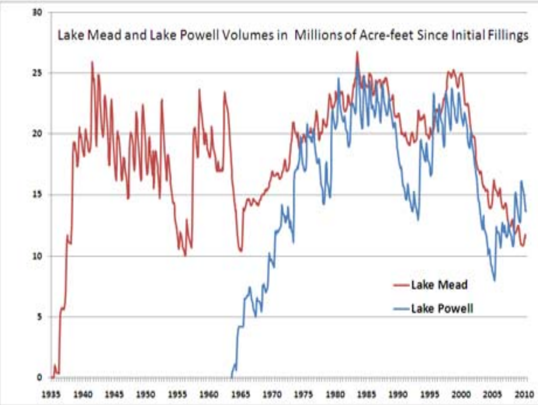
The Aussie Big Dry: Lessons from Australia for the Colorado River Basin



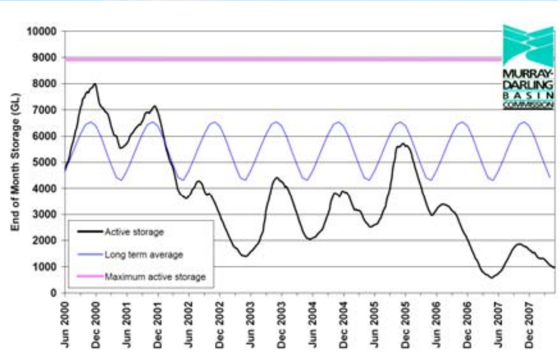


Figure 2. MDBC active storage; June 2000 to April 2008

2010 Colorado River Symposium
Implications of Lower Lake Levels
Colorado River Commission of Nevada
April 21-22
Las Vegas, NV

Brad Udall, Director
CU-NOAA Western Water Assessment
Bradley.Udall@colorado.edu

Lake Powell Summer 2004, 120’ low, ~ 10 maf remaining, 15 maf gone. B. Udall photo

Outline

- CRB Climate Change Studies
- Recent CRB Climate
- Systemic CRB Allocation Problems
- CRB Science Issues
- Lessons from Australia
- Closing Thoughts

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

At Least 7 Colorado River Studies Since 2004…

….Runoff Declines Range from -6% to -45% by 2050
....Best guess now -10% to -20% by 2050

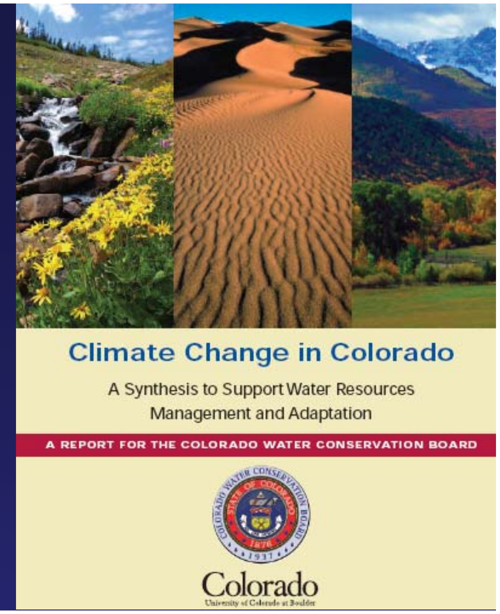


TABLE 5-1. Projected Changes in Colorado River Basin Runoff or Streamflow in the Mid-21st Century from Recent Studies

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

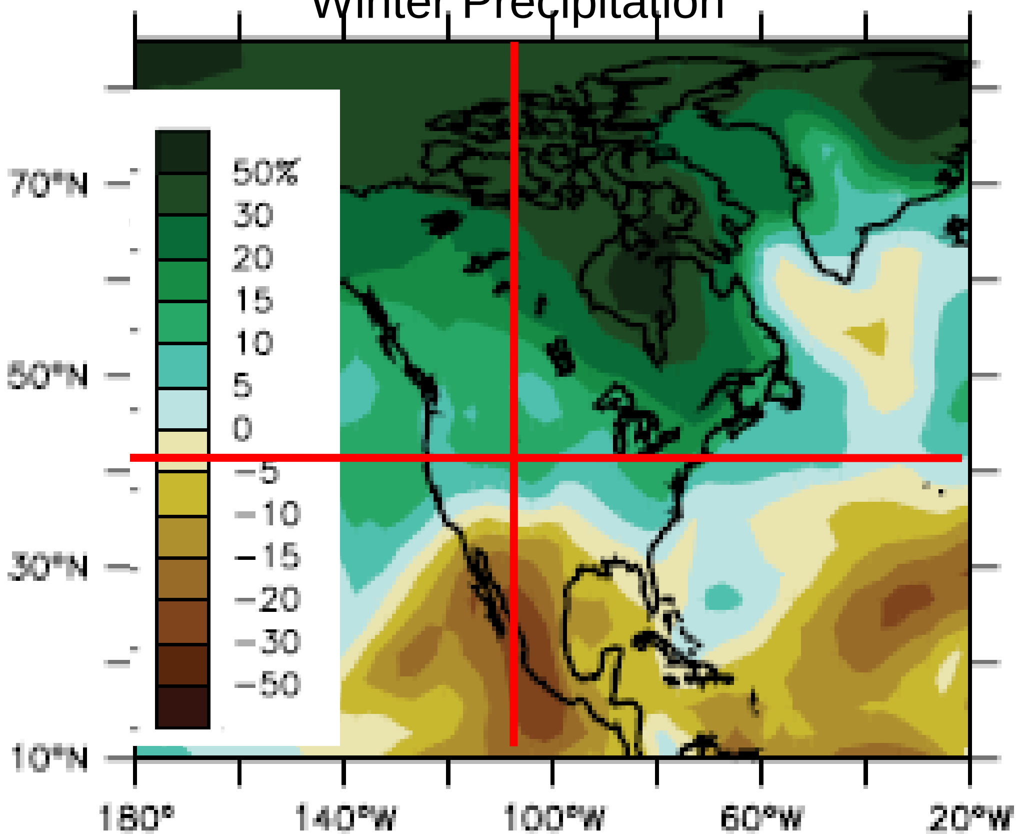
Values and ranges (where available) were extracted from the text and figures of the references shown. Columns provide the number of climate models and individual model runs used to drive the hydrology models, the spatial scale of the hydrology, the temperature and precipitation changes that drive the 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).

Precip and Temp at 2100 A1B –

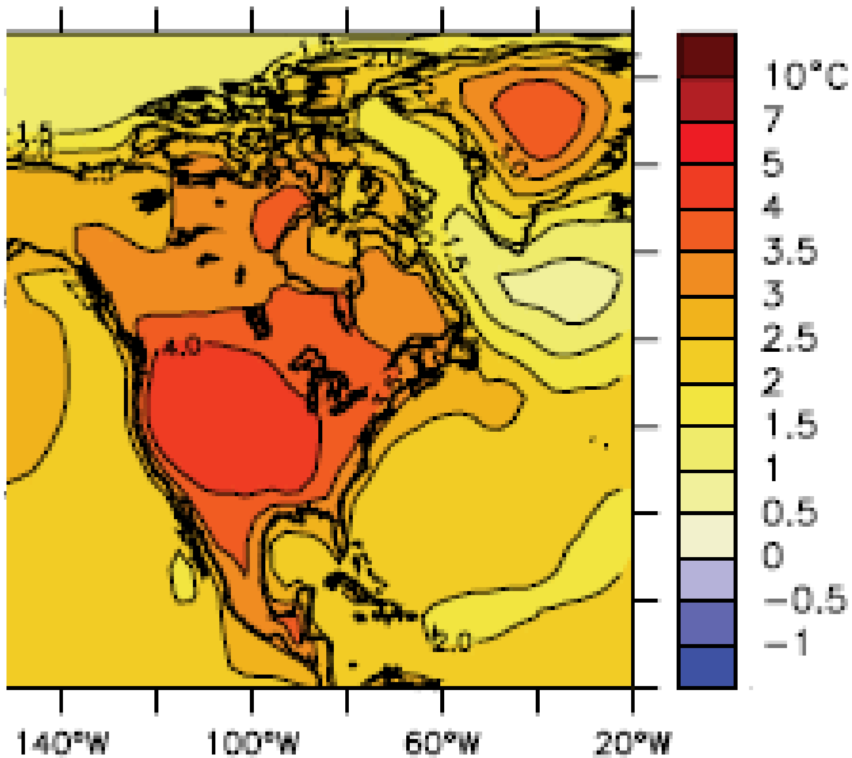
7F = 3-4C Rise

Precip

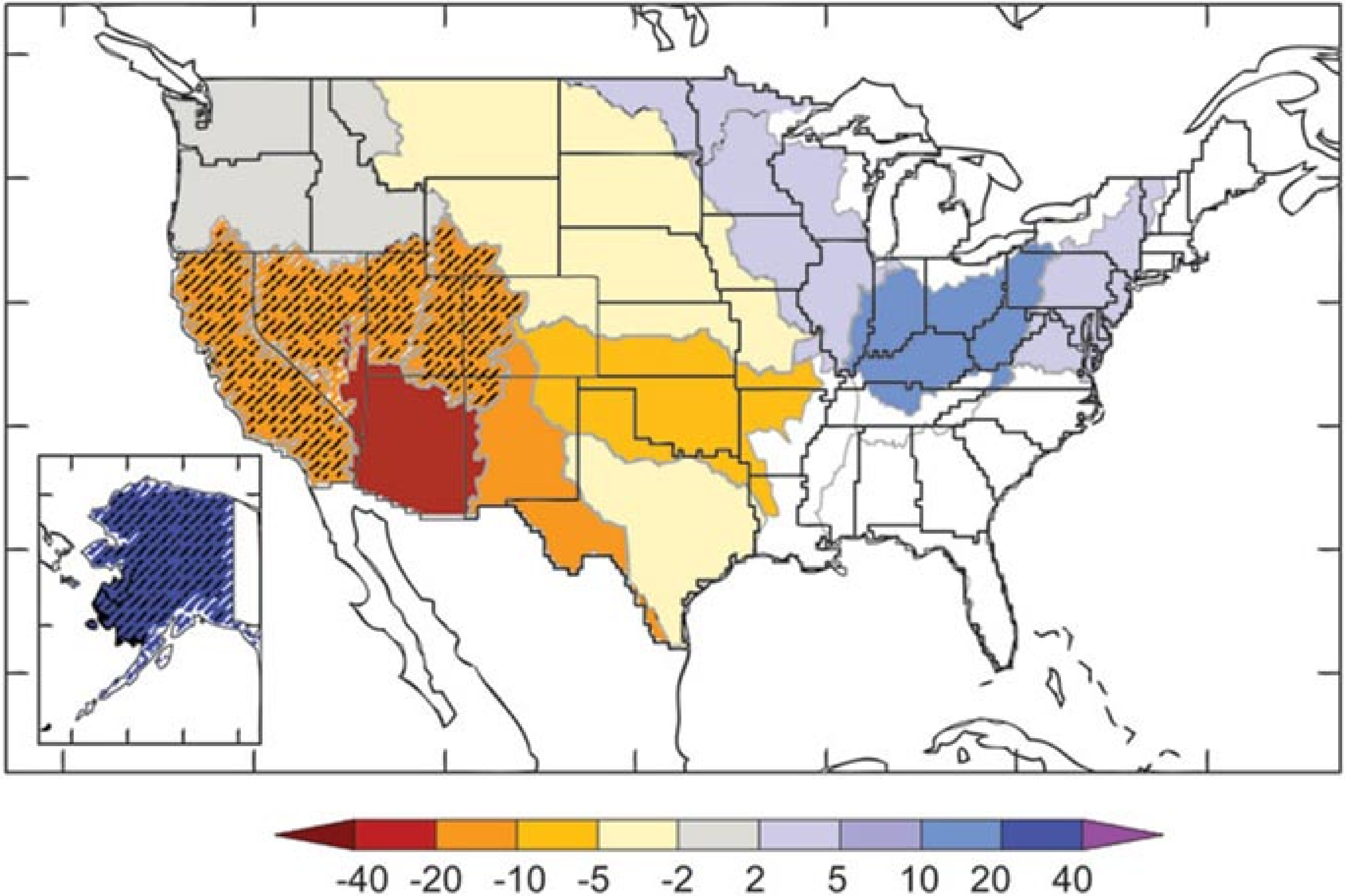
Winter Precipitation



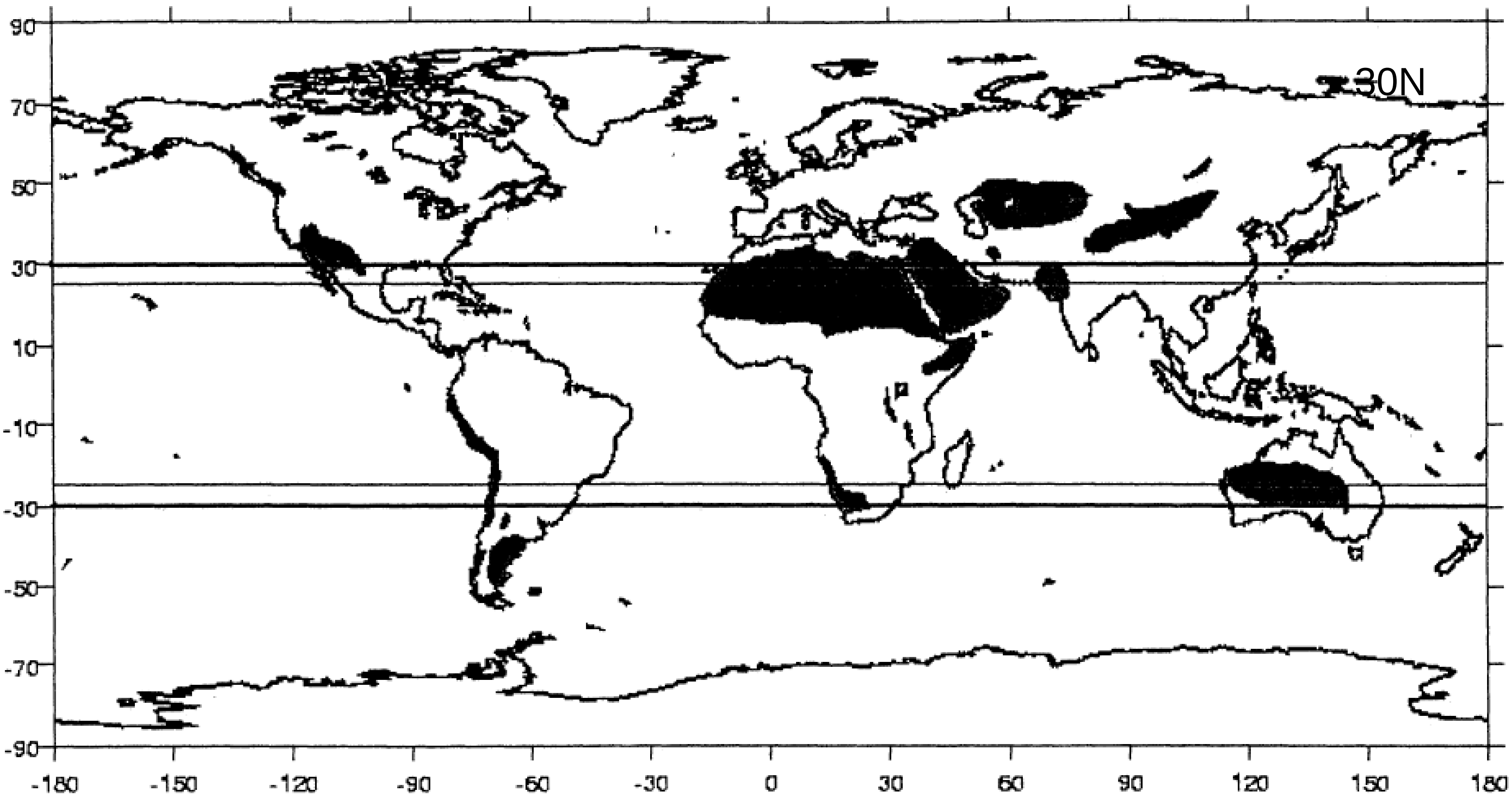
Summer Temperatures



Projected Changes in Annual Runoff

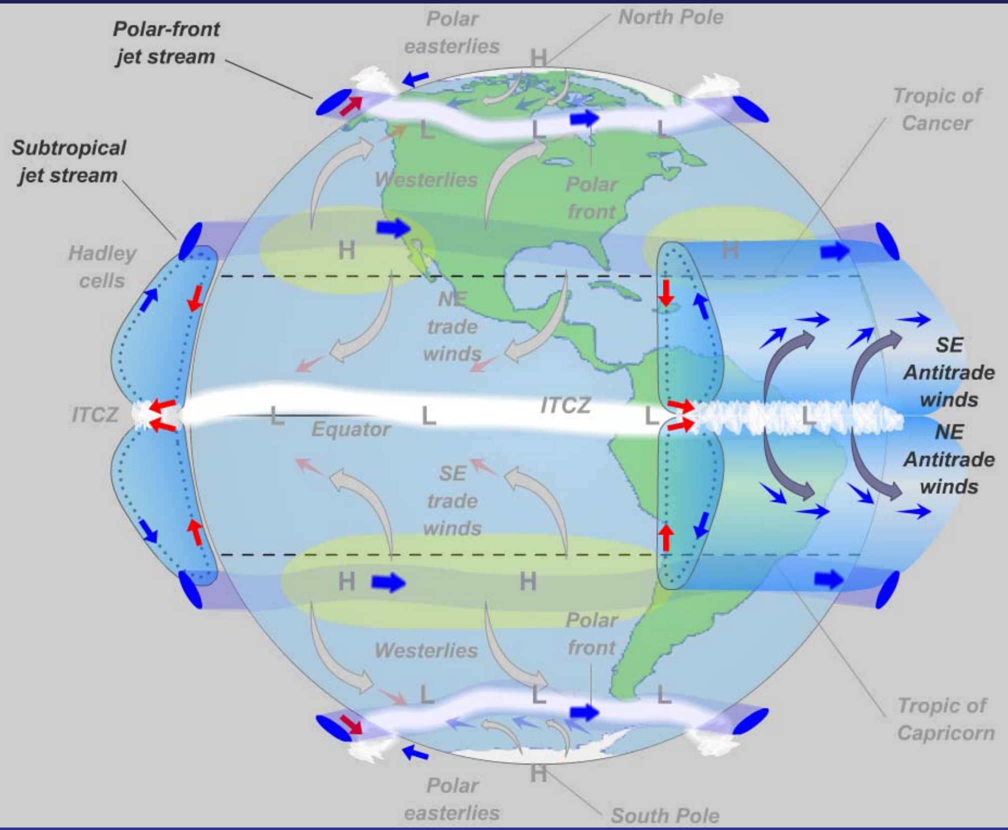


Major Deserts of the World



Hadley Cells 101

- George Hadley, 1700s
- Simple Theory Explains
  - N-S movement of air near equator
  - Trade winds blow from NE/SE
  - Deserts at 30 N/S Latitude
  - Areas of heavy rain at Equator
  - Location of “Subtropical Jet”



