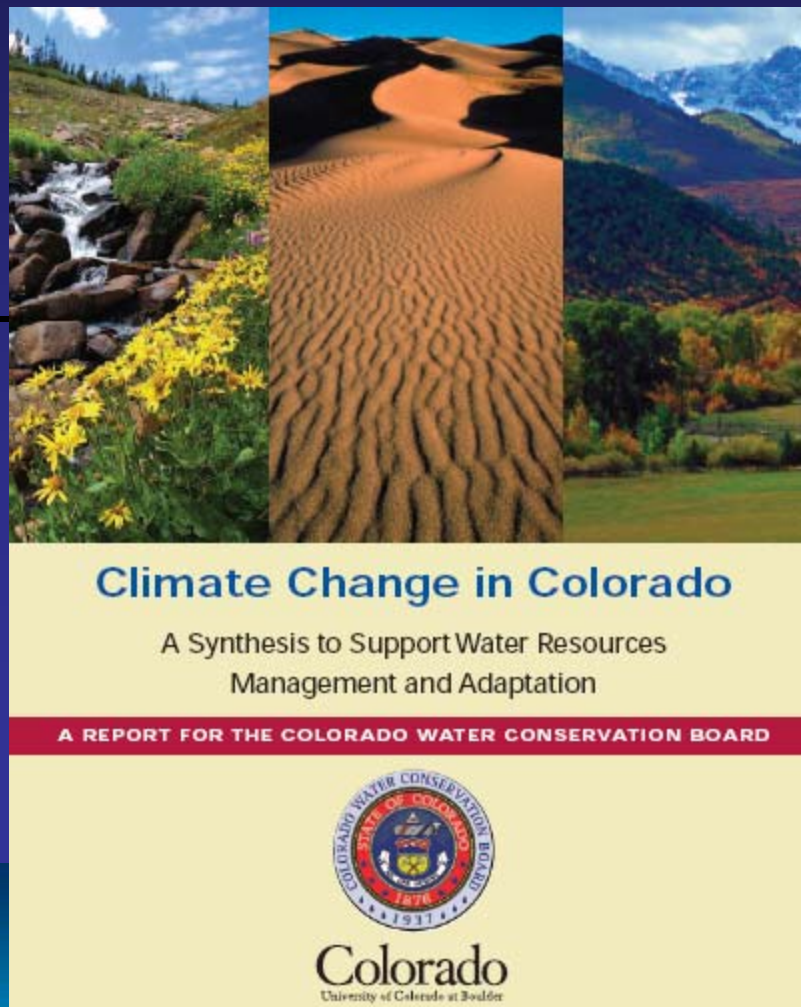
[3]University of Colorado at Boulder, Climate Diagnostics Center
[4]Colorado State University

State of the science regarding the physical aspects of climate change that are important for evaluating impacts on Colorado's water resources, and developing adaptation strategies out to the mid-21st century

Multiple independent measurements confirm widespread warming in the Western U.S.; in Colorado, temperatures have increased by approximately 2°F from 1977–2006. No consistent long-term trends in annual precipitation have been detected.





Recent Colorado River Studies Table

Source: Climate Change in Colorado, 2008

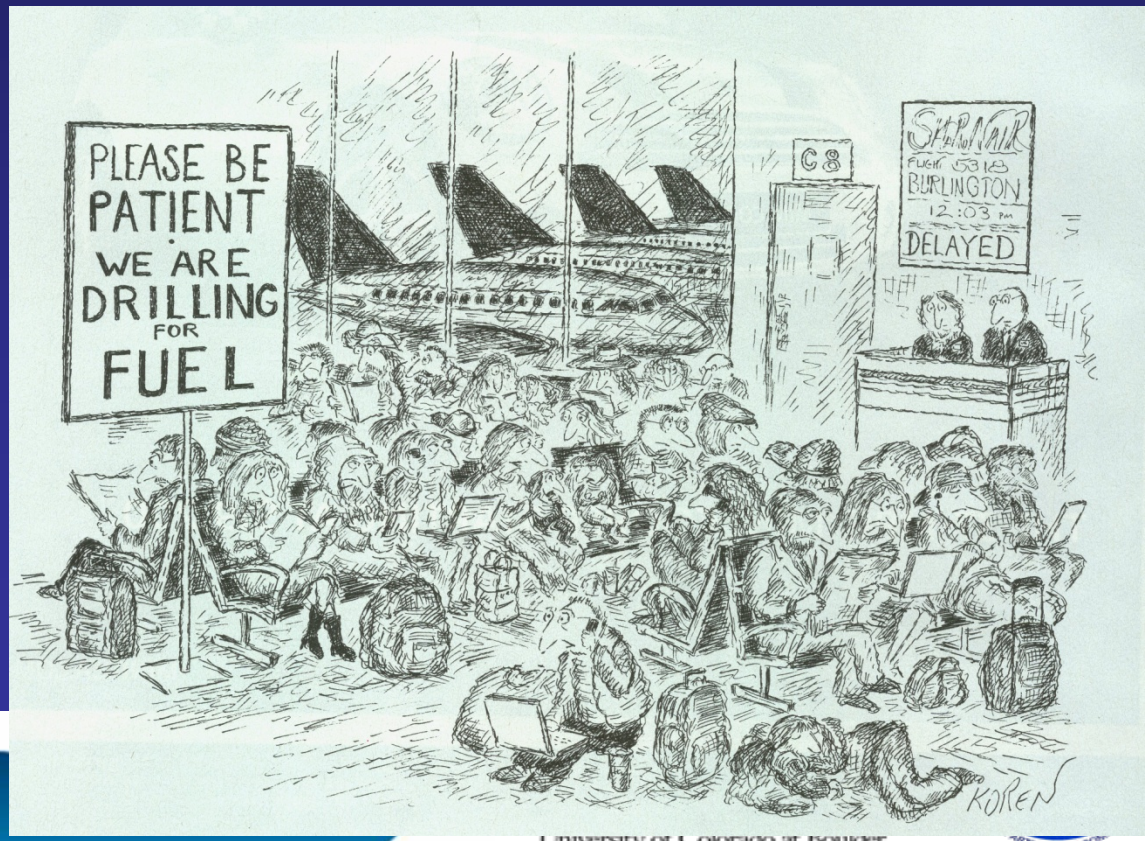
TABLE 5-1. Projected Changes in Colorado River Basin Runoff or Streamflow in the Mid-21st Century from Recent Studies

Study	*GCMs (runs)*	*Spatial Scale*	*Temperature*	*Precipitation*	*Year*	*Runoff (Flow)*	*Risk Estimate*
Christensen et al. 2004	1 (3)	VIC model grid (~8 mi)	+3.1°F	-6%	2040–69	-18%	Yes
Milly 2005, replotted by P.C.D. Milly	12 (24) (~100–300 mi)	GCM grids —	—		2041–60	-10 to -20% 96% model agreement	No
Hoerling and Eischeid 2006	18 (42)	NCDC Climate Division	+5.0°F	~0%	2035–60	-45%	No
Christensen and Lettenmaier 2007	11 (22)	VIC model grid (~8 mi)	+4.5°F (+1.8 to +5.0)	-1% (-21% to +13%)	2040–69	-6% (-40% to +18%)	Yes
Seager et al. 2007*	19 (49)	GCM grids (~100–300 mi)	—	—	2050	-16% (-8% to -25%)	No
McCabe and Wolock 2008	—	USGS HUC8 units (~25–65 mi)	Assumed +3.6°F	0%	—	-17 %	Yes
Barnett and Pierce 2008*	—	—	—	—	2057	Assumed -10% to -30%	Yes

Values and ranges (where available) were extracted from the text and figures of the references shown. Columns provide the number of climate models and individual model runs used to drive the hydrology models, the spatial scale of the hydrology, the temperature and precipitation changes that drive the runoff projections, and whether or not the study quantified the risk these changes pose to water supply (e.g., the risk of a compact call or of significantly depleting reservoir storage).

Outline

- History of Colorado River Climate Change Studies
- Reconciling Disparate Projections
- Implications for the Basin