- Note: major UK Modeling Center named after Hadley

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U.S. DEPARTMENT OF COMMERCE

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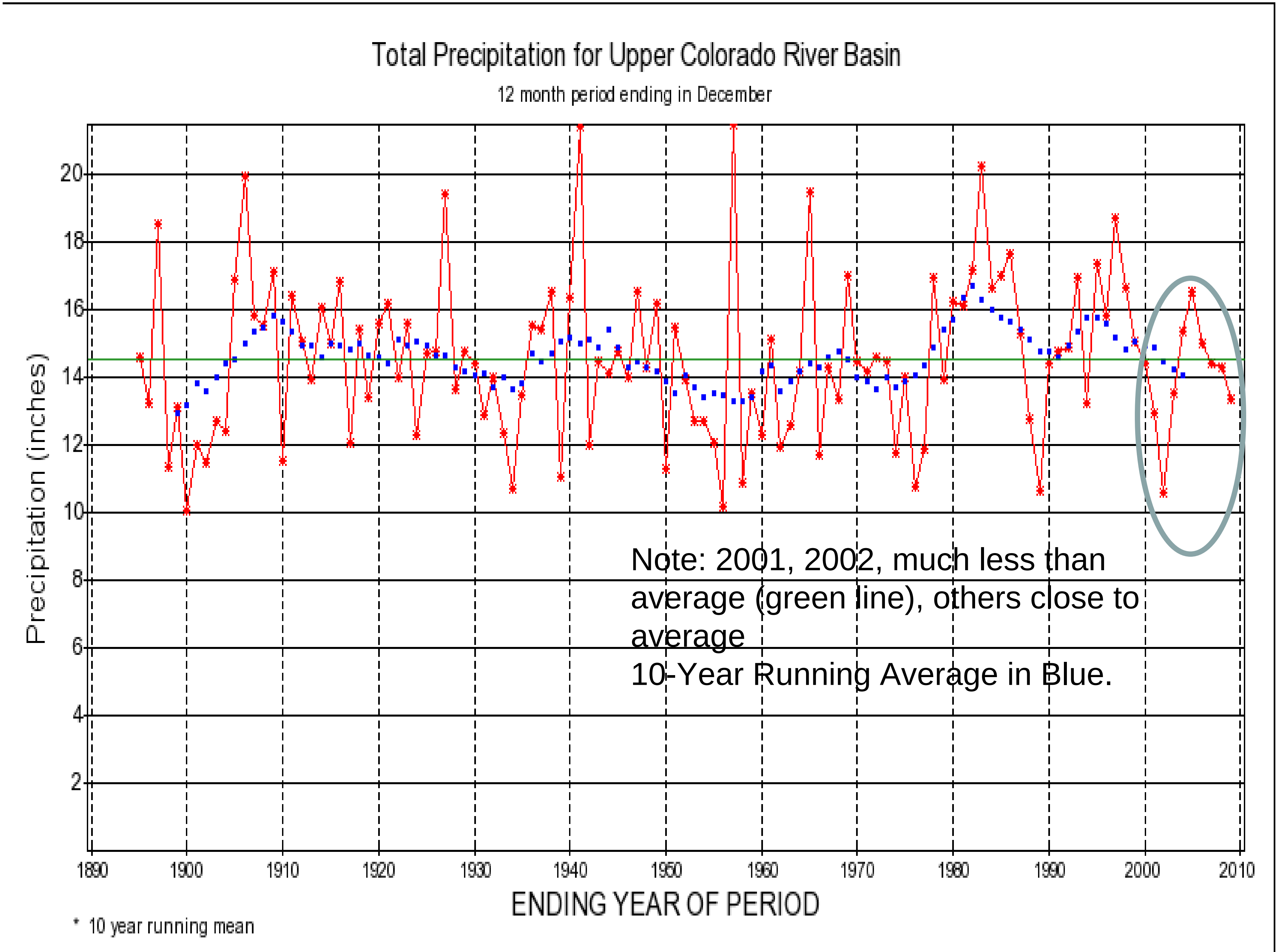
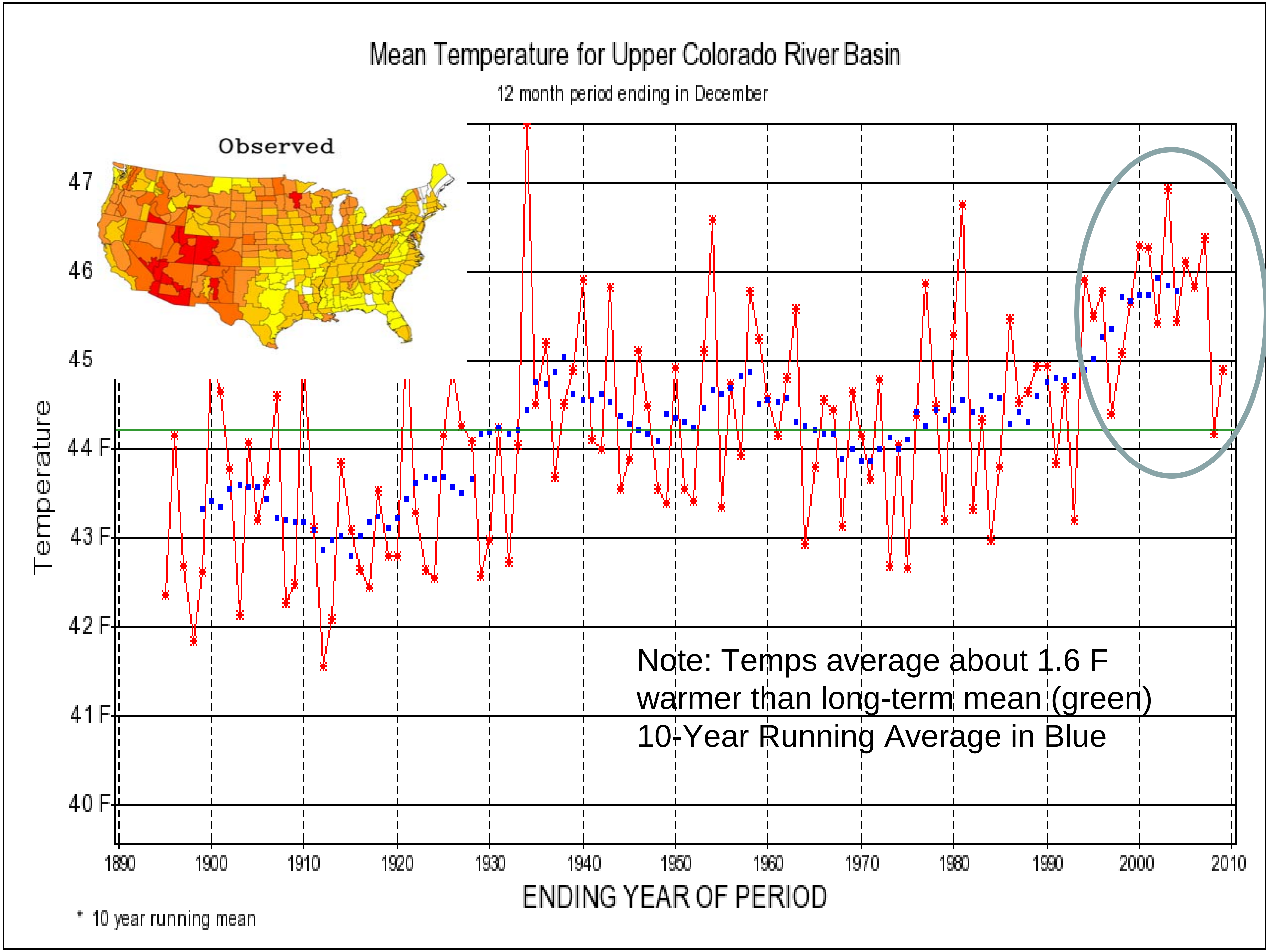
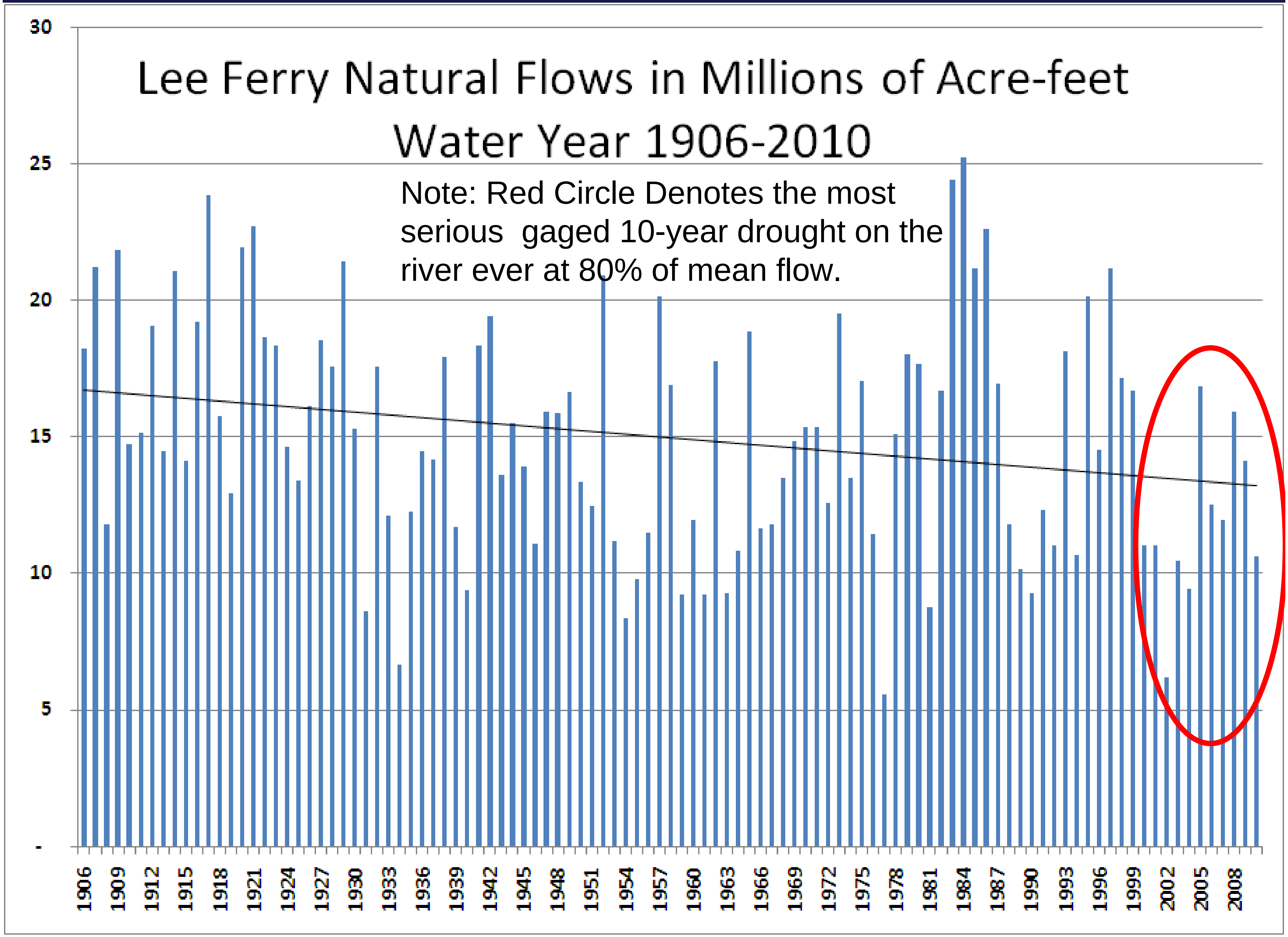


Total Precipitation for Upper Colorado River Basin
12 month period ending in December
Precipitation (inches)
20
18
16
14
12
10
8
6
4
2
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
ENDING YEAR OF PERIOD
* 10 year running mean
Note: 2001, 2002, much less than average (green line), others close to average
10-Year Running Average in Blue.