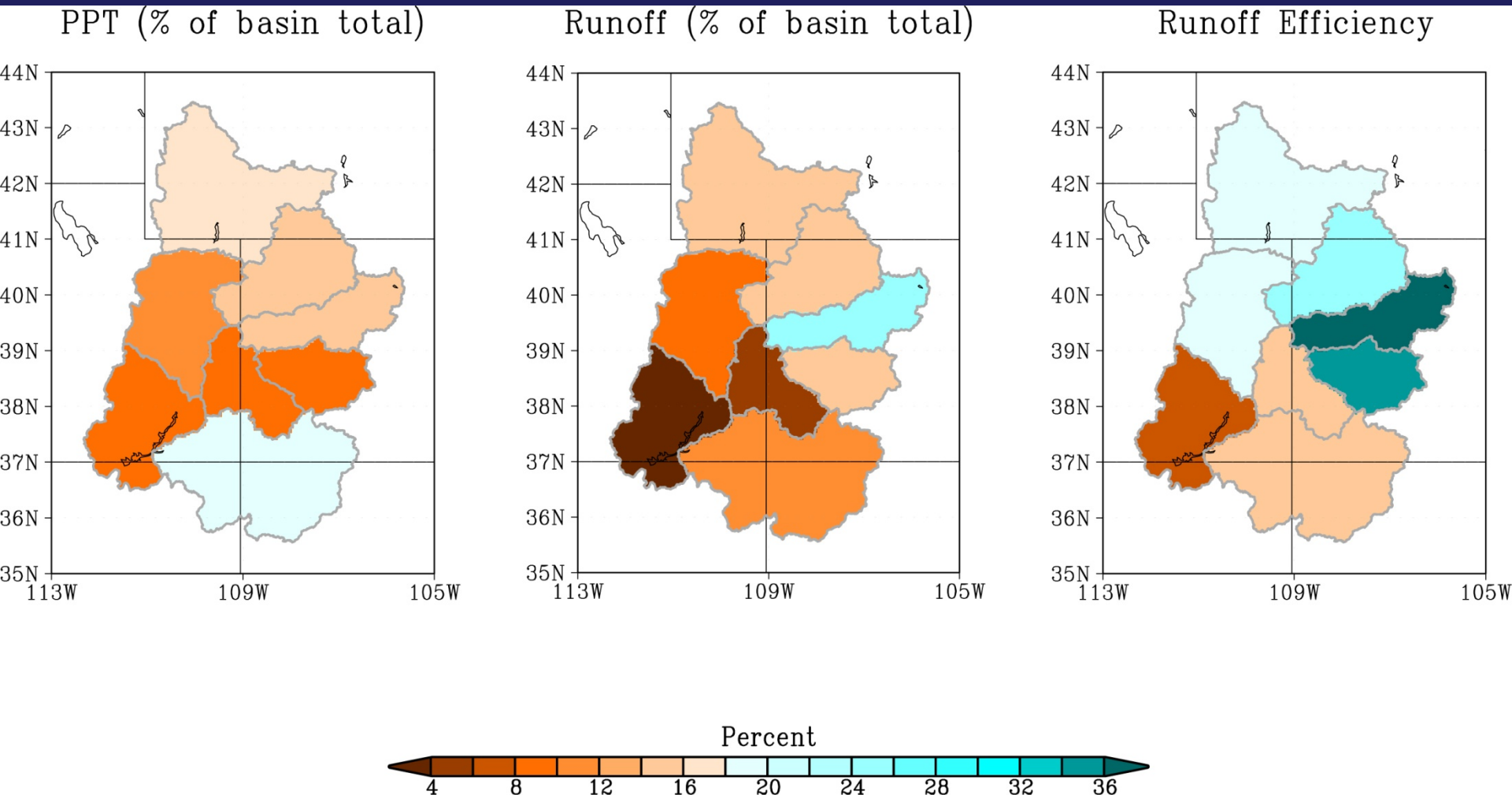


Reconciling Colorado River Projections

- -6% to -45% Modeled Reduction in C. River Flow
- NOAA Funded Study now in 3rd Year
- Scripps, NOAA (Boulder, CBRFC), UW, UA, CU, Reclamation
- 1st Step: Historical Hydrology Model "Bake-off"
- 2nd Step: Drive Hydrology Model w/Climate Models
- Many Hydrology Models: VIC, CBRFC SAC-Snow17, NOAH, Hoerling 'Bucket' Model
- Note: SNWA Hosted Meeting Nov 14 to Discuss
  - 50 Participants from around the Basin