Mean Temperature for Upper Colorado River Basin
12 month period ending in December
Observed
47
46
45
44 F
43 F
42 F
41 F
40 F
Temperature
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
ENDING YEAR OF PERIOD
Note: Temps average about 1.6 F
warmer than long-term mean (green)
10-Year Running Average in Blue
* 10 year running mean



Lee Ferry Natural Flows in Millions of Acre-feet
Water Year 1906-2010
Note: Red Circle Denotes the most serious gaged 10-year drought on the river ever at 80% of mean flow.
30
25
20
15
10
5
-
1906
1909
1912
1915
1918
1921
1924
1927
1930
1933
1936
1939
1942
1945
1948
1951
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
2008

Colorado River Ten-Year Droughts Since 1906 at Lees Ferry

Take Home Message: This is by far the most serious 10-year drought in the historic record. 3.4 % Difference = 5 maf

Rank	% Average	10-Year Total	Start Yr	End Year
1	79.7%	119,081,504	2001	2010
2	80.0%	119,483,455	2000	2009
3	81.7%	122,048,340	1999	2008
4	82.5%	123,302,369	1998	2007
5	83.1%	124,090,505	1959	1968
6	83.1%	124,212,410	1954	1963
7	83.6%	124,880,374	1931	1940
8	84.4%	126,156,961	1953	1962
9	84.8%	126,645,471	1955	1964
10	85.3%	127,482,205	1958	1967

Lee Ferry Flow Natural Flow in Acre-feet By Year Since 2000 as % of Average

Year	Flow in AF	% Avg
2000	11,029,918	74%
2001	11,027,306	74%
2002	6,204,516	41%
2003	10,479,773	70%
2004	9,410,833	63%
2005	16,849,487	113%
2006	12,515,241	84%
2007	11,935,380	80%
2008	15,907,000	106%
2009	14,124,000	94%
2010	10,627,967	71%

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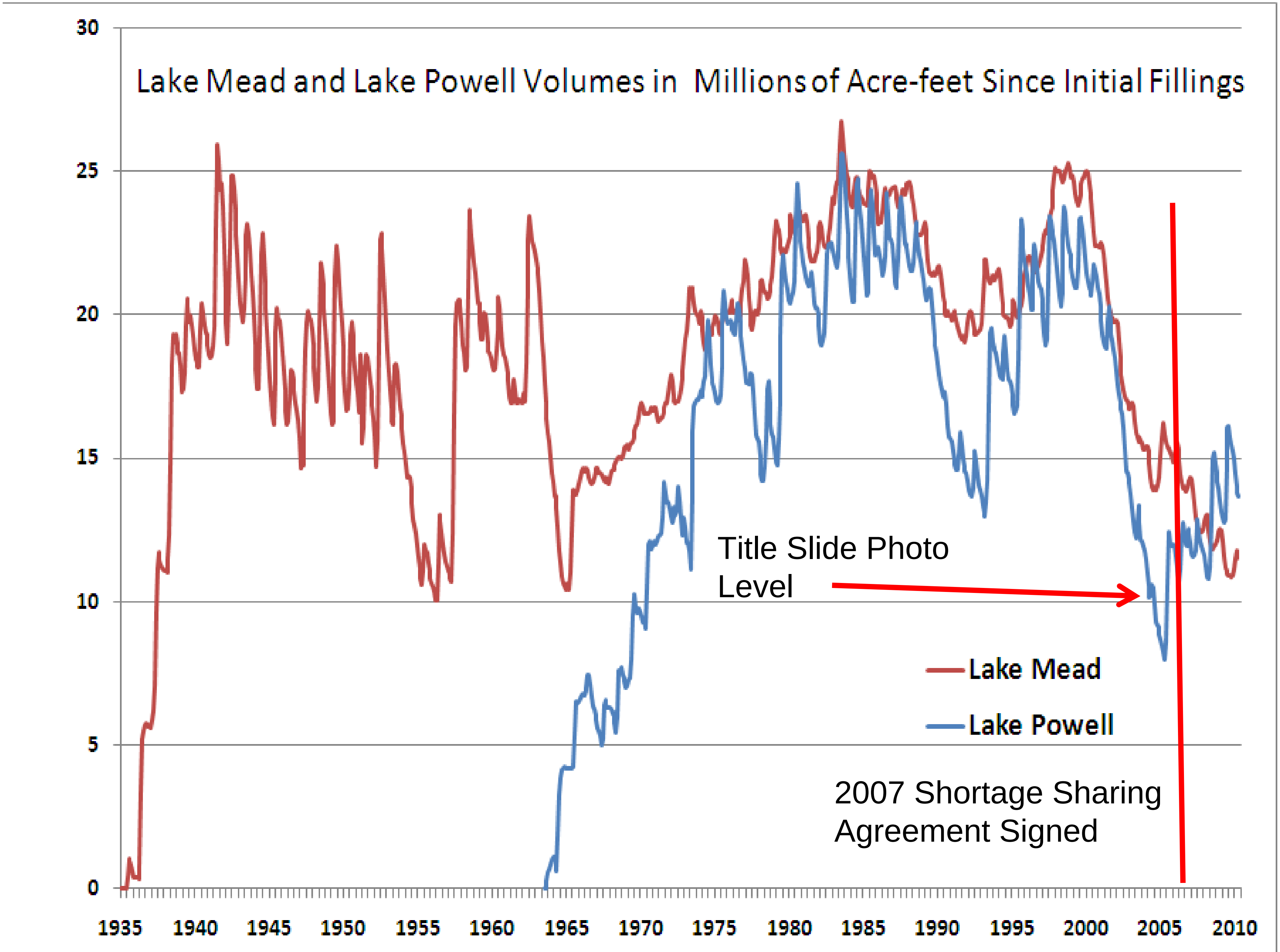
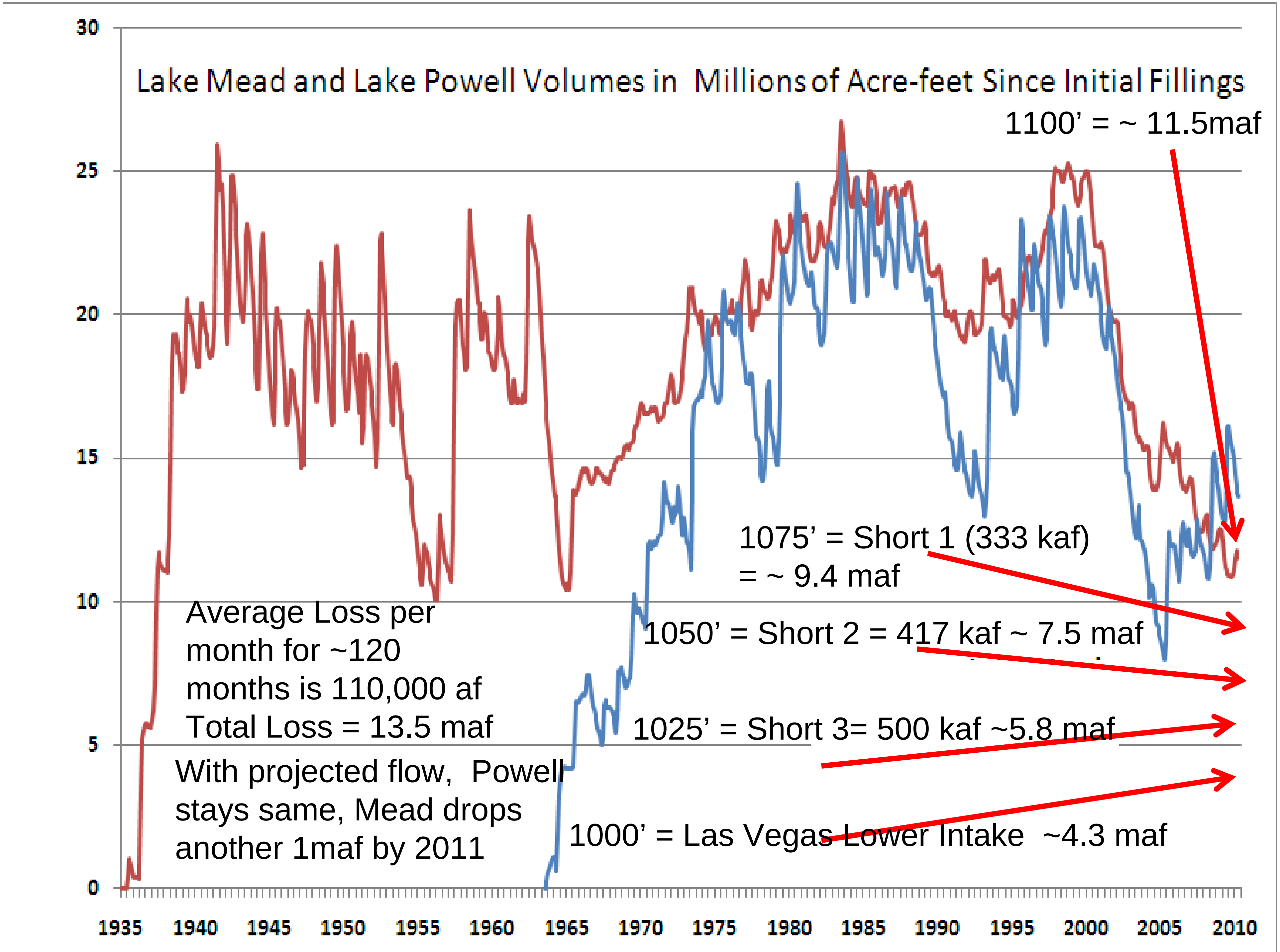
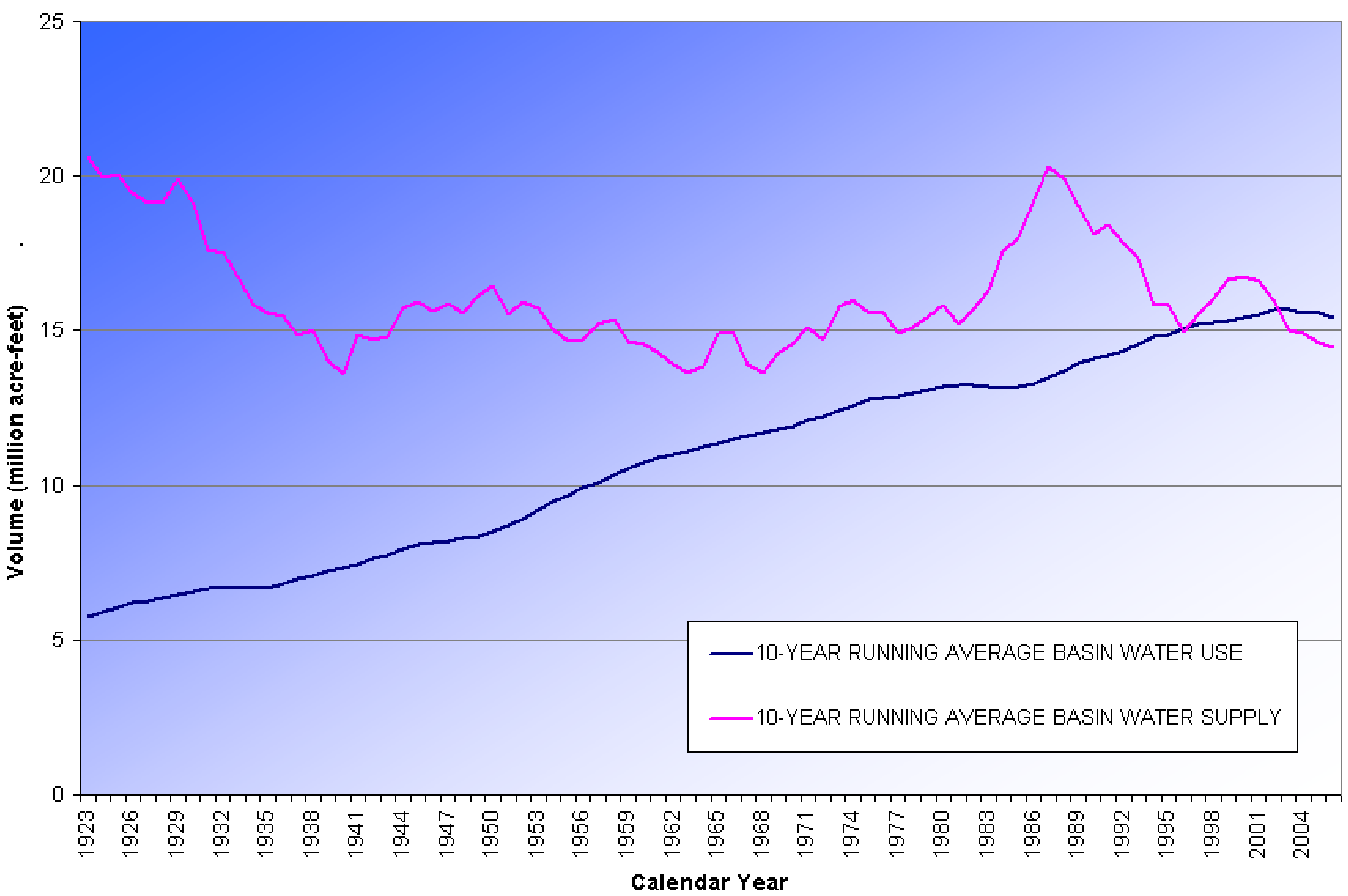

Lake Mead and Lake Powell Volumes in Millions of Acre-feet Since Initial Fillings
30
25
20
15
10
5
0
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Title Slide Photo Level
Lake Mead
Lake Powell
2007 Shortage Sharing Agreement Signed



Lake Mead and Lake Powell Volumes in Millions of Acre-feet Since Initial Fillings
1100' = ~ 11.5maf
1075' = Short 1 (333 kaf)
= ~ 9.4 maf
1050' = Short 2 = 417 kaf ~ 7.5 maf
1025' = Short 3= 500 kaf ~5.8 maf
1000' = Las Vegas Lower Intake ~4.3 maf
Average Loss per
month for ~120
months is 110,000 af
Total Loss = 13.5 maf
With projected flow, Powell
stays same, Mead drops
another 1maf by 2011
30
25
20
15
10
5
0
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

Colorado River Water Supply & Use



RECLAMATION

A Current Problem in the Lower Basin

- Avg Lake Mead Inflows = 9.0 maf
  - 8.23 maf from Powell (Current Operating Rules)
  - 0.77 maf tributaries below Powell
  - 9 maf is all the LB is legally entitled to
- Avg Lake Mead Outflows = 10.4 maf
  - 7.5 maf LB States (4.4 CA, 2.8 AZ, 0.3 NV maf)
  - 1.5 maf Mexico
  - 1.4 maf Evap + Delivery Losses
- Net Balance = -1.4 maf/year
  - (Mead at 11.5 maf now)

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A Lurking Problem in the Upper Basin

- How Much Water Left to Develop?
  - Current uses: ~4.5maf per year
  - At 13.5 maf avg , ~0.5 maf left to develop
  - At 15.0 maf avg, ~1.5 maf left to develop
- 'Hydrologic Leftovers' Creates Uncertainty
- Upper Basin Compact penalizes for overuse, but only determined after the fact
- Terror over Compact 'Call' Ramifications

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How much water to Develop ?

Source: State of Colorado "CRWAS" Study

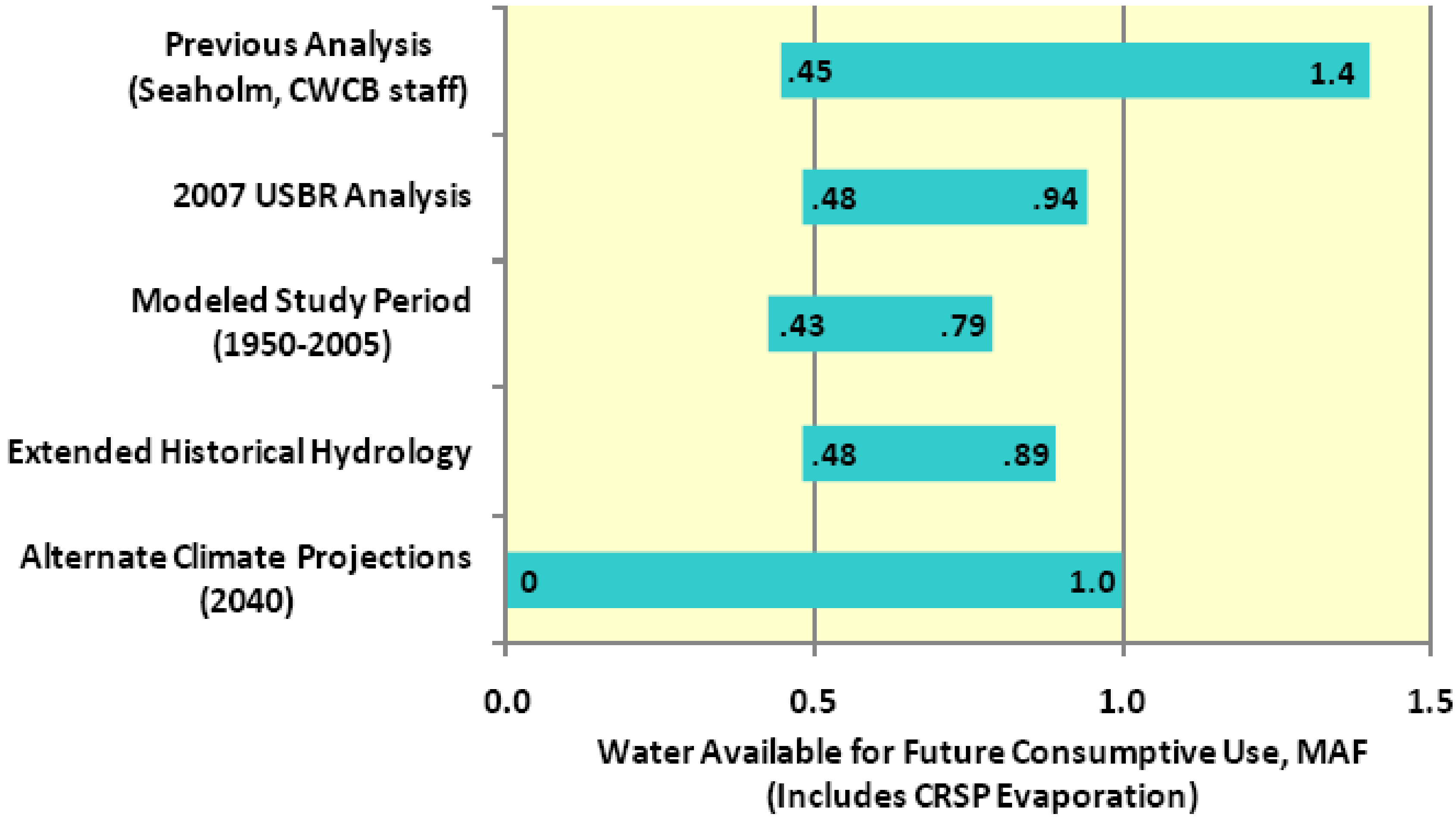
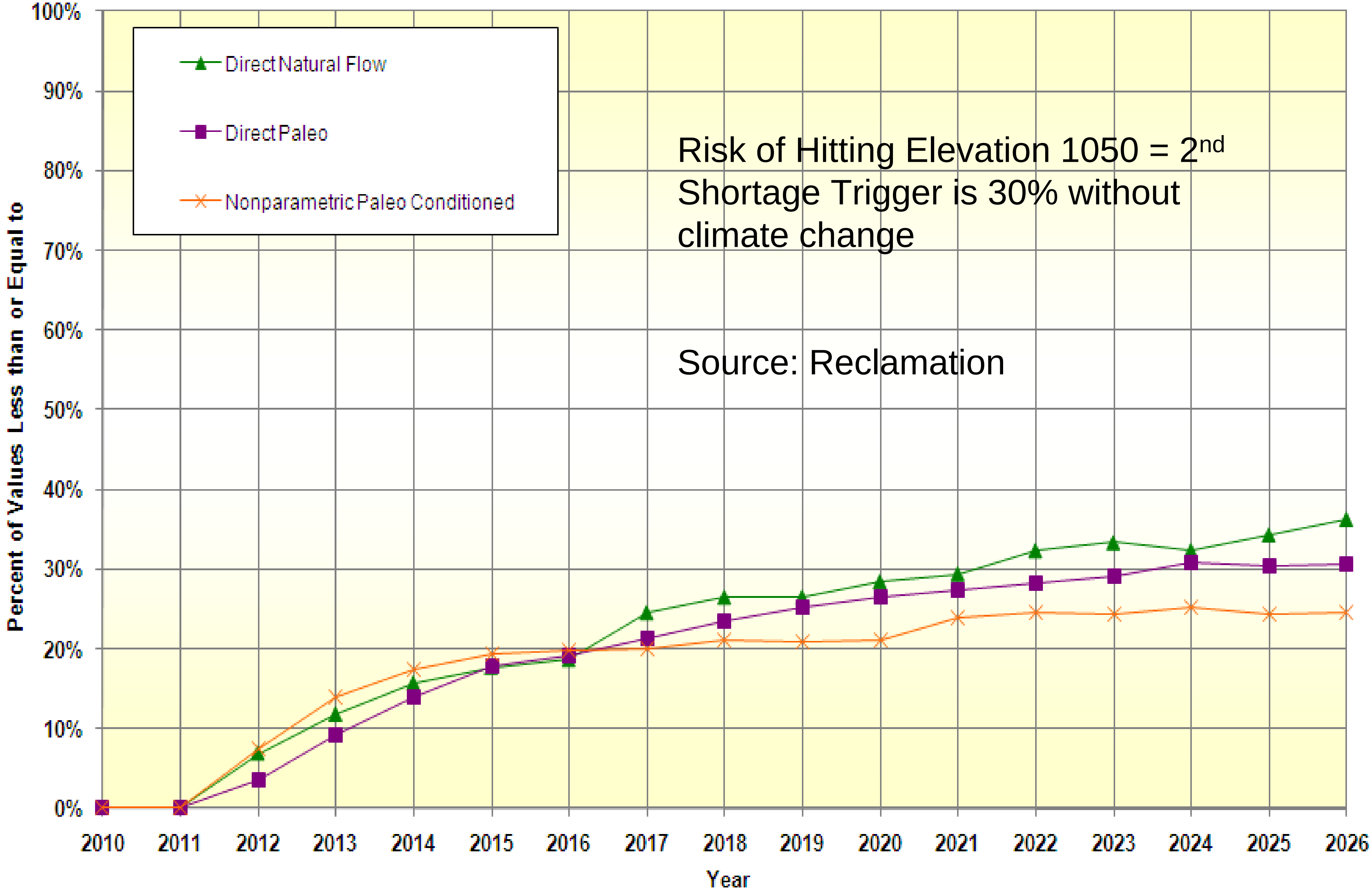