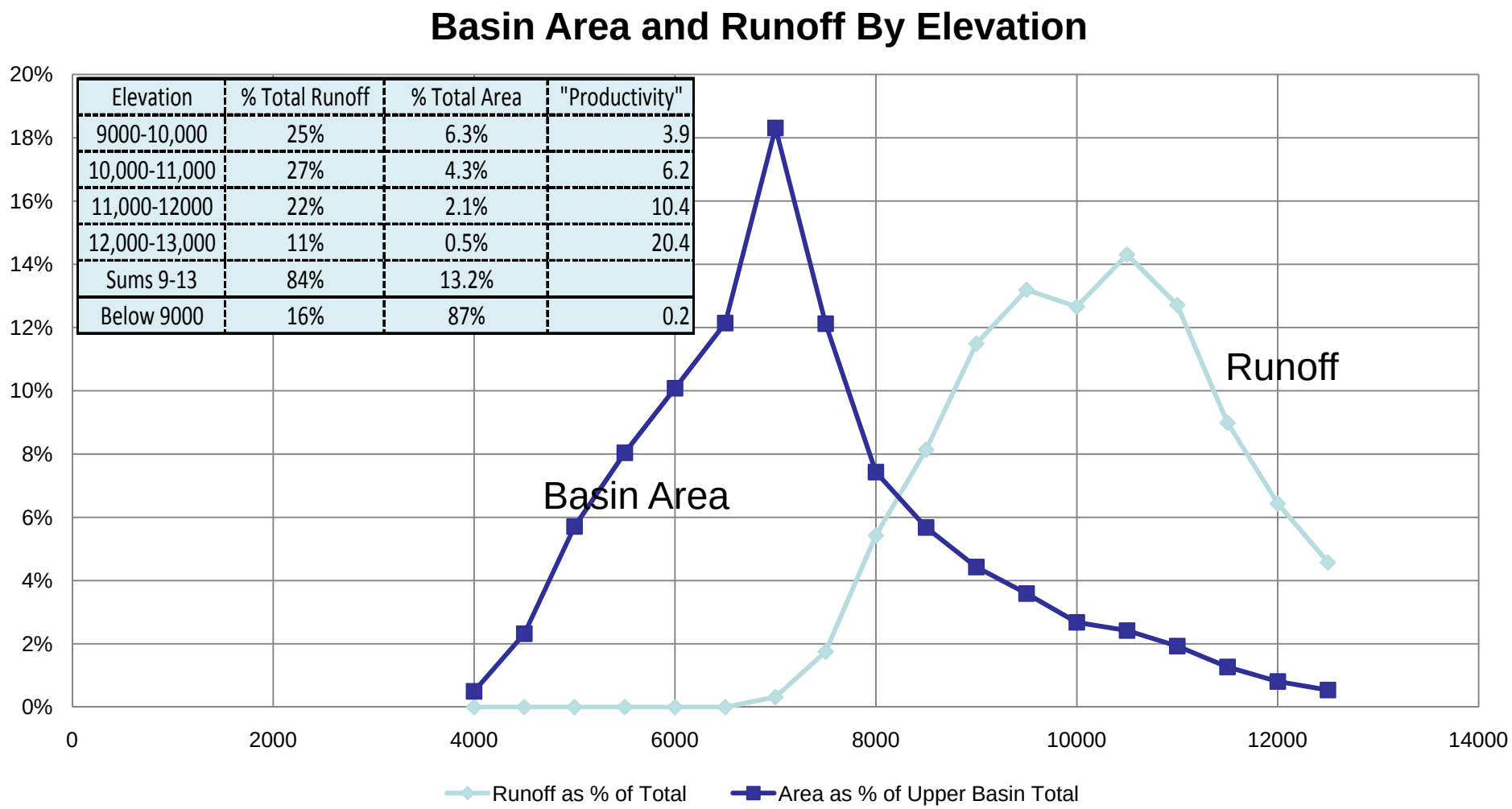
Reconciling Year 1 – Scale Matters

- More Precipitation Does not necessarily lead to more runoff…



Reconciling Year 1- Scale Matters

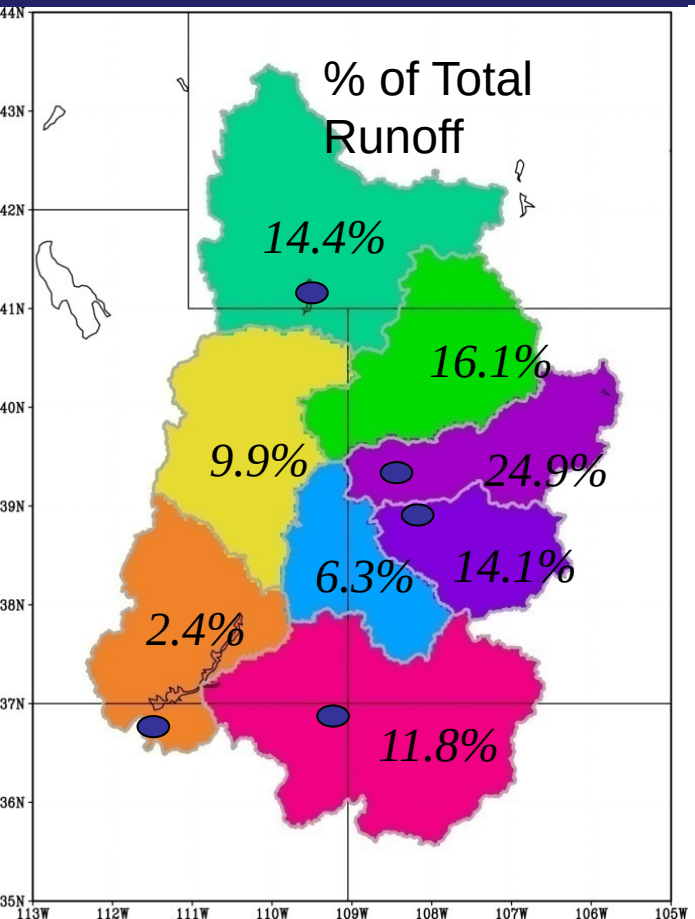
- Most runoff comes from small part of the basin > 9000 feet
  - Very Little of the Runoff Comes from Below 9000’ (16% Runoff, 87% of Area)
  - 84% of Total Runoff Comes from 13% of the Basin Area – all above 9000’