Figure 3-37 –Water Available for Future Consumptive Use by Colorado (MAF)
Revised from preliminary charts presented from January through March 2010
to CWCB, IBCC, Joint Agriculture Committee, and Colorado Water Congress

Figure 6
Lake Mead End-of-July Water Elevations
Percent of Values Less than or Equal to Elevation 1,050 feet



When Will Lake Mead Go Dry?

Water Resources Research, 2008, Barnett and Pearce

- Water Budget Analysis
  - One 50 maf reservoir, increasing UB demands (13.5 in 2008 ->14.1 maf/yr in 2030, 15 maf /yr inflows, current starting contents
  - Linear Climate Change Reduction in Flows w/ some natural variability
- Results With Linear 20% Reduction in mean flows Over 50 years
  - 10% Chance Live Storage Gone by 2013
  - 50% Chance Live Storage Gone by 2021
  - 50% Chance Loss of Power by 2017
- Problems
  - 1.7 maf/year fixed evaporation plus bank storage
  - Missing 850 kaf/yr inflows below Lees Ferry
  - Reservoirs can and do recover, even with declining flows
- Critical Issues Regardless of these Results
  - System is close to Demand = Supply which has big implications
  - Normal climate variability can push us over the edge without climate change

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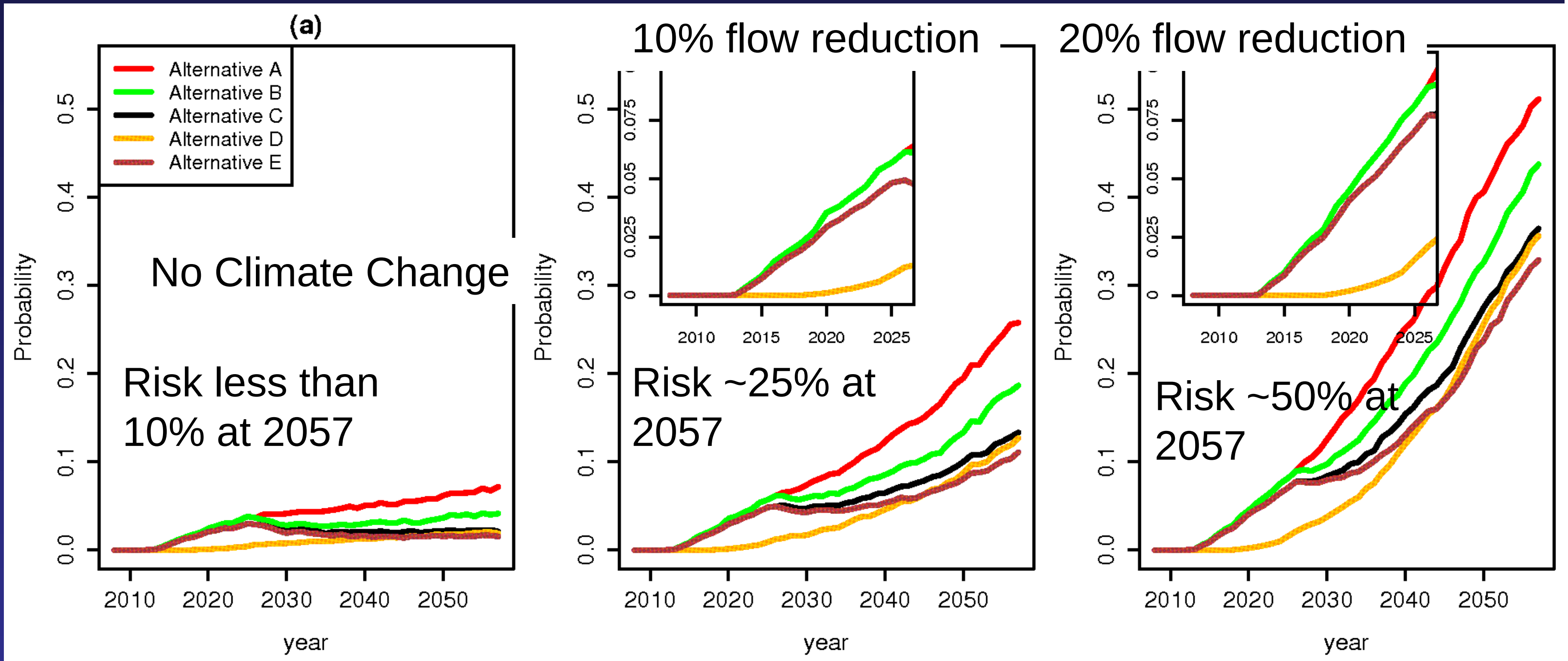
Risk of Reservoir Drying 2009 to 2057 – Can Management Mitigate?

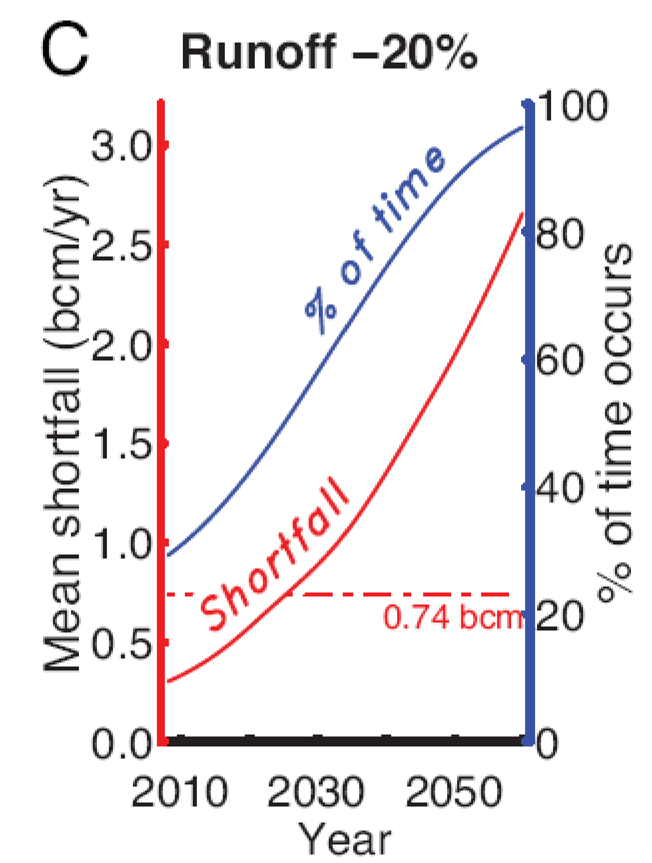


- 5 Future Management Alternatives (colored lines above)
- Near-term risks relatively low
- Management can offer some risk mitigation
- 2057 results for -10% and -20% are unacceptable

(Rajagopalan et al, 2009)

Sustainable Water Deliveries in a Changing Climate – BP 2009

- New Metric for Risk – shortage amounts
- - 10% flow means shortages 58% of time by 2050, -20% 88% of time shortages
- Mean annual shortages are ~10% of total deliveries or 1.5 maf at -10% flow (All of AZ's CAP allocation) by 2050
- With different assumptions mean shortages could by 3.0 maf/year
- Long term sustainable deliveries are 0 to -20% of current amounts



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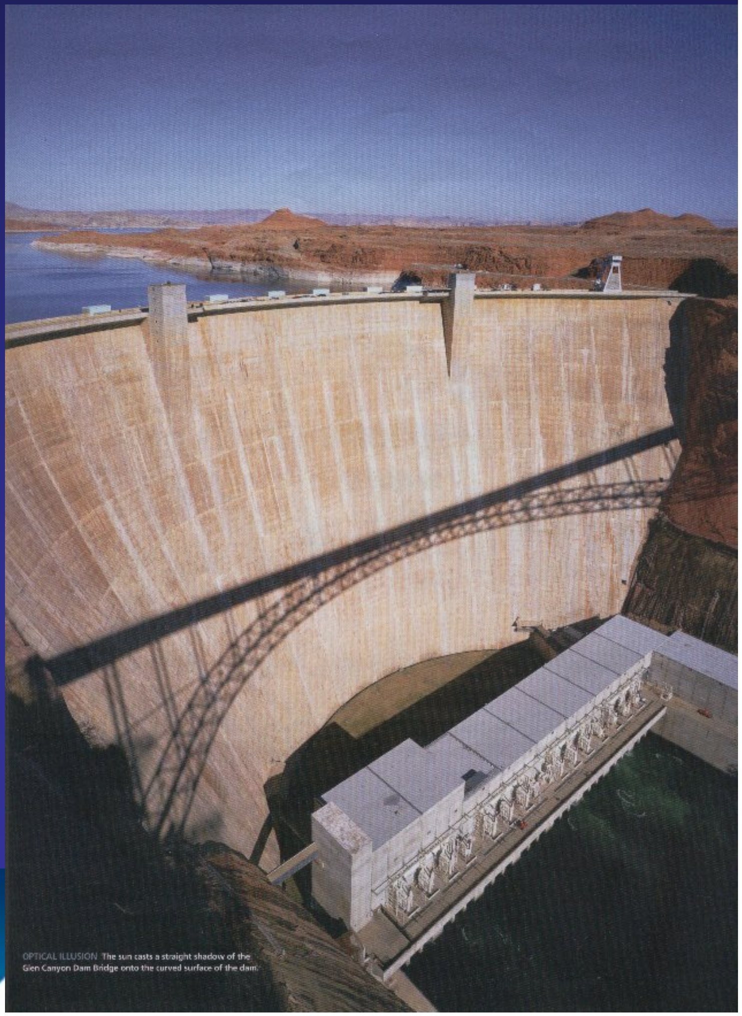
Common to Risk Studies

- On a collision course between supply and demand
- When collision occurs is the real question
- It all depends on starting conditions…
  - If Assume Deficit now, then problems very soon
  - If no deficit now then more time
- There is a broad envelope of risk to consider
  - This is the key lesson for the 21st Century –
  - How do we build resilient systems???



OPTICAL ILLUSION The sun casts a straight shadow of the Glen Canyon Dam Bridge onto the curved surface of the dam.

Western Water Assessment

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- CRB Climate Change Studies
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- **CRB Science Issues**
- Lessons from Australia
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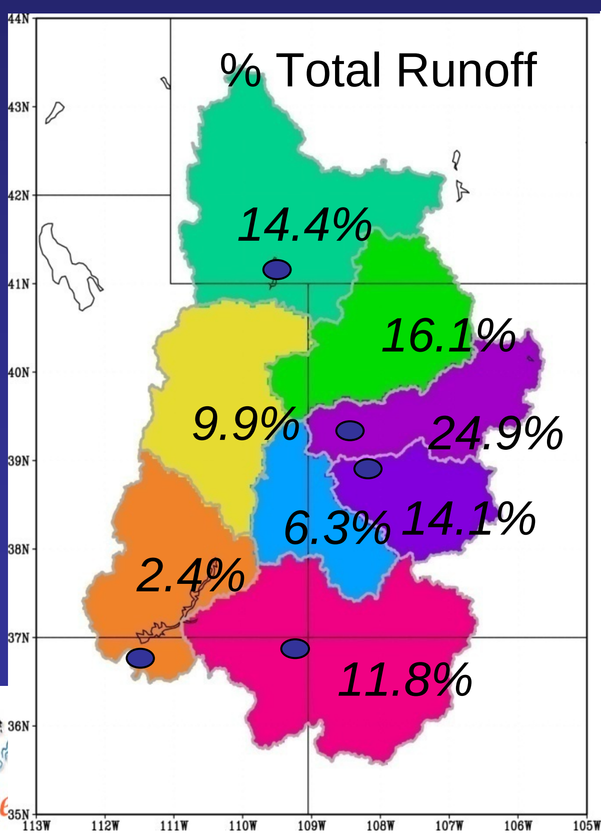
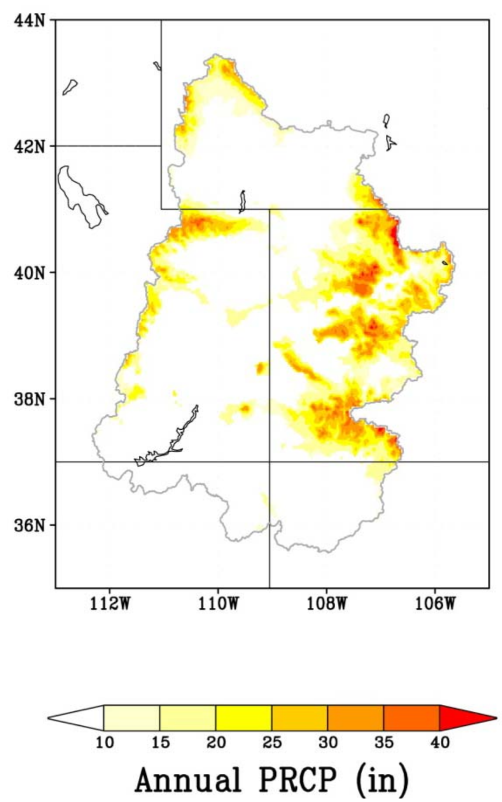
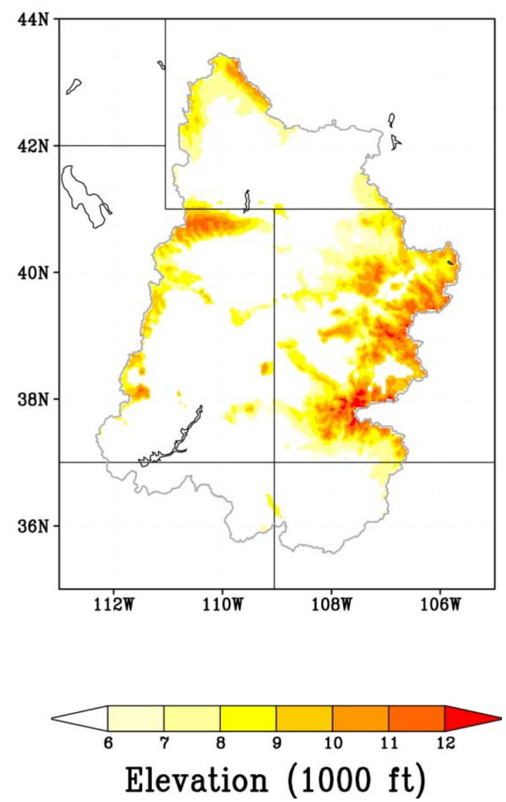
Reconciling Year 1- Scale Matters