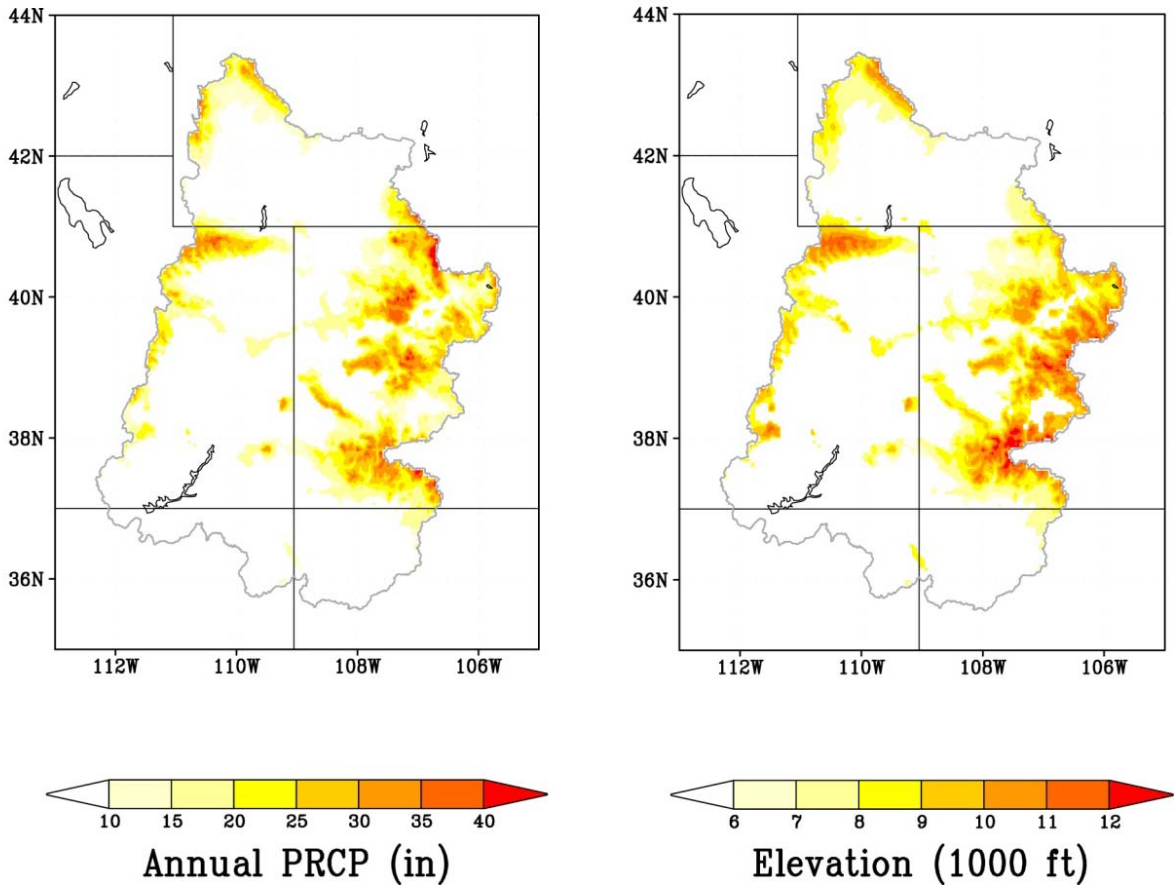


Elevation	% Total Runoff	% Total Area	"Productivity"
9000-10,000	25%	6.3%	3.9
10,000-11,000	27%	4.3%	6.2
11,000-12000	22%	2.1%	10.4
12,000-13,000	11%	0.5%	20.4
Sums 9-13	84%	13.2%	
Below 9000	16%	87%	0.2

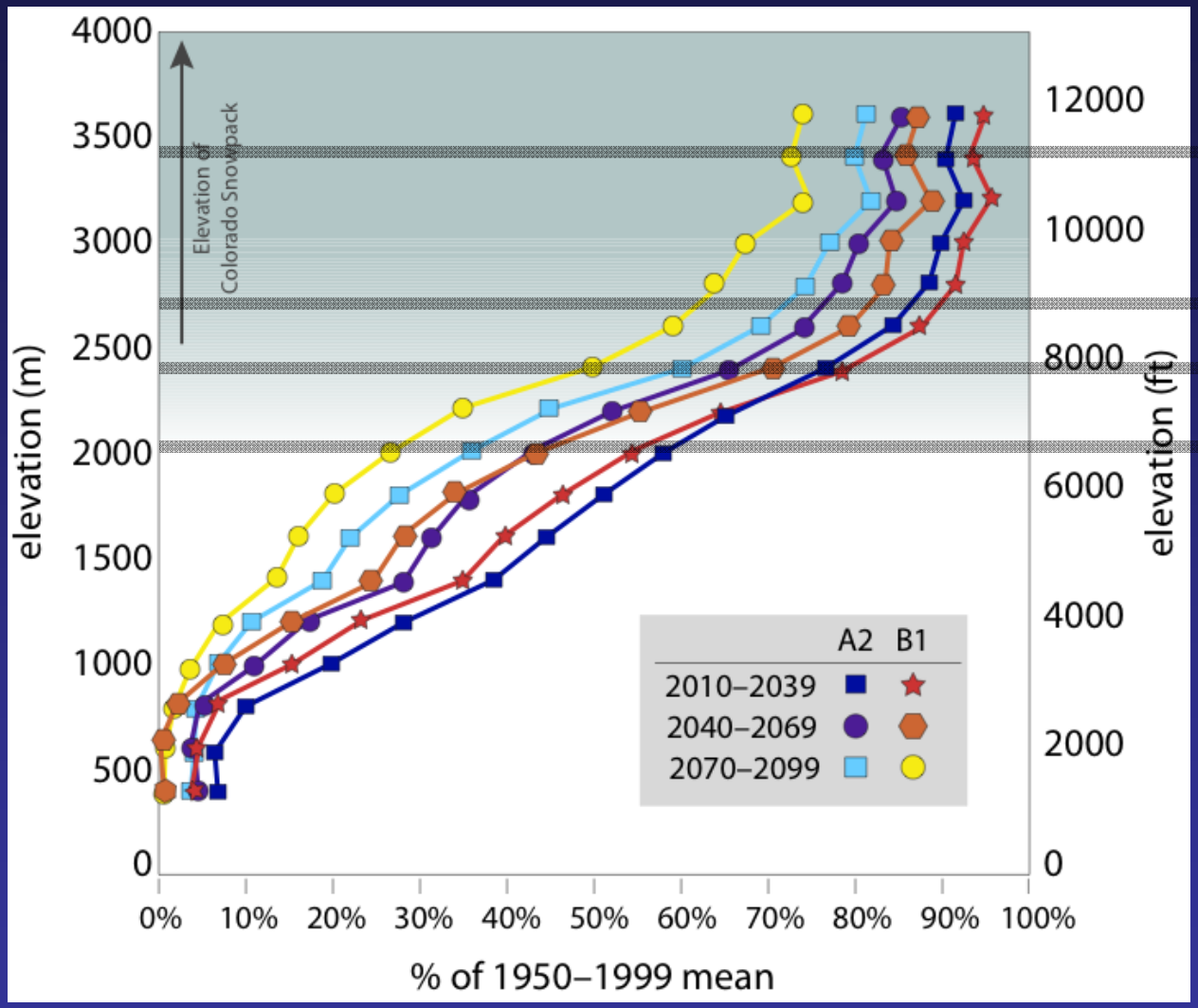
Reconciling Year 1- Scale Matters

- Runoff Efficiency (How much Precip actually runs off) Varies Greatly from ~5% (Dirty Devil) to > 40% (Upper Mainstem)
- You can't model the basin at large scales and expect accurate results
  - GCMs (e.g. Milly, Seager) and H&E 2006 may get the right answer, but miss important topographical effects





Projections: Colorado River Basin Snowpack



Berthoud Pass, CO

Keystone, CO

Aspen, CO

Tahoe, CA

Projected declines in Colorado River snowpack are not as severe as elsewhere in the West at lower elevations.

Reconciling Runoff "Elasticity"

- How Do Hydrology Models Perform During Historical Period?

  - If you only modify Temperature by 1°C?
    - +1C = -4% to -9% runoff
    - Results very model dependent

  - If you only modify Precipitation by -10% / + 10%
    - -10% precipitation = -20% runoff
    - +10% precipitation = +20% runoff
    - Results Independent of the hydrology model

  - +1C Warming Equivalent to -2% to -5% Precipitation
  - At 2050 with 2C Warming, -8% to -18% Runoff w/ No Changes in Precipitation

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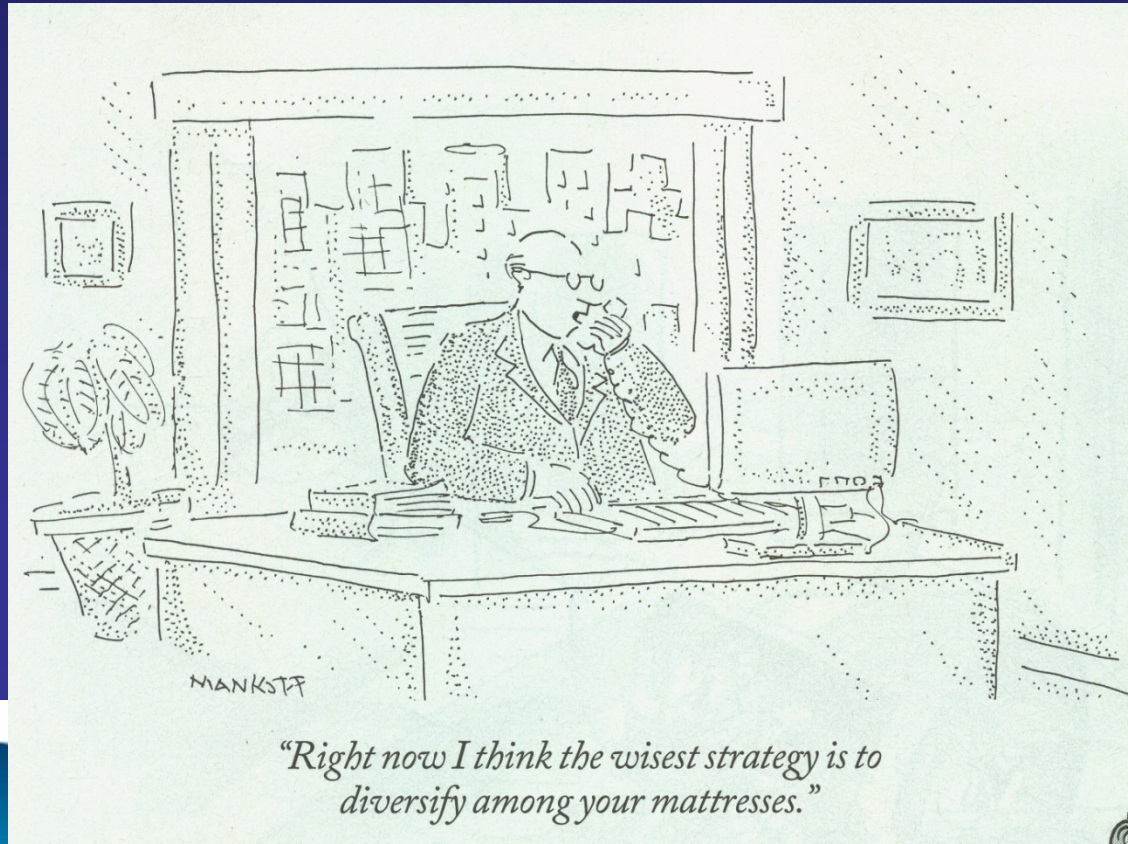