- Most runoff comes from small part of the basin > 9000 feet
- Runoff Efficiency 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) and H&E 2006 likely overstate declines





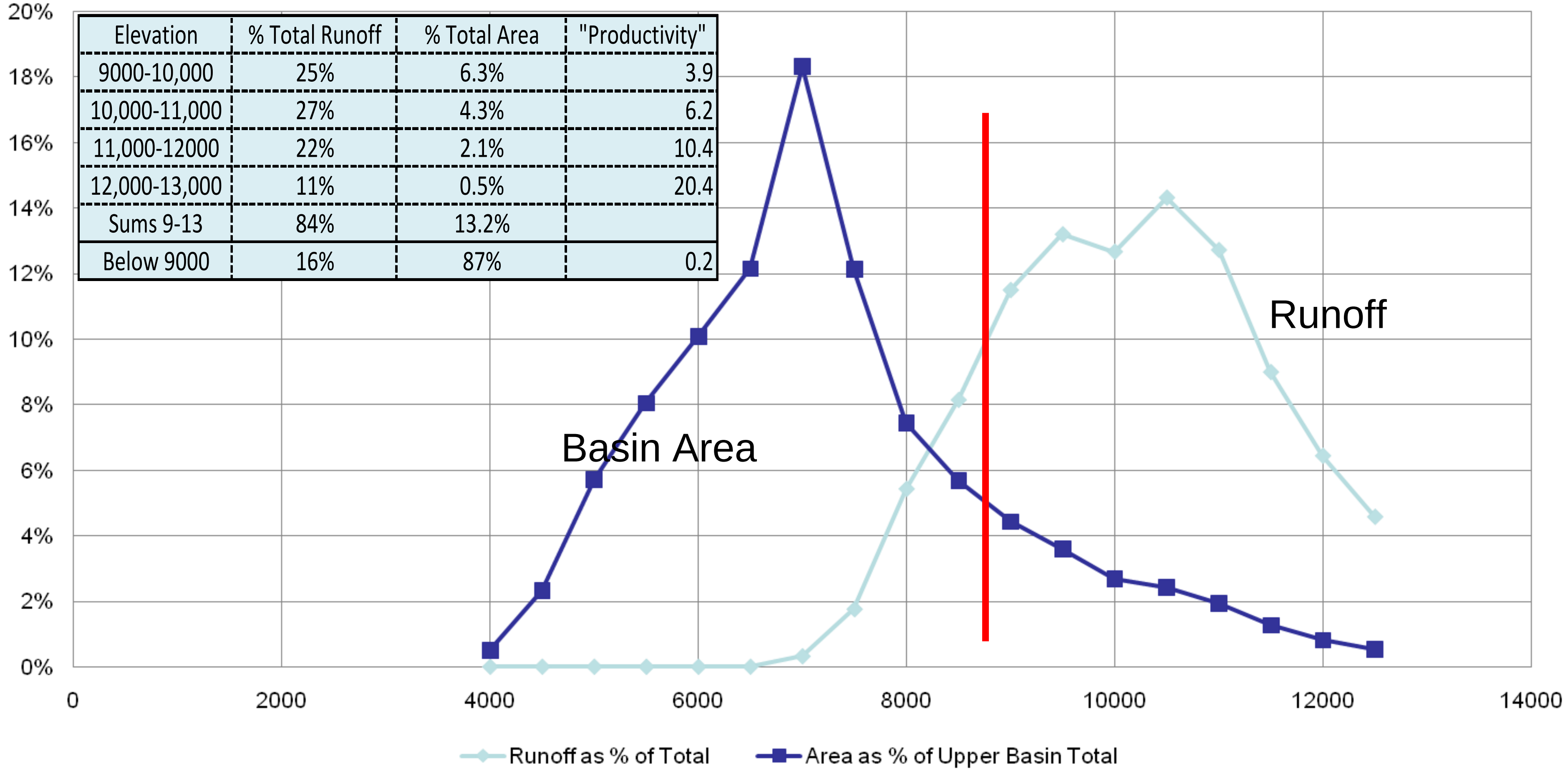


Reconciling Year 1- Scale Matters

- 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’

Basin Area and Runoff By Elevation

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



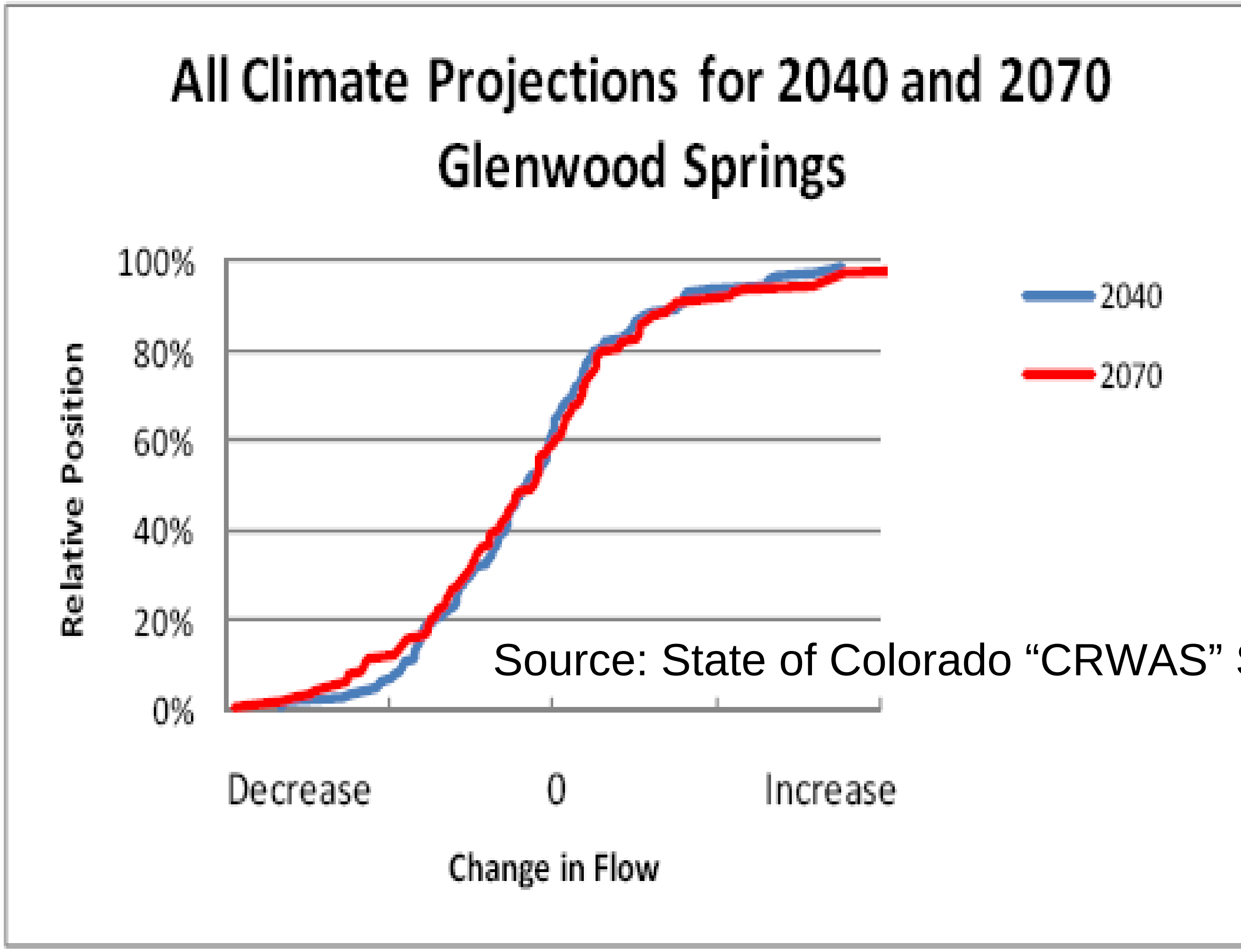
Wild Cards: Dust on Snow

60 Day Advance in Runoff Timing

~5% Loss in Runoff

Hydrology Model Issues

- Why is 2070 no different from 2040?



Source: State of Colorado "CRWAS" Study

Figure 2-10 – Comparison of Relative Impact on Flow at Glenwood Springs All 2040 and 2070 Projections

Demand Issues

- Total Demand Increases by 1.5 to 5 maf at 2040. Average Increase ~ 20%. 18 Days Longer Growing Season
- At 2070 Average Increase ~30%, 30 Days.

Table 3-5 – 2040 Average Annual Study Basin CIR Compared to Historical Conditions (AF)

Source: State of Colorado "CRWAS" Study

Study Basin	Historical Period	Minimum Projection	Maximum Projection	Average of Projections	% Increase From Historical
Yampa River	214,271	225,440	263,438	245,964	15%
White River	45,937	50,123	62,182	56,713	23%
Upper Colorado River	577,043	618,704	736,863	686,314	19%
Gunnison River	618,070	660,364	768,486	724,335	17%
San Juan/Dolores Rivers	554,821	591,795	685,620	647,506	17%
Total	**2,010,142**	**2,146,426**	**2,516,589**	**2,360,832**	**17%**

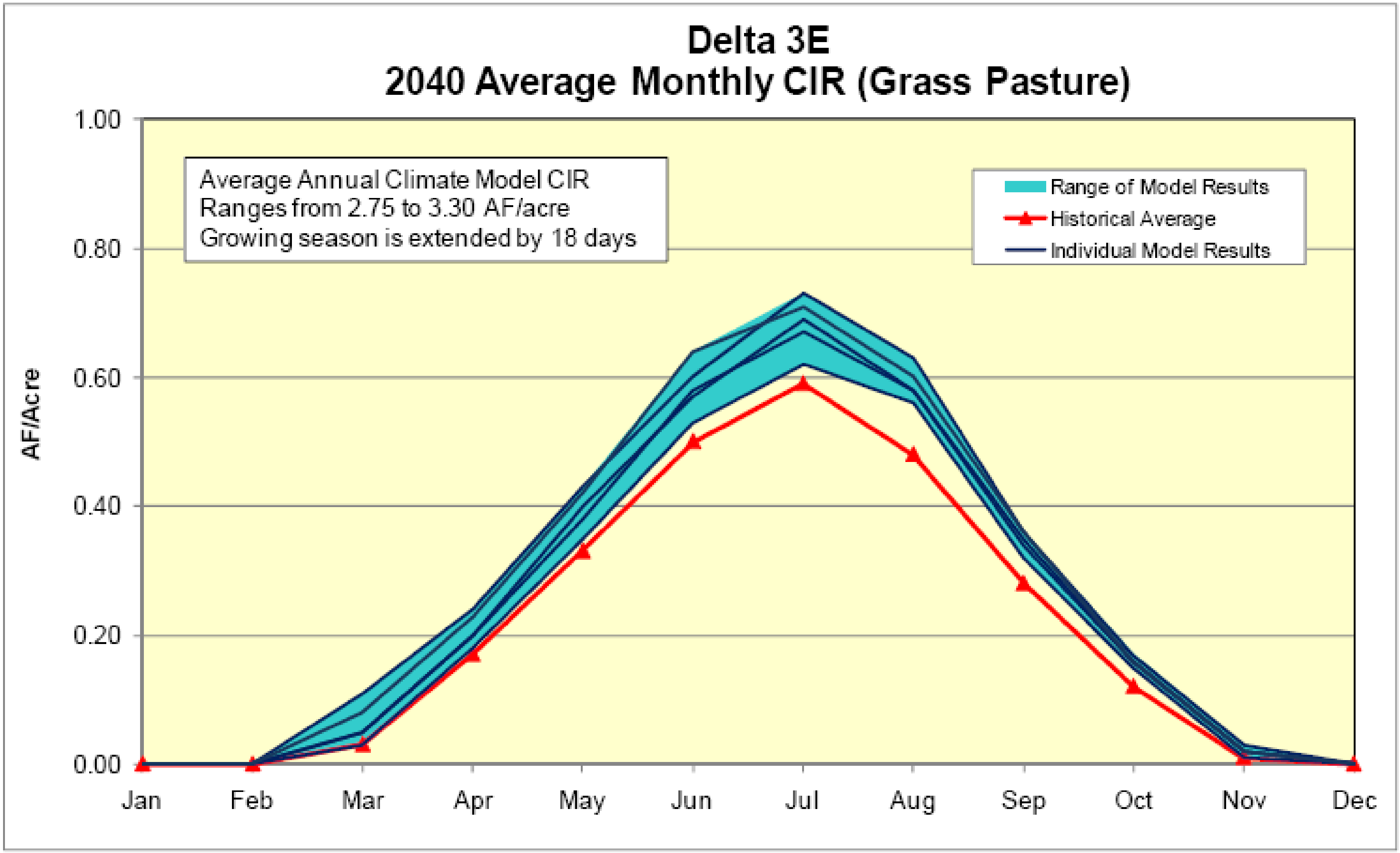


Figure 3-6 – Delta 2040 Average Monthly CIR Comparison

Wild Cards: Pine Beetles

Raffa et al, 2008

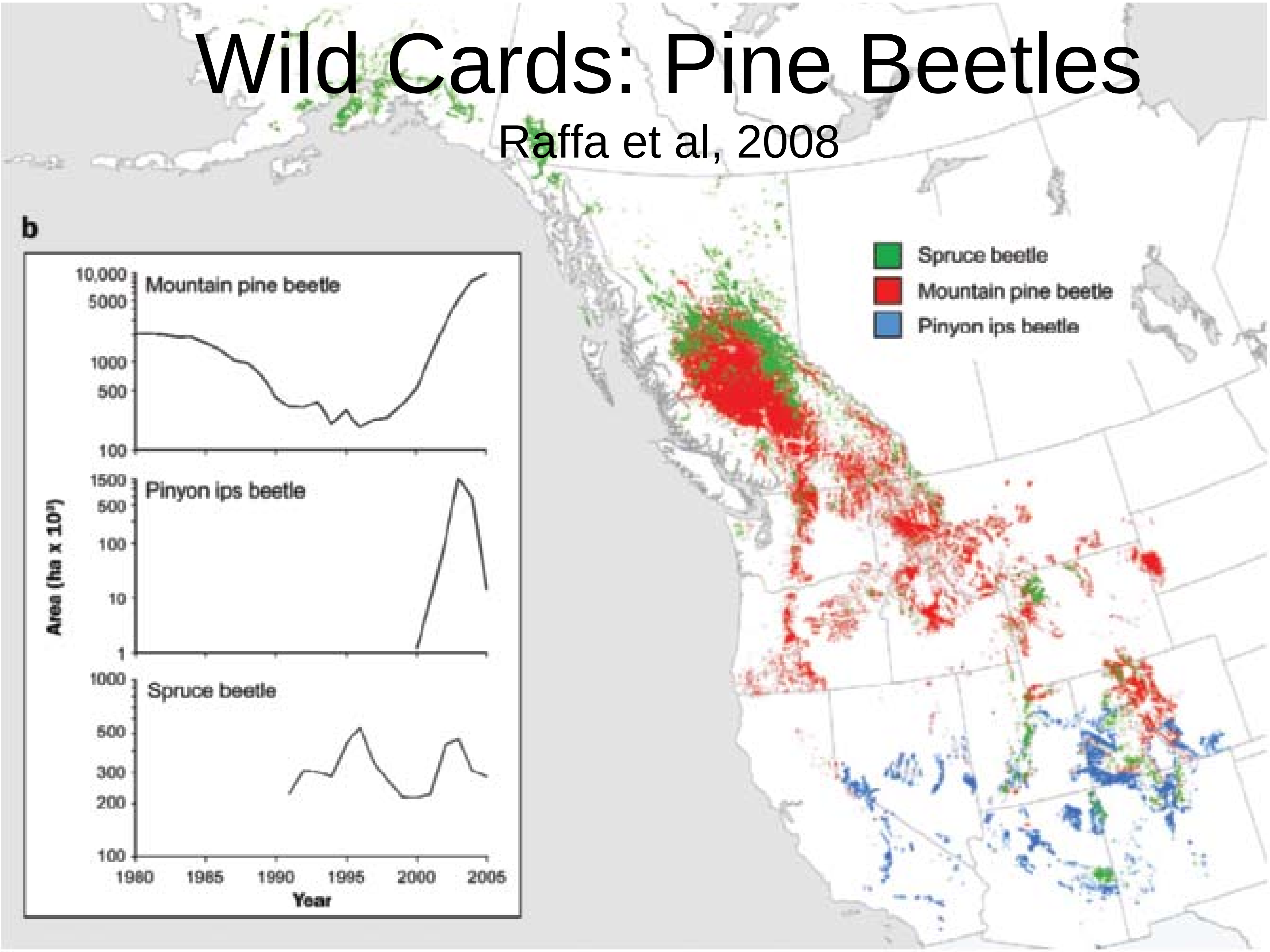


Figure 1. Recent mortality of major western conifer biomes to bark beetles. (a) Map of western North America showing regions of major eruptions by three species. (b) Sizes of conifer biome area affected by these three species over time. Data are from the Canadian Forest Service, the British Columbia Ministry of Forests and Range, and the US Forest Service.

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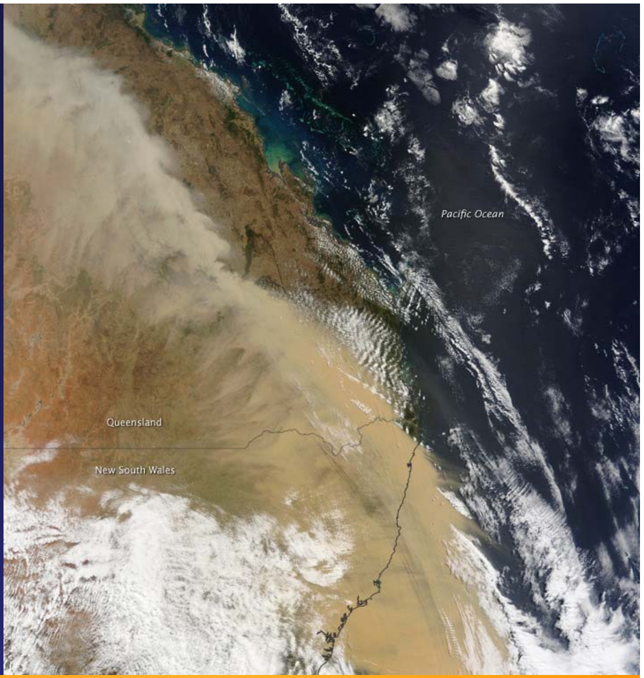
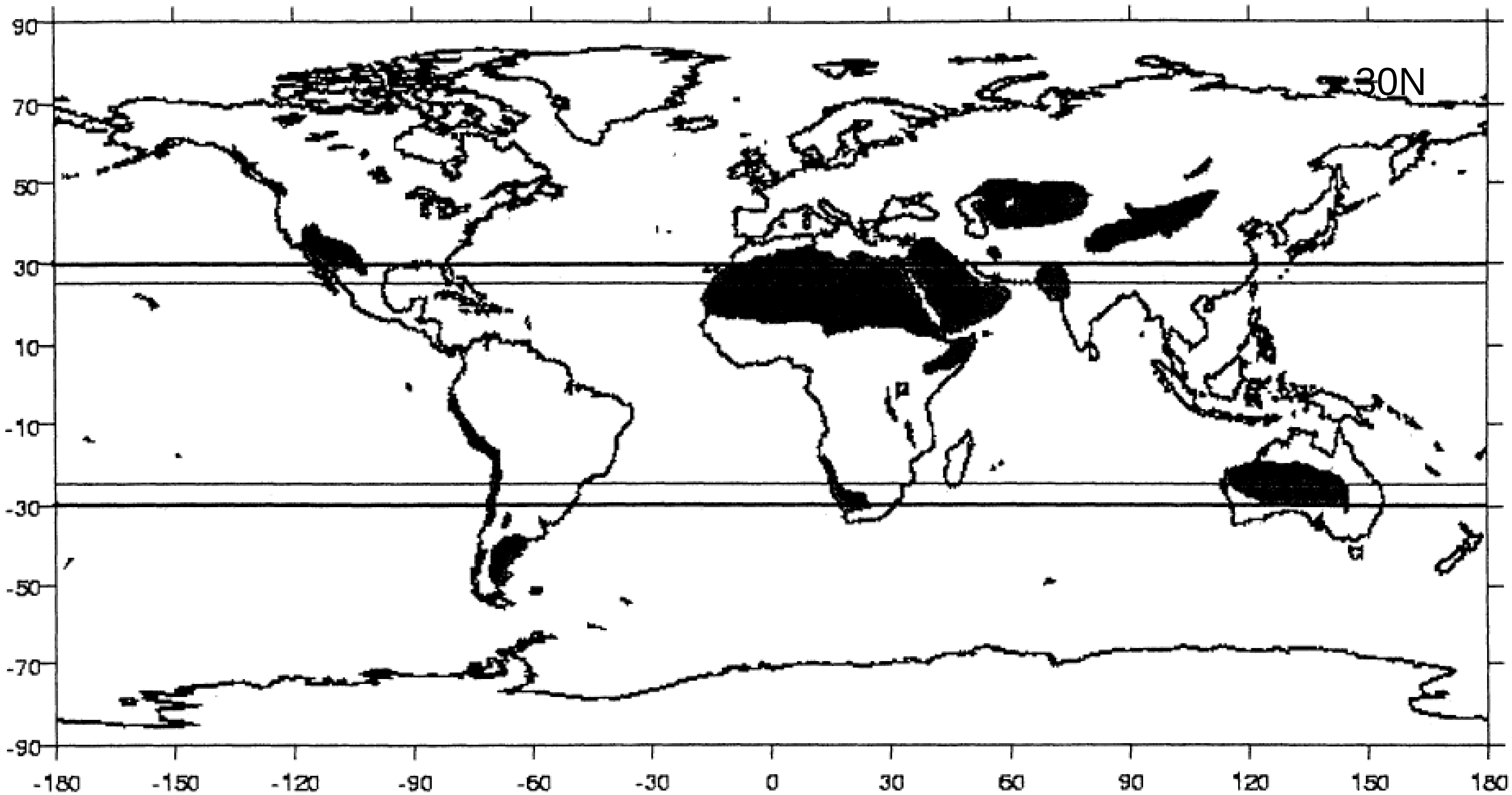
The Aussie Big Dry

- 2000 to 2010
- Unprecedented -40% to -50% reductions in runoff in large parts of the country
- It has changed..
  - Language around water
  - Government Policies
  - Water Management on all levels
- Could it happen here?



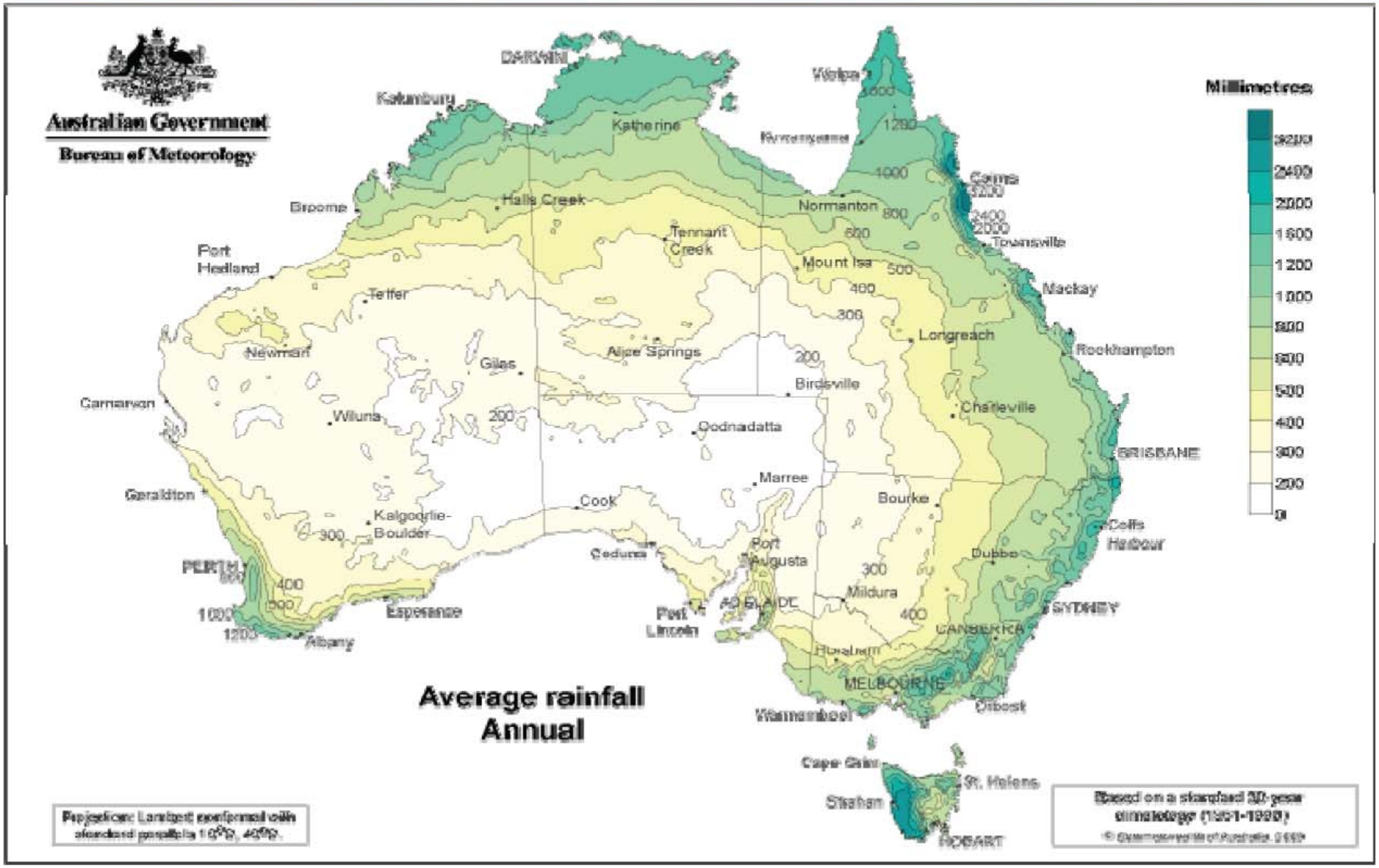
Western Water Assessment

Major Deserts of the World

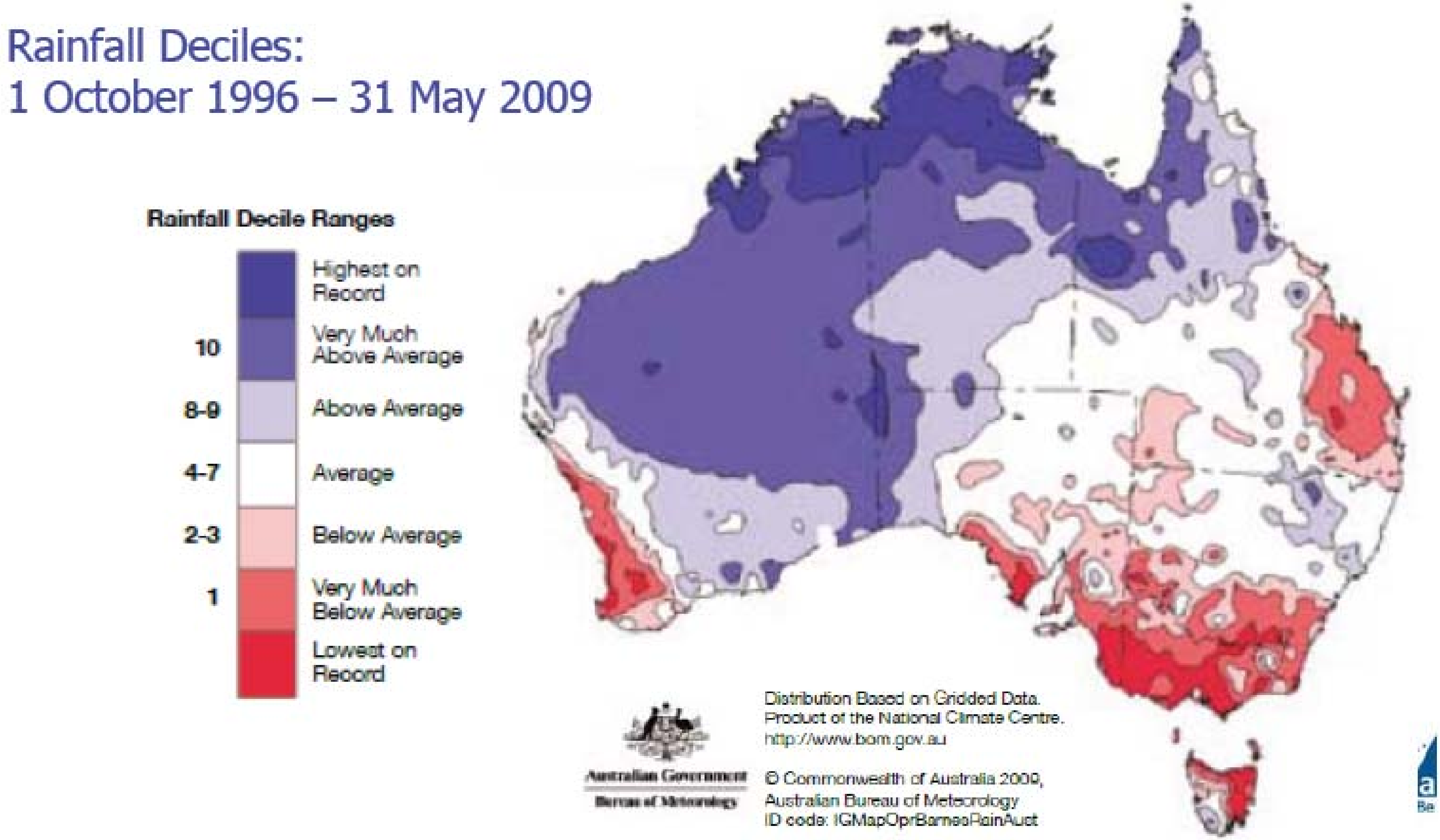


Arctic Ocean
Arctic Ocean
Arctic Ocean
120°
60°
0°
60°
120°
180°
Ellesmere Island
Greenland (Den.)
Banks Island
Victoria Island
Baffin Island
Jan Mayen (Nor.)
Svalbard (Nor.)
Franz Josef Land
Severnaya Zemlya
Novaya Zemlya
New Siberian Islands
Wrangel Island
U.S.A.
Canada
Iceland
Faroe Is. (Den.)
Norway
Finland
Sweden
Russia
Estonia
Latvia
Lithuania
Belarus
United Kingdom
Den.
Ireland
Neth.
Bel.
Germany
Poland
Czech.
Ukraine
Slovak.
Aus.
Hung.
Moldova
France
Switz.
Slov.
Cro.
Bos.
Yugo.
Romania
Bulgaria
Italy
Mac.
Albania
Greece
Turkey
Georgia
Armenia
Azerbaijan
Kazakhstan
Uzbekistan
Turkmenistan
Kyrgyzstan
Tajikistan
Mongolia
N. Korea
S. Korea
Japan
China
Kuril Islands
Aleutian Islands (USA)
60°
Island of Newfoundland
United States of America
Portugal
Spain
Morocco
Tunisia
Algeria
Libya
Egypt
Cyp.
Leb.
Israel
Syria
Iraq
Jordan
Kuwait
Iran
Afghanistan
Pakistan
Nepal
Bhu.
Qatar
U.A.E.
Saudi Arabia
Oman
India
Bang.
Myanmar (Burma)
Laos
Taiwan
Canary Islands (Sp.)
Western Sahara (Mor.)
Mauritania
Mali
Niger
Chad
Sudan
Eritrea
Yemen
Thailand
Vietnam
Cambodia
Philippines
Mexico
Cuba
The Bahamas
Jam.
Haiti
Belize
Guatemala
Honduras
El Salvador
Nicaragua
Costa Rica
Panama
Senegal
The Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Côte D'Ivoire
Sierra Leone
Liberia
Ghana
Togo
Eq. Guinea
Cameroon
C.A.R.
Ethiopia
Djibouti
Somalia
Andaman Islands (India)
Sri Lanka
Maldives
Brunei
Malaysia
Singapore
Federated States of Micronesia
Guam (USA)
North Pacific Ocean
Venezuela
Guyana
Suriname
French Guiana (Fr.)
Colombia
Ecuador
Galapagos Islands (Ecuador)
Uganda
Kenya
Gabon
Rwanda
Burundi
Sao Tome & Principe
Congo
Zaire
Tanzania
Seychelles
Indonesia
Papua New Guinea
Brazil
Peru
Bolivia
Malawi
Angola
Zambia
Mozambique
Madagascar
Zimbabwe
Namibia
Botswana
Mauritius
Indian
Swaziland
South Africa
Lesotho
Australia
New Caledonia
Paraguay
Uruguay
Chile
Argentina
South Pacific Ocean
South Atlantic Ocean
Tasmania
New Zealand
Falkland Islands (Islas Malvinas) (adm. by UK, claimed by Argentina)
South Georgia (adm. by UK, claimed by Argentina)
60°
60°
Antarctica
150°
120°
90°
60°
30°
0°
30°
60°
90°
120°
150°
180°

Australia - Annual rainfall 1961 - 1990



Rainfall During Last 13 Years



Australian Temps 2001-2005

A protracted dry and exceptionally hot period affecting NSW and most of eastern Australia, 2001-2006.