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Barnett and Pierce, 2008
When Will Lake Mead Go Dry?
Water Resources Research
News Release February 12, 2008

“There is a 50 percent chance Lake Mead, a key source of water for millions of people in the southwestern United States, will be dry by 2021”

“… human demand, natural forces like evaporation, and human-induced climate change are creating **a net deficit of nearly 1 million acre-feet of water per year** from the Colorado River system”

Their analysis of Federal Bureau of Reclamation records of past water demand and calculations of scheduled water allocations and climate conditions indicate that the system could **run dry even if mitigation measures now being proposed are implemented.**

‘Barnett said that the researchers **chose to go with conservative estimates of the situation** in their analysis, though **the water shortage is likely to be more dire in reality”**.

UPDATE

•Barsugli et al, 2009 "Comment on When Will Lake Mead Go Dry", Water Resources Research. **BP2008's model was wrong. Risks potentially serious, but a window of opportunity to get policy and management right.**

Barnett, T. P., and D. W. Pierce (2009), Reply to the comment on 'When •Will Lake Mead Go Dry?', Water Resources Research. Their reply to our comment. **'recent drought is the new norm.' Shortage agreements tantamount to inaction.**

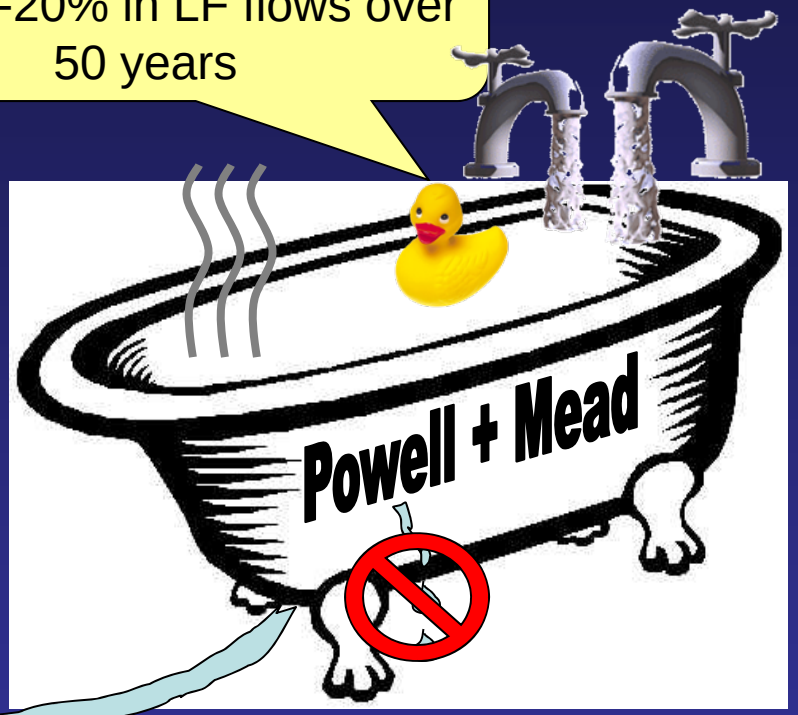
•Rajagopalan et al, 2009, " Water supply risk on the Colorado River: Can management mitigate?" **"risk explodes after 2027, Some system-wide management can reduce risk substantially**".

•Barnett and Pierce, 2009, " Sustainable water deliveries from the Colorado River in a changing climate", PNAS. Similar modeling assumptions •and time frame to our results, but the "spin" is very different. **Flow reverting to their long-term (paleo) average of 14 Maf @ Lees Ferry. Climate change has laready reduced flows by 0.5 - 1 MAF beyond that.**