Clinton Rakich and Perry Wiles
NSW Climate Services Centre, Bureau of Meteorology

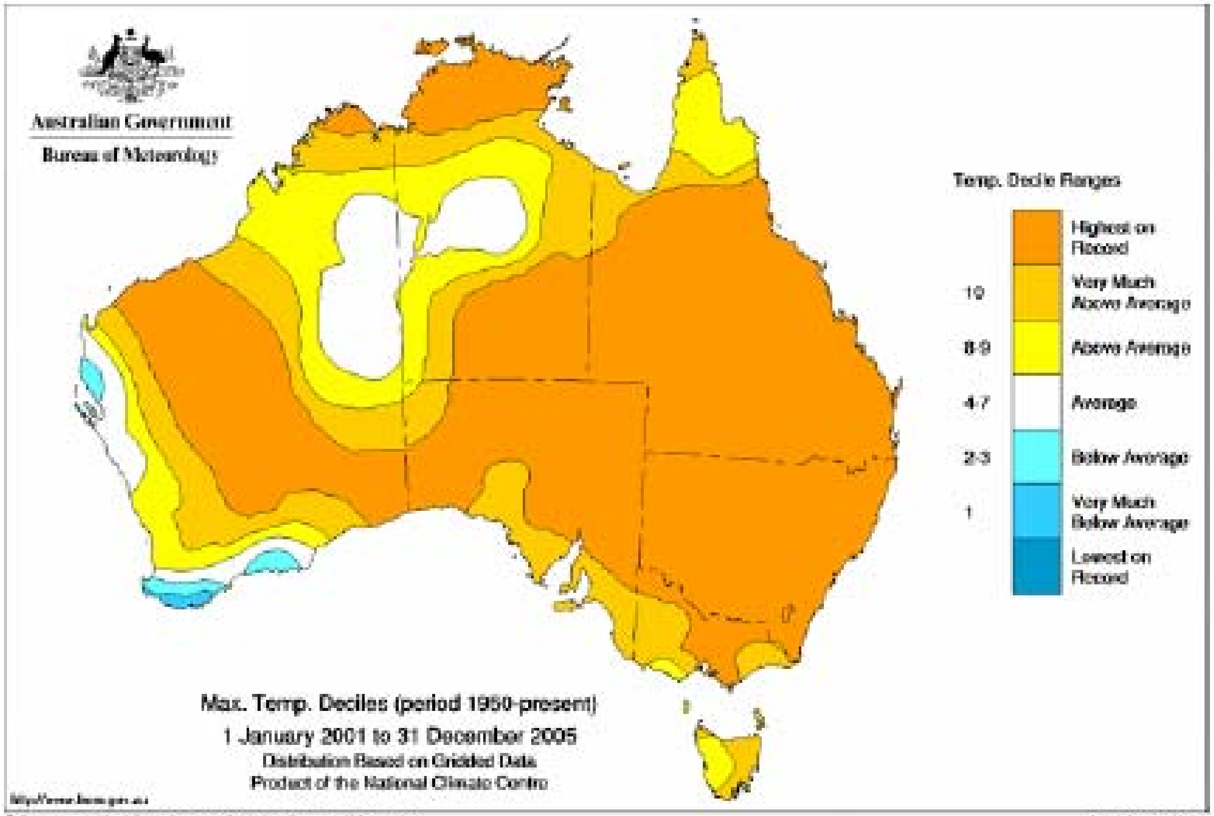
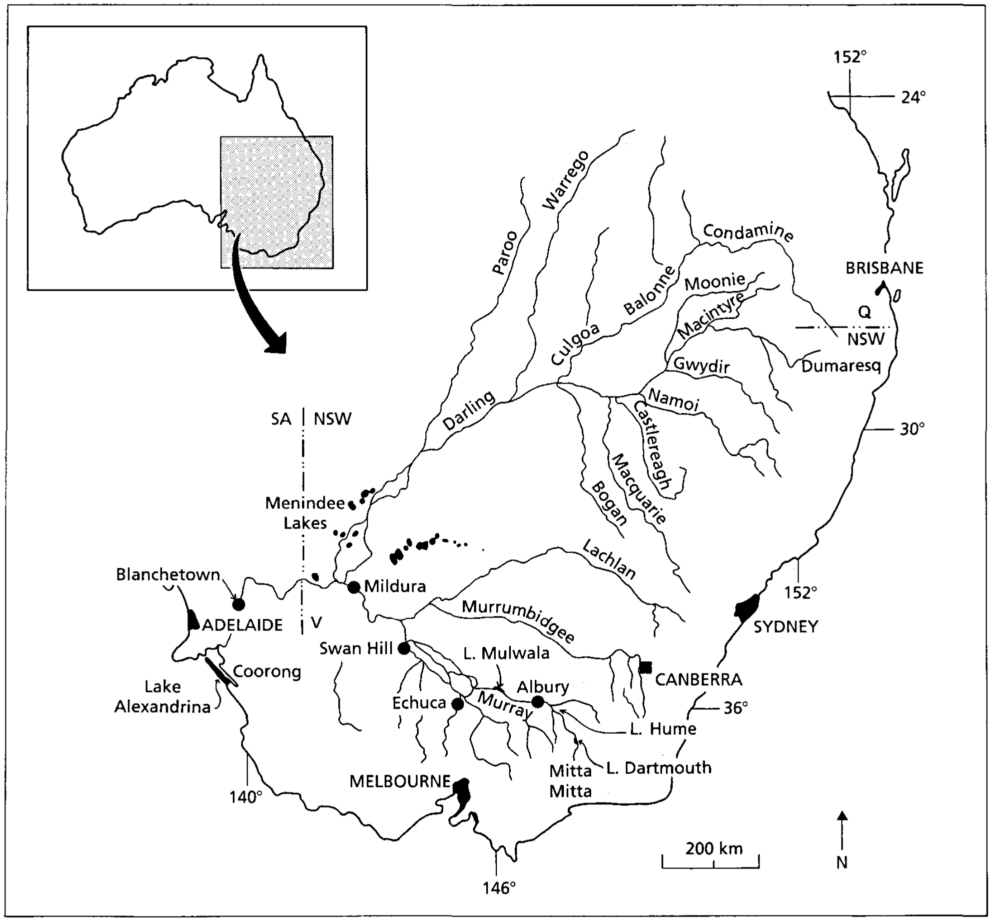


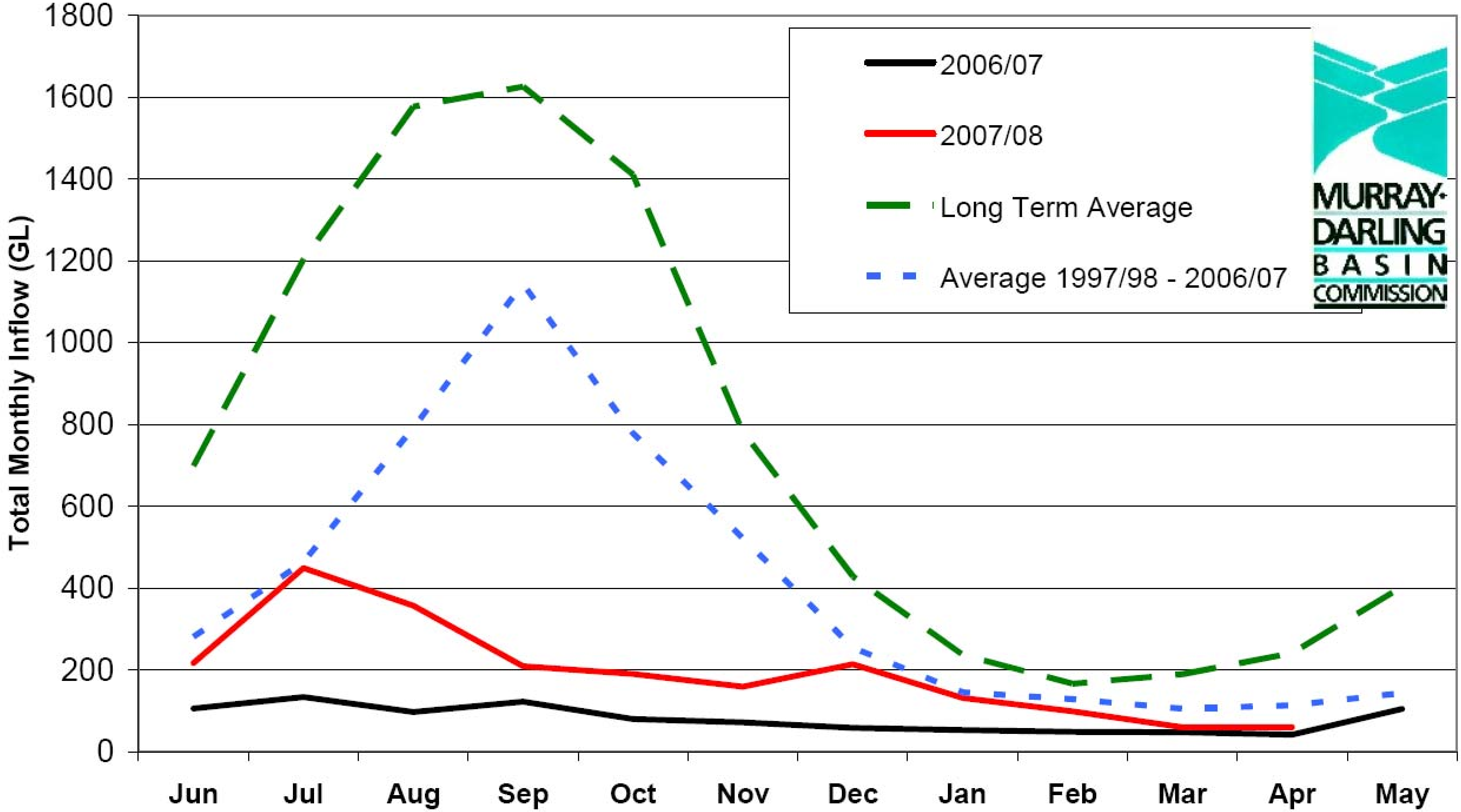
Figure 3. Australian maximum temperature deciles for the period 1 January 2001 to 31 December 2005.

Murray Darling Basin Overview

- 4 States (QLD, NSW, VIC, SA) Plus ACT
- 1,000,000 km2
- 2500 km in length
- ~23,000 GL (~18MAF) 'Usable Flow'
  - Very Lossy System
  - 14,500 GL at Confluence
- 'Low Energy' System
- Snow Melt + Rain Fed
- Total Storage ~1.5x usable, 2.6 x Use
- Most of Australia's Irrigated Land
- Significant Wetlands
- Substantially Over Allocated