Water Balance Model = Inflows - Outflows

Lees Ferry Natural Flow (15.0)
+
Intervening flows (0.8)
-

Climate Change
-10% to -20% in LF flows over 50 years



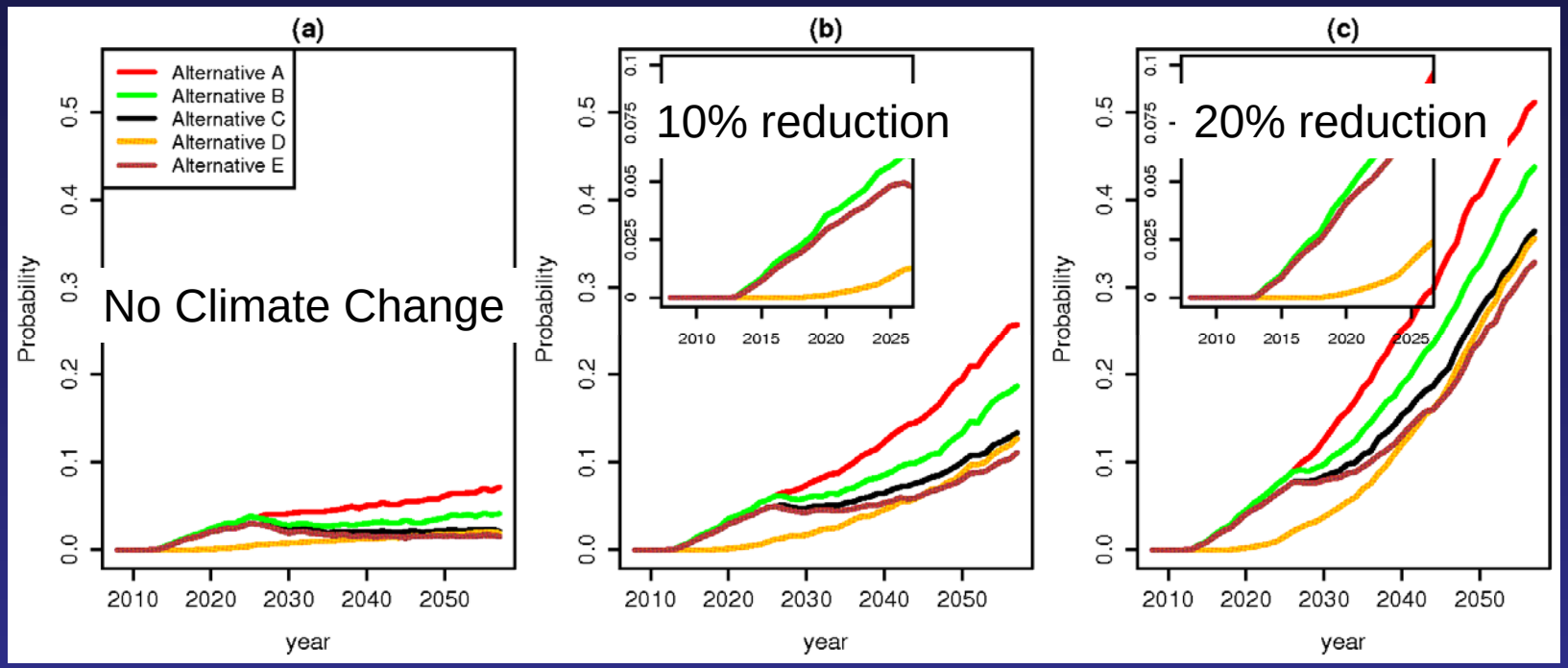
Evaporation (**varies with stage**; -1.4 avg declining to -.1)

UB Consumptive Use =-4.5
LB Consumptive Use
+ MX Delivery + losses =-9.6)

"Bank Storage is near long-term equilibrium'

Initial Net Inflow = +0.4

Risk of Reservoir Drying 2009 to 2057 – Can Management Mitigate?



- 5 Alternatives examined incl. slower demand growth, and earlier onset and more aggressive shortage policy. Also consider uncertainty in demand…
- Near-term risks relatively low
- Management can offer risk mitigation
- Climatic regime largest factor

(Rajagopalan et al, 2009)

Summary

Barnett and Pierce, 2008

- 50% chance of drying by 2021;
- 50 % chance of reaching power pool by 2017.

Barsugli et al, 2009; Rajagopalan et al, 2009;

- 50% chance of drying by 2033 – 2047 (different methodology)
- Average deficits 1.7Maf

Barnett and Pierce, 2009

- Deliveries not met 88% of the time by 2050 for 20% climate reduction in flow.
- Average shortfall: 2.2 Maf.
- Note: their model has deliveries not met 25% of the time in “2009” even under no climate change!

Current and Future Work

- Current Funding
  - Evaluate all IPCC Climate Models for CRB
  - Downscale Climate Model Data using Alternative Methodologies
  - Investigate Runoff 'Elasticity' Using Hydrology Models
  - Investigate High Elevation Impacts on Runoff
  - Stakeholder Workshop (held November 2008)
  - Evaluate Project Effectiveness for Policy
  - Communicate Findings
- Proposed New Work
  - Evaluate Alternative Datasets
  - Diagnose Reasons for Different Temperature Sensitivities
  - Understand Difference Between Seager and Milly
  - Evaluate Runoff Sensitivities using NARCCAP Data
  - Continue to Investigate High Elevation Runoff Physics
  - Track AR5 Model Results as they become available
  - Stakeholder Meeting & Prepare Papers