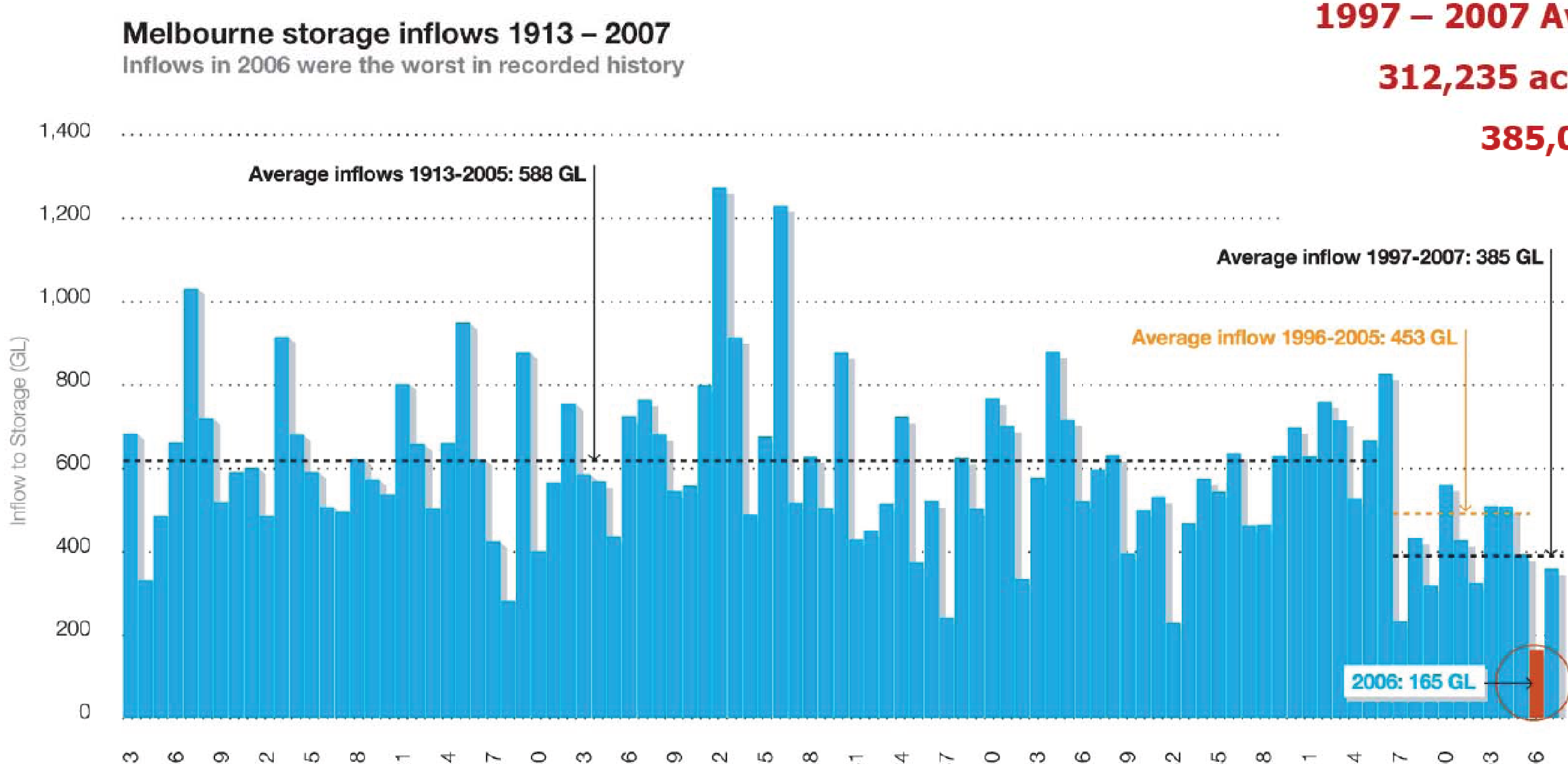


Murray Darling Annual Hydrograph



Murray-Darling Basin Commission May 2008

Water security under threat – 2006/07 crisis year



1997 – 2007 Averag

312,235 acre fe

385,000 M

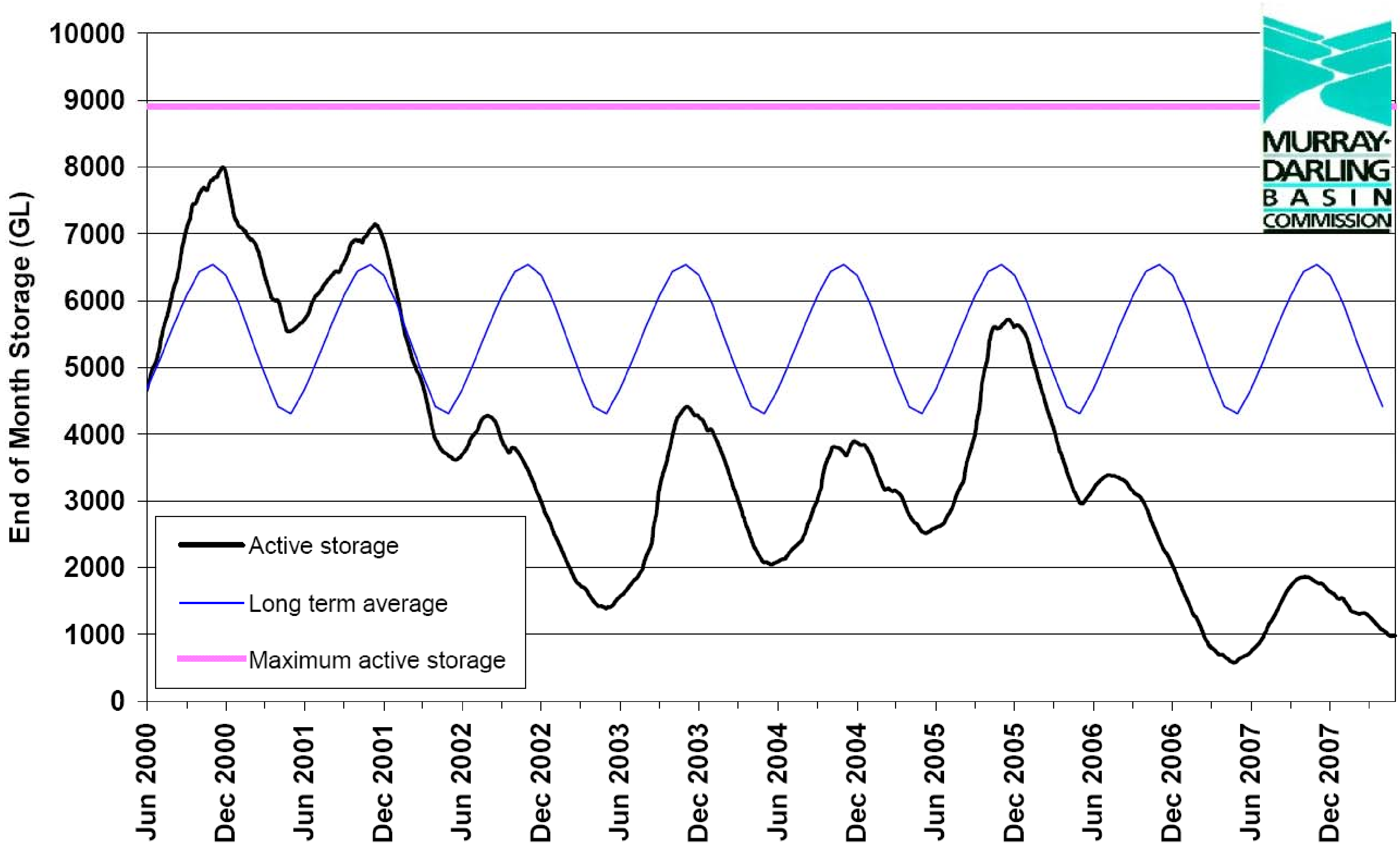


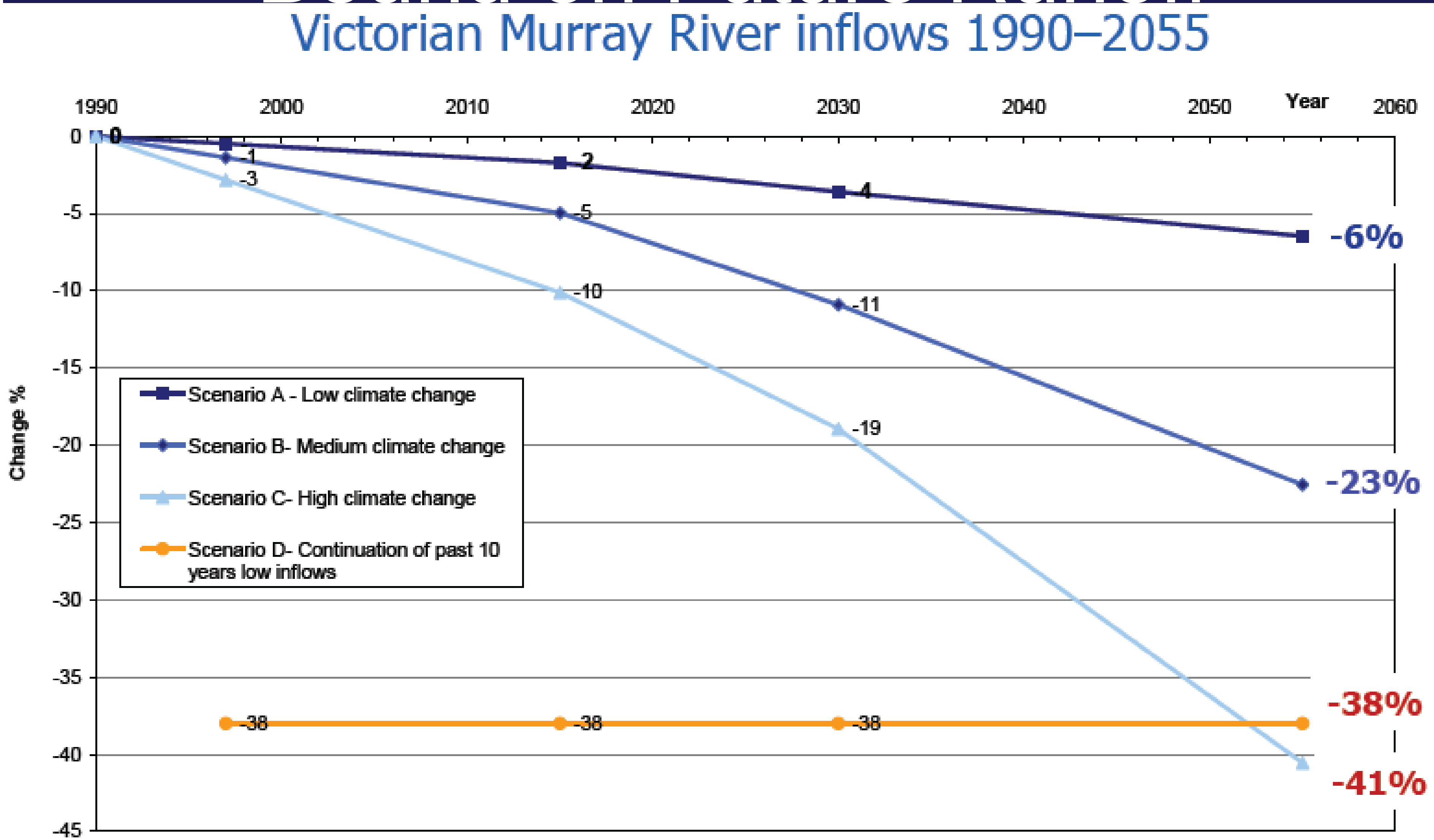
Figure 2. MDBC active storage; June 2000 to April 2008

Major Australian Changes

- Policy Reform
  – 2004 National Water Initiative
  – National Water Commission
  – Water Rights Simplification
  – Water Markets
  – $13B AUD Program = $200B US
- Urban Water Reform
  – Consolidation of water providers
  – Independent Price Setter
- Infrastructure
  – Large Desal Plants in Every Major City
  – Water Recycling
  – Interbasin Transfers
  – Rainwater Harvesting
  – Ag Infrastructure - $2B in

- Conservation
  - Very little outdoor watering
- Science
  - CSIRO Sustainable Yields Study
- Environment
  - $3b AUD Purchase of Water held by Federal government

Models May Not Set Lower Bound on Future Runoff



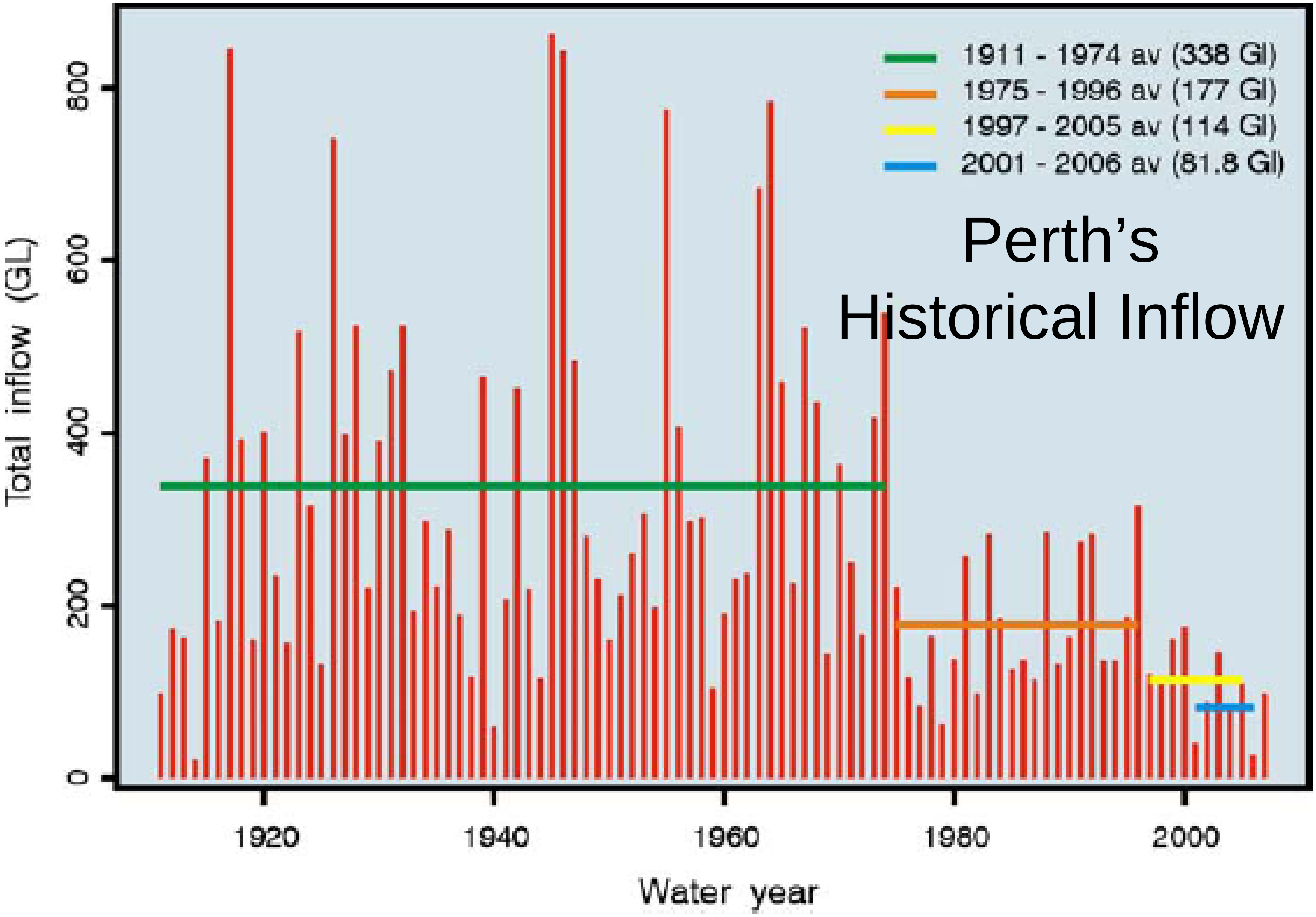


Fig. 5 Annual (May to April) inflow series (GL) for the Integrated Water Supply System. Source: http://www.watercorporation.com.au

Outline

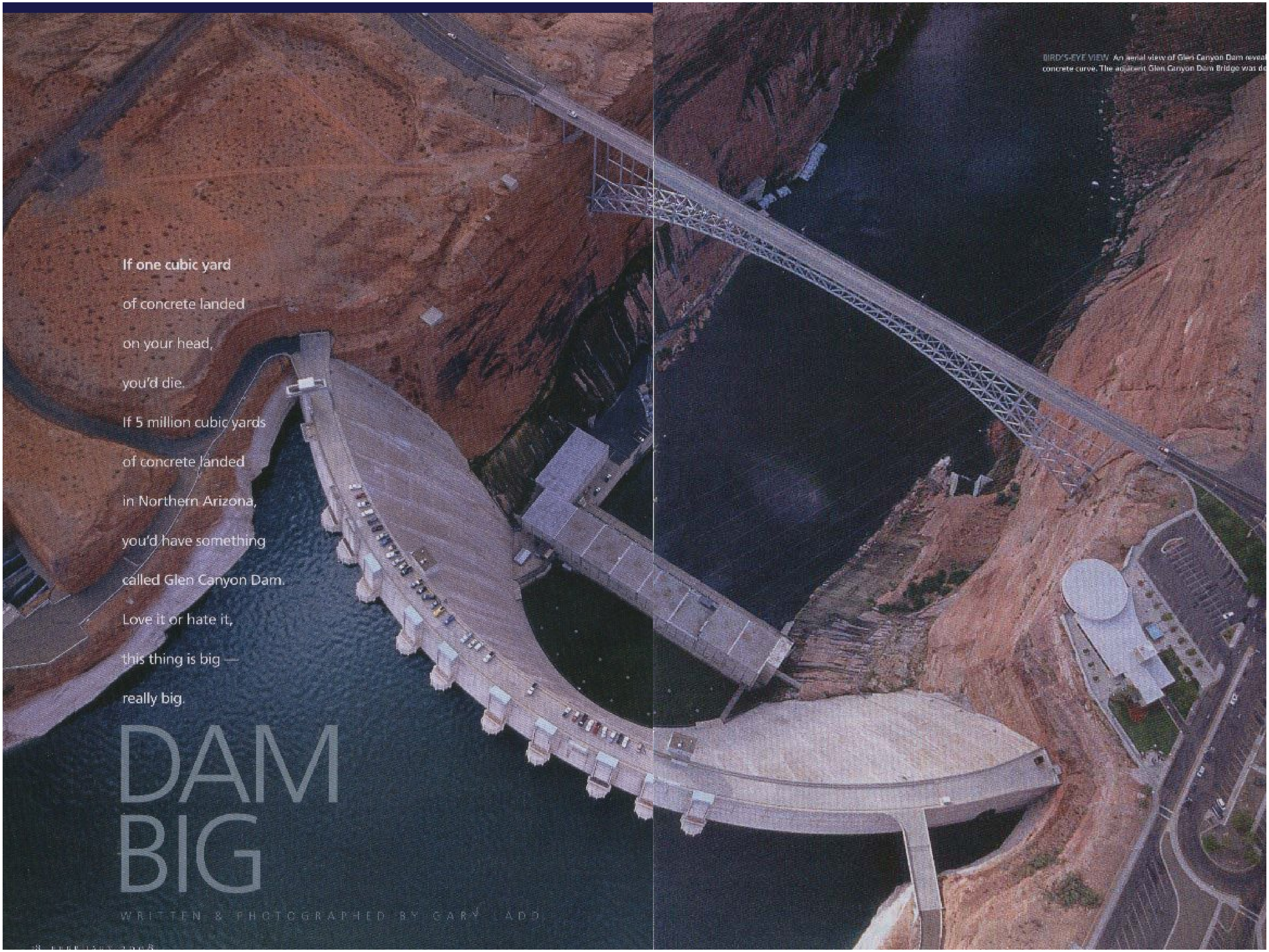
- Climate Change Studies
- Recent Climate
- Systemic Allocation Problems
- Science Issues
- Lessons from Australia
- Closing Thoughts

Western Water Assessment

Colorado
University of Colorado at Boulder

Take Home Points

- CRB in the middle of record setting drought
- Warm temperatures in the Basin at least partly a cause
- Lower Basin is overusing its allocation
  - Big Water Years could delay impact
  - Increasing Demand and Decreasing Supply will advance it
- Upper Basin has no idea how much water left
- Climate Change will likely reduce CRB Flows
- Much Science left to be done
- Australia's 'Big Dry' may be CRB Future
- Australian Water Policies, Infrastructure and Management have changed enormously due to 'Big Dry'



BIRD'S-EYE VIEW An aerial view of Glen Canyon Dam reveal
concrete curve. The adjacent Glen Canyon Dam Bridge was do

If one cubic yard

of concrete landed

on your head,

you'd die.

If 5 million cubic yards

of concrete landed

in Northern Arizona,

you'd have something

called Glen Canyon Dam.

Love it or hate it,

this thing is big —

really big.

DAM BIG

WRITTEN & PHOTOGRAPHED BY GARY LADD